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Modeling the marginal value of rainforest losses: A dynamic value function approach

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ABSTRACT

The economic value of a rainforest is modeled as a dynamic asset subject to fire risk and potential increase in dryness. I solve two Bellman equations, for unburnt and for already burnt forest, to derive analytically tractable expressions for the total expected, spatially differentiated, asset value of the forest in each state assuming constant growth and forest loss rates over time. I derive the marginal expected discounted value loss when losing a small additional piece of forest, at any alternative site in the forest. Marginal forest value is found to increase when the risk of forest fire increases due to forest fragmentation when forest is lost locally; and also when forest dryness, affecting forest values negatively, increases upon forest fragmentation. Both forest fire risk and dryness serve as "multipliers" on the basic services return loss, both within and outside of the forest. Increased forest fire risk is found to *reduce average rainforest value* by reducing their future expected lifespans and current returns; but to *increase marginal forest value* by making primary forest loss avoidance more valuable. I calibrate the model including the impact of the forest fire risk component on forest value, with multipliers in a typical range 1.3–1.5.

1. Introduction

The objective of this paper is to build a simple model framework for studying interactions between forest losses, forest fires, forest dryness, and forest fragmentation. The approach is general, but with the aim for application specifically to the Amazon rainforest biome. To achieve this, I seek to derive analytically tractable expressions for the "marginal value" of rainforest losses that reflect the main factors contributing to it. Among such contributing factors are both more standard stock and flow value impacts of forest losses, where impacts of forest losses can occur both within and outside of the forest; and also impacts of forest fires that could potentially be avoided, including how the likelihood of forest fires depends on initial forest losses and on increased forest fragmentation that may follow from local forest losses. Analyses of similar processes are found in Brando et al. (2012), Nepstad et al. (1999), Mendonça et al. (2004), and Soares-Filho et al. (2012); see also Alencar et al. (2011); Silvestrini et al. (2011); Brando et al. (2014). In the latter paper a model, FISC, with particular application to the Amazon rainforest, is presented which forms a modeling framework for fire activity in the Brazilian Amazon. More recently a second model, EcoFire, has been developed by the same research team for analyzing the expected magnitudes of timber losses resulting from Amazon forest fires. An important related issue, not least in a REDD + context, is the carbon emissions implications of forest losses, which are shown to be enhanced by the mechanisms for forest losses discussed here. This issue is discussed further in the paper's final section.

Traditionally, native and untouched tropical forests hardly ever burn. More recently, however, fires in the Amazon has become a major problem spurred by a confluence of factors, including forest fragmentation and climate change which both have led to greater forest dryness; jointly with anthropogenic factors, as deliberate clearing of Amazon rainforest by fire has become a key strategy for farmers and ranchers to expand their productive areas. As a consequence, forest fires represent the perhaps greatest long-run threat to the integrity of the Amazon rainforest, with an increased risk of reaching a "tipping point" (beyond which large additional forest losses could be induced). See e g Alencar et al. (2006), Nepstad et al. (1999, 2001), and Soares-Filho et al. (2012).

A purpose of the analysis presented in this paper is to provide a basis for forest fire occurrence as a separate item in the marginal valuation of rainforests. Such a value item has, to my knowledge, never before been modeled formally. It has however been discussed informally in a seminal discussion of such issues by Andersen et al. (2002). Forest fire avoidance in the Amazon (or interactions of forest fires with forest losses) was here evaluated as one of three decisive factors behind the need

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for additional protection of the Amazon rainforest, alongside carbon and sustainable timber extraction values. In this paper I model the relationships between forest fires and forest value more formally. I consider the possibility that such a value component can be quantified and parameterized, possibly in the context of (with the aid of) the FISC and EcoFire models as indicated above.

A parallel element of this analysis is to consider the rainfall implications of rainforest losses, as a similar issue in a valuation context. It is by now widely recognized that losses of rainforest likely lead to less rainfall both within and in the vicinity of the rainforest. This impacts forest value negatively, directly via reduced forest returns (v and w below), and indirectly via increased forest fire risk.[1]

This work is part of a more comprehensive effort to go from mapping of biophysical impacts of forest losses, to the economic valuation of such impacts. This is not trivial and has not been accomplished or even attempted in a detailed way at the scale of a macro biome such as the Amazon, which we here have in mind. Background for such analysis can however be found in Farley (2012), de Groot et al. (2012), and Lewis and Wu (2014); and with specific reference to tropical forests in, among other references, Ferraro et al. (2011) and Naidoo and Ricketts (2006). It should however be noted that this literature is not particularly helpful for deriving detailed and spatially differentiated economic values of certain components relevant for the Amazon, such as biodiversity and biological resources, and longer-distance moisture transport impacts of forest losses, which are keys to overall economic valuation in the present case.

