

Reconciling Conservation and Development: A Dynamic Hotelling Model of Extractive Reserves

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ABSTRACT. *The instrument of extractive reserves has been advertised as a novel approach to reconciling biodiversity conservation and economic development. The empirical literature analyzing extractive reserves, however, delivers an ambiguous assessment of its success. This paper asks whether extractive reserves are capable of delivering long-term development benefits, even in theory. The analysis is carried out by assessing the long-run viability of an extractive reserve under a set of favorable conditions, through a dynamic model of spatial competition. We show that for extractive reserves to be even theoretically viable, a number of restrictive conditions have to be fulfilled. (JEL Q32)*

I. INTRODUCTION

The Brazilian Amazon contains some of the world's most biologically diverse ecosystems. These ecosystems generate significant global benefits in the form of ecosystem services, species habitats, and other amenities. On the other hand, the land required for keeping these ecosystems intact and the value of natural resources the Amazon could generate under alternative usage is substantial. This means that a decision not to convert these areas imposes a high opportunity cost on the economy of a developing country as a whole, and on local populations with a high incidence of poverty and destitution in particular (Andersen et al 2003; Southgate 1998; Pearce 1991).

The importance of balancing this trade-off has increasingly been recognized in Brazilian development policy. While the 1960s and 1970s were characterized by the clearing of vast areas in the Amazon region for agriculture and pastureland under am-

bitious development programs, Brazilian development policy started shifting towards considering ecosystem and biodiversity preservation objectives in the late 1980s and in the 1990s (Andersen et al 2003; Andersen and Reis 1997; Southgate 1998). One specific initiative in this context has been the creation of a novel form of property rights arrangements in parts of the Brazilian Amazon under the title of "extractive reserves." They were originally thought of as a proposal for agrarian reform adapted to the needs of populations living from the extraction of non-wood forest products (NWFP).¹ However, today they are included as an element in a new model for Amazon development by preserving the extraction of NWFP through the combination of economic competitiveness with *in situ* conservation of biodiversity (Andersen et al 2003; MMA 2001;

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¹ For a discussion on the creation of the extractive reserves, see Allegretti (1990).

Brown and Rosendo 2000; Lele et al 2000; Wunder 1999; Southgate 1998).

The literature on “extractive reserves” and extractivism is ambiguous in its assessment of the contribution of these property rights assignments to reconciling the conservation-development trade-off. Some observers credit the Brazilian model with considerable success (Allegretti 1990, 1994; Menezes 1994; Andrade 1999), while other observers have questioned its capacity to fulfil its economic development objectives (Brown and Rosendo 2000; Wunder 1999; Assies 1997; Southgate 1998; Almeida 1994; Homma 1992). The latter authors draw this negative conclusion mainly because the revenue objective of extractive reserves cannot be achieved in the presence of competing producers of NWFP, particularly plantations, that—in contrast to extractive reserves—are unconstrained in their production choices. It is argued that this lack of constraints allows plantations to achieve lower production costs and thus to drive extractive reserves out of any market that offers significant profits.

This paper offers an analytical perspective on the question of the viability of an extractive reserve by placing its decisions in both an intertemporal and spatial context. The spatial context is empirically and analytically relevant because market imperfections caused by transportation costs offer the possibility for additional rents to be captured by reserves. This means that taking into account the considerable transportation costs for NWFP, positive production cost differentials between reserves and plantations can exist alongside positive profits—and hence economic viability—for the extractive reserve. The impact of transportation costs and the associated program of road building are extremely relevant for understanding conservation and development in the Brazilian Amazon (Andersen et al 2003). According to recent estimates, transportation costs account for about 10% of the final price of NWFP (CNPT 1997).

In addition to spatial issues, intertemporal aspects, on the other hand, are important because the production cost dynamics

of extractive reserves and plantations differ fundamentally. While the production costs of the reserve are essentially static due to low capital investments and large biological variety, plantations face cost dynamics that have the capacity to both reduce and increase production costs. Reductions in costs arrive through capital investments embodying technological progress or changes in production technologies. On the other hand, productivity in plantations is under constant pressure from diseases, pathogens, and high-yield fatigue requiring more resources to be spent on replenishing the biological capital stock of production as the scale of operation increases (Rubber Board 2002; IRRDB 1997). In Brazil and South Asia, originally resistant rubber clones used in plantations have lost resistance through time due to mutation in pathogens that survive in the epidemiologically favorable environment of plantations (Gonçalves 2002). In fact, disease evolution represents a key limiting factor to increasing productivity and requires continuous R&D expenditure (IRRDB 1998).² Several studies have shown the relevance of pest evolution in terms of yield losses in plantations (Tan et al 1992; Tan 1990; Tan and John 1985; Radziah, Sulong, and Hidir 1996). For instance, looking at the development of the susceptibility of (originally disease-resistant) clones planted in Malaysia, Tan and John (1985) find that after 15 years, the average clone loses 31% of its attainable yield because it has become increasingly susceptible to the two most important diseases aone.³

Taken together, the spatial and intertemporal dimensions render the economic interaction between extractive reserves and

² “There has been limited success in breeding trees which are resistant to specific diseases and other conditions. Where such success has apparently been attained there is mounting evidence that in many cases present breeding techniques merely provide a *transient protection* as the pests or diseases adapt to overcome the resistance.”(IRRDB 1998)

