Ecological Economics 153 (2018) 161–171

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Methodological and Ideological Options

Tropical Forests, Tipping Points, and the Social Cost of Deforestation☆

Sergio L. Franklin Jr.[a,*], Robert S. Pindyck[b]

[a] Superintendência de Seguros Privados, Av. Presidente Vargas 730, Rio de Janeiro, RJ 20071-900, Brazil
[b] Sloan School of Management, Massachusetts Institute of Technology, 100 Main Street, Cambridge, MA 02139, United States

ARTICLE INFO

JEL Classification:
Q5
Q57
C6

Keywords:
Deforestation
Critical transition
Tipping point
Social cost
Forest dieback
Payments for ecosystem services
Amazon

ABSTRACT

Recent work has suggested that tropical forest and savanna represent alternative stable states, which are subject to drastic switches at tipping points, in response to changes in rainfall patterns and other drivers. Deforestation cost studies have ignored the likelihood and possible economic impact of a forest-savanna critical transition, therefore underestimating the true social cost of deforestation. We explore the implications of a forest-savanna critical transition and propose an alternative framework for calculating the economic value of a standing tropical forest. Our framework is based on an average cost method, as opposed to currently used marginal cost methods, for the design of optimal land-use policy or payments for ecosystem services. We apply this framework to the calculation of the social cost of deforestation of the Amazon rainforest.

1. Introduction

A number of studies have assessed the economic benefits of a standing tropical forest by estimating the foregone economic benefits resulting from deforestation. The present value of the foregone economic benefits due to one hectare of deforestation has been compared to the present value of future economic benefits of alternative land uses (e.g., crops and cattle ranching) in order to determine the socially optimal land-use policy. To our knowledge, no studies have accounted for the likelihood and possible economic impact of a large-scale forest dieback.

Ecosystems are exposed to gradual changes in climate, nutrient loading, habitat fragmentation or biotic exploitation, and they are usually assumed to respond in a smooth way. However, studies of forests, lakes, coral reefs, oceans, and arid lands have shown that smooth change can be interrupted by sudden drastic switches to a contrasting state (Scheffer et al., 2001).

A tipping point can be defined as a situation in which an ecosystem experiences a drastic shift to a new state causing significant changes to its biodiversity and ecosystem services. Under certain environmental conditions, the ecosystem can have two or more alternative stable states, separated by an unstable equilibrium. Tropical forests and savannas represent alternative stable states, which are subject to drastic switches at tipping points in response to changes in rainfall patterns and other drivers (Lobo Sternberg, 2001; Warman and Moles, 2009; Staver et al., 2015).

We develop a new framework for calculating the marginal economic value of a standing tropical forest, and explore the implications of forest-savanna critical transitions on the design of optimal land-use policy and payments for ecosystem services. We show that marginal cost methods are not appropriate for the design of optimal land-use policy, or for the design of payments for ecosystem services, and propose the use of an average incremental cost method, with the increment properly defined. We also develop a definition of the average incremental social cost of deforestation that, to some extent, follows the approach used in Pindyck (2016) to measure an average social cost of carbon.

In the next section we discuss the social cost of deforestation of the Amazon as measured by existing marginal cost models. Section 3 explains the nature of the forest-savanna tipping point, and provides evidence that the Amazon rainfall patterns are maintained, in part, by the forest itself. Section 4 proposes a new framework for calculating the marginal social cost of deforestation, taking into account changes in forest resilience. Section 5 introduces the average incremental cost

☆ The authors acknowledge the support from MIT's Center for Energy and Environmental Policy Research, MIT's International Policy Lab, and Centro de Pesquisa e Economia do Seguro of Funenseg, Brazil.

* Corresponding author.
E-mail addresses: sergio.franklin@insead.edu (S.L. Franklin), rpindyck@mit.edu (R.S. Pindyck).

https://doi.org/10.1016/j.ecolecon.2018.06.003
Received 2 May 2017; Received in revised form 3 April 2018; Accepted 10 June 2018
0921-8009/

method and shows how, with the increment properly defined, it can be used for the design of optimal land-use policy and payments for ecosystem services. Section 6 concludes.

