JMHT Vol. XVIII, (2): 138–143, Agustus 2012
EISSN: 2089-2063
DOI: 10.7226/jtfm.18.1.138

Pemikiran Konseptual
ISSN: 2087-0469

Internalizing Externalities through Payments for Environmental Services

Sudarsono Soedomo

Department of Forest Management, Faculty of Forestry, Bogor Agricultural University, Academic Ring Road, Campus IPB Dramaga PO Box 168, Bogor 16680, Indonesia

Received March 5, 2011/Accepted May 14, 2012

Abstract

Forest ecosystems, including plantation forests, provide goods and services that are marketable and non-marketable. Positive externalities produced by forest ecosystems are rarely considered in pricing of marketable products that result in economic inefficiencies. Internalizing externalities is required to improve the economic efficiency. The traditional way to internalize an externality is by providing subsidies or imposing taxes. Recently, payments for environmental services are receiving more attention as an instrument for internalizing externalities provided by forest ecosystems. This promising alternative to improve our environment needs to be studied more extensively. In this paper, it can be indicated theoretically that the Pigovian tax, as a traditional way of addressing environmental problems, is able to mimic the result derived from the employment of environmental services payment. The difference is that environmental services payment improves the welfare of environmental service producers, whereas the Pigovian tax reduces it. A positive Pigovian tax increases the optimal rotation, which is positively associated with environmental improvement, but certainly reduces forest owner's welfare. This difference should be taken into account in the public policymaking so that perverse incentive may be avoided. Payment for environmental services as an additional income to forest growers, not as alternative source of income, is a potential tool to address simultaneously issues of environment and poverty that are frequently contested.

Keywords: externalities, payments for environmental services, tax, perverse incentive, social welfare

**Correspondence author, email: ssoedomo@gmail.com, telp. +62-251-8621244, fax. +62-251-8621244*

Introduction

How to motivate plantation forest owners to increase the biomass of standing stock of their forests? Standing stock stores carbon, so that the more standing biomass is maintained the more carbon is stored. It implies that carbon in the air will be reduced. Environmental quality will be better as concentration of carbon in the air is reduced. Therefore, increasing forest biomass will improve quality of the environment[1]. What incentives or disincentives are needed in order to increase biomass of plantation forests? Can the traditional approach solve the problem without creating perverse incentives? Internalizing environmental costs or benefits is a necessary condition for an effective environmental policy (Bithas 2006). Once a policy is adopted, it should be administered. Very often, we focus more on the policy itself but lack of attention to its implementation (Bontems & Bourgeon 2005). Then a funny phrase emerges stating that the policy was good but never implemented. A policy that was never implemented in essence is not a policy at all.

The classical problem in forest economics is to determine optimal rotation (Löfgren & Mattsson 1995). This problem was solved by Germany forest economist, Faustmann, in 1849. Determination of optimal rotation is still interesting today to be studied further, mainly due to development of human awareness to better appreciate forests more than just timber producer. Determination of forest plantation rotation with payments for environmental services (PES) was written by among others, van Kooten *et al*. (1995), Appels (2001), and Tassone *et al*. (2004).

They analyze the impact of payments for carbon sequestration on the optimal rotation of the Faustmann's plantation forest model. They show that PES increases the optimal rotation.

Forest owners determine the optimal rotation to maximize the present value of net income flow. The longer the rotation, the more biomass that will be contained by a given tract of land. In other words, prolonging the rotation will raise the carbon stored per area unit of land. The further question is how to encourage forest owners to be willing to lengthen the rotation of their forests? What compensation should be given to forest owners?

From different point of view, plantation forest businesses produce timber, as the main product, and externalities that are frequently called environmental services today. The optimal rotation determination is essentially also the optimal production determination. We know that the optimal production is determined by output and input prices. Furthermore, taxes or subsidies tied to every unit of output produced can potentially be used to control the optimal production level. It is what has been acknowledged as Pigovian Tax[2]. Recently, payments for environmental services have been becoming more attractive as a direct payment for compensating what has been done by plantation forest owners.