³ Although this simplification is not admissible on account of the complex biological dynamics that determine yield, this loss of 31% after 15 years can be simplistically thought of as an increase in yield loss of approximately 2.4%, per year.

their plantation competitors more complex and more interesting. Interactions on the output market in which reserves and plantations compete for market share need to be examined now under considerations of spatial competition and dynamic investment choices. In addition, this horizontal interaction between plantations and reserves is complemented by a possible vertical interaction by virtue of the conservation function of reserves: genetic resources demanded by plantations in order to control problems of diseases and pests can be supplied by extractive reserves as designated sites of *in situ* conservation of NWFP plant species. The competitive relationship between extractive reserves and plantations on an output market for NWFP has therefore the potential of being supplemented by a vertical factor supply relationship on the factor input market for genetic resources.

In order to assess the economic perspectives of extractive reserves' viability in a market economy, we attempt to characterize the best competitive scenario for the reserve initially without, and then with, strategic interaction on the input market. To capture the unusual features of this interaction, we develop in this paper a stylized model of spatial competition between a producer with a static cost function and a producer with a dynamic cost function. This paper is therefore related to other dynamic extensions of the Hotelling model (such as Cellini and Lambertini 2002, 2003) where there are intertemporal dynamics that allow for spatial relocation through investment. Here we do not allow for relocation of production, but consider the more relevant implications of production cost dynamics on the viability of extractive reserves.

Two fundamental results emerge from the analysis: We show that extractive reserves are theoretically viable only if 1) exogenous technology-induced cost savings in the NWFP industry are limited; and 2) biological inputs can be traded or are sufficiently expensive. However, as we show in our discussion of the analytical results, the current situation is not conducive to

fulfilling these conditions and, in fact, the property rights in place partially undermine the potential for economic viability of extractive reserves. At the same time, the potential for policymakers to assign property rights that enhance the competitiveness of reserves are very limited.

From normative welfare perspective, it is clear that the instrument of extractive reserves competes with direct transfers as an efficient means of providing conservation efforts (Ferraro and Simpson 2002). Here, we focus on the ability of extractive reserves to generate long-run positive returns for the communities living within them. The question of whether the conservation benefits from extractive reserves strictly outweigh the benefit losses resulting from an uncompetitive market structure, exclusion from biological inputs as public goods and other imperfections is beyond the scope of this paper.

The paper develops as follows. In the next part, we provide a quick overview of the nature and scale of extractive reserves in Brazil, at the moment. We then develop an explicit spatial model of the markets for NWFP and typify the heterogeneous players interacting on this market. In Section 4, we characterize the long-term properties of the market interaction between a plantation and an extractive reserve and derive our main propositions regarding the viability of this instrument. In Section 5, we discuss these analytical results in the context of the existing property rights regime in the input and output markets, then summarize and conclude.

II. EXTRACTIVE RESERVES: ORIGINS AND CURRENT STATUS

Extractive reserves are based on a peculiar property rights structure: The property rights in the land and the biological capital stock situated on the land lie with the federal government. Property rights in the flow of NWFP generated by the biological capital stock, on the other hand, are devolved to traditional communities already settled in the area. Their property rights are codified in long-term concessions to

live in the designated land and exploit its natural resources in an "environmentally sustainable" manner. According to Brazilian law, extractive reserves are considered as territorial spaces of particular ecological and social importance for the country. The stated aim of extractive reserves is to promote the joint objective of forest conservation and economic development in the designated areas by granting the use right of its multiple resources for already settled communities under a specific-use plan.

Three aspects of the extractive reserve model are expected to contribute to this joint objective: 1) the income generated through the resource exploitation allows the population to remain in the forests and prevent alternative uses that rely on land conversion; 2) the explicit public ownership of land resolves property rights uncertainty over the areas involved and thus encourages the conservative use of its resources; and 3) the limitation of economic activities to non-wood forest products (NWFP) contributes to ecosystem maintenance and hence to the conservation objective.

In 2000, extractive reserves encompassed around 21,600 km² (PPG7 2003). Due to the economic importance of rubber extraction for local populations, the concept of extractive reserve has been structured in most cases around the autonomous extraction of native rubber. This is underlined by census data that estimate that 68,000 families were involved in rubber tapping in 1980 (Allegretti 1990). The extraction of latex from rubber trees (*Hevea brasiliensis*) is still the main activity among the extractive ones. The Brazil nut (*Bortholletia excelsa*) and oils, such as Copaiba oil derived from a palm tree (*Copaifera spp.*) also constitute locally important sources of revenue. However, there are many other NWFP been extracted within and outside the reserves with potential for increasing economic relevance (Pires et al. 1998; Smith et al. 1999).

In line with the experience in other NWFP markets, the share of extractive production in rubber production, for example, has been in decline over the last

ten years, from a market share of approximately 50% in 1990, to approximately 7% in 1999 (IBGE 2003). This has led some observers to question the economic rationale underlying the development objective in extractive reserves (Southgate 1998; Assies 1997). A typical characterization of the long-term fate of extractive reserves based on historical experience is provided in Homma (1992): Reserves follow a sequence of discovery, expansion, maturation, and finally decline as more efficient plantations enter the market. In what follows, we propose an analytical framework to examine whether this sequence of profitability stages is an inescapable development for extractive reserves.

