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Modelling the Relationship between Government Policy, Economic Growth, and Deforestation in the Brazilian Amazon

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Abstract

This paper develops a theoretical as well as an empirical model of deforestation and economic development in a tropical forest economy. The empirical model is estimated using panel data for 316 municipalities in the Brazilian Amazon during the period 1970 – 1985. The effects of controversial Brazilian policies, such as road building through the Amazon and subsidized credit to agricultural establishments, are evaluated both in the theoretical model and in the estimated empirical model.

The paper concludes that subsidized credit, while certainly causing deforestation, is so beneficial for economic growth that the benefits seem to outweigh the environmental costs. This does not hold for road building, however, because the opening up of new land by federal road building tend to promote a wasteful use of land.

JEL classification: C33, R11, R13, O18, Q23, Q28

Keywords: Tropical deforestation and economic growth, policy evaluation, multiple equation spatial panel data model.

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1. Introduction

The Amazon basin is by far the largest piece of contiguous tropical rainforest left in the World. Both Venezuela, Colombia, Ecuador, Peru and Bolivia claims part of it, but Brazil has the largest share. Brazil's Legal Amazonia comprises about 5 million square kilometers—more than half the national territory of the fifth largest nation in the World. Apart from the rubber boom around the turn of the century, this huge area has contributed very little to the formal Brazilian economy, however. The area was inhabited by various Indian tribes, but the Indians were not considered "real" Brazilians, they didn't contribute to the gross domestic product, and the government couldn't count on them to defend the national borders.

Early in the 1960s it was therefore decided to initiate a huge development program that should integrate the Amazon region into the rest of the economy and populate it with "real" Brazilians. Around 60,000 kilometers of roads were constructed in the region, several hundred thousand people were helped to resettle along these roads, and millions of others followed without official help. Billions of dollars of credit were extended at negative real rates of interest, and tax breaks and land concessions were offered to the entrepreneurs that were willing to start up agricultural establishments in the region. Billions of dollars were raised from international sources and put into the construction of hydroelectric facilities, ports, and railways.

The result of all this has been dramatic increases in both output, population, and deforestation. The total population of Legal Amazonia increased from 7.3 million in 1970 to 13.2 million in 1985, real GDP increased from $2.2 billion to $13.5 billion during the same period, and 33 million hectares of more or less dense forest were converted into agricultural land. The question is: Is that good or bad? Could it have been better? What can Brazil and the other Amazonian countries learn from this huge development experiment?

The Brazilian government[1] has during the last decade worked on putting together an Amazon panel data set that can be used to econometrically analyze the economic and environmental effects of various government policies. The data set currently covers 316 consistently defined regions during the periods 1970, 1975, 1980, and 1985 and measures a very large number of economic, ecological, and demographic variables.

It is the purpose of this paper to use the Amazon data base to learn as much as possible from the Brazilian experiment about the trade-offs between economic growth and environmental degradation. These trade-offs are not the same for all policy instruments, and the current paper tries to identify which policies are good and which are bad in terms of the trade-off between economic growth and

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[1] Or more specifically, a group of researchers under the direction of Eustáquio J. Reis of the Institute for Applied Economics Research (IPEA) in Rio de Janeiro.

deforestation.

The paper consist of both a theoretical part and an empirical part. Both parts develop a two-sector model of a tropical forest economy specifically with the intension of being able to do policy evaluations. The theoretical model is based on Deacon (1995) while the empirical model is an extension of Andersen (1996) and Andersen & Reis (1996).

The remainder of the paper is organized as follows. Section 2 develops the theoretical model and section 3 discusses actual Brazilian policies and their effect on deforestation and social welfare according to the theoretical model.

Section 4 outlines the empirical model, section 5 discusses the data, and section 6 explains the estimation method and reports the results. Section 7 performs a cost-benefit analysis of deforestation by combining the estimated benefits of deforestation with estimated costs found in the literature. Section 8 compares the results from the theoretical and the empirical analysis and draws some policy conclusions.

2. The model

This section scetches a simplified model of a tropical forest economy. As all theoretical models it represents a compromise between analytical tractability and the complexity of the real world. The choice of model for this paper has been guided partly by the subject we are interested in analyzing, namely the effect of government policies on deforestation and economic growth, and partly by the level of details in the data set we want to use for the empirical analysis. For that purpose, we found the model structure of Deacon (1995) most useful. We have extended his basic model slightly, by adding a non-labor and non-land input to his agricultural production function. This was necessary in order to analyze important policy effects arising from subsidized credit. Otherwise we follow his structure and notation closely.

The economy contains a forest that either can be kept intact or be converted to agricultural land. While intact, the forest provides both rival and non-rival services. Examples of rival services are nuts, fruits, fish, firewood, and building materials which are typically consumed by the resident rural population. Non-rival services include carbon sequestration, bio-diversity protection, watershed protection, and climate stabilization which are beneficial to a much wider population in both space and time. The standing forest is a public, free access resource and anyone can convert part of it to a private market good such as timber or agricultural land. Forest conversion involves a private cost of clearing land.

The economy consists of two sectors. A rural sector which produces agricultural goods and an urban sector which produces manufactured goods. As inputs, the rural sector uses rural labor, converted forest, and other agricultural inputs such as fertilizer, pesticides and farm machinery. The urban sector only uses urban labor. Thus, since the urban sector does not use converted forest as an input, it does not directly cause deforestation.

The economy is assumed to be a small open economy, which implies that it can trade with the outside world at given world prices.

2.1. Assumptions and definitions

The economy is populated by identical individuals who derive utility from the consumption of agricultural goods x^c, manufactured goods y^c, and forest services Q. Forest services are assumed proportional to the forest stock, so Q represents both the level of forest services and the extent of the forest that remains standing. One might object that, in reality, rural residents tend to get higher utility from a given amount of forest than urban residents because they get a lot of goods from the forest for free. Thus, total utility from the forest, would depend on the size of the rural population in the region. This is a fair objection that we will have to ignore for the moment. However, in the empirical application later, we will make use of this distinction and allow the urban and the rural population to derive different utility from the standing forest.

The population is normalized to one individual which has the utility:

$$W = W(x^c, y^c, Q), \tag{1}$$

where $W(\cdot)$ is strictly quasi-concave. In this model, population size is considered constant and exogenous. This is an unpleasant assumption for a tropical forest economy which is normally characterized by massive migration depending on relative economic prospects in different regions. Making the population size depend on the level of utility in the region, would make the model much more realistic[2]. However, it would also make the model analytically intractable for this author. As a compensation for this theoretical deficiency, the empirical part of the paper will model population size as endogenous, depending on accessibility and economic prospects in the region and on population pressure in neighboring regions.

Production of agricultural goods requires converted forest as input. Converted forest is represented by P, the fraction of the forest that is cleared. P and Q are constrained by:

$$Q + P = 1. \tag{2}$$

Production of the two consumer goods and the manufactured input for the agricultural sector are denoted X, Y, and Z, respectively. The production functions are the following:

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[2] In that way we could also capture the fact that the total utility of forest services depends, to some degree, on the number of people living in the region.

$$X = X(L^X, Z, P), \tag{3}$$

$$Y = \alpha L^Y, \tag{4}$$

$$Z = (\alpha/\gamma)L^Z, \tag{5}$$

where L^X, L^Y, and L^Z is labor used to produce X, Y, and Z, respectively. The production of agricultural goods requires both labor, converted land, and manufactured inputs, while the production of urban goods and the intermediate input is assumed only to require labor. The simple production functions for the latter two greatly simplify the model. The fact that services typically comprise a large share of urban activities in an emerging forest economy makes this simplifying assumption more acceptable. However, in the empirical analysis we will allow for a demand for agricultural inputs in the urban sector.

Forest clearing involves cutting trees, removing debris, and draining wetlands, all of which also require some of the economy's labor. The production function for converted forest land is:

$$P = (\alpha/\beta)L^P, \tag{6}$$

where L^P is labor allocated to converting Q into P and α/β is its marginal product. The marginal product of L^P is determined mainly by the original forest cover which is assumed homogenous across the region. In our empirical model we also make this homogeneity assumption for each region, but we allow the marginal product to vary across regions because some regions are much more densely forested than others and thus more difficult to convert into agricultural land.

The labor available to the economy is limited by:

$$L^X + L^Y + L^Z + L^P = 1, \tag{7}$$

which implies that

$$(\alpha L^X + \beta P + \gamma Z) + Y = \alpha. \tag{8}$$

The expression in parentheses is the total private cost of producing X and α, β, and γ are effective prices of the inputs used to produce it. Foregone Y is the unit of account. Thus, Eq. (8) expresses the economy's budget constraint for producing final goods X and Y.

The final goods produced may either be consumed directly or traded with the outside world. The value of the economy's imports and exports are assumed to balance, and the relative price is taken as given at the world relative prices. Let

x^e refer to export of agricultural goods and y^m to import of manufactured goods. Trade balance implies that

$$\nu x^e - y^m = 0, \tag{9}$$

where ν is the fixed international price of X. Both x^e and y^m may be negative, i.e. import of agricultural goods and export of manufactured goods are also allowed. It follows that $x^c = X - x^e$ and $y^c = Y + y^m$.

