Environment and Development Economics 2 (1997): 265–289

Developing-country resource extraction with asymmetric information and sovereign debt: a theoretical analysis*

JON STRAND

Department of Economics, University of Oslo, Box 1095, Blindern, 0317 Oslo, Norway

ABSTRACT. We consider a two-period model of an indebted developing country endowed with a natural resource whose extraction causes negative global externalities, where the country may borrow in period one and there is asymmetric information about its willingness to service its loans. We show that when the resource is large, the interest rate on new borrowing equals the resource growth rate. A greater initial debt level then leads to reduced new borrowing and more rapid extraction. An outside 'donor' may affect the resource extraction of the country. Donor schemes that tie debt reduction to postponing or abstaining from extraction of the resource are more powerful than non-conditional schemes in reducing the extraction rate for governments that actually repay, but may in some cases lead to a greater probability of default through increased debt. While conditional schemes generally are potentially Pareto-superior to non-conditional ones, the welfare of the borrowing country is higher with non-conditional schemes.

1. Introduction

The management of natural resources, and the burdens of foreign debt, are serious problem areas facing many developing countries today. An excessive rate of deforestation may lead to desertification, destruction of wildlife habitats and reduction in genetic diversity, and to climate effects through increased emission of greenhouse gases, thus causing serious global externalities that the rest of the world may be willing to pay substantial amounts to avoid. Similar externalities are associated with the excessive depletion of other biological resources such as wild animal and fish stocks, and of some minerals.[1] High debt levels may aggravate these problems by

* This article is part of the research project 'Environmental Policy under Limited and Asymmetric Information', at the SNF Centre for Research in Economics and Business Administration, Department of Economics, University of Oslo. The project has been supported by the Norwegian Science Foundation (NFR). Part of the article was written while the author was visiting the Department of Economics, Stanford University. I thank Michael Dooley, Marcel Fafchamps, Kenneth Kletzer and Jeffrey Williams, and three anonymous referees, for helpful comments on earlier versions. The usual disclaimer applies.

[1] In addition, internal institutional factors may aggravate these problems. For a general discussion, see Kreuger (1993), and for more specific applications to natural resources, Repetto (1988, 1990), Mahar (1989) and Schramm and Warford (1989). In this paper we will generally ignore such internal management problems.

https://doi.org/10.1017/S1355770X9700003X Published online by Cambridge University Press

putting direct pressure on the countries to extract valuable resources quickly in order to raise revenue or obtain international credit.[2]

Our point of departure for the present article is the observation that these two problems seem to coexist in a number of cases. Several heavily indebted countries are endowed with valuable resources whose extraction causes global externalities that one could have in mind with the model. Among these are some large petroleum-exporting countries (including Nigeria, Venezuela and Mexico); a larger group of countries (predominantly in South and Central America, but also in Central Africa and East Asia) endowed with large tropical forest areas; and even some countries that may earn a short-run profit by harvesting certain animal and fish species at non-sustainable rates (several African and Latin American countries).[3] In the public debate, and to some degree in the literature, much interest has focused on the relationship between deforestation and debt, with a strong presumption that this relationship is positive.[4] The overall purpose of this article is to clarify the theoretical basis for such connections, and for the mechanisms by which resource extraction then can be affected by outsiders.

We study a two-period model of a small country which has an initial debt and may in addition borrow in period one. Sovereign countries cannot be forced to repay their loans. A given country's 'type' (indicating its propensity to repay its debt) is known to the country's government itself, while lenders only know some prior distribution over possible types. The country has a (renewable) natural resource which can be exploited in either of the two periods or saved. We assume in *case a* that the resource is large and some of it extracted in both periods. In *case b*, the resource is small and extracted in one of the periods only. We initially assume that the resource is always fully extracted by the end of period two. There are no extraction costs. Output is homogeneous, and resources can be either ex-

[2] On general developing-country debt problems, see Kletzer (1984, 1994), Bulow and Rogoff (1988, 1989), Sachs (1988), Frenkel *et al*. (1989), Kletzer and Wright (1990), Cohen (1991), and the Winter 1990 issue of the *Journal of Economic Perspectives.*

[3] There is, however, probably no case which perfectly fits our model below. In particular, we assume that the government is in full control of resource extraction and that the resource in principle can be exported in its entirety: assumptions that rarely hold for forest resources which one most naturally has in mind for the model. A problem with interpreting our resource as petroleum or another mineral is that it may be hard to show that their extraction, in the particular countries we have in mind, causes global externalities in excess of those resulting from extraction of the same resources elsewhere. Note also that some recent work, notably the provocative cost–benefit analysis contained in Andersen *et al*. (1996) for the Brazilian Amazon, questions the conventional wisdom that tropical deforestation rates are everywhere socially excessive.

[4] See the discussion of such possible empirical relationships in Murphy (1994) and Kahn and McDonald (1995), both of whom demonstrate significant positive relationships between deforestation and debt on cross-sections of countries; and the overall assessment in Brown and Pearce (1994), where the conclusion as to the evidence to date on the existence of such a general relationship is more cautious.

ported or consumed domestically. The country has given incomes from other sources, and there is no investment.[5]

We consider three versions of the model, in sections 2, 3 and 4 respectively. In *model 1*, borrowers face a fixed interest rate, while 'dishonest' borrower types, intending not to pay back their loans, are constrained to borrow no more than 'honest' borrowers. *Model 2* differs from model 1 only by assuming that there is an established priority of loans with respect to repayment, old loans having priority over new ones. In *model 3* we instead assume that the rate of period one resource extraction can be monitored continuously throughout the period, and lending be made conditional on this rate. We then show that equilibrium must either be of a *pooling* type, where all government types borrow the same and extract the same amount of the resource period one, or be of a *partially separating* type, where some (defaulting) types choose not to borrow; other types borrow and do not pay back their loans; and still other types borrow and pay back.

Section 5 introduces outside parties, called 'donors'. These wish the country to postpone its resource extraction from period one to period two, or if possible indefinitely (beyond period two). They have no intrinsic common interest with creditors or in other ways with borrowers, and their only objective is to reduce possible negative externalities caused by excessive extraction. Most of the discussion in this section departs from model 1. We consider eight possible schemes to be used by donors. *Schemes a–b* are unconditional transfers to the borrower, in periods one and two respectively, while *scheme c* is an unconditional debt write-down in period one. *Scheme d* implies forgiveness of debt in period two, conditional only on debt being serviced in that period. *Scheme e* is a subsidy by the donor, on interest payments on new period one borrowing. *Scheme f* is a conditional debt repayment in period two, where a given amount of debt is repaid per unit of resources extracted. *Scheme g* is a 'debt-for-nature swap', by which is meant a debt write-down in period one, in return for taking over possession of a particular amount of the resource by the donor in period one. Finally, *scheme h* implies a repayment of part of the debt by the donor at the end of period two, in return for saving the resource beyond period two.

Through these schemes, the article identifies a number of ways in which the resource extraction of a sovereign, indebted and resource-endowed developing country can be affected by an outside 'donor' when there is asymmetric information between the borrower and lenders about the borrower's willingness to service his loans. A general conclusion of this discussion is that mechanisms that tie debt relief to resource extraction directly (schemes f–h) are more powerful than unconditional mechanisms (a–e), and that only the former may induce 'permanent resource saving'

[5] The latter is for analytical convenience only; introducing investment in physical capital would not significantly alter the conclusions drawn below. For discussions of investment in relation to developing-country debt problems, see Cohen and Sachs (1986), Krugman (1988), Borensztein (1989) and Cohen (1991), and in relation to resource extraction in cases where the country is credit-constrained, see Strand (1992).

(beyond period two in our model). Moreover, those mechanisms that also reduce the interest rates on new borrowing often have more force than those that work only via a pure debt write-down. When the amount of the resource is small, a (small) unconditional transfer or debt write-down generally has no effect, while the other schemes potentially have effects.

Some previous work exists on the analytical relationship between resources and debt. Rauscher (1990) found that increased debt leads to greater resource extraction, in a similar model with no additional borrowing, in continuous time with a potentially infinite horizon. Barbier and Rauscher (1994) considered the effects of trade interventions on tropical deforestation, and found that they are generally inefficient and may even be counterproductive. Three other papers by the author are worth mentioning. Strand (1992) dealt with a simpler two-period model where the resource-endowed country cannot borrow internationally, with symmetric information and no uncertainty. Strand (1995) extended this framework to consider borrowing, where new borrowing is more expensive than the cost of servicing old loans. Strand (1994) is more closely related to the current article, with pure uncertainty (but symmetric information) about the exogenous income of the country in period two. The current article extends the analysis to the arguably important case of asymmetric information about willingness to service loans. This permits a much richer analysis, both in terms of possible market equilibria and in terms of the mechanisms available to an outsider for affecting resource extraction.