III. A SIMPLE MODEL OF MARKET INTERACTIONS IN NWFP

Extractive reserves generate revenue through sale of their products on markets where they interact with other producers of NWFP. These markets have two peculiar features: 1) heterogeneity of enterprises competing on the market; what is expected of extractive reserves is that they are able to generate revenue on output markets where they will be competing with other producers that are operating using different technological choices and production assets, namely plantations; and 2) spatial structure of enterprise location in the NWFP sector. Due to the considerable distance involved in the domestic market and resultant transportation costs, space is an important determinant of the profitability of operations. Extractive reserves and potential plantations are usually localized in different parts of the country (in rubber production most of the plantations are localized in the southeastern part of the country), with significant product markets located in between. At the same time, production depends on peculiar local characteristics that are not present everywhere: Extractive reserves are, by their very nature, in prescribed locations of high ecological significance. Plantations' location choice, on

the other hand, favors previously disturbed areas of rainforest resulting in production systems characterized by natural re-growth combined with management practices to deliberately eliminate competitive vegetation (Andersen et al 2003; Wunder 1999). This location specificity thus limits the choice of production sites for both extractive reserves and plantations.

The Hotelling-type Market Structure

We capture the spatial peculiarities of the interaction between extractive reserves and their plantation competitors in a stylized way using Tirole's (1988) variant of the Hotelling model (1929). A "linear country" represented by a real line segment between (0,1) provides the spatial structure for the model. Consumers are distributed uniformly⁴ along the country with density 1. Aiming to represent the best competitive scenario for a reserve, we set the model as a duopoly. Thus, there are two firms operating in the market, each located at one extreme of the country, producing the same physical good. Firm *r* (representing an extractive reserve) is located at $x = 0$ and firm *p* (representing a plantation) is located at $x = 1$. Consumers have transportation costs τ per unit of length and have unit demand. Each individual either consumes one unit of the good or doesn't consume at all. Finally, consumers have a reservation price \bar{s} for consuming the good.

For a consumer located at co-ordinate x , the generalized price is $p_r + \tau x$ to buy from firm *r* or $p_p + \tau(1 - x)$ to buy from firm *p*. Given prices p_r and p_p , transportation costs τ , and surplus \bar{s} , the utility of a consumer located at x is, $\bar{s} - p_r - \tau x$ if buying from firm *r*, and $\bar{s} - p_p - \tau(1 - x)$ if buying from firm *p*, or zero if not consuming the good. If the price difference between the firms does not exceed trans-

portation costs along the whole country and if prices are not too high with respect to the consumer surplus, then there exists a consumer with location \bar{x} who is indifferent between buying from firm *r* or *p*. At \bar{x} holds that $p_r - \tau\bar{x} = p_p - \tau(1 - \bar{x})$. Solving this identity for x and $(1 - x)$, respectively, the demand curves for firm *r* and *p* are

$$D_r = x = \frac{P_p - p_r + \tau}{2\tau} \quad [1]$$

$$D_p = (1 - x) = \frac{p_r - p_p + \tau}{2\tau} \quad [2]$$

In this conventional set up, transportation costs ensure horizontal differentiation even with physically identical goods. Transportation costs reduce competition and create "neighboring clientele" (Tirole 1988). Consequently, market power is formed and firms can increase prices above the competition levels, resulting in above-normal profits.⁵

The benchmark case in the Hotelling model arises if firms have identical unit costs, resulting in equal market shares for both firms. In our case, unit costs will differ at any given point in time due to differences in production technology between extractive reserves and plantations and across time due to differences in cost dynamics. Reserves and plantations are also modelled as different with respect to their planning horizon. As the producers in reserves live close to subsistence levels, they are likely to have high discount rates and therefore consider instantaneous profits as the decision criterion while plantations use a net present value of profits. Pricing decisions, and as a result, market shares, will therefore be the outcome of an interaction between two highly heterogeneous agents whose decision problems we outline below.

⁴ In reality, the distribution of consumers is of course not uniform. Moreover, plantations are likely to locate close to consumer's concentrations such as urban centers. However, this only makes the situation more difficult for reserves not fundamentally changing the results.

⁵ One could argue that existence of market power is very unlikely to be verified in reality. In the case of rubber, for example, prices are set in international markets and neither reserves nor plantations in Brazil have any power at all in impacting them. However, this situation does not necessarily apply to other products, which are traded only in domestic markets such as fruits and oils (see Smith et al. 1999; Pires et al. 1998).

The Plantation

We capture the general dynamics of NWFP production as an industry dependent on a mixed stock of physical and biological capital in the dynamics of production costs, c_p , faced by plantations. These costs increase with the scale of output D_p because of disease problems, but increases can be mitigated through simultaneous investments, I , in a breeding program that enhances the genetic basis of the biological assets. Costs decrease, on the other hand, through productivity increases arriving through the physical capital stock.⁶ The behavior of the plantation's cost function c_p over time is then

$$\dot{c}_p(t) = D_p(t) - \frac{I(t)}{1 + I(t)} - K, \quad [3]$$

where I the volume of plantation's investments in biological resources,⁷ and K is the cost decrease associated with plantation's endowments of physical capital. To make this concrete, K denotes the market share exogenous technological progress allows to be served by the plantation without incurring a production cost increase when $I = 0$. To concentrate our analysis in the impact of biological capital, we assume that K is constant, implying a continuous exogenous flow of technological improvement. Given the spatial market structure developed above, the instantaneous profit function for the plantation is

$$\pi_p(t) = [p_p(t) - c_p(t)]D_p(t) - b(t)I(t), \quad [4]$$

where b is the price of biological resources.