EISSN: 2089-2063 ISSN: 2087-0469
DOI: 10.7226/jtfm.18.1.138

The potential whether tax or subsidy can mimic the optimal rotation derived from direct PES is discussed in this paper. What will be the impact of the 2 approaches on the welfare of forest owner? The welfare impact is very important to be considered in selecting appropriate policy instruments in order to achieve the goal. A mistake in choosing the instruments may result in a failure of achieving the goal. Hence, adequate analysis needs to be done prior to making a decision. This paper differs from the one written by Appels (2001) in 2 aspects, e.g. firstly, the plantation forest analyzed in this paper is synchronized plantation forest, and secondly, the Pigovian Tax will be used to mimic the result delivered by payments for environmental services approach.

In order to achieve the goal, this paper is organized as follows. Following this introduction section, section 2 discusses briefly payments for environmental services. Section 3 presents the optimal rotation determination by employing modified Faustmann's model for synchronized forests. The optimal rotation determinations with and without payments for environmental services are discussed. Section 4 discusses the impact of payments for environmental services on the optimal rotation. Section 5 discusses how tax can mimic the same optimal rotation delivered by payments for environmental services. Next section will be discussing the impact of each approach on environment and social welfare. The last section is conclusion.

Payments for Environmental Services (PES)

The concept of PES has emerged from an economic discussion on how to internalize externalities in the production process. Mirroring the discussion on the use of economic instruments to reduce negative externalities such as contamination through the internalization of the costs, in the 1990's there began an exploration on the use of economic instruments to maintain and expand the flow of positive externalities, such as environmental services, by internalizing the benefits, either through direct payments to those responsible for maintaining certain land uses, or through market development and creation of environmental services (Rosa *et al*. 2004).

Payment for environmental services is a relatively new approach, and there is not yet a settled definition of the term. It can be used very broadly to include, for example, pollution charges (Pagiola & Platais 2002). Here it is used more narrowly to focus on mechanisms under which those who provide positive externalities of storing carbon in forest stand are compensated for doing so. Although environmental services in general have public goods properties, the amount of carbon stored in forest stands is relatively easy to measure. In addition, the owners of forest stands can be identified very easily. Hence, payment for carbon storage services can be made rather easily.

As global climate change has been becoming more worrying issue, the carbon reduction from the air becomes more compelling to be materialized immediately. At the same time, development of forest plantation is often hampered by low financial return. From this point of view, payments for environmental services will provide incentive for developing plantation forests. Hence, payments for environmental services are expected to be able to make plantation forest more attractive. The Clean Development Mechanism of the Kyoto Protocol-expires at the end of 2012, even though Indonesia has difficulties in taking advantage of it, offers opportunities to developing countries to tap payments for environmental services from developed coountries (Schoene & Netto 2005).

The main problem of environmental issues is that the environment has the characteristics of public goods. Thus, it is difficult to expect that private individuals are willing to take the initiative to voluntarily improve the environment. Therefore, concerted action is a necessity that cannot be avoided. In this context, the role of government or of a mutually recognized authority in resolving environmental issues is absolutely necessary. Compared with private goods, the transaction and administration of public goods will be more complicated. Direct interaction between providers and users of environmental services may not be efficient.

Direct payment to forest stands as carbon storages is tacitly derived from a wrong view, which is a higher demand for timber is always correlated with more deforestation and forest degradation (Gan & McCarl 2007). Whereas, the higher demand for timber can also be translated into higher reforestation. The question needs to be answered is under what condition a higher demand for timber can be translated into higher reforestation and when this relation fails. The answer has been available around us for quite some time, but apparently very few who pay close attention. The key factor responsible for the success is well-defined land rights. The others supporting factors are competitive price and relatively adequate infrastructure, especially road network. Since 1990 plantation forest, on private lands, in Java Island has been increasing tremendously. In 1990 the private forests were 1.9 million ha, rose to 2.7 million ha within 2000–2003, and felt to 2.6 million ha within 2006–2008 (Balai Pemantapan Kawasan Hutan Wilayah XI Jawa–Madura 2009). Along with the increase in forest area, the standing stock of commercial timber from the private forests has increased within the period of 1990–2008 from 55.9 million m^3 in 1990 to 78.8 million m^3 within 2000–2003, but slightly felt to 74.8 million m^3within 2006–2008. Has Java Island passed through the turning point of Environmental Kuznets Curve?