2.2. The social optimum

The welfare optimum is found by maximizing the individual utility function (1) subject to the budget constraint (8) and the trade balance constraint (9). The model has 13 variables, but only 4 of these are independent. It is most useful for the following policy discussion if we focus on the amount of converted land P, the rural labor force L^X, export of agricultural goods x^e, and the use of fertilizer and other non-land and non-labor inputs in the rural sector Z. Making the appropriate substitutions and inserting constraints (2), (8), and (9) into the utility function (1), the maximand is

$$W = W\left\{X(L^X, Z, P) - x^e; \alpha - (\alpha L^X + \beta P + \gamma Z) + \nu x^e; 1 - P\right\}. \tag{10}$$

The first-order conditions for this problem are:

$$\partial W/\partial L^X = W_X X_L - W_Y \alpha = 0 \tag{11}$$

$$\partial W/\partial Z = W_X X_Z - W_Y \gamma = 0 \tag{12}$$

$$\partial W/\partial P = W_X X_P - W_Y \beta - W_Q = 0 \tag{13}$$

$$\partial W/\partial x^e = -W_X + W_Y \nu = 0, \tag{14}$$

where $W_X = \partial W/\partial x^c$, and so forth. Dividing through by W_Y, we get expressions in terms of M_{XY} and M_{QY}, the marginal rates of substitution between X and Y and between Q and Y, respectively. Condition (11) implies that $M_{XY} \cdot X_L = \alpha$, the marginal value product of labor used to produce X should equal its marginal cost in foregone Y, which is α. Similarly, condition (12) implies that $M_{XY} \cdot X_Z = \gamma$, the marginal value product of capital inputs used to produce X should equal its marginal cost in foregone Y. Condition (13) implies that $M_{XY} \cdot X_P = \beta + M_{QY}$, the marginal value product of cleared land should equal its marginal cost in foregone Y, which is β, *plus* the marginal value of foregone forest services. The last term, M_{QY}, is external to the individual forest user. Finally, condition (14) implies that $M_{XY} = \nu$, which means that the consumer's marginal value of x^c should equal the world price of X.

2.3. Government Policy

Government policies can be modelled as taxes and subsidies on the economy's inputs, outputs, and trade volume. Since there are four independent variables in our model, we need to consider four policy instruments. Let the per unit tax rates on L^X, x^e, P, and Z be denoted λ, τ, π, θ, respectively, and let all tax revenues, $R^\lambda \equiv \lambda L^X$, $R^\tau \equiv \tau x^e$, $R^\pi \equiv \pi P$, $R^\theta \equiv \theta Z$ be rebated to the consumer in lump sum.

The forest is a free access resource and each user regards its service flow as fixed when choosing the variables he or she can control. These choices are dictated by utility optimization, and it is convenient to break the maximization problem into two steps. The first step is to minimize the private costs of producing X. This leads to the following Lagrange equation:

$$L = (\alpha + \lambda)L^X + (\beta + \pi)P + (\gamma + \theta)Z + \mu(X - X(L^X, P, Z)), \tag{15}$$

where first order conditions are

$$(\alpha + \lambda) - \mu X_L = 0 \tag{16}$$

$$(\beta + \pi) - \mu X_P = 0 \tag{17}$$

$$(\gamma + \theta) - \mu X_Z = 0. \tag{18}$$

The solution to this problem is

$$L^X = L^X(\alpha + \lambda, \beta + \pi, \gamma + \theta, X) \tag{19}$$

$$P = P(\alpha + \lambda, \beta + \pi, \gamma + \theta, X) \tag{20}$$

$$Z = Z(\alpha + \lambda, \beta + \pi, \gamma + \theta, X) \tag{21}$$

$$\mu = \mu(\alpha + \lambda, \beta + \pi, \gamma + \theta, X). \tag{22}$$

Equations (19) to (21) are cost-minimizing (constant output) factor demand functions and (22) gives the marginal private cost of X. Inserting these factor demand functions into the Lagrange equation (15) yields the "private cost function"

$$C = C(\alpha + \lambda, \beta + \pi, \gamma + \theta, X). \tag{23}$$

The consumers budget constraint can now be rewritten as

$$\begin{aligned}\alpha + R^{\lambda} + R^{\pi} + R^{\theta} + R^{\tau} &= C(\alpha + \lambda, \beta + \pi, \gamma + \theta, X) \\ &\quad -(\nu - \tau)x^e + y^c. \end{aligned} \tag{24}$$

The left hand side of (24) is the consumers endowment, and the right hand side is expenditure on x^c and y^c. The expenditure used on consumption of X is the costs of producing X minus the after tax export revenues.

In the second step, we substitute (24) into the utility function (10):

$$\begin{aligned} W &= W\{X - x^e; \alpha + R^{\lambda} + R^{\pi} + R^{\theta} + R^{\tau} \\ &\quad -C(\alpha + \lambda, \beta + \pi, \gamma + \theta, X) + (\nu - \tau)x^e; 1 - \overline{P}\}. \end{aligned} \tag{25}$$

The individual chooses X and x^e to maximize (25), taking P and lump sum taxes as given. The solution to this problem satisfies

$$\partial W/\partial X = W_X - W_Y C_X = 0 \tag{26}$$

$$\partial W/\partial x^e = -W_X + (\nu - \tau)W_Y = 0, \tag{27}$$

which imply that $M_{XY} = C_X = \nu - \tau$. Thus, the consumer equates the marginal value of X both to the after tax marginal cost of X and to the net world price of X. Equilibrium production of X can then be written as

$$X = X(\alpha + \lambda, \beta + \pi, \gamma + \theta). \tag{28}$$

Using (20) and (28), the equilibrium amount of forest conversion can be written as

$$P = P(\alpha + \lambda, \beta + \pi, \gamma + \theta, X(\alpha + \lambda, \beta + \pi, \gamma + \theta)), \tag{29}$$

and equilibrium exports as

$$x^e = x^e(\alpha, \beta, \gamma, \nu, \lambda, \pi, \theta, \tau). \tag{30}$$

Equation (29) is a constant output factor demand function for converted land. Its equilibrium value depends on the technological parameters α, β, and γ, on the exogenous world price ν, and on government policy variables λ, π, θ, and τ. This function plays a central role in the subsequent policy analyses.

2.4. Unregulated equilibrium

In the absence of any taxes and subsidies, the market equilibrium is inefficient, both in the mix of inputs used to produce X and in the mix of final products consumed. From the first order conditions (11) to (13) we know that the social optimum satisfies $X_P/X_L = (\beta + M_{QY})/\alpha$ and $X_P/X_Z = (\beta + M_{QY})/\gamma$. By contrast, conditions (16) to (18) show that the market equilibrium satisfies $X_P/X_L = (\beta+\pi)/(\alpha+\lambda)$ and $X_P/X_Z = (\beta+\pi)/(\gamma+\theta)$. In the unregulated equilibrium where $\lambda = \pi = \theta = 0$, we then have $X_P/X_L = \beta/\alpha$ and $X_P/X_Z = \beta/\gamma$. That is, the production of X uses a technology that is too P intensive because the marginal value of foregone forest services are ignored when making the technology decision.

Imposing a tax on the use of P alone and setting the tax rate at $\pi = M_{QY}$ repairs the inefficiency in the choice of production methods. It also repairs the inefficiency in the mix of final goods consumed. Recall from (17) that the private marginal cost of X is $\mu = (\beta + \pi)/X_P$. Increasing this cost by imposing a tax $\pi = M_{QY}$ shifts the consumption away from X towards Y until $M_{XY} = (\beta + M_{QY})/X_P$, the social optimum.

3. Real government policies

It was shown in the general equilibrium framework above that a single Pigouvian tax on forest clearing solves all the inefficiencies related to the missing market for forest services. The tax fills in the missing price and restores the allocation that would be achieved if markets were complete. This simultaneously reduces deforestation and increases welfare.

However, this simple economic argument seem to have been disregarded in actual tropical forest economies around the world. In Brazil, for example, the actual policies during the previous three decades has been almost the opposite of what the theoretical analysis above suggests. The government has subsidized forest clearing by providing infrastructure, tax-incentives, and cheap credit to farmers who wanted to convert some Amazonian rain forest into agricultural land.

The set of Brazilian policies launched in the 1960s to promote economic development in the Amazon region have been strongly accused in the literature of causing environmental damage with consequences reaching far beyond the Brazilian borders (e.g. Binswanger 1991; Browder 1988; Mahar 1989; Gillis & Repetto 1988, and Deacon 1995). The deforestation effect of some of these policies seem intuitively clear. Subsidized credit to large scale cattle ranching, for example, has been blamed for the clearing of millions of hectares a forest that would not have been cleared in the absence of these government incentives. However, most claims of the relationship between government policies and deforestation have largely emerged from case studies and descriptive accounts, without an explicit conceptual framework (**?**). Little research has been conducted to actually model and quantify the effects of the different policies.

In the remaining part of this section, we will analyze the theoretical consequences of some of the Brazilian policies, and in the following sections, the consequences will be evaluated in an econometric model estimated on panel data for 316 regions in the Brazilian Legal Amazonia during the period 1970 to 1985.

3.1. Road building

The lack of infrastructure in the Amazon region had severely restricted access until the beginning of the 1960's, leaving the rain forest essentially undisturbed. However, an ambitious road building program was launched in order to facilitate the occupation and economic development of the region. During the subsequent 25 years the federal and state road network in Legal Amazonia increased from essentially zero to about 60,000 kilometers of roads of which about 20% were paved (**?**, p. 12). The provision of roads was in many cases accompanied by official campaigns and fiscal incentives intended to encourage people to settle along the roads. These incentives included free transportation to the Amazon, a 100 hectare plot with sure title for each settler, and a six-month household subsidy to tide the family over difficult upstart period (**?**, p. 110).