⁶ There is sound evidence on the importance of replacing biological material (IRRDB 1998; Rubber Board 2002; Gonçalves 2002) and existence of a number of research experiences and breeding programmes (IRRDB 1998; Rubber Board 2002; Priyadarshan and Gonçalves 2002; Gonçalves et al. 1998; Gonçalves et al. 1999; Gonçalves et al. 1995).

⁷ For a discussion on this functional form, see Cellini and Lambertini (2002, 2003). To keep the structure consistent with the adopted Hotelling-type set up, avoid the possibility of negative demands, and keep the problem interesting we constrain I and K , such as $K + \frac{I}{I+1} \leq 1$, and $K < 1$.

Based on these assumptions, the problem of a single-product plantation with an infinite planning horizon and discount rate ρ is to

$$\max \int_0^{\infty} e^{-\rho t} \pi_p dt, \quad [5]$$

subject to dynamic constraint [3] and appropriate endpoint conditions. The problem for the plantation is therefore to maximize the net present value of profits from NWFP production subject to the dynamics of the cost function driven by capital stocks.

The Extractive Reserve

In contrast to plantations, extractive reserves cannot choose the least-cost combination of inputs for a given output level due to the use conditions under which they are granted access rights (Browder 1992). There are also important dynamic differences between reserves and plantations. On the one hand, low intensity of physical capital and the persistence of traditional methods suggest that there is no significant efficiency-enhancing technological progress occurring in reserves-based NWFP. On the other hand, because of the abundance of biological capital and the low intensity of production, depreciation of the biological capital stock in NWFP production in reserves is negligible. Under these conditions, NWFP production in reserves neither benefits from technological progress, nor suffers from depreciation: Extraction costs today are roughly what they were a hundred years ago (Dean 1987). In the context of developing a stylized model of the market of NWFP, this suggests that one of the agents in the market, namely the reserve, faces no intertemporal constraint of the type captured in expression [3] in its optimization problem.⁸

Based on the spatial market structure developed above, the instantaneous profit

⁸ However, due to difficulties in expanding the production related to the presence of a forested environment it is likely that reserves experience decreasing returns to scale. For the sake of simplicity, we assume constant returns.

function for the plantation in each NWFP market is

$$\pi_r = [p_r(t) - c_r(t)]D_r(t), \tag{6}$$

with the reserve having control over the gate price p_r of its NWFP. Thanks to the local abundance of genetic diversity in biological capital used for NWFP, reserves can also supply one peculiar product that is not a NWFP, namely biological inputs required by the plant-breeding process. A complete characterization of the problem of extractive reserves therefore needs to reflect both the diversified nature of its operations on output markets where NWFP are traded and its potential activities on input markets.

In the following section, we assess under which conditions the interactions between these two types of highly heterogeneous agents in spatially differentiated markets can result in long-run non-negative profits for extractive reserves.

IV. LONG-RUN MARKET OUTCOMES

In this section, we determine the long-run properties of the demand shares of reserves and plantation. We first look at the interaction on individual output markets in isolation, and then proceed to analyze the case where the reserve takes decisions on the input market into account.

Markets for Existing NWFP

The solution of the profit maximization problem for plantation and reserve considering only one NWFP provides the dynamic paths for the gate prices of plantations and reserves, p_p and p_r , on that market, as well as the dynamic path of the production costs in the plantation, c_p . Where plantation and reserve interact only on the output market, the reserve does not supply biological inputs I . Given [6] and [1], its problem is

$$\max \pi_r = (p_r - c_r) \left(\frac{p_p - p_r + \tau}{2\tau} \right), \tag{7}$$

with the first order condition

$$\frac{\partial \pi_r}{\partial p_r} = \frac{p_p - 2p_r + c_r + \tau}{2\tau} = 0 \tag{8}$$

Expression [8] determines the pricing decision of the reserve given the gate price of the plantation, p_p , the transportation cost τ , and the unit cost of the reserve, c_r . The plantation, on the other hand, solves the following problem given [5] and [4]:

$$\max \int_0^{\infty} \left[(p_p - c_p) \left(\frac{p_r - p_p + \tau}{2\tau} \right) - bI \right] e^{-\rho t} dt. \tag{9}$$