2. Model 1: fixed-interest loan contracts

Consider a developing country with a two-period horizon, endowed with a natural resource S_1 at the start of period one. The country is small, so its borrowing does not affect world market interest rates, nor does its resource extraction affect world market resource prices. S_1 can be extracted in either or both of the periods, with no extraction cost, and either consumed directly or exported at no cost. Remaining resources grow in value at the rate g, i.e.,

$$S_2 = (1 + g)(S_1 - R_1), \tag{1}$$

where R_i is extraction in period i (= 1, 2). In most of the article we assume that the resource is always fully extracted by the end of period two, i.e. $R_2 = S_2$.[6] In principle, we may have $R_1 = 0$, $R_2 = 0$, or both positive. The country has other exogenous incomes X_1 and X_2 in the two periods, both known at the start of period one. It has an initial debt D_1, to be serviced at an exogenous world market interest rate of ρ, which is also the funding rate of creditors. Assume that the country borrows L_1 in period one, to be paid back with an interest rate of r, and that $-L_2$ is the debt repayment in period two. Then consumption C_i in each period is given by

$$C_i = X_i + R_i + L_i, \; i = 1, 2. \tag{2}$$

[6] This is always efficient for the country in the absence of third-party (or 'donor') involvement, which we assume here. We discuss such involvement in section 5 below.

https://doi.org/10.1017/S1355770X9700003X Published online by Cambridge University Press

The debt to be serviced in period two is given by

$$D_2 = (1 + \rho)D_1 + (1 + r)L_1. \tag{3}$$

We assume that a sovereign nation cannot be forced to make any debt repayments in period two. On the other hand, the borrowing country faces a fixed penalty *P*, in terms of consumption value in period two, if it chooses to default on its loans (or alternatively, faces a bonus of *P* if the loan is repaid).[7] It is then clear that the borrower will choose one of two options: either repay its loan in full, or default and make no debt repayments in period two.[8] Assume initially that the country chooses not to default and can borrow freely, facing a given rate of interest. Then the country maximizes its intertemporal utility

$$W = u(C_1) + \delta u(C_2), \tag{4}$$

where $u' > 0$, $u'' < 0$, $u' \rightarrow \infty$ for $C \rightarrow 0$, $u' \rightarrow 0$ for $C \rightarrow \infty$, with respect to L_1, R_1 and R_2, subject to constraints $R_1 \geq 0$, $R_2 \geq 0$, $R_2 \leq S_2$, and $L_1 \geq 0$, and where $\delta \in (0, 1)$ is its discount factor.

We distinguish between three different models, according to how the loan interest rate *r* is determined. In the present model 1, all countries face a *given r* on a given quota of loans, which may or may not equal the optimal loan size for non-defaulting ('honest') country types given the corresponding *r*. When the loan size is optimal for honest countries, these perceive themselves as unconstrained in the credit market, facing a fixed *r*. Countries that intend to default in period two must be constrained to borrow the amount borrowed by those intending not to default. This requires observability of each country's loan volume, but this information is not used by creditors to differentiate the rate of interest according to loan vol-

[7] The reasons why sovereign borrowers often actually repay their loans in the absence of formal enforcement are complex, and have been much discussed in recent literature. Much of this discussion is summed up in Cohen (1991) and Kletzer (1994). They argue that repayment incentives depend on the nature of the punishments suffered by a defaulting borrower, and on what types of punishments creditors actually have incentives to impose *ex post* on defaulting borrowers. Penalties may be suffered in the form of current reductions in consumption, as here, or as restrictions on or disruptions to future trade; see Eaton and Engers (1992) for an analytical discussion. As noticed by Kletzer (1994), the average return on lending to potential problem debtors has compared favourably to that on safer loans, implying a long-run equilibrium relationship in the market for lending to 'high-risk' countries.

[8] Alternatively, the borrower may in some circumstances enter into negotiations with creditors, possibly resulting in repayment of part but not all of the debt. In our context, some fraction of the debt could be viewed as due at some future time, beyond the horizon of the current model, or possibly (at the cost of some less severe penalty) forgiven by the creditors. As argued in much of the literature (e.g. Bulow and Rogoff, 1988; Kletzer, 1989; Ozler, 1989; Fernandez and Rosenthal, 1990), rescheduling and renegotiation of the debt would frequently be Pareto-preferred *ex post* by the lender and creditor together to an outright default with no repayment. Bargaining over debt repayments is also considered in Strand (1994).

ume or the rate of resource extraction.[9] Such conditioning is considered in model 2, in section 3 below.

The Lagrangian for countries that intend to pay back their debt in period two is then

$$H = u(X_1 + R_1 + L_1) + \delta u(X_2 + R_2 - (1+\rho)D_1 - (1+r)L_1) \\ - \lambda_1[S_2 - (1+g)(S_1 - R_1)] + \lambda_2 R_1 + \lambda_3 R_2 + \lambda_4 L_1. \quad (5)$$

The first-order conditions with respect to L_i, R_1 and R_2 are now for such countries, u_i denoting partial derivatives of u in period i (= 1, 2):

$$\frac{\partial H}{\partial L_1} = u_1 - \delta(1+r)u_2 + \lambda_4 = 0 \quad (6)$$

$$\frac{\partial H}{\partial R_1} = u_1 - \lambda_1(1+g) + \lambda_2 = 0 \quad (7)$$

$$\frac{\partial H}{\partial R_2} = \delta u_2 - \lambda_1 + \lambda_3 = 0. \quad (8)$$

Consider here first possible solutions with positive borrowing, i.e. $L_1 > 0$ and $\lambda_4 = 0$. We then find that $R_1 > 0$, $R_2 = 0$ if and only if $g < r$, while $R_1 = 0$, $R_2 > 0$ if and only if $g > r$. When $g = r$ we generally have an internal solution with $R_1, R_2 > 0$.

Consider next solutions with no borrowing by honest governments. Assume that such government would always borrow a positive amount given that $g \geq r$. No borrowing then requires $g < r$ and $R_1 > 0$, with $R_2 \geq 0$. With $R_2 > 0$, (6)–(8) yield $\lambda_4 > 0$ for $g < r$, while for $R_2 = 0$, $\delta(r - g)u_2 = (1 + g)\lambda_3 + \lambda_4$, implying that $\lambda_4 > 0$ if λ_3 is 'not too great'.

The country itself is assumed to know its own penalty P suffered upon a default, while creditors do not. To these, P is distributed across potential debtor types according to the continuous distribution $F(P)$, with support $[0, P_m]$, and the period two utility of a defaulting country can be written as $u(X_2 + R_2 - P)$.[10] A country is then exactly indifferent about defaulting or not, provided that $P = D_2 = P_1$. We now distinguish between cases a and b.

Case a: S_1 is sufficiently large that $R_1, R_2 > 0$ always

Now the country can smooth its consumption through varying the rate of resource extraction, without resorting to borrowing. An equilibrium with positive borrowing for 'honest' types must then always imply $r = g$.[11] This case is of interest in our context only when $g > \rho$, i.e. the resource growth

[9] Our model corresponds to the cases discussed by Kletzer (1984, 1989), where there is observability of a country's total loan volume. Clearly, our model cannot accommodate Kletzer's non-observability case, since dishonest borrowers would then demand an unlimited amount of credit in period one, leading to a breakdown of the credit market.

[10] This is particularly relevant if the penalty takes the form of a loss in period two consumption. This assumption in any case helps to make the model analytically tractable.

[11] This is no more than a standard criterion for optimal extraction, and essentially a restatement of Hotelling's rule. For countries with substantial amounts of more specific (e.g. forest) resources, g, and thus r, may differ.

rate exceeds creditors' funding cost in the world market.[12] In the opposite case, the country would always pay back all its initial debts in period one by extracting a sufficient amount of the resource, something we have ruled out by assumption.

We now wish to derive the conditions for existence of a solution with positive borrowing in this case, and the equilibrium rate of borrowing for 'honest' types. This rate is in turn mimicked by 'dishonest' types (i.e. those not intending to pay their debt back). The condition requiring creditors to break even on a positive amount L_1 of lending in period one is then $(1 + \rho)L_1 = (1 + g)[1 - F((1 + \rho)D_1 + (1 + g) L_1)]L_1$, or alternatively,

$$1 - F((1 + \rho)D_1 + (1 + g)L_1) = (1 + \rho)/(1 + g). \tag{9}$$

The condition for existence of a solution with $L_1 > 0$ is here obviously that

$$1 - F((1 + \rho)D_1) > (1 + \rho)/(1 + g). \tag{10}$$

When (10) fails to hold, no equilibrium with positive lending exists in the model. Intuitively, default occurs for 'too many' borrower types, even with no new borrowing. When (10) holds,

$$\frac{dL_1}{dD_1} = -\frac{1 + \rho}{1 + g.} \tag{11}$$

Thus L_1 drops when D_1 increases, so as to keep the total debt to be paid back in period two at a given level.