Public provision of roads acts as a subsidy to forest clearing. It is clearly much easier to clear forest along a road than on a plot surrounded by dense virgin forest on all sides. A subsidy to forest clearing is represented by $\pi < 0$ in our model. We can find the marginal deforestation effect arising from a change in this tax rate by differentiating (29):

$$\frac{dP}{d\pi} = \frac{\partial P}{\partial \pi} + \frac{\partial P}{\partial X} \cdot \frac{\partial X}{\partial \pi} < 0 \tag{31}$$

The first partial derivative on the right-hand side of (31) is the effect on demand for forest clearing following from an increase in the cost of clearing, holding output constant. This is an input substitution effect and it is guaranteed to be negative if the production function is concave. The remaining product on the right-hand side is an output effect, which is also negative because the two derivatives $\partial P/\partial X$ and $\partial X/\partial \pi$ are necessarily of opposite sign when trade with the outside world is possible[3]. Thus, a marginal increase in the tax rate on forest conversion will imply less forest conversion, regardless of the level of π, λ, θ, τ, and ν. Or equivalently, introducing a subsidy to forest conversion will increase deforestation, unambiguously.

It is more difficult to evaluate the welfare effects of a change in π, because the effects depend on the initial tax regime. We can write equilibrium welfare under

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[3] If X is not traded, it may act as a Giffen good, so that more of it is used when it is taxed. This may make $\partial X/\partial \pi$ positive and partially or wholly reverse the negative input substitution effect.

an arbitrary tax regime, λ, π, θ, and τ as

$$\begin{aligned} W^* &= W\{X(\cdot) - x^e(\cdot); \alpha + \lambda L^X(\cdot) + \theta Z(\cdot) + \pi P(\cdot) + \tau x^e(\cdot) \\ &\quad -C(\alpha+\lambda, \beta+\pi, \gamma+\theta, X(\cdot)) + (\nu - \tau)x^e(\cdot); 1 - P(\cdot)\}. \end{aligned} \tag{32}$$

The welfare effect of a marginal change in the tax rate on P is then

$$\begin{aligned} \frac{\partial W^*}{\partial \pi} &= \frac{\partial W}{\partial X} \cdot \left(\frac{\partial X}{\partial \pi} - \frac{\partial x^e}{\partial \pi} \right) \\ &\quad + \frac{\partial W}{\partial Y} \cdot \left(\lambda \frac{dL^X}{d\pi} + \theta \frac{dZ}{d\pi} + \pi \frac{dP}{d\pi} + P(\cdot) + \tau \frac{\partial x^e}{\partial \pi} - \frac{dC}{d\pi} + (\nu - \tau) \frac{\partial x^e}{\partial \pi} \right) \\ &\quad - \frac{\partial W}{\partial Q} \cdot \frac{dP}{d\pi}, \end{aligned} \tag{33}$$

where $dL^X/d\pi = \partial L^X/\partial\pi + (\partial L^X/\partial X)\partial X/\partial \pi$, $dZ/d\pi = \partial Z/\partial \pi + (\partial Z/\partial X)\partial X/\partial\pi$, $dC/d\pi = \partial C/\partial \pi + (\partial C/\partial X)\partial X/\partial \pi$, and $dP/d\pi = \partial P/\partial\pi + (\partial P/\partial X)\partial X/\partial\pi$. Using the duality relation $P(\cdot) = \partial C/\partial\pi$ and (26) and (27) this simplifies to:

$$\frac{\partial W^*}{\partial \pi} = \frac{\partial W}{\partial Y} \cdot \left(\lambda \frac{dL^X}{d\pi} + \theta \frac{dZ}{d\pi} + \pi \frac{dP}{d\pi} + \tau \frac{\partial x^e}{\partial \pi} \right) - \frac{\partial W}{\partial Q} \cdot \frac{dP}{d\pi}. \tag{34}$$

The total welfare effect of changing the tax on deforestation consists of two parts. The last term $-(\partial W/\partial Q)dP/d\pi$ represents the welfare change from reducing deforestation. This effect is unambiguously positive since $\partial W/\partial Q > 0$ and $dP/d\pi$ was previously shown to be negative. The first term represents an income effect arising from a change in the revenue yield from the pre-existing tax-system. If all taxes were initially zero this effect would be zero, but if the economy was initially taxed the effect could be both positive and negative rendering the overall welfare effect of changing π ambiguous. Only in the absence of any initial taxes can we say that a marginal increase in π is welfare enhancing.

3.2. Subsidized credit to agricultural establishments

The agricultural sector in Brazil has been blessed with a favorable credit situation implying that the real interest rate on loans for agriculture was much lower than in the non-agricultural sector. From 1970 to 1986 the real interest rate in agriculture was actually negative, with rates down to ÷40% p.a. (**?**, Figure 3).

Credit is mainly used to buy fertilizer, pesticides, farm equipment, perennial crops, and other non-land and non-labor inputs. Thus, subsidized credit acts as a subsidy to the input Z in our model. The deforestation effect of a marginal increase in the tax rate θ on Z is given by

$$\frac{dP}{d\theta} = \frac{\partial P}{\partial \theta} + \frac{\partial P}{\partial X} \cdot \frac{\partial X}{\partial \theta} \tag{35}$$

The first partial derivative in (35) is the effect on demand for forest clearing following from an increase in the cost of other inputs than land and labor. This is an input substitution effect and the sign is ambiguous. If P and Z are substitutes, the input substitution effect is positive, but if they are complements it will be negative.

The remaining product on the right-hand side is an output effect which is negative because the normality of P and Z ensures that $\partial P/\partial X > 0$ and $\partial X/\partial \theta < 0$. Thus, a marginal increase in the tax rate on non-land and non-labor inputs will imply less forest conversion if P and Z are complements, regardless of the level of π, λ, θ, τ, and ν. If they are substitutes, however, the effect is ambiguous. Thus, the introduction of subsidized credit need not necessarily lead to more deforestation, especially not if the inputs purchased with this credit acts as a substitute to converted land.

The welfare effect of a marginal change in the tax rate on Z is

$$\begin{aligned}\frac{\partial W^*}{\partial \theta} \;=\; & \frac{\partial W}{\partial X} \cdot \left(\frac{\partial X}{\partial \theta} - \frac{\partial x^e}{\partial \theta} \right) \\ & + \frac{\partial W}{\partial Y} \cdot \left(\lambda \frac{dL^X}{d\theta} + \theta \frac{dZ}{d\theta} + Z(\cdot) + \pi \frac{dP}{d\theta} + \tau \frac{\partial x^e}{\partial \theta} - \frac{dC}{d\theta} + (\nu - \tau) \frac{\partial x^e}{\partial \theta} \right) \\ & - \frac{\partial W}{\partial Q} \cdot \frac{dP}{d\theta}, \end{aligned} \tag{36}$$

Using the duality relation $Z(\cdot) = \partial C/\partial \theta$ and (26) and (27) this simplifies to:

$$\frac{\partial W^*}{\partial \theta} = \frac{\partial W}{\partial Y} \cdot \left(\lambda \frac{dL^X}{d\theta} + \theta \frac{dZ}{d\theta} + \pi \frac{dP}{d\theta} + \tau \frac{\partial x^e}{\partial \theta} \right) - \frac{\partial W}{\partial Q} \cdot \frac{dP}{d\theta}. \tag{37}$$

If all taxes were initially zero the tax revenue effect drops out and leaves us with the welfare effect from changes in the amount of deforestation. If P and Z are complements then $dP/d\theta < 0$ and the welfare effect is guaranteed to be positive. If they are substitutes, however the sign of the welfare effect cannot be determined.

The total welfare effect of introducing subsidized credit is therefore ambiguous. Only in the case of no initial taxes and P and Z being complements can we say that the subsidy is unambiguously bad.

3.3. Growth poles

The Program of Agricultural, Livestock, and Mineral Poles in Amazonia (POLOAMAZONIA) was designed to create a more favorable investment climate in Amazonia for private enterprise. The program focused on fifteen "growth poles" scattered throughout Amazonia, where infrastructure and investment were to be concentrated and entrepreneurial activities subsidized.

One of the first big projects was the Carajás Iron Ore Project in northern Pará. This project was implemented to efficiently exploit the huge deposits of high-grade iron ore which had accidentally been discovered in the remote Serra dos Carajás. The project included the construction of a 890-kilometer railroad from the mining site to São Luís in Maranhão, port facilities to handle the mine's annual output of 35 million tons, and urban infrastructure (?, p. 41). Eight of the other 14 growth poles included mining or oil exploration projects.

These kinds of projects are classified as urban activities in our model since they require very little converted forest as input and since the output is counted as industrial output. In our general equilibrium framework, a subsidy to the urban sector is equivalent to a tax on the agricultural sector. A general tax on X is equivalent to taxing L^X, Z, and P at the same ad valorem rate ρ. For simplicity, suppress all other taxes and notice that the maximand for the consumer (25) changes to

$$W = W\{X - x^e; \alpha + R^\rho - (1+\rho)C(\alpha, \beta, \gamma, X) + \nu x^e; 1 - \overline{P}\}. \tag{38}$$

The first order conditions to this problem imply that $M_{XY} = (1+\rho)C_X = \nu$, which means that equilibrium P is given by

$$P = P(\alpha, \beta, \gamma, X(\alpha, \beta, \gamma, \nu/(1+\rho))), \tag{39}$$

The deforestation effect caused by this tax is therefore described by a simple output effect

$$\frac{dP}{d\rho} = \frac{\partial P}{\partial X} \cdot \frac{\partial X}{\partial \rho} < 0.$$

This effect is unambiguously negative since P is a normal input and $\partial X/\partial\rho < 0$. Thus, a subsidy to mining growth poles should theoretically reduce deforestation.