Subject to

$$\dot{c}_p = \left[\frac{p_r - p_p + \tau}{2\tau} - \frac{I}{1+I} - K \right], \tag{3}$$

$$c_p(0) = c_p^0, \text{ and}$$

$$\lim_{T \rightarrow \infty} c_p(T) \text{ free.}$$

It is clear from the formulation of the problems of reserve and plantation that their decisions are interdependent through their respective choice of a gate price. It is also evident from the plantation's problem that it will use a combination of price choice and investment to manage the intertemporal cost constraint [3]. To derive the optimal paths for p_p and c_p , we derive the first order conditions from the related current value Hamiltonian

$$H = (p_p - c_p) \left(\frac{p_r - p_p + \tau}{2\tau} \right) - bI + \mu \left[\frac{p_r - p_p + \tau}{2\tau} - \frac{I}{1+I} - K \right], \tag{10}$$

where $\mu = \lambda e^{\rho t}$ and λ is the co-state variable associated with this dynamic problem. The first order conditions for an optimum are

$$\frac{\partial H}{\partial p_p} = \frac{p_r - 2p_p + c_p + \tau}{2\tau} - \frac{\mu}{2\tau} = 0, \tag{11}$$

$$\frac{\partial H}{\partial I} = -b - \frac{\mu}{(1+I)^2} = 0, \tag{12}$$

$$\dot{\mu} - \rho\mu = -\frac{\partial H}{\partial c_p} = \frac{p_r - p_p + \tau}{2\tau}. \tag{13}$$

Expression [11] highlights the critical trade-

off that the plantation faces in its pricing decision between the marginal revenue objective under spatial competition, on the one hand, and the marginal benefits from decreasing pressure on cost (through a reduction in output), on the other hand. Equation [12] shows the alternative instrument of managing cost dynamics through the investment in the biological capital stock at price b . Expressions [11] and [12] together define an optimal combination of the two instruments given b , transportation cost, τ current production cost, c_p , and gate price of the reserve, p_r :

$$I(t) = \sqrt{\frac{2p_p(t) - p_r(t) - c_p(t) - \tau}{b}} - 1. \quad [14]$$

We will exploit the link in [14] between price on the output market and demand on the market for biological inputs more fully in the next section. Examining the output market in isolation, expressions [8], [11], [12], and [13] allow us to solve for the steady state loci of prices p_p and p_r and plantation's costs c_p :

$$p_p|_{\dot{c}_p=0} = c_r + \tau \left[3 - 4 \left(\frac{I}{1+I} + K \right) \right], \quad [15]$$

$$p_r|_{\dot{c}_p=0} = c_r + 2\tau \left[1 - \left(\frac{I}{1+I} + K \right) \right], \quad [16]$$

$$c_p^* = c_r + 3\tau - \left(\frac{I}{1+I} + K \right) \left(6\tau + \frac{1}{\rho} \right), \quad [17]$$

The steady state is therefore determined by the static cost of NWFP production in the reserve, c_r , transportation costs, τ , discount rate, ρ , and exogenous technological progress, K .

At the same time, in the steady state it has to hold that

$$D_p = \left(\frac{I}{1+I} + K \right), \quad [18]$$

$$D_r = 1 - \left(\frac{I}{1+I} + K \right). \quad [19]$$

These results imply that the higher I and K , the larger the plantation's capacity to reduce costs, and therefore the higher will

be the demand share of plantation in the steady state. Substituting optimal values for p_p , p_r , and c_p into [14] we get

$$\frac{I}{(1+I)^3} + \frac{K}{(1+I)^2} = b\rho. \quad [20]$$

Equations [14] and [20] show the relationship between b and I , and therefore also between demand shares and b . Although both expressions do not allow for a closed-form solution of I , it is easy to see that the lower the price at which the plantation can satisfy its demand for biological inputs, the higher the investment and consequently the smaller the long-term profits for the reserve since as $b \rightarrow 0$, $I \rightarrow \infty$, and therefore $D_p \rightarrow 1$. Expressions [14] and [20] give rise to a threshold price denoted by b^* at which the extractive reserve will earn a long-run profit of zero:

$$b^* = \frac{K^2}{\rho}. \quad [21]$$

On the basis of condition [21], we can establish the following propositions:

PROPOSITION 1. *If $b > b^*$, then the extractive reserve can sustain long-run positive profits.*

PROPOSITION 2. *If $b < b^*$ and $c_p^0 > c_r + \mu - 3\tau$, then the extractive reserve can earn interim positive profits while c_p converges to the limit price at which reserve exits.*

PROOFS: See Appendix.

Propositions 1 and 2 have important implications: The first is that the viability of reserves is determined by two variables, the rate of cost savings induced by exogenous technological progress and the price of biological inputs. While policy has no control over the former, policy-makers could partially determine the latter (and hence the viability of extractive reserves) by modulating the public good characteristics of biological inputs through choices between alternative property rights regimes (see Section 5). However, expression [21] highlights also that the threshold price of inputs necessary to ensure long-run positive profits increases quadratically in the amount of exogenous technological progress, implying

that such policy choices will be very sensitive to the rate of cost savings experienced by plantations. This is intuitive and highlights the important interplay between the amount of technology-induced cost savings and the price of biological inputs.

The second implication is that presence of temporary profits in extractive reserves is not conclusive evidence of their long-run viability. On the other hand, evidence of declining market shares is not conclusive evidence of long-run non-viability. This means that even though extractive reserves may be experiencing the "economic cycle" postulated by Homma (1992), that cycle need not necessarily end in the death of the extractive reserve. We conclude therefore that examining the output market in isolation, long-run positive profits in extractive reserves are more likely if transportation costs are high, exogenous technological progress low, and the price of biological inputs high.