Consider next effects on resource extraction of changes in X_1, X_2 and D_1, for 'honest' country types (all of which will select identical levels of R_1 and R_2). These are derived in Appendix 1. We there find that increased X_1 reduces, while increased X_2 increases, R_1, in both cases by less than the change in X_i, and borrowing is unaltered. Higher X_1 implies greater wealth, and higher consumption C_i in both periods, and the increase in C_2 is due entirely to increased R_2. When X_2 increases, we have the opposite effect, i.e. the increase in C_1 is due entirely to increased R_1.[13]

An increase in D_1 has an effect on R_1 which is similar but opposite to that of X_1. Such an increase reduces period one borrowing such that D_2 is kept fixed, and the reduction in C_2 is implemented through a reduction in R_2.

While all 'honest' country types always have the same resource extraction profile, 'dishonest' types generally do not when creditors cannot use observations on resource extraction to condition their loans. In Appendix 1 we derive comparative statics for these, and show that $|dR_1/dP| \in (0, 1)$. Thus a 'more dishonest' country (with a lower P) extracts more of its resource in period one, but the increase is less than the reduction in P. Essentially, lower P implies greater wealth given a default, and thus greater

[12] This constraint may appear to limit the model to studying resources with high (value) growth rates. Alternatively, there may be positive (and possibly marginally increasing) extraction costs, and expectations about future reductions in these costs. Strand (1992) incorporates such costs explicitly, and derives optimal extraction profiles in this case.

[13] These effects are analogous to those of unconditional aid, in Strand (1992), for a country cut off from international credit markets.

consumption in both periods. The increase in period one consumption must be due to increased R_1, since borrowing is the same for all types.

Case b: S_1 small, either $R_1 = 0$ or $R_2 = 0$, and marginal utilities of consumption are not affected by R_i

In this case we assume that neither the country's behaviour nor marginal conditions in other respects are affected by the resource, and credit market equilibrium for the country can be derived as if there were no resources. Now $r \neq g$ in general. For a creditor to break even in expected terms on a loan to the country, we must have

$$(1 + \rho)D_1 + \frac{1 + \rho}{1 - F(P_1)} L_1 = P_1, \tag{12}$$

where P_1 is the debtor default cut-off level (equalling the amount to be paid back by the country in period two), and $(1 + \rho)/[1 - F(P_1)] = 1 + r$, where r is the interest rate on new loans. Equation (12) implies that to each level of $P_1 \geq (1 + \rho)D_1$ there corresponds a unique volume of loans $L_1 \geq 0$, making lenders break even. Along the $L_1(P_1)$ schedule for lenders (denoted by superscript 'S' below),

$$\frac{dL_1}{dP_1} = \frac{1 - F(P_1)}{1 + \rho} \left\{ 1 - \frac{1}{[1 - F(P_1)]^2} f(P_1)L_1 \right\}. \tag{13}$$

Here $dL_1^s/dP_1 > 0$ always for P_1 close to $(1 + \rho)D_1$. Moreover, as P_1 approaches P_m, $L_1 \rightarrow 0$. For intermediate values of P_1, $L_1 > 0$. An honest country is now willing to borrow a positive amount L_1 for any given r (assuming $R_1 = R_2 = 0$) whenever

$$u_1(X_1 + L_1) - \delta(1 + r)u_2(X_2 - (1 + \rho)D_1 - (1 + r)L_1) \geq 0. \tag{14}$$

In the following we will assume that (14) always holds with strict inequality for $L_1 = 0$. Then there always exist equilibria with positive borrowing in period one.[14] Relation (14) with equality then represents the demand function for credit from honest borrower types, denoted by superscript 'D' in the following. In Appendix 1 we find that $dL_1^D/dP_1 < 0$ everywhere, along the loan demand schedule for honest-country types. Equilibrium in the international lending market for the case of uniformly decreasing dL_1^S/dP_1 for lenders is illustrated by Figure 1. In this case the $L_1^D(P_1)$ schedule typically intersects the $L_1^S(P_1)$ schedule where $dL_1^S/dP_1 > 0$. Equilibrium is then uniquely given by the pair (P_1^*, L_1^*), and is stable.

Alternatively, in Figure 2, dL_1^S/dP_1 is not monotonously decreasing. The L_1^S and L_1^D curves here intersect at point P_{12} with a corresponding loan volume L_{12}. The question is, however, whether this can be an equilibrium for lenders. An alternative is to offer the greater loan volume L_{13}, at the lower interest rate $1 + r_3 = (1 + \rho)/[1 - F(P_{13})]$, which, however, requires rationing of borrowers since loan demand L_{14} exceeds supply L_{13} at this interest rate. If such a rationed supply can be credibly offered, it will, however, attract all demand, since the contract (L_{13}, r_3) is clearly preferable to (L_{12}, r^2) for all potential borrowers.

[14] These equilibria correspond closely to those discussed by, e.g., Stiglitz and Weiss (1981) and Eaton *et al.* (1986).

https://doi.org/10.1017/S1355770X9700003X Published online by Cambridge University Press

We are now ready to discuss resource extraction in case b. Honest countries will extract the resources fully in period one whenever $g < r$, and fully in period two whenever $g > r$, as long as they are not rationed in the credit market at the given r. An increase in X_1, and a reduction in D_1 and X_2, will now reduce loan demand by shifting the L_1^D curve in Figure 1 downwards. This implies lower equilibrium levels of both L_1 and r. There is then a possibility of a switch from $r > g$ to $r < g$, and thus in this case postponement of extraction from period one to period two.

With rationing (as for the possible solution (P_{13}, L_{13}) in Figure 2) the situation is more complicated. Now honest governments extract the resource

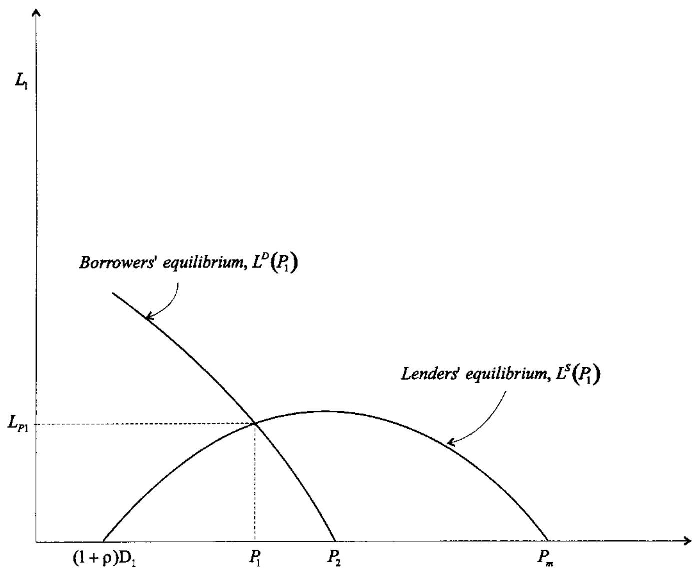

Figure 1. *Illustration of credit market equilibrium in case b.*

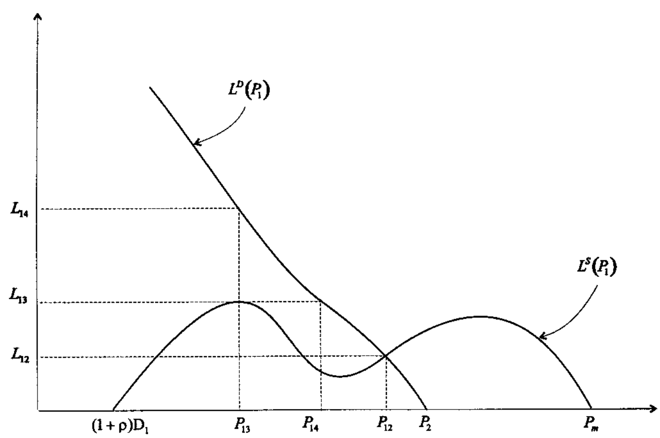

Figure 2. *Credit market equilibrium with rationing in case b.*

https://doi.org/10.1017/S1355770X9700003X Published online by Cambridge University Press

in period two whenever $g > r_4$, corresponding to P_{14} in Figure 2, where $r_3 < r_4 < r_2$. Thus, whenever $g \in (r_4, r_2)$, creditors' offering a loan contract with rationing instead of market-clearing leads honest borrowers to postpone resource extraction from period one to period two. A downward shift in the L^D curve (caused by higher X_1 and/or lower D_1 or X_2) may now imply that the new equilibrium is a non-rationed one (and always when the shift is sufficiently great).