Forest fire occurrence and spread is one (key) example of an externality by which the value of protecting a given forest area can be affected. There exist other such examples, some of which are similar, including the occurrence and spread of invasive species and diseases, and factors behind illegal logging. There exists a related, methodologically-oriented, literature dealing with spatial externality impacts of damages to forests (such as from invasive species, or of the onset of a forest fire, which in both cases can do extensive damage), which is explicitly dynamic and with some focus on option values of taking or not taking action; see e g Kassar and Lasserre (2004), Saphores and Shogren (2005), Sims et al. (2014), and Sims and Finnoff (2012, 2013). This literature focuses on choices between immediate action (which is costly but may eliminate the problem) and a "wait and see" approach (to wait for more precise information which is beneficial in cases where the situation improves exogenously and stochastically, but can also lead to more extensive damage when outcomes turn out to be less favorable). Much of this literature is formulated as optimal policy decisions to reduce or minimize the various respective problems dealt with, frequently in an option (or quasi-option) value context similar to Dixit and Pindyck (1994) and Pindyck (2000, 2007). Such analytical approaches provide a rich modeling framework, including analyses of sets of circumstances under which multiplier effects on rainforest damage, could arise; and where the option value of waiting to intervene would usually play a major role. I however view such modeling tools as less applicable in my case, as the (expected) impacts of forest losses can typically be viewed as well-known, from the modeling frameworks mentioned above. Also, I select not to focus only on site-specific impacts but also on general (average) impacts across a large biome. Both these factors speak in favor of abstracting away option values in my formulation. Our modeling framework is however still rather directly applicable to such issues since, in particular, further spread of diseases, invasion of species and illegal logging can be spurred by forest fragmentation and dryness, which together weaken the trees and make them more susceptible to such attacks. Illegal logging can also increase in response to increased forest fragmentation, in particular since access costs are often reduced.

I will in Section 2 present a simple basic model, and on this basis derive and interpret the relevant measures of marginal rainforest value in Section 3. Section 4 presents some numerical parameter and model calibration examples. Section 5 concludes.

[1] See e g Costa et al. (2016), who provide a comprehensive analysis of such issues in the context of the Amazon biome; and references cited there.

2. The Model

This model can be thought of as applying to both "micro scales" (a particular plot of forest subject to immediate deforestation and its control), and the "macro scale" (deforestation occurring throughout the biome, or in relevant major parts of it). This will be explained more carefully below. I will start with defining and discussing the main variables that enter into this analysis.

$1-L$ = currently remaining forest on a unit of land area that was, initially, fully forested. L is already lost forest. I will throughout invoke a linearity (or proportionality) assumption whereby impacts of any forest loss considered are proportional to forest loss, over a relevant small range. Recall the purpose of this analysis, namely to study *marginal* changes in forest cover, at alternative sites throughout the biome, so that changes are always small but may differ by site. Linearity of impacts is then the natural representation of impacts as a first-order Taylor approximation to the relevant impact functions, which is always the correct representation when changes are very small. Linearity in addition reflects an underlying assumption that no catastrophic developments (such as massive dieback or extinctions) will induced by only marginal changes, which is also the only reasonable assumption when changes are marginal. I do not try to explain any initial lack of forest on a plot (represented by L); it can be due to past fires or logging (legal or illegal), or because that part of the plot was never forested.

F = forest lost due to fire on a unit of land. I take F as exogenous; considering L (the typical fraction of the forest already lost before a future fire event) to be small. I assume that some forest always remains after a fire, so that $F < 1-L$.

D = forest dryness, which is a function of the share of lost forest, $D(L)$. Since dryness is a macro phenomenon (forest losses on a given small forest plot have impacts for dryness across the entire biome), $D'(L)$ (>0) will represent the macro dryness impact due to a marginal (local) forest loss (as more lost or less remaining forest makes the remaining forest drier, via various hydrological processes).[2]

r = periodic interest rate for discounting of future costs and benefits, assumed constant.

λ = intensity (continuous-time flow probability) of fire occurrence, where $\lambda = \lambda(L, D)$ with $\lambda'_L(L, D) > 0$, $\lambda'_D(L, D) > 0$ (less forest on a given plot, and more generally drier forest, both raise the probability of fire for the remaining forest on that plot). The occurrence of forest fire on any unit plot is considered to be governed by an associated Poisson process with constant transition probability (or intensity of occurrence) λ. This model assumes that forest fires are governed by random processes. In reality fires occurring in forests such as the Amazon are often set by humans (Mendonça et al. (2004)); the full implications of that issue are not considered explicitly here.

Note that dryness D is a biome-wide phenomenon implying that the λ function, considering impacts on D, is a biome-wide average and not a plot-specific value. This will be explained more carefully below.

We assume for simplicity that fire can occur only once on a given plot. Local fires may in reality take a two- (or even multi-) stage form, with a second stage often having as serious, or more serious, consequences. The Appendix A develops an example to two possible fire occurrences on a given plot, often considered more realistic. The Appendix A however shows that not much precision or generality is lost by collapsing the two-fire case to a one-fire case, with simple reinterpretation of the parameters F and λ.

[2] For discussion of some such mechanisms see Costa et al. (2016). Note that a small forest localized loss will induce only an even much smaller increase in macro forest dryness. But since this effect applies to all standing forest, the overall impact via dryness will have the same dimension as the impact via (local) forest fire risks.