Modified Faustmann's Model for Synchronized Forest

To construct synchronized forest as a modified Faustmann's model, let's assume that forest areas of H hectares are divided into T plots, T where is the optimal rotation we want to determine. It is well known as normal plantation forest. The growth of standing forest volume follows $V(t)$ where $t \in [0, T]$ is stand age, so that at the optimal rotation the timber volume produced is $V(t)$. The price of timber harvested at any age is p_1 that is assumed to be independent from stand age[3], while environmental services are priced p_2 per unit volume of standing stock annually. We assume that only carbon stored in themain stem is considered for the payment. We also assume that the whole areas have the same quality. The plantation forests are managed for infinite period of time and the interest rate, r, is assumed to be constant forever. Development cost of plantation per hectare is c, which is spent at the beginning of the rotation, and there is no any other cost needed prior to harvesting.

In order for the discussion to be understood rather easily, firstly I will present the optimal rotation determination of normal plantation forest without carbon storage compensation. Next discussion will be the optimal rotation determination of normal plantation forest with carbon storage compensation. The compensation will be given as long as the standing stock of plantation forest is maintained on the field. During the first rotation, the standing stock of plantation forest increases up to steady state level when the oldest stand reaches its optimal rotation age.

Optimal rotation without carbon storage services payment Without carbon storage compensation, the revenue earned by forest manager only come from selling timber at price p_1. The objective of the management is to maximize net present value (NPV) of net income stream by choosing the optimal rotation. This objective can be written as equation *[1]*:

$$\max_{\{T\}}\left[\left(\frac{H}{T}\right)\left(e^{-rT}p_1V(T)-c\right)\right]\sum_{t=0}^{\infty}\left[\frac{1}{1+r}\right]^t \quad [1]$$

First order necessary condition for the maximum NPV is in equation *[2]*:

$$V'(T)=rV(T)+\frac{V(T)}{T}-\frac{c\,e^{rT}}{p_1T} \quad [2]$$

The optimal rotation is found by solving the equation *[2]* for T[4]. Equation *[2]* basically says that marginal revenue of delaying equals marginal cost of waiting plus marginal cost of net annual income. This notion can be seen more easily by rewriting equation *[2]* as equation *[3]*:

$$V'(T)p_1e^{-rT}=rV(T)p_1e^{-rT}+\frac{V(T)p_1e^{-rT}}{T}-\frac{c}{T} \quad [3]$$

Optimal rotation with carbon storage services payment Standing stock at the time just prior to harvesting is, which is resulted from summing up of all standing stocks from different ages. In continuous notation it is:

Harvesting will take an amount of $V(T)$ away from the total standing stock and the timber harvested is sold at the price of p_1 - it is assumed to be constant forever, while the remaining standing stock is given a compensation for carbon storage services. Let us assume that the service compensation is p_2 per year for each unit of standing stock maintained in the field. In terms of per unit of timber, it is assumed that $p_1 < p_2$[5]. Let us further assume that the compensation will have been given since the very beginning of plantation. From the first harvesting and on, any time the standing stock available in the field that stores carbon is assumed to be constant at equation *[4]*:

$$\left[S(T)-V(T)\left(\frac{H}{T}\right)\right] \quad [4]$$

Forest manager will choose the optimal rotation to maximize the present value of the net income stream. Since both the timber harvested and the standing stock produce income stream, the forest manager should attempt to optimize, at least in a certain condition, the income coming from the timber harvested and the one coming from carbon storage services by choosing the optimal rotation. The manager's objective can be formulated as equation *[5]*

$$\max_{\{T\}}\left[\int_0^T e^{-rt}\frac{H}{T}p_2V(t)dt+\frac{H}{T}\left(e^{-rT}(p_1-p_2)V(T)-c\right)\right]\sum_{t=0}^{\infty}\left[\frac{1}{1+r}\right]^t \quad [5]$$

The first order necessary condition that must be met for the optimal rotation is in equation *[6]*:

$$V'(t)=eV(T)+\frac{V(T)}{T}-\frac{V(T)}{p_1-p_2}\left[p_2+\frac{c\,e^{rT}}{TV(T)}+\frac{e^{rT}p_2}{TV(T)}\int_0^T e^{-rt}p_2V(t)dt\right] \quad [6]$$

Now it is the time to answer the initial question concerning the effect of payment for carbon storage services on the optimal rotation of fully regulated plantation forest. To answer this question, I will exploit the equation *[2]* and equation *[6]* that will be presented in the section 4.