However, most of the growth poles in the POLOAMAZONIA program, also have an element of agricultural, and especially livestock, subsidy. Such a subsidy to the agricultural sector would, of course, tend to have the opposite effects of the ones for the mining poles. Thus, the total effect of the POLOAMAZONIA program is ambiguous, and its contribution to deforestation remains to be tested empirically.

3.4. The Manaus Free Zone (MFZ)

Manaus was once the very rich rubber capital of the Amazon, but income in the region collapsed when rubber seeds were stolen and rubber trees successfully cultivated in Southeast Asia. In order to provide new possibilities to the million-citizen big Amazonian capital, the Brazilian government decided to create a free import-export processing zone. The result is a flourishing electronics industry in the middle of the rain forest, with Brazil's lowest prices on most electronic consumer goods.

An exemption from import tax on manufactured goods is, in our model, equivalent to a tax on agricultural export. The theoretical effect of an export tax τ on agricultural products can be found by differentiating (29):

$$\frac{dP}{d\tau} = \frac{\partial P}{\partial X} \cdot \frac{\partial X}{\partial \tau} < 0 \tag{40}$$

The negative sign follows from the assumption that P is a normal input and from the concavity of the production function which guarantees that $\partial X/\partial \tau < 0$. Thus, a marginal increase in the tax rate on agricultural export will imply less forest conversion, regardless of the level of π, λ, θ, τ, and ν. Thus, the MFZ should theoretically work to reduce deforestation.

The welfare effect of a marginal change in the tax rate on x^e is

$$\frac{\partial W^*}{\partial \tau} = \frac{\partial W}{\partial Y} \cdot \left(\lambda \frac{dL^X}{d\theta} + \theta \frac{dZ}{d\theta} + \pi \frac{dP}{d\theta} + \tau \frac{\partial x^e}{\partial \theta} \right) - \frac{\partial W}{\partial Q} \cdot \frac{dP}{d\tau}. \tag{41}$$

If all taxes were initially zero the tax revenue effect drops out and leaves us with the welfare effect from changes in the amount of deforestation. A tax on x^e has just been shown to reduce deforestation, so the welfare effect is unambiguously positive in the case of zero initial taxes.

3.5. Summarizing the theoretical effects of government policies

Table 1 summarizes the results from the theoretical analysis. The table shows the likely theoretical effects of three main categories of Brazilian development policies.

Table 1: Theoretical effects of actual Brazilian policies

	Road building	Subsidized credit	Growth poles
Deforestation	+ +	+ + (if complements) (?) (if substitutes)	– – (mining) + + (livestock) – – (free zone)
Welfare	(–)	(–) (if complements) (?) (if substitutes)	(+) (mining) (–) (livestock) (+) (free zone)

+ + Unambigously positive.

(+) Probably positive, but may be negative under certain conditions.

(?) May be either positive or negative.

The effects on the level of deforestation are in general much more clear than the effects on welfare. Road building is clearly expected to contribute to deforestation, while the effect of credit policies and growth poles are less clear. The growth poles associated with urban activities such as mining and manufacturing are generally good, while the growth poles associated with livestock and agro-processing are generally bad.

If credit is used to buy agricultural inputs that substitutes for the use of newly cleared land then it will tend to reduce deforestation. In relatively developed areas where farmers have title to their land and new land is not freely available, it is likely that farmers will use the credit to intensify their agricultural practices by buying perennial crops, fertilizers, and pesticides. However, big ranch owners in less established areas may use the obtained credit to hire additional labor to clear more land and thereby expand their land possessions. This will clearly increase deforestation. Which effect dominates is an empirical question that will be addressed in the second part of this paper.

4. An empirical analysis of Brazilian policies in the Amazon

In this section we will complement the above theoretical analysis with an empirical analysis of the deforestation and welfare effects arising from the Brazilian policies that have been implemented to encourage occupation and development of the Amazon region.

The empirical model is a two-sector model consisting of a rural and an urban sector. It is modelled as a system of six equations. The main equation models the rural sector's demand for converted land. The remaining five equations models rural and urban population, rural and urban output, and land prices, respectively. Each equation is explained in detail in the following subsections.

4.1. The rural sector's demand for agricultural land

Before 1960 there was little economic incentive to create agricultural establishments in the Amazon. Most of the region was virtually inaccessible, there were no local markets for neither inputs nor outputs, and there was a total lack of social infrastructure. This changed, however, when the Brazilian government through ambitious road building and settlement programs decided to open up the region and "bring men without land to the land without people." During the subsequent decades several million people suddenly found it economically sensible to settle down in the Amazon[4].

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[4] The population in Legal Amazonia increased from 7.2 million in 1970 to 16.6 million in 1991 (IPEA/DESMAT 1996). About 40% of the increase was caused by migration into the area, so the number of immigrants in that period is 3-4 million.

The settlement was not evenly distributed over the region, though. The eastern and southern regions received far more migrants than the western and northern regions, and clearing is visibly concentrated along the major highways, their feeder roads, and the big rivers, thus giving evidence to the critical importance of accessibility. In our empirical model, accessibility of a region is proxied by i) distance to the federal capital, Brasília, ii) extension of the road network, iii) length of main rivers in region, and iv) the level of clearing in neighboring municipalities.

As population densities increase in early settled areas, land becomes more scarce and land prices are pushed up. The supply of land is expected to be very elastic for low levels of clearing, so that an increase in demand has only a small effect on the price of land. However, as clearing approaches 100% of total municipality area, the supply is becoming very inelastic, and an increase in demand will have a dramatic effect on land prices. To capture the effect of relative land availability in our empirical model, we use the following four variables: i) rural population density, ii) land prices, iii) lagged level of clearing, and iv) lagged share of cleared land.

Besides the fundamental requirements of accessibility and availability of land, demand is affected by the economic prospects in a region. Because of the long distances and the high costs of transporting agricultural goods, farmers in the Amazon depend heavily on the availability of local markets. Local market conditions in the Amazon are improving, as can, for example, be seen from the following: The number of urban residents per rural resident in Legal Amazonia has increased steadily from 0.6 in 1970 to 1.2 in 1991. Furthermore, urban output grew at an impressive rate of 14% per year in the period $1970 - 1985$. The variables used to capture the local market conditions are the following: i) urban residents per rural resident, ii) growth of urban output in the region, iii) road length in region, and iv) distance to the state capital.

Other factors directly related to the profitability of agricultural settlement are land prices and fiscal subsidies and incentives. Agriculture in the Amazon has been an attractive tax shelter because of the virtual exemption from income taxation (**?**, p. 20). This exemption naturally adds to demand for agricultural land, but it does so evenly over the whole region, and we are unable to measure the effect in our empirical model. However, some regions were officially designated as growth poles, and enjoyed extra favorable conditions[5]. We include a dummy for these regions to capture non-credit incentives. The distribution of credit incentives is proxied by the amount of SUDAM credit[6] obtained in each region in

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[5] The Program of Agricultural, Livestock and Mining Poles in Amazonia (POLAMAZONIA) was designed to create a more favorable investment climate in Amazonia. The program concentrated on fifteen "growth poles" where infrastructure and investment were to be concentrated and entrepreneurial activities subsidized. One example of a growth pole is the Free-Zone of Manaus. For a full list and descriptions of the growth poles in Legal Amazonia, see Andersen *et al* (1996).

[6] Credit granted by the Superintendency for Amazonian Development (SUDAM) was heavily subsidized. Given the rates of inflation, the government was in effect offering enourmous

1985.

For a potential migrant the level of rural income per rural capita in the previous period is a good indicator for his expected future income. Relatively high expected income in a region will add to demand for converted land in that region so this variable is also included in our model.

There is a good reason to believe that there are qualitative differences between newly cleared land and old cleared land in the Amazon. Because of the burning method typically applied, newly cleared land is highly productive and relatively pest-free compared to old agricultural land which requires very different farming methods based on different types of crops and the addition of fertilizers and pesticides.

The considerations above lead us to assume the following function for the demand for newly cleared land in region i during the period from time $t-1$ to time t:

$$\begin{aligned}\Delta CLR_{i,t} \quad = \quad & f(\text{distance to federal capital}_i,\ \text{road length}_{i,t-1}, \\ & \text{river length}_i,\ \text{level of clearing in neighboring regions}_{i,t-1} \\ & \text{rural population density}_{i,t-1},\ \text{level of clearing}_{i,t-1}, \\ & \text{share of land cleared}_{i,t-1},\ \text{change of urban output}_{i,t}, \\ & \text{distance to state capital}_i,\ \text{urban residents per rural resident}_{i,t-1}, \\ & \text{growth pole dummy}_i,\ \text{SUDAM credit}_{i,t-1},\ \text{land prices}_{i,t-1}, \\ & \text{rural income per rural capita}_{i,t-1},\ \text{municipality area}_i).\end{aligned}$$

For estimation purposes, we assume that the function is log-linear. In the data set there are 5 calendar years between each observation, which means that changes refer to the change in the natural logarithm of a stock variable during the 5 year period between time $t-1$ and time t.

