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Optimal rate of paper recycling

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ABSTRACT

This paper uses a dynamic land allocation model combined with the infinite rotation problem to determine theoretically, the recycling rate that maximizes the forest area and, thus, the number of trees under social management thereby integrating both positive externalities generated by the forest and social costs of not recycling. The results suggest that, when the recycling rate is low, increasing it to its optimal level will result in more land area being devoted to forestry and, thus, more trees. However, increasing it beyond its optimal level will reduce the number of trees in the long run. In addition, the recycling rate that maximizes the forest area is optimal in the sense that it also maximizes the social net benefit. An application shows that increasing the recycling rate up to its optimal level considerably increases the forest area. The increase in the social net benefit is very small.

1. Introduction

Over the last three decades, intensive campaigns have sought to promote the recycling of paper. In addition to reducing pollution and conserving landfill space, the main argument in favor of recycling paper is that it preserves trees, which is justified by the fact that trees generate positive externalities such as direct amenities, soil conservation, and carbon sequestration. Therefore, it has become part of our habit to recycle pulp and papers products. In many countries, this resulted in an increase in the recovery rate of papers and hence in the increase of the recycling rate. For example in Canada the recovery rate was 11% in 1990 and more than doubled to reach 24% in 2012.[1] The rapid increase in the rate of recycling paper has recently generated more debate about the real goal of paper recycling. Darby (1973) and Tatoutchoup and Gaudet (2010) pointed out that, if the reason for recycling is to save trees by protecting the forest area, increasing the rate of recycling from any admissible level will actually have the reverse effect in the long run by reducing the forest area and, thus, the number of trees. However, these papers addressed the issues only from the perspective of a private land owner. Neither the positive externalities generated by the forest nor the societal costs of failing to recycle are taken into account. This paper integrates both positive externalities of trees and social costs of not recycling to analyze from the societal perspective whether there exists a recycling rate that maximizes the forest area and how it affects the net social benefit.

To analyze the problem, I follow Tatoutchoup and Gaudet (2010) approach by specifying a simple dynamic model of land allocation under social management between forestry activities and alternative uses, such as agriculture that incorporates the infinite rotation problem à la Faustmann. In addition, the benefits of forests beyond their utility as a feedstock for manufacturing (direct amenities, carbon sequestration) and the societal cost of failing to recycle (landfills cost that include the disposal charge cost and environmental cost due to pollution) are integrated in the model.

A few researchers, such as Barbier and Burgess (1997), Lopez et al. (1994), and Ehui and Hertel (1989), have analyzed the land allocation problem among many uses. However, none of these papers used Faustmann's framework to determine the optimal rotation (optimal cutting age); furthermore, they implicitly assumed that the output produced is entirely consumed, excluding the recycling. Wiseman (1993) used a hypothetical input output model to show that increasing the recovery rate of waste paper will decrease the demand of virgin fiber in U.S., while Kinnaman et al. (2014) have determined in Japan the recycling rate that minimizes the average

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[1] Source: Statistics Canada.

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social cost of municipal waste. Both papers focused only on empirical aspects. Moreover, the production of virgin wood, and the land allocation problem are ignored.[2]

This paper is organized as follows. Section 2 presents the theoretical model. In Section 3, I first determine the equilibrium allocation of land. Then I solve for the optimal rate of recycling. Finally, a numerical application ends the section. Section 4 concludes the paper.

2. The model

Let's consider a fixed area of land A to be allocated between forestry production and another alternative use of land say, agriculture. The forestry production consists of infinite sequences of the planting and harvesting of trees. Indeed, at each planting time t_{i-1}, where $i-1$ denotes the $(i-1)$th planting of trees with $i \geq 1$, the forest owner determines a new allocation of land between both productions. Hence,

$$f_{i-1} + a_{i-1} = A \quad i = 1, \ldots, \infty \tag{1}$$

where f_{i-1} and a_{i-1} are areas of land devoted to forestry and agriculture, respectively. Let $T_i = t_i - t_{i-1}$ denote the cutting age of trees (rotation i of length T_i) planted at time t_{i-1} and harvested at time t_i, which is also the next planting time. Let $X(T_i)$ denote the volume of timber per unit of land available at the harvesting time t_i or rotation T_i. Then the total volume of wood harvested at time t_i is $h_i = f_{i-1}X(T_i)$. The function $X(\cdot)$ is the timber growth function and depends only on the age of a tree. It is defined for $\tau \geq \tau_0$, with $X(\tau_0) = 0$, and is assumed to be increasing, twice differentiable and concave.

In addition to the harvesting activities, the forest generates amenity services for society (captured from the carbon sink) that are valued by the society and given by $\pi_{ab}(T_i, f_{i-1}) = f_{i-1}\int_{\tau_0}^{T_i} B(\tau)e^{-r\tau}d\tau$, where $B(\tau)$ is the flow of amenities for a stand of age τ. It is defined for $\tau \geq \tau_0$, with $B(\tau_0) = 0$, and is assumed to be increasing, twice differentiable and concave. The parameter r represents the discount rate.