Effect of carbon storage payment on the optimal rotation Let us denote the optimal rotations resulted from equation *[2]* and equation *[6]* by T_1^* and T_2^* respectively. Assuming that $T_1^* > T_2^*$ then by using equation *[2]* we will have:

$$\frac{V'(T_2^*)}{V(T_2^*)}\geq r+\frac{1}{T_2^*}-\frac{ce^{rT_2^*}}{p_1T_2^*V(T_2^*)} \quad [7]$$

Substituting equation *[7]* into this last equation and manipulating the result will yield in equation *[8]*

$$\frac{1}{(p_1-p_2)}\left[p_2+\frac{c\,e^{rT_2^*}}{V(T_2^*)T_2^*}+\frac{e^{rT_2^*}p_2}{V(T_2^*)T_2^*}\int_0^{T_2^*}e^{-rt}p_2V(t)dt\right]\leq\frac{c\,e^{rT_2^*}}{p_1T_2^*V(T_2^*)} \quad [8]$$

Since $p_1 > 0$-, $p_2 \geq 0$, and $p_1 \geq p_2$, then expression *[8]* holds when the following 3 equations are satisfied:

$$0\leq\frac{p_2}{p_1-p_2}\leq\frac{c\,e^{r\,T_2^*}}{p_1\,T_2^*\,V(T_2^*)} \quad [9]$$

$$0\leq\frac{p_2}{p_1-p_2}\frac{e^{rT_2^*}p_2}{T_2^*\,V(T_2^*)}\int_0^{T_2^*}e^{-rt}V(t)dt\leq\frac{c\,e^{r\,T_2^*}}{p_1\,T_2^*\,V(T_2^*)} \quad [10]$$

$$0\leq\left[\frac{1}{p_1-p_2}\right]\frac{c\,e^{r\,T_2^*}}{T_2^*\,V(T_2^*)}\leq\frac{c\,e^{r\,T_2^*}}{p_1} \quad [11]$$

Expression *[11]* can be simplified into equation *[12]*

$$0\leq\left[\frac{1}{p_1-p_2}\right]\leq\frac{1}{p_1} \quad [12]$$

However, since $p_1\geq 0$, $p_2\geq 0$, and $p_1\geq p_2$ then it must be the case that $0\leq p_1-p_2\leq\frac{1}{p_1}$ implying that:

$$\left[\frac{1}{p_1-p_2}\right]\geq\frac{1}{p_1} \quad [13]$$

It can easily be seen that equation *[13]* contradicts against equation *[12]*. Hence, we have to reject the assumption and conclude otherwise, that is. It says that payment for carbon storage services will increase the optimal rotation of fully regulated forest. By employing the first-order stochastic dominance[6], we know that for the same area of land fully regulated forest with a longer rotation will have more biomass than the one with a shorter rotation. In other words, payment for carbon storage services will improve the quality of the environment by storing more

JMHT Vol. XVIII, (2): 138–143, Agustus 2012
EISSN: 2089-2063
DOI: 10.7226/jtfm.18.1.138

ISSN: 2087-0469

carbon in forest stand instead of letting it fly in the air. Payments for environmental services may potentially attract more people to cultivate plantation forest.

Tax or Subsidy?

Despite weaknesses it contains, Pigovian tax or subsidy is a perfect approach to internalizing externalities (Baumol 1972; Green & Sheshinski 1976; Parry 2012). A Pigovian tax is a tax levied on a market activity that generates negative externalities. If externalities generated are positive, then the tax must be negative, meaning a subsidy. To analyze whether or not taxation or subsidy is able to mimic the result delivered by the Equation *[6]*, I rely on the equation *[2]* Let denote the plantation development tax per hectare. This tax imposition will change the equation *[2]* into:

$$V'(T) = rV(T) + \frac{V(T)}{T} - \frac{(c+\tau_1)e^{rT}}{p_1 T} \qquad [14]$$

In order for the equation *[14]* to be able to produce the same optimal rotation as it was produced by the Equation *[6]* ,then the following condition must be satisfied:

$$\frac{(c+\tau_1)e^{r\,T_2}}{p_1\,T_2\,V(T_2)} = \frac{1}{(p_1 - p_2)}\left[p_2 + \frac{c\,e^{r\,T_2}}{T_2\,V(T_2)} + \frac{e^{r\,T_2}\,p_2}{T_2\,V(T_2)}\int_0^{T_2} e^{-rt}\; p_2\,V(t)\,dt\right] \qquad [15]$$

Solving the equation *[15]* for yields:

$$\tau_1^* = \frac{p_1 p_2}{(p_1 - p_2)}\,e^{-r\,T_2}\,T_2\,V(T_2) + \frac{p_2}{(p_1 - p_2)}\,c + p_1\,p_2^2 \int_0^{T_2} e^{-rt}\,V(t)\,dt \;\geq 0 \qquad [16]$$

For, the equation *[16]* will produce nonnegative. It means that to achieve the same environmental quality as it was delivered by payment for environmental services approach, then plantation development cannot be given a subsidy. The opposite is true, that plantation development must be taxed. A plantation development subsidy can increase the optimal rotation when as it has been mentioned earlier, this assumption is not realistic.