4.2. Population dynamics

Total population in Legal Amazonia grew at an average annual rate of 4.0% during the period $1970-1991$. The urban part of the population expanded much faster than the rural, though, leading to a dramatic change in the composition of the population. Since rural and urban inhabitants have very different effects on deforestation, it is important to model these two groups separately. Urban inhabitants typically work in the service sector and are therefore assumed to have no direct impact on deforestation. There will, nevertheless, be an indirect effect through the demand for agricultural goods.

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amounts of money at negative real rates of interest (?).

4.2.1. Rural population

The size of the rural population is determined partly by the size of the inherent population and partly by new immigration. The number of immigrants depends both on push and pull factors. Push factors are population pressure in neighboring areas, while the main pull factor is economic possibilities in the region. The economic attractiveness of a region depends on its accessibility, productivity, market conditions, and fiscal subsidies.

The increase in the rural population in region i from time t to time $t-1$ can then be predicted by estimating the following function:

$$\begin{aligned}\Delta POP\_RURAL_{i,t} \;=\; & f(\text{rural population}_{i,t-1}, \text{rural population growth in} \\ & \text{neighboring regions}_{i,t}, \text{distance to federal capital}_i, \\ & \text{road length}_{i,t-1},\ \text{river length}_i,\ \text{rural income per capita}_{i,t-1}, \\ & \text{level of urban output}_{i,t-1},\ \text{growth of urban output}_{i,t}, \\ & \text{urban income per capita}_{i,t-1}, \text{distance to state capital}_i, \\ & \text{growth pole dummy}_i,\ \text{SUDAM credit}_{i,t-1},\ \text{municipality area}_i)\end{aligned}$$

4.2.2. Urban population

The size of the urban population is also partly determined by the inherent urban population and partly by immigration. A relatively high urban income per urban capita is expected to attract people to the city, both when compared to rural incomes and when compared to urban incomes in other regions.

Other pull factors are fiscal incentives and a good urban infrastructure. As an indicator of urban infrastructure we use a composite variable which is the sum of the share of households which have running water, the share of households which have electricity, and the share of households which have sanitary installations.

Thus, we expect to be able to estimate the size of the urban population in region i at time t from a function of the following form:

$$\begin{aligned}\Delta POP\_URBAN_{i,t} \;=\; & f(\text{urban population}_{i,t-1},\ \text{rural population}_{i,t-1}, \\ & \text{urban income per capita}_{i,t-1},\ \text{rural income per capita}_{i,t-1}, \\ & \text{road length}_{i,t-1},\ \text{neighbors' road length}_{i,t}, \\ & \text{growth pole dummy}_i,\ \text{SUDAM credit}_{i,t-1}, \\ & \text{urban infrastructure}_{i,t-1},\ \text{municipality area}_i).\end{aligned}$$

4.3. Rural and urban output

Agriculture's share of total regional output has fallen steadily from 30% in 1970 to only 17% in 1985. This trend alone has a dampening effect on deforestation since we have assumed that only agro-pastoral activities have any significant effect on deforestation.

The growth rate of urban output is expected to depend on location and accessibility, fiscal subsidies, and the quality of the urban infrastructure. The square of urban population size is included to allow for increasing or decreasing returns to scale.

$$\begin{aligned}\Delta GDP\_URBAN_{i,t} \;=\; & f(\text{road length}_{i,t-1},\ \text{river length}_i,\\ & \text{growth pole dummy}_i,\ \text{SUDAM credit}_{i,t-1},\\ & \text{urban infrastructure}_{i,t-1},\ \text{urban population}_{i,t-1},\\ & \text{urban population}^2_{i,t-1},\ \text{urban income per capita}_{i,t-1},\\ & \text{change in cattle herd}_{i,t},\ \text{municipality area}_i).\end{aligned}$$

Similarly, the growth rate of rural output is expected to depend on accessibility and fiscal incentives plus vegetation and soil conditions. The quality of soil in the municipality is proxied by the estimated area of high yield soils. Diminishing returns are expected to be even more pronounced in the case of rural output than in the case of urban output.

The value of agricultural production in developing countries is in general very dependent of world prices for agricultural products. The development of these prices is largely external to the Amazonian rural sector, and we therefore include a trend term to allow for such external effects which are common to the whole region.

The equation for rural output then becomes:

$$\begin{aligned}\Delta GDP\_RURAL_{i,t} \;=\; & f(\text{road length}_{i,t-1},\ \text{river length}_i,\\ & \text{neighbors' road length}_{i,t-1}, \text{SUDAM credit}_{i,t-1},\\ & \text{growth pole dummy}_i,\ \text{municipality area}_i,\\ & \text{natural forest area}_i,\ \text{high quality soil area}_i,\\ & \text{level of clearing}_{i,t-1},\ \text{rural population}_{i,t-1},\\ & \text{rural income per rural person}_{i,t-1},\ \text{trend}).\end{aligned}$$

4.4. Land prices

The difference in land prices between the South and the North have been a powerful magnet driving migrants to the Amazon. In 1980, for example, a farmer could, on average, buy 14 hectares of land in the North for every hectare he sold in the South (Andersen *et al*, 1996, Table 8.1).

There are also big variations in land prices within the Amazon region and these differences are expected to depend on soil quality, market conditions, and the distribution of government incentives. As proxies for market conditions we include: i) road length, ii) new road building, iii) river length, iv) distance to federal capital, v) distance to state capital, and vi) urban income per urban capita. Soil conditions may be captured by: vii) area with high yield soil, viii) agricultural productivity, and ix) growth of agricultural output. The third factor that may influence land prices is government subsidies, since particularly attractive tax and credit conditions would tend to be capitalized into land prices. To capture this effect we include x) the growth pole dummy and xi) the amount of SUDAM credit obtained.

As cleared land approaches 100% of a given area, little land is available for new clearing and land will develop scarcity value. To capture this effect, we include xii) the lagged share of cleared land.

To capture possible changes in relative land prices compared to other places in Brazil, we also include time dummies in our empirical model of land prices.

Thus, the function determining the growth of land prices in region i between time $t-1$ and time t becomes:

$$\begin{aligned}\Delta LANDPRICE_{i,t} \quad = \quad & f(\text{length of roads}_{i,t-1}, \text{change in length of roads}_{i,t}, \text{river length}_{i}, \\ & \text{length of planned roads}_{i,t}, \text{distance to federal capital}_{i}, \\ & \text{distance to state capital}_{i}, \text{urban income per capita}_{i,t-1} \\ & \text{area with high yield soil}_{i}, \text{growth of agricultural output}_{i,t} \\ & \text{cleared share}_{i,t-1}, \text{growth pole dummy}_{i}, \text{SUDAM credit}_{i,t-1}, \\ & \text{T75-dummy, T80-dummy, land price}_{i,t-1}, \text{municipality area}_{i}\ )\end{aligned}$$

5. The data

All data used for this project is extracted from a large panel data set[7] constructed and maintained at IPEA[8] in Rio de Janeiro. Data on economic, demographic, agricultural, and ecological variables have been collected for the years 1970, 1975, 1980, and 1985 for 316 consistently defined geographic areas in Legal Amazonia. For a more comprehensive description of the data set and the variables used for this project, see the Amazon report by Andersen *et al* (1996).

5.1. Cleared land

Cleared area is estimated from comprehensive land surveys conducted by IBGE every five years[9]. Private land used for annual crops, perennial crops, planted

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[7] DESMAT (Dados Ecológicos e Sociais para Municípios da Amazônia Tropical), February 1996.

[8] Instituto de Pesquisa Econômica Aplicada (Institute for Applied Economics Research).

[9] The data from 1991 is unfortunately very incomplete. Because of recession, the Brazilian Institute of Geography and Statistics were not allocated sufficient funds to complete the sched-

forest, natural pasture, planted pasture, and fallow land is considered cleared, while all public land plus private land kept as natural forest is considered virgin.

Legal Amazonia comprises an area of approximately 5 million square kilometers. By 1985 about 23% of this area had been privatized, while only about 14% had been cleared[10].

5.2. Other variables

Rural and urban populations are derived from the Brazilian Demographic Census for 1970, 1980, and 1991. The population values for 1975 and 1985 are calculated by geometric interpolation.

Data on urban and rural output and on land prices are obtained from the Agricultural Census, the Industrial Census, the Commercial Census, and the Service sector Census for 1970, 1975, 1980, and 1985.

Infrastructure conditions are estimated from 1976 and 1986 road maps from the Department of Roads in the Ministry of Transportation. Several sub-categories are available: state roads and federal roads, paved, non-paved and planned. Complementary information on accessibility is provided by the municipal network of rivers (with more than 2.1 meters of depth at least 90% of the time) estimated from maps available in the 1985 Statistical Yearbook.

The distances between the administrative center of each municipality and the state and federal capitals are used as proxies for access conditions to local and national markets.

Detailed data on soil quality was obtained from EMBRAPA maps. This paper uses the land area judged to have high yield soil as a proxy for soil quality in the municipality.

Data on credit from different sources (Banco do Brasil, SUDAM, and other government entities) is available, but for 1985 only. To construct SUDAM credit variables for earlier periods, we use information on the number of SUDAM projects in each municipality in each period[11] and data on the aggregate level of SUDAM credit as reported in Schneider (1995, Table 1.3)[12]. In order to capture non-credit incentives, such as tax holidays, import and export duty exemptions, and various subsidies, a dummy was created for all municipalities located partly or wholly in

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uled censuses. The latest period from which all the agricultural data is available is therefore 1985.

[10] The 14 % clearing mentioned here is higher than the usually quoted deforestation estimates derived from satellite imagery (about 7-8% in 1988 according to Fearnside 1996) because clearing includes land conversion not only in densely forested areas but also in cerrado and savanna areas.