Dishonest governments extract the resource in period one whenever

$$u_1(X_1 + L_1) > \delta(1 + g)u_2(X_2 - P). \tag{15}$$

When (15) holds for $P = P_1$, it holds for all $P < P_1$, and $R_1 > 0$, $R_2 = 0$ for all countries that default. In the opposite case, resources are exploited fully in period one for country types with $P \in [0, P_e]$, and in period two for country types with $P \in (P_e, P_1)$.

3. Model 2: loan interest rate conditional on loan volume; no resource extraction monitoring

In this model, the only difference from model 1 is that creditors offer borrowers a loan contract whereby the rate of interest is not fixed but a function of loan volume for all borrowers. This can be visualized in two alternative ways. The first is that all loans (old and new) given to a particular country are provided by one creditor or a coordinated group of creditors. The other is that there is an established priority ordering for the repayment of loans, where old loans have priority over new ones.[15] Along a zero-profit schedule for lenders, and given that all types borrow the same amount L_1,

$$\frac{dr}{dL_1} = \frac{(1 + r)^2 f(P_1)}{1 - F(P_1) - (1 + r)f(P_1)L_1} = A(L_1). \tag{16}$$

For relevant solutions, $dr/dL_1 > 0$. The corresponding relationship $r(L_1)$ now replaces r in (5). The first-order conditions of an honest government with respect to R_1 and R_2 are now still (7)–(8), while the condition with respect to L_1 is replaced by

$$u_1 - \delta[1 + r + L_1A(L_1)]u_2 + \lambda_4 = 0. \tag{17}$$

We also distinguish in this model between the two main cases in section 2 above.

Case a: $R_1, R_2 > 0$, S_1 large

For honest governments and $\lambda_2 = \lambda_3 = 0$, we now have

$$r + L_1A(P_1, L_1) - g = \lambda_4/\lambda_1. \tag{18}$$

Here $\lambda_4 = 0$ whenever $L_1 > 0$. Then with positive borrowing, $r = g -$

[15] There are, however, problems with both explanations, limiting the model's realism. With the first one, it may be difficult to visualize the credit market facing a given country as perfectly competitive, when there is only one supplier of credit. The second may be problematic when loans are actually incurred by individual private borrowers and the government cannot automatically be called on to serve as guarantor for these.

$L_1A(L_1) < g$. In the marginal case where $L_1 = 0$, $r = g$ and the condition is the same as in section 2 above. The set of parameter values under which there exists an equilibrium with positive lending is then also the same.

For a given positive L_1, however, the solution is different from that in section 2. Since r is lower here, P_1 is lower, i.e. fewer country types default, and L_1 lower. This implies that R_1 is higher by the same amount.

Case b: $R_1 = 0$ or $R_2 = 0$, S_1 small

As in section 2, assume that the country behaves as if it had no resources, in determining L_1. The first-order condition of an honest government with respect to L_1 is then

$$u_1(X_1 + L_1) - \delta[1 + r + L_1A(L_1)]u_2(X_2 - (1 + \rho)D_1 - (1 + r)L_1) = -\lambda_4, \quad (19)$$

where as before $\lambda_4 = 0$ whenever $L_1 > 0$. Thus, as in case a, the criterion for existence of an equilibrium with $L_1 > 0$ is the same as in section 2, with free borrowing at a given interest rate. For a given $L_1 > 0$, however, equilibrium is different from that in section 2, in much the same way as in case a. The added term L_1A implies increased borrowing cost at the margin, reducing both L_1 and r. Moreover, P_1 is on the domain $[(1 + \rho)D_1, P_{13}]$ in Figure 2, given an $L_1(P_1)$ schedule with the shape depicted there.[16]

The marginal interest rate $r + L_1A$ is now increased relative to the resource growth rate g. This implies that the resource will now be extracted in period one in more cases (in particular when $r < g < r + L_1A$, which would imply $R_1 = 0$ in the model of section 2, but $R_2 = 0$ here). The pressure on resource extraction thus increases. The same holds for dishonest governments: in (15), L_1 is reduced, increasing u_1 and leading to $R_1 > 0$ in 'more' cases.

Thus, overall, we find that period one resource extraction for honest governments is greater than in model 1. The reason is that borrowing countries here face a higher marginal loan interest rate, which makes them borrow less and instead rely more on resources for consumption in period one. On the other hand, fewer country types in general default. Since defaulting countries have higher resource extraction rates than non-defaulting ones, we cannot in general determine the direction of the effect on overall expected period one extraction.

4. Model 3: borrowing terms conditional on resource extraction

In this section we extend model 2 to the case where resource extraction in period one can be continuously monitored by creditors, and lending terms be made conditional on extraction. The interest rate still depends on loan volume as in model 2, but now the interest rate and loan volume may also depend on resource extraction in period one. Only case a will be considered here: in case b the resource is too small to be of value as a mechanism for differentiating loan contracts. Two possible solutions are relevant, namely, (I) pooling equilibria, and (II) partially separating equi-

[16] This is because when P_1 approaches P_{13} from below, dP_1/dL_1 approaches plus infinity.

libria. These are discussed in more detail in Appendix 2. All cases studied up to now have been pooling equilibria, in the sense that all borrower types borrow the same amount.

When monitoring of resource extraction in period one is feasible, loan terms can be made conditional on the rate of extraction. Models 1–2 above then no longer represent equilibrium behaviour for creditors, since the resource extraction rate of dishonest governments is systematically different from that of honest governments (and higher in period one). At a pooling equilibrium in this section, the resource extraction rate must be the same for all types of governments. This implies that such an equilibrium is more favourable with respect to overall resource extraction than the corresponding equilibrium under model 2: dishonest-country types now have a more favourable extraction profile by extracting less in period one, while honest-country types behave in the same way as under model 2.

Consider next the possibility of a *fully separating equilibrium*, where loans are extended only to government types that intend to pay them back, and to all these. As we show in Appendix 2, such equilibria do not exist in our model. Instead, *partially separating equilibria* may exist, where loans are extended to some defaulting types, while other defaulting types (with the lowest P levels) choose not to borrow. Now period one loans are made conditional on a particular (low) resource extraction rate in period one. The idea exploited is that countries intending to pay their loans back find it favourable to accept a loan contract with a low rate of interest, conditional on a low resource extraction rate, whereas those that intend to default find it preferable to extract the resource early (since they will have a relatively smaller 'need' to extract the resource in period two, as they then do not intend to pay back any debt at all). As shown in Appendix 2, such equilibria always exist when the volume of unrestricted loans is positive but low.

This solution has the potential to induce a very low resource extraction rate in period one among countries that choose to borrow, since, as noted, such a low extraction rate can be made a condition for lending. Among countries that choose to default, the extraction rates will, however, be higher than the corresponding rates in models 1–2. The reason for this is that such country types will now be totally cut off from international borrowing, and thus cannot consume out of additional borrowed means in period one. Their optimal consumption profile then implies that more is consumed out of the resource in period one.

5. Mechanisms for donor involvement

We now introduce an outside third party, here called a donor, which may affect the lending and repayment terms of the borrowing country and thereby its rate of resource extraction. This may be of interest to study when outside parties prefer lower rates of resource extraction than those chosen by the countries themselves. We now also ask whether the country can be made to save the resource beyond period two; so far, this issue has not been relevant, since we have assumed that neither the country itself nor its creditors have any interest in saving the resource beyond period two.

We assume that donors and creditors are separate entities, and all donors ignore effects on the rate of repayment of old loans, which is sometimes affected by the type of policy chosen. For a small donor, such as a small environmentally oriented non-governmental organization, this is generally unproblematic. It may, however, be more problematic for a large international financial organization (such as the World Bank or the International Monetary Fund) or for a large rich-country government.

We will discuss eight possible donor mechanisms. In the discussion, we depart from model 1 and the pooling equilibrium solution for model 3. In both cases, borrowing countries are assumed to face a given interest rate on period one loans. The main difference between the two models is then that under a pooling equilibrium in model 3, resource extraction is affected in the same way for honest and dishonest governments, while under model 1 it is not. Moreover, particular donor instruments may help to facilitate the implementation of a separating solution under model 3, and be used strategically for this purpose by the donor. Most attention will be paid to case a above, where the resource is large.

(a) Exogenous transfer in period one

The country here receives a free gift in period one, increasing its exogenous period one income by $dX_1.dR_1/dX_1 \in (-1, 0)$, from (A2) in Appendix 1. This implies that the country postpones extraction of an amount of the resource equivalent to some fraction, but never all, of the gift received.

(b) Exogenous transfer in period two

The effect on R_1 of a gift dX_2 in period two is given in (A3) in Appendix 1. Such a gift *increases* period one extraction: borrowing is unaltered, and the wealth increase from higher X_2 implies higher consumption out of the resource in period one.