2. The Social Cost of Deforestation as Measured by Existing Marginal Cost Models

Other studies have tried to estimate the social cost of Amazon deforestation by applying the concept of total economic value (*TEV*) to assess the economic benefits of a standing tropical forest and the foregone economic benefits resulting from deforestation (Torras, 2000; Andersen et al., 2002; Margulis, 2004). The total economic value of a natural resource is the sum of its direct use, indirect use, option, and existence values,[1]

$$TEV = \text{Direct use value} + \text{Indirect use value} + \text{Option value} + \text{Existence value}, \quad (1)$$

where:

- The direct use value of a standing tropical forest stems from sustainable harvesting of timber and non-timber products, such as nuts, fruits and latex, and from ecotourism.
- The indirect use value depends on the ecological functions performed by the forest, such as water recycling, soil and watershed protection, fire prevention, and carbon storage. Estimates of the indirect use values linked to water recycling, erosion control and watershed protection are rarely made, due to the lack of evidence of the ecological impact of a few hectares of deforestation. Estimates of the indirect use value linked to carbon storage are based on the estimates of net carbon emissions per hectare cleared, and cost of additional ton of carbon released into the atmosphere (i.e., marginal cost of carbon).
- The option value refers to uncertain benefits that can be realized at some point in the future, and reflects the willingness to preserve an option for the potential future use of the forest. Most studies estimate only the option value of biodiversity protection, based on the prospects of forest biodiversity yielding new drugs, and their future medicinal benefits.
- The existence value is unrelated to both current and optional use, and arises because people are willing to pay for the existence of an environmental asset without ever directly using it. The existence value includes the value that society is willing to pay to secure the survival and well being of other species.

The Amazon rainforest, shown in Fig. 1, covers around 530 million hectares of land (Soares-Filho et al., 2006),[2] and includes territory belonging to nine nations. Brazil holds about 60% of the forest area, followed by Peru with 13%, Colombia with 10%, and Venezuela, Ecuador, Bolivia, Guyana, Suriname and French Guiana with smaller amounts.

The range of ecosystem services and benefits provided by the Amazon rainforest can be classified as private, local/regional public, and global. Private benefits are always local and include, for example, the profits derived from timber and non-timber products that can be harvested from the forest. Local and regional public benefits include water recycling, nutrient recycling, fire control, erosion control and watershed protection. Global benefits include, for example, carbon storage and biodiversity protection.

Over the last few decades the Amazon forest has experienced rapid land use change, with 15% of the original area deforested by 2003 (Soares-Filho et al., 2006). Among the nine nations with forest territory, only Brazil generates and shares spatially detailed information on annual forest extent and change. In particular, the size of the Brazilian Amazon forest has decreased year by year and is now approaching 80% of its original area (INPE, 2015). Although Brazil has substantially reduced deforestation rates, these rates are increasing in other Amazon countries (Hansen et al., 2013).

Fig. 1. Map of the Amazon rainforest.

Table 1 shows estimates for the present value of the foregone economic benefits from one hectare of Amazon deforestation. These are marginal values in that they represent the change in value for a small change in the forest area, at current deforestation levels. The numbers in this table are derived from estimates from four deforestation cost studies of the Brazilian Amazon, Andersen et al. (2002), Margulis (2004), Soares-Filho et al. (2017a) and Soares-Filho et al. (2017b). In order to make these estimates comparable and accessible, the collected values were updated to 2017 US$ values (i.e., adjusted for inflation), and converted into present values using a common discount rate, 2.5%, based on survey results in Pindyck (2016). In addition to the sources for each estimate, Table 1 also shows the method used for each calculation.

The present value of the foregone economic benefits from one hectare of deforestation, PV_{O_t}, has been incorrectly interpreted as the marginal economic value of a standing tropical forest, and it has been compared to the present value of future economic benefits of alternative land uses (e.g., crops and cattle ranching), AU_t. Deforestation cost studies have shown that, at current deforestation levels, the foregone economic benefits due to deforestation are much lower than the future economic benefits of alternative land uses. Some have argued that Amazon ecosystems are subject to non-linearities — i.e., sudden dramatic increases in the magnitude of damage once the forest area is reduced below some critical threshold — so that additional deforestation can result in rapid increases in the marginal economic value.[3]

Something is missing from these marginal economic value calculations. The greatest non-linearity in the total economic value of a tropical forest occurs at the deforestation threshold that triggers the forest-savanna critical transition, but no existing cost studies account for the likelihood and possible impact of a catastrophic shift to the savanna state. In fact, when the first economic impact of forest degradation appears, the forest ecosystem may have already started the self-propagating transition to the savanna state, which will almost certainly be irreversible. We turn to that next.

[1] See, for example, Pearce (1993).

[2] One hectare is equal to 10,000 square meters, or roughly 2.47 acres.

[3] See, for example, Torras (2000) and Andersen et al. (2002). According to Strand (2017), losses of rainforest likely lead to less rainfall and increased forest fire risk, which in turn increase marginal forest value by making primary forest loss avoidance more valuable.