[11] Constructed by Alexander Pfaff at MIT.

[12] Specifically, we first distribute credit under the assumption that all projects in a given municipality receive the same annual amount of credit as in 1985. If the aggregate level of credit for the earlier years then doesn't sum to what Schneider (1995) reports, we multiply all numbers by a factor that makes them do so.

a designated POLOAMAZONIA growth pole.

The Demographic Censuses from 1970 and 1980 provide data on the urban infrastructure conditions. A proxy for the quality of urban infrastructure was created by adding together the share of households that have electricity, the share of households that have running water, and the share of households that have sanitary installations.

5.3. Neighbor variables

Distances between all municipality centers were calculated from the coordinates of the administrative center of each municipality. These distances are used to calculate neighbor variables, which are variables describing conditions in neighboring municipalities. The variable measuring the level of clearing in neighboring municipalities, for example, is constructed as a weighted average of the level of clearing in the closest five municipalities. The weights are inversely proportional to the distance between municipality centers and scaled to sum to one.

The neighbor variables are used to explicitly model a pronounced spatial correlation in clearing and economic activity across the Amazon region. This spatial correlation arises because economic activity is not randomly distributed but rather follows a moving agricultural frontier. In front of the frontier there is little economic activity and thus little clearing. On the frontier, there is rapid clearing and a quickly emerging economy, while the area behind the frontier is characterized by a high level of clearing, a more mature economy, but less new clearing.

6. Estimation and specification testing

The six equations were all assumed to be log linear and estimated[13] using a general-to-specific principle along with the set of specification tests described below. We started out by including all the theoretically relevant explaining variables, then deleted those that were statistically insignificant, one by one, until all remaining coefficients were statistically significant at the 1% level. The 1% level was chosen both because of the rather large sample size of almost a thousand observations and because experience had shown us that coefficients that were not significant at the 1% level were very sensitive to changes in the set of explanatory variables and to the removal of outliers.

Each equation was then subjected to the following series of specification tests, and depending on the results some adjustments may have been made:

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[13] Both Gauss 386 and Eviews 1.1 were used in the estimations. Eviews were used for testing down, for standard test-statistics, and for systems estimation, while Gauss were used to create neighbor variables, to test for poolability and fixed effects, and for doing simulations.

Chow test for poolability over time This test tests for the validity of pooling data from 3 different time periods. First we make a pooled regression and obtain the Restricted Residual Sum of Squares ($RRSS$). Then we make separate regressions for each time period and sum the Residual Sum of Squares (RSS) from each regression to obtain the total Unrestricted Residual Sum of Squares ($URSS$). Based on these sums of squares, we calculate the following F-statistic:

$$F_{timepool} = \frac{RRSS - URSS}{(T-1)K} - \frac{URSS}{T(N-K)}$$

which follows an $F((T-1)K; T(N-K))$ distribution. Finally we calculate the P-value, which is the probability of obtaining an F-statistic as large as the one we just calculated, given that the null hypothesis is true. Thus, low P-values are bad, given that we want our null hypotheses to hold. Fortunately the null was not rejected for any of the six equations at any reasonable level of significance. Tables 3 to 8 report the specific P-values for each equation, both for this test and for the additional tests described below.

Chow test for excluding region specific fixed effects In panel data models, it is customary to deal with the heterogeneity between regions by including region specific fixed effects in the form of a region specific intercept term. This is done under the assumption that all the coefficients of interest are identical across regions, but that there might be other unobserved, time invariant characteristics that differ among regions.

In this data set we have a lot of variables available which potentially could capture region specific fixed effects *explicitly*. In that case we would not only know that there are differences, but we would know *why* there are differences. These differences may be explained by soil quality, location, river access, distance to major cities, original vegetation, and many other things which we have variables to proxy for.

In this paper, we have a strong preference for explicitly modelling these effects, rather than just including a region-specific intercept in our model. Not only because it gives us more information, but because some of the coefficients of interest cannot be estimated in the fixed effect model because the variables are time-invariant.

To test whether it is reasonable to disregard possible fixed effects, we have developed the following Chow test: First we make a pooled regression without fixed effects and obtain the $RRSS$ from this regression. Then we estimate a fixed effect model with N individual intercepts and obtain the $URSS$ from that. Based on these two Sum of Squares, we calculate the following F-statistic:

$$F_{nofix} = \frac{RRSS - URSS}{(T-1)K} - \frac{URSS}{TN - N - K}$$

which follows an $F((T-1)K;TN-N-K)$ distribution. Finally we calculate the P-value for the null hypothesis of no fixed effect. In the cases where the null was strongly rejected we tried to include state-dummies to reduce the problem. Even though the null was still rejected for some equations, we can maintain the specification without fixed effects with the argument that the potential reduction in bias does not outweigh the increase in variance and the loss of parameters of interest.

Normality test Normality was extremely strongly rejected by the Jarque-Bera test for all equations. The rejections were generally due to excess kurtosis rather than skewness. This is a warning sign that there may be some highly influential outliers. Therefore we removed the worst outliers, and did indeed find that in some cases it changed a coefficient from significant at the 1% level to insignificant. Both the variable of that coefficient and the outliers were then removed, and all tests were performed again on the adjusted equation. Normality is still rejected for all equations, but not as strongly as before.

Test for spatial correlation All our estimations are made under the assumption that the observations are independent both over time and across space. While we cannot make an autocorrelation test with only 3 time observations, it is possible to make an equivalent test for correlation in the spatial dimension.

In order to apply the principles of the standard autocorrelation tests we have to reduce the two-dimensional space in which the regions are located to a one-dimensional space like the time dimension. This is done by lining up all the regions according to their location so that we start from one corner of the Amazon and then take the nearest municipality, and the next-nearest, etc. There is room for ambiguity here, of course, but fortunately we didn't have to actually do this ordering, because the municipalities were originally numbered according to location, so we just had to sort all data according to municipality number.

When that is done, we can use the large sample Breusch-Godfrey Serial Correlation LM test statistic[14] as a proxy for a test of spatial correlation. We make the test with 5 neighbors, which is also the limit we have chosen for the construction of spatial variables.

When the null of no spatial correlation were rejected, we tried to include additional spatial variables to reduce the correlation problem. This usually helped and the remaining spatial correlation problems are small.

Tests for heteroskedasticity Heteroskedasticity in the error terms makes conventionally calculated standard error unreliable. With panel data sets as the current one, based on data from big and small, forested and deforested, untouched

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[14] Reported by Eviews 1.1. See Johnston (1984, pp. 319-321) for details about the test.

and economically developed regions, it is almost impossible to avoid heteroskedasticity in the error terms. Therefore we should bear in mind that the reported standard errors and t-values may be misleading. Typically the coefficients are not as significant as they look.

We report two different tests for heteroskedasticity. The first is the ARCH test proposed by Engle (1982) where we regress the squared residuals on the squared residuals of 5 neighbors. The second is White's heteroskedasticity test (White 1980) where we regress the squared errors on the original regressors plus the squares of the original regressors. The last test is the toughest, since the null hypothesis underlying the test assumes that the errors are both homoskedastic and independent of the regressors and that the linear specification of the model is correct. Failure of any one or more of these conditions could lead to a significant test statistic. And indeed it does for all our equations. The fact that the ARCH test do not reject the null nearly as strongly as the White test, suggests two things: First, that we may be ignoring important non-linearities in our data, and second, that the coefficients of interest may not be stable across regions. These two problems deserve further scrutiny, but the present paper will have to live with them.

6.1. Estimation results

After having gone through a series of specification tests and model adjustments the model was deemed "as good as possible". It was then considered to estimate the six equations as a system using the Seemingly Unrelated Regression (SUR) method to take advantage of any cross-equation correlation in the error terms. However, this would result in the loss of a substantial number of observations (224), since all equations would be estimated with the smallest common number of observations (826). It also meant that a handful of variables became insignificant and that further testing would become more difficult.

To judge which method was best, OLS or SURE, we made an in-sample test of each model in the following way. We made a multi-period forecast from 1970 to 1985 using the estimated parameters of each model along with actual values of all exogenous variables and the actual values of the endogenous variables in 1970. This resulted in a set of forecasts for the years 1975, 1980, and 1985, for each model. These forecasts were compared to the actual values, and a sum of squared errors were obtained for each endogenous variable over all regions over all three forecasting periods. A comparison of the two models showed that the OLS model outperformed the SURE model for all equations by having a lower sum of squared errors for all endogenous variables. Consequently, we chose the OLS results. These are reported in Tables 2 to 7.

The amount of newly cleared land is almost exclusively determined by the demand for new agricultural land, which in turn depend on the expected profitability of that land. The profitability depends on factors such as accessibility,

Table 2: Demand for newly cleared land

Dependent variable: ΔCLR_t		
Explaining variables:	Coefficient	T-value
Constant	2.879	6.9
Distance to federal capital	-0.237	-5.3
Road length$_{t-1}$	0.047	5.0
Neighbors' change in clearing$_t$	0.281	6.4
Rural pop. density$_{t-1}$	-0.002	-2.7
Level of clearing$_{t-1}$	-0.325	-15.9
Growth of urban output$_t$	0.095	2.8
Land prices$_{t-1}$	-0.097	-4.5
Cattle herd$_{t-1}$	0.149	10.6
Change in cattle herd$_t$	0.267	11.2
Change in agricultural output$_t$	0.164	4.4
Change in land prices$_t$	-0.280	-11.6
Dummy for Mato Grosso	0.168	2.7
Number of observations	831	
Adjusted R^2	0.486	
Specification tests		P-value
Normality test		0.0000
Spatial correlation test		0.1748
ARCH test		0.0373
Whites test		0.0000
Test for poolability over time		0.9999
Test for fixed effects		0.0002

availability, market conditions, and fiscal incentives.