(c) Exogenous debt forgiveness in period one

With exogenous debt forgiveness D_{10} in period one, $dR/dD_{10} = -\, dR_1/dD_1 \in (-1, 0)$ from (A4). An exogenous debt forgiveness thus lowers initial resource extraction, by less than the value of debt forgiven. Since P_1 is constant, independent of D_{10}, $dL_1/dD_{10} = (1 + \rho)/(1 + g)$, implying that honest-country types increase period one borrowing to keep total debt service in period two constant.

From (A2) and (A4), $-dR_1/dD_1 = [(1 + \rho)/(1 + g)][dR_1/dX_1]$. Apparently, therefore, debt forgiveness affects R_1 by less than a similar free gift. Note, however, that (for a small dD_1) $(1 + \rho)/(1 + g)$ can be interpreted as the purchase price of old debt claims in secondary debt markets. With access to such markets, a reduction in R_1 can be accomplished with equal efficiency for the donor either through an increase in X_1 or through a reduction in D_1.[17]

(d) Debt forgiveness in period two, conditional on the loan being paid back

Under model 1 above, assume that an amount D_{20} is paid back in this way.

[17] As many authors have noted, among them Bulow and Rogoff (1988), Dooley (1988) and Cohen (1991), when the amount of debt forgiveness is large, the market price of remaining debt is likely to increase, complicating our analysis.

https://doi.org/10.1017/S1355770X9700003X Published online by Cambridge University Press

$P_1 = (1+\rho)D_1 + (1+g)L_1 - D_{20}$ is still a constant and independent of D_{20}, for honest-country types, and the fraction of defaulting types still constant. The donor is indifferent about forgiving one unit of D_{10}, and $(1+\rho)$ units of D_{20}. Denote the present value of the total debt forgiven in this way, as seen from period one by the donor, by D_{2D}. Since only honest governments' debts are forgiven,

$$dR_1/dD_{2D} = [dR_1/dD_{10}]/[1 - F(P_1)]. \quad (20)$$

Period two debt forgiveness reduces initial resource extraction much like period one debt forgiveness and transfers, but opposite to a period two transfer. From (20), the effect on resource extraction per unit of total debt forgiven by the donor is greater now than with debt forgiveness in period one. Intuitively, the donor now avoids buying back old debt of countries that in any case default, thus reducing creditors' value of old debt. Still, the effect is the same per unit of money expended by a donor with access to a secondary market for old debt, as described under scheme c above (since $1 - F(p_1) = (1+\rho)/(1+g)$). With such access, forgiving period one debt, and forgiving period two debt conditionally on the rest of it being paid back, are thus equivalent mechanisms for the donor.[18]

(e) Donor subsidies on new loans

Instead of paying back the borrowing country's debt directly, the donor now reduces the interest rate on new loans in period one (corresponding to scheme a above given fixed debt repayment), or on loans actually repaid in period two (corresponding to scheme d). In case a, this mechanism is essentially identical to scheme a for a given total amount of subsidy, since the equilibrium interest rate facing an honest country is still the same (given by $r = g$), and since the total amount of debt incurred by the country is the same.[19]

(f) Debt repayment in period two conditional on resource extraction in period one

We now assume that the repayment of debt in period two is tied to the rate of resource extraction in period one, for countries willing to service their debt in period 2.[20] Departing from a pooling equilibrium in model 3, all

[18] Considering schemes a–d under case b, with a small resource stock, a small gift or debt forgiveness as a rule has no effect on resource extraction. A large transfer may, however, in principle shift the solution from one with the entire extraction in period one, to another solution where the entire extraction is made in period two.

[19] In case b, however, the equilibrium interest rate will be lowered directly by the subsidy. Then r may fall from a level above g to below this level, resulting in extraction in period two instead of one. Then interest rate subsidies have clear advantages over a pure debt forgiveness.

[20] Note that schemes whereby direct period two aid is made conditional on period one resource extraction are always inferior to schemes working via conditional period two debt repayment, at least versus honest governments. The only apparent advantage of the former scheme is that also dishonest governments' resource extraction can be affected by a direct period two transfer that is conditional only on resource extraction and not on debt repayment. Such a scheme is considered in Strand (1992), in the context of a model of pure aid and no borrowing.

https://doi.org/10.1017/S1355770X9700003X Published online by Cambridge University Press

government types' extraction rates are affected in the same ways. Such a scheme has more favourable properties, with respect to inducing the country to postpone resource extraction, than any of the schemes above. First, such a conditional mechanism is more favourable with respect to countries paying back their loans, since it works more directly on resource extraction as a target. Secondly, when the pooling equilibrium in model 3 applies, also dishonest countries' behaviour is affected in the same way, by assumption. A more careful analytical discussion of this case is contained in Appendix 3.

(g) 'Debt-for-nature swaps'

Here the donor purchases a unit dS_1 of the resource in period one, in return for a debt forgiveness of dD_1 in period one.[21] In case a, a swap of dD_1 for dS_1 is acceptable to the borrower whenever $dD_1 = [(1 + g)/(1 + \rho)]dS_1$, where $(1 + \rho)/(1 + g)$ corresponds to the secondary market debt value. The swap is thus one-for-one as viewed by a donor with access to such a secondary market. The effects of a debt-for-nature swap are then identical to those of a cash purchase of the same amount of the resource in period one. Note also that none of the country's other conditions change; thus R_1 remains constant, and the only change is that part of it now goes directly to service its initial debt.

From the above discussion it would appear that there are no intrinsic advantages to swapping debt with resources, over a direct cash purchase of the same resources. Note, however, that a debt-for-nature swap that is marginally favourable to an honest government is always unfavourable to a dishonest one. An implication of this is that whenever such swaps can credibly be executed, they may help to implement more efficient, partially separating equilibria within model 3. Willingness to engage in such swaps may then signal willingness to service loans, and make it possible to extend more efficient loan packages to repaying borrowers, at a partially separating equilibrium.[22] The detailed analysis of such joint lending and swaps will here be left for future analysis. In Appendix 2 we, however, briefly indicate how such a swap initiated by the donor may be combined with a contingent commercial lending scheme, making debt-for-nature swaps preferable to direct cash purchases of the same resources.

(h) Debt forgiveness at the end of period two, conditional on resources spared by that time

Consider R_1 given, and whether the donor may induce the country to ab-

[21] Alternatively, such a swap could in principle be executed in terms of a contingent debt reduction in period two. We will here disregard this possibility.

[22] This mechanism, of course, hinges on the degree of certainty with which control of the resource is actually transferred to the donor. Otherwise, a country intending to default on its loans in the future could simply engage in a phoney 'debt-for-nature swap' in period one (in order to masquerade as an honest type and thereby obtain loans), and later confiscate the resources that were initially swapped. Essentially, this is equivalent to the question whether resources lying within the boundaries of a sovereign borrowing nation can credibly be used as collateral for international loans. The proposed mechanism can work only when this is the case.

stain from consuming the remaining resource S_2 in period two. This can work only for honest-country types, intending to pay their loans back. The condition required to induce the country to save dS_2 in period two is simply $dD_2 = dS_2$, where dD_2 is the amount of debt forgiven. Note that such a debt repayment in return for resource saving, or even a promise of such a conditional repayment in period one, cannot contribute to increasing the total volume of debt incurred by the country in period one. For one thing, the loan demand of an honest country will be unchanged, and there are no effects on default incentives in period two.

Finally, such a mechanism can work only for honest governments. A government that defaults on its debt attaches no value to an *ex post* debt write-down, and will not be induced to repay when debt is exchanged for resource-saving one-for-one in period two. Only when the debt write-down is greater than the value of the resource saved could more government types be induced to pay their loans. back. In such a case, initial borrowing would, however, also increase; its full analysis must be left for future work.

6. Conclusions and final comments

In this final section we will briefly discuss some problems with the analysis above, and point out some possible avenues for future research.

(1) Much of our analysis hinges on the assumption of asymmetric information between borrowers and lenders, where the borrower's propensity to repay its loans is not fully known to lenders. While similar informational assumptions have been invoked in the related literature, notably Kletzer (1984) and Eaton *et al.* (1986), this problem may be small compared to that raised by pure and symmetrically distributed uncertainty related to the future ability of debtors to repay their loans.[23] Our attitude here is that asymmetric information even in this context is a potentially serious problem, in particular versus countries whose leadership is volatile or changes frequently. The issue of pure uncertainty is dealt with in a related paper (Strand, 1994); the next step should be to combine these two approaches in one unified model.