Markets for Inputs

In this section, we explore the implications of allowing an extractive reserve to trade not only in outputs, but also in biological inputs of plantations. In such a case, the price of biological inputs b is no longer exogenously set, but determined by the interaction between the reserve and the plantation. Currently, there is no functioning market for such biological inputs, but it is clear that the presence of such a market would create incentives for reserves to observe the traits of various tree varieties with respect to yield, disease resistance, quality of output, and so forth, plausibly at a lower cost than a search process not relying on this prior information (Rausser and Small 2000; Goeschl and Swanson 2003). Even though it is generally agreed that the creation of such a market in the real world faces difficulties given the nature of genetic resources, there is a policy push in the direction of markets for biological material. In such a market, reserves would have to be considered as a potentially important player as they are located in areas of high biodiversity and their pop-

ulations have privileged conditions for acquiring knowledge regarding resistance to diseases and productivity of native species. For these reasons, the nature of the interaction between the two conservation policies of creating extractive reserves and markets for genetic resources needs to be better understood.

The presence of a trade in biological inputs introduces a vertical dimension into the horizontal interaction between the extractive reserve and the plantation. The reserve now has to take into account the impact of pricing decisions of both inputs and outputs on total profits. Formally, this requires extending its profit function, π , by the revenues on the input market, $b(t)I(t)$ such that

$$\pi_r(t) = [p_r(t) - c_r]D_r(t) + b(t)I(t). \quad [22]$$

We assume that biological inputs are produced at approximately zero cost.⁹ The reserve has therefore two instruments available, output price, p_r and input price, b . The first order conditions are

$$\frac{\partial \pi_r}{\partial p_r} = \frac{p_p - 2p_r + c_r + \tau}{2\tau} - \frac{1}{2} \sqrt{\frac{b}{2p_p - p_r - c_p - \tau}} = 0, \quad [23]$$

$$\frac{\partial \pi_r}{\partial b} = \sqrt{\frac{2p_p - p_r - c_p - \tau}{b}} - 1 = 0. \quad [24]$$

Comparing [23] with the optimal condition [8] when b is exogenously set, we see that the extractive reserve will set the gate price, p_r , for NWFP lower than previously. The reason is that from the point of view of the reserve operating on both markets, b and p_r are strategic substitutes. This becomes clear when solving [24] to determine the optimal combination of the instruments

⁹ This assumption can be relaxed without affecting the essential conclusions of the paper.

$$b(t) = \frac{2p_p(t) - p_r(t) - c_p(t) - \tau}{4}. \quad [25]$$

which highlights the negative relationship between the two instruments. Expressions [23] and [25] can then be used to determine the market equilibria in both markets. First, on the input market, substituting [25] into [14] determines a unique and constant level of investment in biological capital by the plantation equal to 1, when the reserve can set the price b . Second, substituting [23] and [25] into the plantation's first order conditions determines the steady state prices and plantation cost in terms of the parameters of the model and lead to the following proposition.

PROPOSITION 3. *If $K > \frac{1}{4}$, the reserve will make positive long-run profits on both the output and input market. If $\frac{1}{4} \leq K \leq \frac{1}{2}$, the reserve will make positive long-run profits on the input market only.*

PROOF: See Appendix.

The intuition behind the proposition is the following. $K = \frac{1}{4}$ implies the optimal gate price of the reserve equals its marginal costs, implying zero profits on the output market. If $\frac{1}{4} < K \leq \frac{1}{2}$, the reserve would have a too little share of the output market to cover production costs since its gate price would be smaller than its marginal cost. If $K = \frac{1}{2}$, the reserve would have no demand in the steady state. However, the reserve still collects revenues on the input market of the amount, $\pi_r = \frac{1}{4\rho}$.

In a setting where the extractive reserve can interact on both the output and input market therefore, the reserve can achieve a higher market share in the output market by calibrating the price of biological inputs. In this case, the plantation will face larger constraints in reducing costs. However, as shown above, these constraints can be compensated through plantation's capacity to

reduce cost through physical capital. If K is large enough, the reserve will still be driven out of the output market. Nevertheless, to the extent that reserves can supply biological inputs, some mitigating compensation for the revenue loss on the NWFP market becomes available as D_p expands. We conclude therefore that the possibility of trading on the input market will ensure positive long-run profits for the extractive reserve.

An additional implication of Proposition 3 is that under this peculiar market structure, the optimal balance between revenue objectives on the input and output market extractive reserve demand shares will lie in a fixed allocation of market shares on which the amount of technological progress impacts in a linear fashion (see Appendix).¹⁰ In contrast to the plantation in whose interest it is to force the reserve to exit from the market, the extractive reserve will never find it profitable to monopolise the output market.¹¹

Do reserves strictly benefit from the creation of a market for genetic resources? This depends on a number of model parameters, most important, on the relative strength of the spatio and intertemporal effects. To illustrate, let us compare the position of the reserve interacting on the output market only with that of the reserve interacting on both given an (exogenous) price of biological inputs b equal to b^{**} , the optimal endogenous price chosen by the reserve, and $K = \frac{1}{4}$. Deriving the reserve profits in both cases, we arrive at the following proposition.

PROPOSITION 4. *If in the case of interaction only in the output market $b = b^{**}$ and*

¹⁰ In this case, to keep consistent market shares we have to assume $K \leq \frac{1}{2}$.

¹¹ One possible extension is to consider the question of whether the reserve can deter market entry by the plantation through limit pricing. Given the role of NWFP production in extractive reserves to provide subsistence income, entry deterrence is in our mind not a credible strategy for extractive reserves to pursue.