Accessibility of land in a particular municipality was captured by its distance to the federal capital, road length in that municipality, and by the clearing situation in neighboring municipalities. Access is easier the higher the level of clearing in the neighboring municipalities. All three variables have the expected signs and are highly significant.

The coefficient of the lagged level of clearing is negative and highly significant. This is evidence of the saturation effect. As the level of clearing gets high, less forest is available for new clearing. The supply restrictions are further captured by rural population density. The more densely populated the municipality, the less new clearing can take place.

Economic prospects in a region are captured by urban output growth which indicates favorable local market conditions and by the lagged level of agricultural output.

The negative coefficients on land prices indicate that clearing mostly takes place in frontier areas where land prices are still low. As the frontier becomes more developed and land prices increase, permanent agriculture becomes relatively more attractive compared to the slash-and-burn methods practiced in land abundant areas.

Finally there are highly significant and positive coefficients on the size of the cattle herd in the previous period and on the change in the cattle herd. This supports the widespread accusations of cattle farming as the main cause of land clearing.

Table 3: Rural population equation

Dependent variable: ΔPOP_RURAL_t		
Explaining variables:	Coefficient	T-value
Constant	-0.345	-7.0
Neighbors' change in rural population$_t$	0.657	13.4
Road length$_{t-1}$	0.011	3.5
Growth of urban output$_t$	0.105	9.9
Urban income per urban capita$_{t-1}$	0.037	4.8
Change in cattle herd$_t$	0.026	3.3
City dummy	0.087	2.8
Dummy for Rondônia	0.390	4.1
Dummy for Pará	0.074	4.8
Dummy for Maranhão	0.065	4.9
Number of observations	831	
Adjusted R^2	0.410	
Specification tests		P-value
Normality test		0.0000
Spatial correlation test		0.9156
ARCH test		0.0075
Whites test		0.0000
Test for poolability over time		1.0000
Test for fixed effects		0.9948

The growth rate of the rural population is mainly determined by population pressure from neighboring municipalities, as shown by the highly significant coefficient to neighbors' change in rural population. Market conditions in the municipality are captured by four variables: i) urban income per urban capita, ii) the growth rate of urban output, iii) road length, and iv) a city dummy indicating whether there is a major city located in the municipality.

There is a significantly positive coefficient on the change in the cattle herd, indicating the massive need for rural labor to clear forest to establish new pastures.

The increase in the urban population is mainly determined by the pull effect of relatively high urban income per urban capita compared to rural income per rural capita. This shows from the highly significant positive coefficient on the

Table 4: Urban population equation

Dependent variable: ΔPOP_URBAN_t		
Explaining variables:	Coefficient	T-value
Constant	-0.152	-2.0
Urban population$_{t-1}$	-0.032	-6.9
Rural income per rural capita$_{t-1}$	-0.039	-3.9
Urban income per urban capita$_{t-1}$	0.080	9.4
Road length$_{t-1}$	0.023	6.5
Neighbors' change in road length$_{t-1}$	0.050	5.2
SUDAM credit$_{t-1}$	0.006	5.2
Neighbors' change in urban pop$_{t-1}$	0.291	5.3
Municipality area	0.027	5.8
Dummy for Amapá	-0.129	2.8
Number of observations	872	
Adjusted R^2	0.321	
Specification tests		P-value
Normality test		0.0000
Spatial correlation test		0.4360
ARCH test		0.4475
Whites test		0.0000
Test for poolability over time		1.0000
Test for fixed effects		0.7561

first variable and the negative coefficient on the second. Accessibility is also important as indicated by positive coefficients on lagged road length and the increase in roads in neighboring municipalities. Finally, subsidized credit from SUDAM appear to be a factor, even though this credit was specifically intended for agricultural establishments. The high significance of this coefficients supports the allegation that much of the highly subsidized credit granted to especially cattle ranches, were channeled to more profitable investments in the cities (where the ranch owners usually resided and conducted other business).

Table 5: Rural output equation

Dependent variable: ΔGDP_RURAL_t		
Explaining variables:	Coefficient	T-value
Constant	2.088	9.7
Road length$_{t-1}$	0.036	4.1
Change in road length$_t$	0.049	3.6
SUDAM credit$_{t-1}$	0.012	4.4
Municipality area	0.065	6.8
Rural income per rural pop$_{t-1}$	-0.256	-10.1
Neighbors' road length$_{t-1}$	-0.033	-2.7
Agricultural income$_{t-1}$	-0.088	-5.9
Neighbors' change in agricultural income$_t$	0.403	9.8
Dummy for Pará	0.143	4.3
Number of observations	947	
Adjusted R^2	0.409	
Specification tests		P-value
Normality test		0.0000
Spatial correlation test		0.1132
ARCH test		0.0002
Whites test		0.0000
Test for poolability over time		0.9483
Test for fixed effects		0.0000

The highest agricultural growth rates are clearly experienced at the agricultural frontier, rather than in more developed areas. This shows on the negative coefficients on rural per capita incomes, on lagged level of agricultural output, and on neighbors' road length.

Subsidized credit gets a significantly positive coefficient in this regression. In contrast to popular perception, this indicates that subsidized credit did have positive effects on agricultural output. That is, not all credit was absorbed by non-performing large-scale cattle ranchers focusing on land speculation. Road building also contributes to the growth of agricultural output and the highly significant coefficient on neighbors' change in agricultural output indicates a strong frontier effect.

Table 6: Urban output equation

Dependent variable: ΔGDP_URBAN_t		
Explaining variables:	Coefficient	T-value
Constant	0.4894	3.4
SUDAM credit$_{t-1}$	0.012	4.5
Urban output per urban capita$_{t-1}$	-0.102	-4.8
Municipality area	0.049	4.8
Change in cattle herd$_t$	0.089	4.1
Neighbors' change in agricultural output$_t$	0.502	11.7
Dummy for Mato Grosso	0.14	2.9
Number of observations	826	
Adjusted R^2	0.275	
Specification tests		P-value
Normality test		0.0000
Spatial correlation test		0.0000
ARCH test		0.0003
Whites test		0.0000
Test for poolability over time		0.7361
Test for fixed effects		n.a.^{a}

a. Too many missing observations caused the estimation procedure to fail when the fixed effect matrix were included.

Subsidized credit again appear to be an important factor for urban development, even though subsidized credit was intended for the rural sector. The highly significant coefficient supports the allegation that many of the funds intended for agro-pastoral activities were channelled away from the rural sector to the urban sector where returns tended to be higher. The positive coefficient on the cattle herd also supports this, because the credit often was attached to the cattle.

While the growth rate of urban output in neighboring municipalities was not significant, the growth rate of rural output was. This is probably because there is much more economic interaction between a city and its surrounding rural areas than between two cities.

Table 7: Land price equation

Dependent variable: $\Delta LANDPRICE_t$		
Explaining variables:	Coefficient	T-value
Constant	2.908	10.5
Distance to state capital	-0.062	-3.4
Urban income per urban capita$_{t-1}$	0.164	5.0
Landprices$_{t-1}$	0.562	-21.8
Municipality area	-0.111	-6.3
Neighbors' change in landprices$_t$	0.253	6.2
Dummy for Acre	-0.682	-4.3
Dummy for Pará	-0.229	-3.6
Dummy for Amapá	-0.542	-3.1
Dummy for Maranhão	-0.229	-3.6
Dummy for Mato Grosso	0.425	4.9
Number of observations	873	
Adjusted R^2	0.527	
Specification tests		P-value
Normality test		0.0000
Spatial correlation test		0.0014
ARCH test		0.0000
Whites test		0.0000
Test for poolability over time		1.0000
Test for fixed effects		0.0000

The significantly negative coefficient on the lagged level of land prices show that land prices tend to rise rapidly in the beginning but stabilize as land prices reach a level reflecting the true productivity of the land. The positive coefficient on neighbors change in landprices is a again a sign of a pronounced spatial correlation caused by the frontier effect.

The negative coefficient on the distance to the state capitals show that land prices tend to grow more rapidly the closer the land is located to major markets. The importance of good markets are further captured by the positive coefficient to the level of urban income per urban capita.

6.2. Model evaluation

To evaluate the estimated model, we simulate the behavior of the six endogenous variables during the sample period using actual values in 1970 as starting values, and actual values of all exogenous variables during the whole period. Table 8 compares the simulated values in 1985 with the actual values in 1985. It also reports the correlation between the simulated and actual values at municipality level. The last column reports the logarithm of the sum of squared deviations between the actual and simulated values of the endogenous variables across all regions and over all three forecasting periods. It is thus an aggregate measure of how well the model captures the dynamics and thereby is able to make multi-step ahead forecasts.

Table 8: Model evaluation

Variable	Actual 1985 value	Simulated 1985 value	Correlation[a]	log (SSE)[b]
Urban population (millions)	6.5	6.3	0.98	11.08
Rural population (millions)	6.7	6.5	0.82	11.22
Urban GDP (billion 1985-US$)	11.2	7.5	0.95	18.58
Rural GDP (billion 1985-US$)	2.3	1.9	0.79	16.62
Cleared area (million hectares)	68.7	57.1	0.96	9.42
Average land price (1985-US$)	131	83	0.13	4.09

a. The correlation at municipality level between the actual and simulated values in 1985.

b. The sum of squared errors calculated across all municipalities over all three forecasting periods for each variable. This amounts to some very large numbers, so the logarithm is reported rather than the actual sums.