(2) In the model above we have assumed that the country's government is fully in charge of its resource extraction, and allocates resources in the best interest of its population. While a first step in a research process, this is probably a very naive way of viewing government policy in most developing countries. Many problems of overexploitation of developing-country resources, discussed, for example, by Repetto (1988, 1990), are instead claimed to be due to policies that are faulty and 'irrational' or benefit particular interest or pressure groups. Moreover, the control of resources is often clearly not fully in the hands of central government, but rather in those of small farmers, landholders or other individual agents. A more realistic model should come to grips with such issues.

[23] See in this connection Guesnerie's (1986) comment on Eaton *et al.* (1986), where such arguments are invoked.

(3) In our model we assume two periods, and a simple penalty imposed in period two on a defaulting borrower. This is unsatisfactory, but it is unclear how an extension to more (potentially infinitely many) periods can be achieved without excessively complicating the analysis; and in that case how the main results would change. This is also an important topic for future research.[24]

(4) A key assumption above is that the policies of 'donors' are unconstrained. In particular, donors can commit to any future policy with respect to debt relief or subsidy. This is clearly too simple a view over the potential timeframes relevant here. Country governments and their policies change, and so do the policies of large financial institutions such as the World Bank and the IMF. Even worse, different interest groups behind such institutions may have diverging and shifting preferences.[25] An objective of future research in this area may be to analyse credible donor policies, and the limitations a credibility requirement places on the set of implementable policies.

(5) Finally, we have analysed effective policies as viewed by donors, but have said little about the developing countries' own preferences concerning these policies. In general, extraction-contingent mechanisms are potentially Pareto-superior to non-conditional mechanisms (since they contribute to a lower rate of resource extraction and thus presumably to an overall more efficient global resource use). Non-contingent mechanisms may still be preferable for the developing countries themselves, at least for a given amount of resources expended by the donor.[26] This underlies the principle that the debt reduction schemes considered here should come *in addition to*, and not *replace*, already existing schemes for supporting the countries in question. A further analysis of the overall efficiency of the various schemes must, however, await future research.

[24] In some recent models of bargaining with sovereign debt, notably Bulow and Rogoff (1989) and Fernandez and Rosenthal (1990), the analysis is extended to a potential infinity of periods, where the debt is constantly recontracted. It is, however, uncertain how the current asymmetric information framework would carry over to a larger number of periods. Rauscher (1990) studies the effect on resource extraction of greater debt with continuous time and infinite horizon, in a simpler model than ours. His main conclusion is, rather unsurprisingly, that greater debt leads to more rapid resource extraction.

[25] A related issue is to what degree such individual 'donors' are able to act fully on behalf of all interested outside parties, and thus, potentially, fully able to internalize the negative externalities resulting from excessive resource extraction. An institution such as the World Bank should be more suited for this task than an individual government or private environmental organization.

[26] As an illustration, consider first a non-contingent debt write-down, which clearly must increase the utility of an honest borrower. A marginally favourable debt-for-nature swap, however, will leave an honest borrower at the same utility level as before the swap.

References

Andersen, L.E., C.W.J. Granger, L.-L. Huang, E.J. Reis and D. Weinhold (1996), 'Report on Amazon deforestation', mimeo, University of Aarhus/ University of California, San Diego.

Barbier, E. and M. Rauscher (1994), 'Trade, tropical deforestation and policy interventions', *Environmental and Resource Economics* **4**: 75–90.

Borensztein, E. (1989), 'The effect of external debt on investment', *Finance and Development* **16**(3): 17–19.

Brown, K. and D. Pearce (1994), *Trade, Tropical Deforestation and Policy Interventions*, London: Earthscan.

Bulow, J. and K. Rogoff (1988), 'The buyback boondoggle', *Brookings Papers on Economic Activity* **2**: 675–698.

Bulow, J. and K. Rogoff (1989), 'A constant recontracting model of sovereign debt', *Journal of Political Economy* **97**: 155–178.

Cohen, D. (1991), *Private Lending to Sovereign States*, Cambridge, MA: MIT Press.

Cohen, D. and J. Sachs (1986), 'Growth and external debt under risk of repudiation', *European Economic Review* **30**: 529–560.

Dooley, M. (1988), 'Buybacks and the market valuation of external debt', IMF staff paper 35, International Monetary Fund, Washington, DC, 215–229.

Eaton, J. and M. Engers (1992), 'Sanctions', *Journal of Political Economy* **100**: 899–928.

Eaton, J., M. Gersowitz and J.E. Stiglitz (1986), 'The pure theory of country risk', *European Economic Review* **30**: 481–513.

Fernandez, R. and R. Rosenthal (1990), 'Sovereign debt renegotiations: a strategic analysis', *Review of Economic Studies* **57**: 331–349.

Frenkel, J.A., M.P. Dooley and P. Wickham, eds. (1989), *Analytical Issues in Debt*, Washington, DC: International Monetary Fund.

Guesnerie, R. (1986), 'Comment on Eaton, Gersowitz and Stiglitz (1986)', *European Economic Review* **30**: 515–519.

Kahn, J.B. and J.A. McDonald (1995), 'Third-world debt and tropical deforestation', *Ecological Economics* **12**: 107–123.

Kletzer, K.M. (1984), 'Asymmetries of information and LDC debt with sovereign risk', *Economic Journal* **94**: 287–307.

Kletzer, K.M. (1989), 'Sovereign debt renegotiation under asymmetric information', *in* J. Frenkel, M. Dooley and P. Wickham, eds., *Analytical Issues in Debt*, Washington, DC: International Monetary Fund, 208–241.

Kletzer, K.M. (1994), 'Sovereign immunity and international lending', *in* F. van der Ploeg, ed., *Handbook of International Macroeconomics*, Amsterdam: North-Holland.

Kletzer, K.M. and B.D. Wright (1990), 'Sovereign debt renegotiation in a consumption-smoothing model', Economic Growth Center Discussion Paper No. 610, Yale University.

Kreuger, A. (1993), *The Political Economy of Policy Reform in Developing Countries*, Cambridge, MA: MIT Press.

Krugman, P. (1988), 'Financing vs. forgiving a debt overhang: some analytical notes', *Journal of Development Economics* **29**: 253–268.

Mahar, D. (1989), 'Government policies and deforestation in Brazil's Amazon region', Washington, DC: The World Bank.

Murphy, P. (1994), 'Debt and deforestation in developing countries', mimeo, University of California, Santa Barbara.

Ozler, S. (1989), 'On the relation between reschedulings and bank value: theory and evidence', *American Economic Review* **79**: 1117–1131.

Rauscher, M. (1990), 'The optimal use of environmental resources by an indebted country', *Journal of Institutional and Theoretical Economics* **146**: 500–516.

Repetto, R. (1988), *The Forest for the Trees? Government Policies and the Misuse of Forest Resources*, Washington, DC: World Resources Institute.

Repetto, R. (1990), 'Deforestation in the tropics', *Scientific American* **162**(4): 18–25.
Sachs, J. (1988), 'The debt overhang of developing countries', *in* J. de Macedo and R. Findlay, eds., *Debt, Growth and Stabilization: Essays in Honour of Carlos Dias Alejandro*, Oxford: Blackwell.
Schramm, G. and J.J. Warford, eds. (1989), *Environmental Management and Economic Development*, Baltimore, MD: Johns Hopkins Press.
Stiglitz, J.E. and Weiss, A. (1981), 'Credit rationing in markets with imperfect information', *American Economic Review* **71**: 393–410.
Strand, J. (1992), 'Foreign aid, capital accumulation and developing country resource extraction', *Journal of Development Economics* **38**: 147–163.
Strand, J. (1994), 'Developing country resource extraction with sovereign debt', mimeo, Stanford University.
Strand, J. (1995), 'Lending terms, debt concessions, and developing countries' resource extraction', *Resource and Energy Economics* **17**: 99–117.

APPENDIX 1

Analytical discussion of model 1

From (7)–(8) we have for honest-government types in case a:

$$u_1\left(X_1 + R_1 + \frac{1}{1+g}D_2 - \frac{1+\rho}{1+g}D_1\right) = \delta(1+g)u_2(X_2 + R_2 - D_2). \tag{A1}$$

We find the following comparative-static results:

$$\frac{dR_1}{dX_1} = -\frac{u_{11}}{u_{11} + \delta(1+g)^2\, u_{22}} \tag{A2}$$

$$\frac{dR_1}{dX_2} = \frac{\delta(1+g)u_{22}}{u_{11} + \delta(1+g)^2\, u_{22}} \tag{A3}$$

$$\frac{dR_1}{dD_1} = \frac{1+\rho}{1+g}\,\frac{u_{11}}{u_{11} + \delta(1+g)^2 u_{22}}. \tag{A4}$$

Note that (A2) and (A4) differ by a factor of $(1+\rho)/(1+g)$, expressing the equilibrium market value of claims to (a small amount of) old debt.