$K = \frac{1}{4}$ the reserve would be better off not interacting on the input market if $\tau > \frac{2}{\rho}$.

PROOF: see Appendix.

This result makes explicit the connection between the spatial dimension of the model, relevant for profits in the output market, and the temporal dimension associated with plantation's cost reduction by investing in inputs. If transportation costs are high, market power on the output market is strong. Since we know from [25], that the gate price of the reserve and the price it charges for inputs are strategic substitutes, adding the interaction on the input market has an ambivalent on the reserve's profit. This means that operating on the input market will only generate higher total profits for the reserve if the plantation's demand for investment is sufficiently price-inelastic, that is, its discount rate is low.

V. DISCUSSION AND CONCLUSION

The instrument of extractive reserves has been advertised as a novel approach to reconciling biodiversity conservation and economic development. It is on the basis of this claim that their number and size is currently undergoing expansion in the Brazilian Amazon as well as in other parts of the developing world.

In this paper, we develop a stylized model representing the best possible scenario for reserves in that it considers exclusively a duopolistic spatially differentiated market structure. In addition, we set up the model making assumptions that enhance the capacity of reserves to remain competitive in the long-run, such as constant marginal costs in reserves and uniform distribution of consumers along the market space. We also assume that opportunity costs of land use in reserve are zero, establishing as the "viability condition" only the presence of non-negative profits in the long-run. Finally, we consider the situation where a market for biological inputs exists, creating a second role for reserves as suppliers of plantations. Under this very

favorable scenario, we examine the conditions for reserves to fulfil their development objectives. What makes the peculiar approach chosen in this paper worthwhile in our view, is that it evaluates the conservation tool of extractive reserves in its spatial and intertemporal context. This adds an important novel dimension to the literature assessing the use of reserves.

From the analysis of the long-run profits for the extractive reserve in a setting of spatial competition with a plantation in the previous section, we have four main results. First, the rate of exogenous efficiency gains benefiting the plantation is the essential determinant of the viability of an extractive reserve. If the flow of cost savings to plantations is substantial, the constraints on production in extractive reserves become fully binding and will drive its profits in the output market to zero over a finite time horizon. However, if this flow is not substantial, then the market imperfections can sustain long-term positive profits. Secondly, for these market imperfections to result in long-term positive profits, the price of biological inputs must exceed a certain threshold level. If the plantation can invest cheaply in its biological capital stock, then it will be able to drive extractive reserves out of the output market. Thirdly, a change in the property rights regime that enables an extractive reserve to exclude others from free access to the biological assets contained within it can overcome some of the viability problems. In that case, the combination of market imperfections and the reserve's dual role as both a competitor on the output market and a provider of production inputs can ensure long-run positive profits. Finally, unless the price of biological inputs is insignificant, the assignment of property rights over biological inputs to the reserve does not necessarily improve the welfare position of the reserve's community. Whether property rights over biological inputs enhance or reduce the reserve's welfare is jointly determined by the discount rate and transportation costs. Consequently, the contribution of novel property rights assignments to the viability of reserves requires a case-by-case assessment.

Looking at the long-run results, we must then ask whether the favorable conditions upon which the model is structured are likely to be approximated in reality. The first observation is that a dozen of reserves have already been created and that policymakers are pursuing an increase in this number. The market structure is therefore more competitive and rents available to reserves on both input and output markets will be significantly lower. Policymakers need to take this into account when deciding how many extractive reserves should be created that are linked through a common market since additional entrants reduce the long-run profits of incumbent reserves.

Secondly, there is no evidence suggesting that efficiency gains in plantations will be limited in the long term to a level that permits reserves to compete in the output market. In fact, significant amounts of public funds are spent on systematic research aiming—for instance—to increase productivity in rubber plantations in Asia and Brazil.

Thirdly, no domestic property rights regime over biological inputs is currently in existence in Brazil. If the policy objective is to ensure the viability of extractive reserves as a conservation tool sustained on the basis of revenues from NWFP output markets, then concurrent policy efforts to facilitate an amelioration of the biological capital stock in plantations are counterproductive. This highlights the inherent tensions between the use of extractive reserves to conserve significant amounts of biological inputs and two other existing policy choices, namely a property rights regime that treats biological inputs as public goods and concurrent public subsidies into enhanced biological capital stocks for plantations through—for instance—public breeding programmes. Both of these policy choices undermine the development objective of the extractive reserves by having plantations benefit from an inexpensive supply of these essential inputs into NWFP production. This reduces expenses for inputs, enabling them to compete even more effectively with extractive reserves

on the NWFP markets that are supposed to generate the revenues to develop reserves economically.

Finally, additional sources of market power exist that this paper cannot fully cover. As an example, there are a number of initiatives trying to market NWFP emphasising quality differences, which, if successful, could generate market power for reserves. However, in order to explore this possibility, an appropriate model would need to allow firms to move across market space. We take up the issue of product differentiation in extractive reserves in a related paper (Goeschl and Iglori 2003).

In summary, the model suggests that for reserves to survive in the long-run, a number of conditions must hold in conjunction. However, these are very strict conditions that are not usually satisfied in reality. Where they are not, there is little evidence that policymakers have enough scope to change the current situation sharply and enhance the reserve's possibilities in a considerable way. Therefore, our analysis underlines the significant challenges ahead if the objectives and design of extractive reserves remain unchanged and their expansion continues to be advertised.