By using the same procedure, the taxation on timber sale can be determined to produce the same optimal rotation. Let denote the sale tax per cubic meter of timber sold. The equation *[2]* becomes:

$$V'(T) = r\,V(T) + \frac{V(T)}{T} - \frac{c\,e^{rT}}{(p_1 - \tau_2)T} \qquad [17]$$

In order for the optimal rotation to be T_2*, then the following condition must be met:

$$\frac{V(T_2^*)}{(p_1 - p_2)}\left[p_2 + \frac{c\,e^{r\,T_2^*}}{T_2^*\,V(T_2^*)} + \frac{p_2\,e^{r\,T_2^*}}{T_2^*\,V(T_2^*)}\int_0^{T_2^*} e^{-rt}\,p_2\,V(t)\,dt\right] = \frac{c\,e^{r\,T_2^*}}{(p_1 - \tau_2)T_2^*} \qquad [18]$$

Solving the equation *[18]* for τ_2 yields:

$$\tau_2^* = p_2\,\frac{\left[p_1\,T_2^*\,V(T_2^*) + c\,e^{r\,T_2^*} + p_1\,p_2\,e^{r\,T_2^*}\int_0^{T_2^*} e^{-rt}\,V(t)\,dt\right]}{\left[p_2\,T_2^*\,V(T_2^*) + c\,e^{r\,T_2^*} + p_2^2\,e^{r\,T_2^*}\int_0^{T_2^*} e^{-rt}\,V(t)dt\right]} \geq 0 \qquad [19]$$

We can see that both numerator and denominator always have positive sign. Hence, τ_2* must have positive sign that implies it must be a tax. It means that a timber sale tax can be used to lengthen the optimal rotation. Similar to the plantation development tax, this timber sale tax also creates additional burden to the party who has produced positive externalities, who is supposedly given a compensation for the services provided. Of course, it is socially unjust and cannot be justified. A similar result is presented by Tassone *et al.* (2004) for Faustmann's scenario. Justus Wesseler suggests a contingent incentive to overcome the problem, that is the subsidy is delivered when the plantation owners meet the rotation required (personal communication).

Impact on Environment and Welfare

Individually, impact of a subsidy, either to product price or development costs, on the optimal rotation is negative, due to a lower standing stock, but the whole impact could be positive. It is true that a subsidy makes forest owners lower the optimal rotation, but the subsidy might attract more land owners to grow plantation forest. In other words, a subsidy will possibly make more plantation forests with a shorter rotation. Of course, we cannot determine the net impact with certainly unless we know subsidy elasticity of optimal rotation and of forest expansion. In general, however, inclusion of the external benefits from carbon uptake results in rotation ages only a bit longer than the financial (Faustmann) rotation age (van Kooten *et al.* 1995). Similar result apparently holds for synchronized normal forest.

In terms of social welfare, payment for environmental services is better approach compared to taxation approach. Both approaches are able to produce the same environmental quality but utterly different social welfare. Objective function as it is formulated in the equation *[1]* shows that net present value of perpetual forest management increases with a decrease in costs of plantation development or an increase in the sale price. In other words, an imposition of a tax either on the plantation development or timber sale will reduce the profit. Hence, the imposition of the Pigovian tax to improve environmental quality in this case is absurd, in which plantation forest owner who generates positive impacts on the environment should incur environmental costs. The decrease in the profit for plantation forest owner is economic disincentive for developing plantation forest in the long run. So, we need a new way to address the problem.