The first-order conditions with respect to R_1 and R_2 for dishonest government types are from (7)–(8):

$$u_1\left(X_1 + R_1 + \frac{1}{1+g}\,D_2 - \frac{1+\rho}{1+r}\,D_1\right) = \delta(1+g)u_2(X_2 + R_2 - iP), \tag{A5}$$

where P is drawn from F on $[0, D_2)$. dR_1/dD_1 will generally be given by (A4). For fixed X_i and D_1, the relationship between R_1 and P is given by

$$\frac{dR_1}{dP} = -\frac{\delta(1+g)u_{22}}{u_{11} + \delta(1+g)^2 u_{22}} < 0. \tag{A6}$$

The equilibrium condition for honest countries can in case b be written as

$$u_1(X + L_1) = \delta\,\frac{1+\rho}{1-F(P_1)}\,u_2\left(X_2 - (1+\rho)D_1 - \frac{1+\rho}{1-F(P_1)}\,L_1\right), \tag{A7}$$

for $P_1 \geq (1+\rho)D_1$. Equations (12) and (A7) now solve for L_1 and P_1.

Implicitly differentiating (A7) with respect to L_1 and r (= $(1 + \rho)/[1 - F(P_1)] - 1$) yields

$$\frac{dL_1}{dr} = \delta \frac{u_2 - (1 + r)L_1 u_{22}}{u_{11} + \delta(1 + r^2)u_{22}} < 0 \qquad \text{(A8)}$$

where $dr/dP_1 = \{(1 + \rho)L_1/[1 - F(P_1)]^2\}f(P_1) > 0$. Thus $dL_1^D/dP_1 < 0$ everywhere, along the loan demand schedule for countries intending to pay back their loans ('honest' countries). The loan volume demanded is thus falling in P_1 and hits zero for $P_1 = P_2$, given by

$$u_1(X_1) = \delta \frac{1 + \rho}{1 - F(P_1)} u_2(X_2 - (1 + \rho)D_1), \qquad \text{(A9)}$$

where $P_1 \in ((1 + \rho)D_1, P_m)$.

APPENDIX 2
Discussion of model 3

I. Pooling equilibria

At a pooling equilibrium, loans are given in the same amount to all government types. A question is whether conditioning loans to honest governments on the rate of resource extraction can be beneficial for lenders. For this to be the case, P_1, and thus the probability that the loan will be serviced in period two, must be functions of R_1 and R_2. From the relationship $D_2 = P_1$ we find (using (3)) that this is not the case, implying that in our model there is no role for resource extraction to serve as a device for loan conditionality, given a pooling equilibrium. The only way in which the current model differs from case a in model 2 is that dishonest governments now are 'forced' to select the same resource extraction rate as that of honest ones. From (A3), R_1 is gradually higher for defaulting government types with gradually lower P, in sections 2 and 3. For these governments, R_1 will be lower given a pooling equilibrium here. The expected level of R_2 over all government types will thus be lower here.

A condition for a pooling equilibrium to exist is that defaulting governments must prefer borrowing to not borrowing, given that they will be constrained in setting R_1 and R_2. Note that if a government with $P = 0$ prefers the borrowing option, all government types will prefer to borrow, since the desirability of borrowing is falling in P for defaulting governments. This implies the following condition:

$$u(X_1 + R_{11} + L_1) + \delta u(X_2 + R_{21}) > u(X_1 + R_{10}) + \delta u(X_2 + R_{20}), \qquad \text{(A10)}$$

where R_{i0} and R_{i1} refer to such a government's unconstrained and constrained choices of R_i respectively, in the two solutions. Relation (A10) fails to hold when R_{10} is significantly larger than $R_{11} + L_1$, L_1 is small and D_1 large, and always when L_1 is only slightly positive and D_1 of some magnitude.

II. Separating equilibria

Consider first the possible existence of a *fully separating equilibrium (FSE)*. This must have the following characteristics:

- Government types on the domain $[0, P_0]$ do not demand loans, and

https://doi.org/10.1017/S1355770X9700003X Published online by Cambridge University Press

- Government types on the domain $[P_0, P_m]$ demand loans, and actually pay them back, $0 < P_0 < P_m$.

Two questions here arise for creditors, namely,

(1) is it feasible to design a loan contract that will implement such a separation? and
(2) given that the contract is feasible, can it profitably be offered?

Formally, we will attempt to construct a FSE that would yield at least as high utility to honest-government types as that derived in section 3a, and that (at least) breaks even for creditors. The following condition must then hold:

$$u(X_1 + R_{1R} + L_{1R}) + \delta u(X_2 + R_{2R} - (1+\rho)D_1 - (1+r_R)L_{1R}) \geq u(X_1 + R_1 + L_1) + \delta u\left(X_2 + R_2 - (1+\rho)D_1 - \frac{1+\rho}{1-F(P_1)}L_1\right), \quad \text{(A11)}$$

where L_{1R} is the amount of lending now offered by creditors at interest rate r_R, and R_{1R}, R_{2R} are the associated resource extraction levels on which lending is made conditional. Note that at a FSE, $r_R = \rho$ at a zero-profit solution for creditors. At a partially separating equilibrium (PSE), to be discussed below, some government types may borrow and default, and then $r_R > \rho$. In addition to (A11), the incentive compatibility condition

$$(1+\rho)D_1 + (1 + r_R L_{1R}) \leq P \quad \text{(A12)}$$

must hold for country types that select a loan contract. Consider next the derivation of the level P_0 of P that leaves a country type indifferent about taking a loan or not. Clearly, (A12) must hold for such a type at a separating equilibrium given that it accepts the loan L_{1R}. Moreover, such a country type will not default given that it declines to borrow. Indifference about borrowing or not then implies the condition

$$u(X_1 + R_{1R} + L_{1R}) + \delta u(X_2 + R_{2R} - (1+\rho)D_1 - (1+r_R)L_{1R}) = u(X_1 + R_1) + \delta u(X_2 + R_2 - (1+\rho)D_1). \quad \text{(A13)}$$

(A11) and (A13) together imply

$$u(X_1 + R_1) + \delta u(X_2 + R_2 - (1 + \rho D_1)) \geq u(X_1 + R_1 + L_1) + \delta u(X_2 + R_2 - (1+\rho)D_1 - ((1+\rho)/(1 - F(P_0)))L_1), \quad \text{(A14)}$$

where R_i are the unconstrained optimal levels given loan repayment, and $L_1 > 0$ is the optimal loan size. But then (A14) implies a contradiction, since a possible optimal loan size clearly must have been zero in the original model. Thus no FSE can exist when the original pooling equilibrium (PE) implies $L_1 > 0$. Consider now the case of $L_1 = 0$ in the PE. This implies that the interest rate $r = (1+\rho)/[1 - F((1+\rho)D_1)] - 1$ is sufficiently high to deter any new loan demand from honest governments. Here, however, with full separation, $r_R = \rho$ by construction, at which interest rate loan demand may still very well be positive. In this case, (A14) holds with equality, implying that (A11)–(A13) by themselves do not prevent the existence of a FSE. The participation conditions, for choosing not to borrow for a government on $[0, P_0)$, but to borrow for a government on $[P_0, P_m)$, are

$$u(X_1 + R_1) + \delta u(X_2 + R_2 - (1 + \rho)D_1) > u(X_1 + R_{1R} + L_{1R}) + \delta u(X_2 + R_{2R} - P),\ P \in [(1 + \rho)D_1, P_1). \quad \text{(A15)}$$

$$u(X_1 + R_1) + \delta u(X_2 + R_{2R} - P) > u(X_1 + R_{1R} + L_{1R}) + \delta u(X_2 + R_{2R} - P),\ P < (1 + \rho)D_1. \quad \text{(A16)}$$

In both cases (A15) and (A16), inequality is incompatible with equality in (A13). Thus no FSE exists, since it is incompatible with dishonest-country types choosing not to borrow. Consider next possible *partially separating equilibria (PSEs)*. These have the property that some country types at equilibrium choose not to borrow; other types choose to borrow but default; while still other types borrow and pay their loans back. At such equilibria, non-borrowers must be characterized by $P \in [0, P_0)$, defaulting borrowers by $P \in [P_0, P_1)$, and repaying borrowers by $P \in [P_1, P_m]$; where $0 < P_0 < P_1 < P_m$. This is easily seen by noting that types differ only in P. For a given loan size, then, default occurs for low P ($<P_1$) and repayment for high P ($\geq P_1$). Moreover, among defaulters, those with low P ($<P_1$) are more eager to extract their resource early, and thus have a lower utility in a resource-extraction-constrained solution with relatively low period one extraction (as must be the case here; see the demonstration below), and then less prone to borrow, than governments with higher types $P \in [P_0, P_1)$. We will investigate whether a viable loan contract, fulfilling (A11), of this type can exist. To derive P_0, assume first $P_0 \leq (1 + \rho)D_1$, and is given by

$$u(X_1 + R_1) + \delta u(X_2 + R_2 - P_0) = u(X_1 + R_{1R} + L_{1R}) + \delta u(X_2 + R_{2R} - P_0). \quad \text{(A17)}$$