Table 8 shows that there is little relationship between the R^2s of the estimated equations and their forecasting performance. The equation explaining land prices had the highest R^2 of all equations, but it clearly performs very badly. It consistently underestimates the real prices during all time periods, and the correlation between simulated and actual values is only 0.13. The rest of the equations are performing much better, having correlations of 0.79 - 0.95. However the two output equations also consistently underestimate the true values.

To avoid persistent biases in our model we tried to vary the constant terms of each equation to see how that affected the sum of squared errors for our six equations. Some small changes (within the 95% confidence intervals) did indeed improve model performance in terms of reducing the sum of squared errors over all three forecasting periods[15].

6.3. The causes of deforestation

To find out how much deforestation was caused by the aggressive development policies pursued during the 1970 – 1985 period, we compare the results from a factual simulation (using actual values of all exogenous values) with the results from a counter-factual simulation, where we set new road building, subsidized

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[15] After advice from professor Tore Schweder at University of Oslo, I also tried to vary the other coefficients to see if the dynamics of the model could be improved by that. Of particular concern was the coefficients to neighbor variables (spatially lagged dependent variables), since simultaneity problems may have caused them to be wrongly estimated by OLS. However, no other coefficients than the constant terms could be adjusted to improve the overall performance of the model.

credit, and growth pole-incentives to zero during the 1970 – 1985 period, while maintaining all other exogenous values at their actual levels. Any difference between the two simulations must therefore be attributed to the development policy package. The results, using the fine tuned model, are shown in Table 9.

Table 9: In-sample simulations

	Simulated values in 1985	
	Active scenario	Passive scenario
Urban population (millions)	6.3	4.8
Rural population (millions)	6.5	5.7
Urban GDP (billion 1985-US$)	11.4	7.6
Rural GDP (billion 1985-US$)	2.4	1.7
Cleared area (million hectares)	78.7	69.0
Average land price (1985-US$)	131	128

The simulations show that extra deforestation of 9.6 million hectares can be attributed to the aggressive development policies. 72% of this is explained by road building and 28% by subsidized credit. Growth poles were not found to have any significant effect on clearing.

The simulations also show that the development policies caused an extra GDP increase of $4.5 billion, of which 85% took place in the urban sector. This amounts to extra GDP in 1985 of $466 per hectare of extra cleared land.

7. Cost-benefit analysis of deforestation

The differences in output between the active and the passive scenario suggests that there is a trade-off between economic growth and forest clearing.

With the past mix of development policies, each extra hectare of land cleared yielded a GDP increase of $466. This value should be compared to the costs incurred by the development policies. That is, the costs of road building, the costs of providing subsidized credit, as well as the costs of deforestation.

According to Diniz (1985), from 1974 to 1986, the two programs PIN and PROTERRA together invested approximately 13 billion dollars in roads and settlement programs along the roads. This amounts to about $50/year per hectare of land cleared. The value includes both the direct infrastructure costs and the costs of the settlement programs that should encourage people settle along the roads.

During the period 1970 – 1985 rural credit worth $276.4 billion was granted in Brazil at real interest rates varying between −1.4% to −37.7% p.a. (Young 1996, Table 5.7, quoting Goldin & Rezende 1993). If the government could have invested this money with a real return equal to the social discount rate (for example, 2%), then the cost of subsidizing credit amounted to $54 billion (assuming that the credit was granted for 12 months periods on average). According to Mahar (1989), the Amazon region received less than 2% of the credit subsidy. Thus, dividing a credit subsidy to the Amazon of about \$1 billion[16] with the 27 million hectares cleared during the 1970 − 1985 period, we get a fiscal cost of subsidizing credit of about \$3/year per hectare of cleared land.

Allowing for infrastructure costs, settlement costs, and the cost of subsidizing credit, we get a net GDP increase in the order of \$400 per year per hectare of cleared land. At a 2% discount rate this amounts to a net present value of \$20,000/ha.

According to Andersen (1997), the costs of deforestation (lost sustainable logging, lost ecological services, bio-diversity loss, carbon release to the atmosphere, etc.) is in the order of \$18,000/hectare when applying a social discount rate of 2% (not including the funds transferred from the federal government to stimulate deforestation). This estimate comes with a large degree of uncertainty, however. Thus, the overall costs of deforestation appear to be approximately equivalent to the benefits when seen from the viewpoint of some global planners.

It is worth investigating the different components of the development policy separately. Road building causes substantial deforestation but is predicted to have only a small effect on output. This is because federal road building suppresses land prices and promotes wasteful use of land. The trade-off between output due to road building and clearing due to road building is estimated by our model to be \$113/year/hectare. Deducting the direct costs of road building from the benefits, we get net benefits in the order of \$63/year/hectare which amounts to a net present value of only \$3,150. This is clearly not sufficient to cover the global costs of deforestation.

Subsidized credit yields quite large returns in the form of higher rural and urban output. If the development policy consisted only of subsidized credit, the trade-off between deforestation and GDP would increase to about \$1,336/year per hectare of land cleared. This amounts to a net present value of \$66,800/hectare, which is substantially higher than the estimated costs of deforestation. Credit has a positive effect on rural GDP because credit allows investment in perennial crops which give higher yields per hectare than the cheaper annual crops (see Andersen 1996). Subsidized credit, which was intended for agro-pastoral activities, is also estimated to have a substantial effect on urban output. This is partly because of the stimulation of the urban agro-processing industries. An additional explanation may be that the people who were most successful in obtaining subsidized rural credit were urban based, and much of the credit granted for, for example, cattle ranching was never used for cattle raising, but rather for higher yielding urban investments. Credit, as opposed to road building and growth pole incentives, has the advantage of flowing naturally to the highest yielding projects.

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[16] This number is supported by Binswanger (1989, p. 15) who state that the fiscal costs of subsidizing livestock ranches exceeded US\$ 1 billion in 1975 − 1986.

Subsidized credit is therefore the most efficient development instrument in terms the trade-off between GDP and deforestation.

Table 10 summarizes the empirical effects of the three categories of policies. The first row gives the total area that is estimated to have been cleared during the period $1970 - 1985$ as a consequence of each policy. The second row gives the estimated net present value of the additional economic growth that has been caused by the policies *minus* the global costs of deforestation (put at \$18,000/ha no matter what the policy).

Table 10: Empirical effects of actual Brazilian policies

	Road building	Subsidized credit	Growth poles
Deforestation	+ 6.8 mio ha	+ 2.6 mio ha	0 ha
Global Welfare	– \$14,850/ha	+ \$48.800/ha	– \$18,000/ha

8. Conclusions

The present paper has made both a theoretical and an empirical analysis of the deforestation and welfare effects of the Brazilian policies that was implemented during the period 1970 - 1985 with the aim of integrating the Amazon region into the rest of the economy. The two analysis supplement each other very well.

The theoretical analysis indicated that road building would increase deforestation and probably have a bad effect on welfare. This was convincingly supported by the empirical model, which showed that road building during that period caused (directly and indirectly) the clearing of about 6.8 million hectares of more or less dense Amazonian forest. The total welfare effect of this was estimated to be negative, but the Brazilian part of the welfare gain was actually positive.

The theoretical analysis was inconclusive regarding the effects of subsidized credit because we couldn't determine whether the inputs obtained by this credit acted mainly as a substitute or mainly as a complement to cleared land. The empirical analysis showed that it tended to act as a complement in the sense that it caused an increase in deforestation of about 2.6 million hectares. However, the credit clearly also encouraged urban activities thereby increasing economic growth without causing significant deforestation. The total welfare gain was estimated to be positive, with the Brazilian gains far exceeding the global costs.

The theoretical analysis was also inconclusive about the effect of growth poles because some types of growth poles work in the direction of less deforestation, while others work in the direction of more deforestation. The empirical analysis confirms this ambiguous result by getting no significant effects from the growth pole policy - neither on the level of deforestation nor on the growth of output. With no significant growth in output we end up with a negative total welfare effect because of the negative global externalities.

The policy implications arising from this analysis are clear. If the government can secure that credit is available on favorable terms, it will have a large, positive effect on economic growth in the Amazon. It will also cause deforestation, but the trade-off has been estimated to be so favorable that it can justify deforestation—even when taking all the local and global externalities into account. The favorable effect of subsidized credit works through several mechanisms. First, the advantage of subsidized credit capitalizes into land prices, and higher land prices promote more efficient use of land. Second, the availability of credit allows farmers to fullfil their desire of investing in the more expensive but more sustainable and more profitable perennial crops. Finally, if the private returns to agriculture is too low, the credit can be channelled to more profitable urban activities which cause little deforestation.

Road building, on the other hand, need to be planned carefully in order to secure positive effects. Road building is harmful when it opens up new land and drives land prices down. It is good, however, if it improves infrastructure conditions in already cleared areas and thus pushes land prices upwards.

While subsidized credit is the most cost-effective way of stimulating economic growth, it is not the most equitable. Subsidized credit is generally only available to people who already own land and these constitute a small minority in Brazil. Road building, on the other hand, makes cheap frontier land available for everybody. Poor people will tend to benefit relatively more from this policy, because their lower opportunity costs makes them more likely to move to the frontier. There is thus a trade-off between efficiency and equity when choosing policy instruments. The present paper has focused only on the efficiency aspect.

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