Payments for environmental services seem to offer such alternative a way of improving environmental quality at individual level of plantation. They provide correct incentives to plantation forest owner to a certain level, beyond which the payments will work in the opposite direction. As an additional income, the payments increase the welfare of plantation forest owner. Applying payments for environmental services to poor forest farmers can potentially achieve 2 goals; they are improving quality of the environment and reducing poverty. Unfortunately, the government of the Republic of Indonesia still had an understanding that the payment of carbon storage is a business that needs to be burdened with royalty, not as compensation for positive externalities deserve accepted by forest owners (see Regulation of Forestry Minister P.36/Menhut-II/2009). In the appendix of P.36/Menhut-II/2009, we can see that the government intends to take away 10% of PES to private forests, which are usually small in size and owned by low income farmers who need to be helped.

It is true that PES is consistent with environmental improvement at both individual and aggregate levels, but its implementation could be more complicated than providing a subsidy. Storing carbon in standing forests as required by forest carbon trading systems is so complicated and potentially inefficient. The buyers should monitor the carbon stored periodically due to the principal-agent problem. Errors are very likely encountered in calculating carbon storage (Tavoni *et al*. 2007). In short, transaction costs of carbon trading are potentially high (van Noordwijk *et al*. 2008). While a contingent subsidy can be executed more easily. Especially for small-scale plantation owners, the optimal rotation is determined more by the needs of the family than by considerations of profit maximization.

To this day, carbon trading in Indonesia is still limited to a very noisy discourse rather than significant realities. Too much lip services than reality for the benefit of forest owners. Effort of several parties in Indonesia to take advantage of CDM was ended in failure. Many administrative requirements, especially with regard to legal documents on the ground, are very difficult to fulfill. Again, this suggests that the carbon trade transaction costs are still too high, so that carbon trading still cannot be implemented efficiently. So much efforts have been made to make the forest carbon markets work, such as institutional arrangement (Corbera *et al*. 2009), carbon banking to open more opportunity to small scale forest owners (Bigsby 2009), and carbon pricing stored in standing forests (Hunt 2008). In a very limited scale, carbon trade has occurred in Indonesia. The closest example is the forest of Mount Walat which receives revenue from the carbon storage payments for a period of 30 years. Another example, which is frequently mentioned, is a "Mandatory PES" for water service in Lombok (Pirard 2012).

The lip service is increasingly apparent as just a mere promise when we compare between the realization of carbon trading with the subsidies given to fossil fuels. What a great irony when the activities that emit carbon were heavily subsidized, while aid to activities that capture and store carbon is only such very noisy a discourse. Fuel subsidy given in 2006 was Rp64.2 trillion, in 2007 was Rp83.8 trillion, and in 2008 was Rp139.1 trillion. Comparing these real subsidies and Regulation of Forestry Minister P.36/Menhut-II/2009 generates ironic situation, which is ruining the environment is rewarded while improving the environment is punished. Reducing carbon emission is just rhetoric unless supported by healthy fiscal policies that promote carbon stock in standing as well as in preserved timber.

Conclusion

Any improvement of quality of the environment must should be based on the goal to enhance human welfare, both buyers and providers of environmental services. Payments for environmental services can improve quality of the environment and at the same time increases forest owner's welfare. While a tax can improve quality of the environment but reduce forest owner's welfare individually. In other words, payments for environmental services offer win-win solution, while a tax forces win-lose solution to achieve the same quality of the environment individually. Providing a subsidy may decrease environmental quality at individual level, but aggregately it might deliver a better environmental quality because more land owners might be attracted by the subsidy to grow forests. Public policymakers need to be aware of this difference. We need policies that depart from a good idea and at the same time we also must consider how to implement them effectively and efficiently. It is clear that payments for environmental services is a good idea and makes sense, but how to make it happen?

References

Amacher GS, Ollikainen M, Koskela E. 2009. *Economics of Forest Resources*. Cambridge, Massachusetts: The MIT Press. http://dx.doi.org/10.1017/S1355770X0800483X.

Appels D. 2001. *Forest Rotation Lengths under Carbon Sequestration Payments.* Working paper, Conference of Economists. Perth: University of Western Australia.

Balai Pemantapan Kawasan Hutan Wilayah XI Jawa-Madura. 2009. *Potensi Kayu dan Karbon Hutan Rakyat di Pulau Jawa Tahun 1990-2008*. Yogyakarta: Kementerian Kehutanan RI.

Baumol WJ. 1972. On taxation and the control of externalities. *American Economic Review* 62(3):307–322.

Bigsby H. 2009. Carbon banking: Creating flexibility for forest owners. *Forest Ecology and Management* 257(1):378–383. http://dx.doi.org/10.1016/j.foreco.2008.09.018.