For simplicity, let's assume that the virgin wood is only used to produce a final recyclable good say, paper. Let's also assume that the virgin wood and the recycled product (recycling paper) are perfect substitutes.[3] Then, the final good can be produced using either virgin wood or the recycled product or both. For simplicity, let's assume that one unit of input produces one unit of output. Therefore, the total quantity of input available at date t_i is

$$S(t_i) = f_{i-1}X(T_i) + \delta S(t_{i-1}) \tag{2}$$

where δ is the recycling rate and $S(t_0) = S_0$ is the given stock available at the initial planting date t_0. Because virgin wood and the recycled product are perfect substitutes, the market price of input denoted by $p_{t_i} = P(S(t_i))$ is also the market price of timber. The inverse demand function is assumed to have the following properties: $P(S(t_i)) \geq 0 \quad P'(S(t_i)) < 0$ and $\lim_{S(t_i)\to\infty} P(S(t_i)) = 0$. Thus, the profit of forest activities at planting time t_{i-1} for rotation i of age T_i is $\Pi_f(T_i, f_{i-1}; S(t_i)) = [P(S(t_i)) - c]f_{i-1}X(T_i)e^{-rT_i} - kf_{i-1}$, where $c \geq 0$ denotes the harvesting cost per unit of volume and $k \geq 0$ is the planting cost per acre. The market price of input is assume to be competitive.

[2] Additional surveys on land allocation problem are contained in Tatoutchoup and Gaudet (2010).

[3] This is a simplifying assumption. Assuming differently will not add any insights to the issues addressed in this article.

After harvesting, a fraction of final product δh_i will be recycled and the remaining quantity $R_i = (1-\delta)h_i = (1-\delta)f_{i-1}X(T_i)$ will end up in the landfill. This imposes a societal cost denoted by $C(R_i)$ namely, the cost of failing to recycle, which includes waste disposal charge cost and environmental cost (additional pollution due to an increase in the landfill). For simplicity, let's assume that $C(R_i) = \theta R_i$, where θ is the unit cost of not recycling.

Finally, the profit of agriculture at the planting date t_{i-1} is given by $\pi_a(T_i, a_{i-1}) = \int_{t_{i-1}}^{t_i} g(a_{i-1})e^{-r(\tau - t_{i-1})}d\tau = g(a_{i-1})(1-e^{-rT_i})/r$, where $g(a_{i-1})$ represents the instantaneous profit from agriculture. The function $g(\cdot)$ is assumed to be increasing, twice differentiable and strictly concave. The present value of the social net benefits at time t_{i-1} from the total land use over the rotation of length T_i is thus

$$\begin{aligned}\Pi(T_i, f_{i-1}, a_{i-1}, R_i; S(t_i)) =& \pi_f(T_i, f_{i-1}; S(t_i)) + \pi_{ab}(T_i, f_{i-1}) \\ & - C(R_i)e^{-rT_i} + \pi_a(T_i, a_{i-1}).\end{aligned}$$

3. Optimal land allocation and optimal rotation

Before going on to solve for the optimal recycling rate which is the recycling rate of paper that maximizes the social net benefit, I first determine the optimal allocation of land between the two alternative uses and the optimal harvesting age of trees for any given value of the recycling rate δ. This enables to analyze the impact of the recycling rate on both the social net benefit and the forest area.

Therefore, the problem of the regulator is to choose a sequence of $\{T_i, f_{i-1}, a_{i-1}, R_i\}_{i=1}^{\infty}$ that maximizes the sum of the discounted social net benefit at the initial planting date t_0 given by $V(S_0) = \sum_{i=1}^{\infty} \Pi(T_i, f_{i-1}, a_{i-1}, R_i; S(t_i))\, e^{-r(t_{i-1}-t_0)}$, subject to Eq. (1) and to $f_{i-1} \geq 0, a_{i-1} \geq 0, i = 1, \ldots, \infty$.[4] At this stage the regulator cannot affect the stock $S(t_i)$, and takes it as given. Later the regulator will endogenize $S(t_i)$ to maximize the forest land area. Substituting for a_{i-1} from Eq. (1) and $R_i = (1-\delta)f_{i-1}X(T_i)$ into $V(S_0)$, and ignoring the non-negativity constraints, the problem is to choose $\{T_i, f_{i-1}\}_{i=1}^{\infty}$ to maximize $\sum_{i=1}^{\infty} \Pi(T_i, f_{i-1}, A - f_{i-1}, (1-\delta)f_{i-1}X(T_i); S(t_i))\, e^{-r(t_{i-1}-t_0)}$. The necessary first-order condition for interior solutions are given respectively by[5] $\partial V(S_0)/\partial f_{i-1} = 0$, and $\partial V(S_0)/\partial T_i = 0 i = 1, \ldots, \infty$. After some algebraic manipulation and as denoted by $p(S(t_i)) = P(S(t_i)) - c - (1-\delta)\theta$, I obtain

$$p(S(t_i))\, X(T_i)e^{-rT_i} - k + \int_{\tau_0}^{T_i} B(\tau)e^{-r\tau}d\tau = \frac{g'(A - f_{i-1})}{r}(1 - e^{-rT_i}) \tag{3}$$

$$p(S(t_i))\, X'(T_i) + B(T_i) + g(A - f_{i-1}) = rp(S(t_i))\, X(T_i) + rV(S_i) \tag{4}$$

where $V(S_i)$ is the discounted sum of the social net benefits starting at time t_i while $p(S(t_i)) = P(S(t_i)) - c - (1-\delta)\theta$ represents the social net price per unit of timber harvested. It is the market price net of harvesting cost and the unit cost of failing to recycle. Condition (3) says that the net marginal benefit of allocating land to forestry equals the net marginal benefit of allocating land to agriculture. While condition (4) says that marginally delaying the rotation T_i, the increment in the social value of wood resulting from forest growth plus the amenity benefits and the net benefit from agriculture, must be equal to the forgone interest on the social value of the stand, plus the interest foregone from delaying all future harvesting.

[4] The regulator can be the government, a local or a federal public administration.

[5] Without loss of generality, I will focus on interior solutions.