APPENDIX

Proof of Proposition 1

From the previous analysis we have

$$D_p = \left(\frac{I}{1+I} + K \right), \quad [18]$$

$$\frac{I}{(1+I)^3} + \frac{K}{(1+I)^2} = b\rho. \quad [20]$$

From [18], we know that if $\frac{I}{1+I} = 1 - K$, the plantation takes the whole market over and the reserve makes no profit in the long run. Rearranging this equation, we can get the investment level $I^* = \frac{1-K}{K}$ that leads to $D_p = 1$. Substituting I^* into [20], we get $b^* = \frac{K^2}{\rho}$. As we know that

$\frac{\partial I}{\partial b} < 0$, if $b > b^*$, then $D_p > 1$, $D_r > 0$, and therefore, $\pi_r > 0$ in the long run.

Proof of Proposition II

Following the proof of Proposition I, we know that if $b \leq b^*$ the reserve cannot make positive profits in the long run. For the reserve to make temporary positive profits we need $D_r = \frac{P_p - P_r + \tau}{2\tau} > 0$ and therefore $p_p - p_r > -\tau$. From the first order conditions of plantation and reserve, we get

$$p_p = \frac{1}{2}(p_r + c_p + \tau - \mu) \tag{26}$$

$$p_r = \frac{1}{2}(p_p + c_r + \tau) \tag{27}$$

Solving [26] and [27] for p_p and p_r , we get

$$p_p = \frac{1}{3}c_r + \frac{2}{3}c_p + \tau - \frac{2}{3}\mu, \tag{28}$$

$$p_r = \frac{2}{3}c_r + \frac{1}{3}c_p + \tau - \frac{1}{3}\mu. \tag{29}$$

If we apply the condition $p_p - p_r > -\tau$ to [28] and [29], we see that if $c_p^0 > c_r + \mu - 3\tau$, then $D_p > 0$ and the reserve will be making positive profits until c_p converges to c_p^* .

Proof of Proposition III

Substituting equations [23] and [25] into the plantation first order conditions, we get

$$p_r^* = cr + \frac{t}{2} - 2\tau K, \tag{30}$$

$$p_p^* = cr + \frac{t}{2} - 4\tau K. \tag{31}$$

If $K < \frac{1}{4}$, then $D_r > 0$ and $p_r^* > c_r$. Therefore, the reserve will be making profits in the output market. If $K = \frac{1}{4}$, $D_r > 0$ but $p_r^* = c_r$, then the reserve would make zero profits in the output market. If $\frac{1}{4} < K < \frac{1}{2}$, then the reserve's demand share would be positive, but $p_r^* \leq c_r$. Therefore, the reserve

would make negative profits and it is not economical to participate in the output market. Thus, effectively $D_r = 0$ in this case and the plantation could charge the limit optimal price (when $K = \frac{1}{4}$) that would be small enough for the reserve to exit the output market. If $K = \frac{1}{2}$, then $D_r = 0$ and the reserve would exit of the output market anyway. Considering that $K \leq \frac{1}{2}$ the demand functions and optimal prices in the steady state would then be

$$p_p^* = \begin{cases} cr + \frac{\tau}{2} - 4\tau K & \text{if } K < \frac{1}{4} \\ cr - \frac{\tau}{2} & \text{otherwise} \end{cases}, \tag{32}$$

$$p_r^* = \begin{cases} cr + \frac{\tau}{2} - 2\tau K & \text{if } K < \frac{1}{4} \\ 0 & \text{otherwise} \end{cases}, \tag{33}$$

$$b^{**} = \begin{cases} \frac{1}{4\rho} \left(K + \frac{1}{2} \right) & \text{if } K < \frac{1}{4} \\ \frac{1}{4\rho} & \text{otherwise} \end{cases}, \tag{34}$$

$$D_p^* = \begin{cases} K + \frac{1}{2} & \text{if } K < \frac{1}{4} \\ 1 & \text{otherwise} \end{cases}, \tag{35}$$

$$D_r^* = \begin{cases} \frac{1}{2} - K & \text{if } K < \frac{1}{4} \\ 0 & \text{otherwise} \end{cases}. \tag{36}$$

For any given $D_p > 0$, the reserve will be making profits in the input market as $I > 0$ and $b^{**} > 0$. If $\frac{1}{4} < K \leq \frac{1}{2}$ the reserve exits the output market and $D_p = 1$.

Therefore, the reserve will be making profits only in the input market and $\pi_r = \frac{1}{4\rho}$.

Proof of Proposition IV

If in the case with interaction only in the output

market $b = b^{**}$, then $I = 1$. If $K = \frac{1}{4}$, then $p_p = c_r$ and $p_r = c_r + \frac{\tau}{2}$. Substituting these prices in the reserve profit function we get $\pi_r = \frac{\tau}{8}$. In the case of interaction in the input market if $K = \frac{1}{4}$, then $D_p = 1$, $D_r = 0$ and $\pi_r = \frac{1}{4\rho}$. Comparing π_r in both cases we find that the reserve would be better off not interacting on the input market if $\tau > \frac{2}{\rho}$.

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