When $P_0 \in [(1 + \rho)D_1, (1 + \rho)D_1 + (1 + r_R)R_{1R})$, the condition for P_0 is

$$u(X_1 + R_1) + \delta u(X_2 + R_2 - (1 + \rho)D_1) = u(X_1 + R_{1R} + L_{1R}) + \delta u(X_2 + R_{2R} - P_0). \quad \text{(A18)}$$

Assume in the first case that a solution to (A17) exists for some $P_0 > 0$ (if no such solutions exist, we again have the solution of section 3). For the contract to have the desired properties, a higher L_{1R} must correspond to a lower P_0, since more government types must choose to borrow (and default) the higher is L_{1R}. Differentiating (A17), we find

$$\frac{dP_0}{dL_{1R}} = \frac{u_1(R)}{\delta[u_2(N) - u_2(R)]} < 0, \quad \text{(A19)}$$

where $u_i(R)$ and $u_i(N)$ are the marginal utilities of income in the current contract solution and the unconstrained solution, respectively. Equation (A19) implies $u_2(R) < u_2(N)$, implying $R_{2R} > R_2$ and thus $R_{1R} < R_1$. When instead $P_0 \geq (1 + \rho)D_1$ and P_0 is given by (A18), $dP_0/dL_{1R} > 0$ and the solution cannot have the desired properties. Consequently, a viable solution must imply $P_0 \in [0, (1 + \rho)D_1)$. Consider next the derivation of P_1. A government of type P_1 must be indifferent about defaulting or not, given that it borrows L_{1R}. This implies that (A12) holds with equality for $P = P_1$. For

$P \in [P_0, P_1)$ the borrower must also prefer borrowing to not borrowing. In particular, for $P = P_1$ we must have

$$u(X_1 + R_1) + \delta u(X_2 + R_2 - (1 + \rho)D_1) < u(X_1 + R_{1R} + L_{1R}) + \delta u(X_2 + R_{2R} - (1 + \rho)D_1 - (1 + r_R)L_{1R}), \tag{A20}$$

where it is recognized that $P_1 > (1 + \rho)D_1$ and that the country thus would not default given no additional borrowing. Combining (A20) with (A17), we find that the existence of a PSE requires

$$u(X_2 + R_{2R} - (1 + \rho)D_1 - (1 + r_R)L_{1R}) - u(X_2 + R_2 - (1 + \rho)D_1) > u(X_2 + R_{2R} - P_0) - u(X_2 + R_2 - P_0). \tag{A21}$$

Since u is strictly concave, $R_{2R} > R_2$, and $P_0 < (1 + \rho)D_1$, (A21) can be fulfilled for some $L_{1R} > 0$, but not for large L_{1R}. Moreover, the scope for increasing L_{1R} is greater the greater is R_{2R} relative to R_2. (A11) and (A20) together imply that for a PSE to exist, the contract (R_{1R}, R_{2R}, L_{1R}, r_{1R}) must be preferred to both no borrowing at all and to the PE. Since L_{1R} is limited by (A21), such a solution cannot exist when L_1 in the PE is sufficiently large: it is then never possible to make some low P types choose not to borrow in period one. One interesting special case in which the possible existence, and properties, of such a contract can be studied is that where $L_1 = 0$ in sections 2–3 and 4I. This implies that loan demand at interest rate $r_0 = (1 + \rho)/[1 - F((1 + \rho)D_1)] - 1$ equals zero. Here, however, the equilibrium interest rate will instead be given by

$$r_R = \frac{1 - F(P_0)}{1 - F(P_1)}(1 + \rho) - 1. \tag{A22}$$

When $F(P_0)$ is 'not too small', and L_{1R} small, $r_R < r_0$, and loan demand may well be positive. The optimal loan contract can then be derived maximizing the left-hand side of (A1) with respect to R_{1R} (using (1)) and L_{1R}, with P_0 given from (A17), P_1 from (A12) (with equality), and r_R from (A22). Formally, this will give a five-equation system for the determination of R_{1R}, L_{1R}, P_0, P_1 and r_R. Consider finally the effects of a debt-for-nature swap, implemented by a donor country and coordinated with lending by commercial creditors. Assume a very simple case, where total commercial lending offered to the country in period one still is L_{1R}, and a small amount of the resource ΔR_{1R} is swapped with a small debt forgiveness ΔL_{1R} in period one, so as to keep a borrowing (and repaying) country indifferent *ex ante*. Provided the commercial lending contract is unaltered, the effect of such a swap on P_0 then works only via R_{1R}, where dP_0/dR_{1R} is given by dP_0/dL_{1R} in (A19). Thus P_0 is increased, i.e. fewer government types choose to borrow. The effect on P_1 is found from (A12), where L_{1R} is reduced by ΔL_{1R}. Thus P_1 is reduced, i.e. more government types choose to repay their loans. The swap would thus lead to fewer defaulting governments asking for loans, and to fewer borrowing governments defaulting, thus increasing the efficiency of the credit market by lowering the rate of interest for a given amount of lending, or alternatively, making a larger amount of lending feasible at a PSE. This would in turn facilitate the tying of lending to a low resource-extraction rate in period one. The scheme's only apparently adverse effect is (through the increase in P_0) to reduce the fraction of government types whose resource extraction is affected favourably by the swap.

APPENDIX 3

Further discussion of donor mechanism f

Assume for simplicity that donors pay back an amount αR_2 of the debt in period two, to countries that then do not default. In the first-order conditions (6)–(8) for an honest borrower in model 1, (8) is now changed to read

$$\delta(1 + \alpha)u_2 - \lambda_1 + \lambda_3 = 0. \tag{A23}$$

In case a, this implies that at equilibrium, $u_1 = \delta(1 + \alpha)(1 + g)u_2$, and $1 + r = (1 + \alpha)(1 + g)$. Consequently, r increases in α. Intuitively, an increased α has the same effect on an honest borrower as that of an increase in the resource growth rate g. This pushes up the interest rate, which makes the borrower indifferent about borrowing and extracting the resource in period one. A consequence of increased r is then that P_1 goes up, and $1 - F(P_1)$, interpreted as the fraction of government types that actually service their loans, drops. We will depart from a pooling equilibrium in model 3 and assume that period one borrowing is made conditional on resource extraction corresponding to that of honest governments, and also assume that the country faces a given interest rate as in model 1. All government types then have the same resource extraction rate R_1. In this case P_1 now again is the level at which a borrower is indifferent about defaulting or not, given by

$$P_1 = (1 + \rho)D_1 + (1 + \alpha)(1 + g)L_1 - \alpha R_2. \tag{A24}$$

We may now derive

$$\frac{dR_1}{d\alpha} = -\frac{u_{11}(S_1 - R_1 - L_1)}{[1 - F(P_1)][u_{11} + \delta(1 + \alpha)^2(1 + g)^2 u_{22}]} + \frac{\delta(1 + \alpha)(1 + g)u_2}{[1 - F(P_1)][u_{11} + \delta(1 + \alpha)^2(1 + g^2 u_{22}]} - \frac{1}{(1 + \alpha)(1 + g)f(P_1)}. \tag{A25}$$

We have here taken into consideration that the resource extraction of defaulting countries is affected in the same way as that of honest types. The first term in (A25) is the full income effect of increased period two income when *a* increases, which (but for the term $-L_1$) is equivalent to the income effect of a period two debt forgiveness (under scheme b). This term is negative whenever $S_1 - R_1 - L_1 > 0$. The element $-L_1$ represents the offsetting effect on income of increased α, when the interest rate to be paid on new loans taken in period one thereby increases. Note that L_1 unambiguously increases with α. Conceivably, $S_1 - R_1 - L_1 < 0$, i.e. the full income effect may be negative. The two last terms are always negative. The second term is the regular substitution effect, whereby resource consumption is rela-

https://doi.org/10.1017/S1355770X9700003X Published online by Cambridge University Press

tively more expensive in period one than in period two. The third term works via the zero-profit constraint on lenders, where a higher equilibrium interest rate gives room for more period one borrowing, and less need to finance period one consumption through resource extraction. Next consider the case with no period one resource-extraction monitoring. The solution under scheme f is then somewhat more complicated. First, countries that choose to default now select a level of R_1 corresponding to that of defaulting countries under schemes c and d. Secondly, the level of P that makes honest countries indifferent about defaulting or not now tends to exceed P_1.