Bithas K. 2006. The necessity for environmental taxes for the avoidance of environmental thievery. A note on the paper "environmental responsibility versus taxation". *Ecological Economics* 56(2):159–161. http://dx.doi.org/10.1016/j.ecolecon.2005.11.026.

Bontems P, Bourgeon JM. 2005. Optimal environmental taxation and enforcement policy. *European Economic Review* 49(2):409–435. http://dx.doi.org/10.1016/S0014-2921(03)00036-9.

Corbera E, Soberanis CG, Brown K. 2009. Institutional dimensions of payments for ecosystem services: an analysis of Mexico's carbon forestry programme. *Ecological Economics* 68(3):743–761. http://dx.doi.org/10.1016/j.ecolecon.2008.06.008.

EISSN: 2089-2063
ISSN: 2087-0469
DOI: 10.7226/jtfm.18.1.138

Gan J, McCarl BA. 2007. Measuring transnational leakage of forest conservation. *Ecological Economics* 64(2):423–432. Special Section-Ecosystem Services and Agriculture. http://dx.doi.org/10.1016/j.ecolecon.2007.02.032.

Green J, Sheshinski E. 1976. Direct versus indirect remedies for externalities. *Journal of Political Economy* 84(4):797–808. http://dx.doi.org/10.1086/260477.

Hunt C. 2008. Economy and ecology of emerging markets and credits for bio-sequestered carbon on private land in tropical Australia. *Ecological Economics* 66(2–3):309–318. http://dx.doi.org/10.1016/j.ecolecon.2007.09.012.

Löfgren KG, Mattsson L. 1995. Thorsten Streyffert (1892–1983): Economist and forester. *Journal of Forest Economics* 1(3):395–407.

Pagiola S, Platais G. 2002. Payments for environmental services. *Environment Strategy Notes* 3:1–4.

Parry IWH. 2012. Reforming the tax system to promote environmental objectives: An application tomauritius. *Ecological Economics* (in press). http://dx.doi.org/10.1016/j.ecolecon.2012.02.014.

Pirard R. 2012. Payments for environmental services (PES) in the public policy landscape: a “mandatory” spices in the Indonesian recipe. *Forest Policy and Economics* 18:23–29. http://dx.doi.org/10.1016/j.forpol.2011.09.002.

Rosa H, Barry D, Kandel S, Dimas L. 2004. *Compensation for Environmental Services and Rural Communities: Lessons from the Americas.* Working papers. Political Economy Research Institute. Amherst: University of Massachusetts.

Schoene D, Netto M. 2005. The Kyoto Protocol: what does it mean for forests and forestry? *Unasylva* 56:3–11.

Tassone VC, Wesseler J, Nesci FS. 2004. Diverging incentives for afforestation from carbon sequestration: an economic analysis of the EU afforestation program in the south of Italy. *Forest Policy and Economics* 6:567–578. http://dx.doi.org/10.1016/S1389-9341(03)00006-6.

Tavoni M, Sohngen B, Bosetti V. 2007. Forestry and the carbon market response to stabilize climate. *Energy Policy* 35:5346–5353. http://dx.doi.org/10.1016/j.enpol.2006.01.036.

van Kooten GC, Binkley CS, Delcourt G. 1995. Effect of carbon taxes and subsidies on optimal forest rotation age and supply of carbon services. *American Journal of Agricultural Economics* 77(2):365–374. http://dx.doi.org/10.2307/1243546.

van Noordwijk M, Suyamto DA, Lusiana B, Ekadinata A, Hairiah K. 2008. Facilitating agroforestation of landscapes for sustainable benefits: tradeoffs between carbon stocks and local development benefits in Indonesia according to the fallow model. *Agriculture, Ecosystems and Environment* 126(98–112):5346–5353.

Note

1 = Biomass also plays role in protecting water regime and controlling soil erosion. In general, we assume that environmental services rise as standing biomass increases.

2 = Although it is called tax, the Pigovian tax could be a subsidy, that is when the optimal tax is negative.

3 = This assumption is just for simplicity. We know that timber price harvested from young stand is cheaper that harvested from older stand.

4 = This result is slightly different from the necessary condition for optimal rotation of Faustmann's scenario taking the form of:

$$V'(T) = rV(T)\left[V(T)e^{-rt} - \frac{c}{p}\right]\left[\frac{r}{1-e^{-rt}}\right]$$

However, applying L'Hopital rule will produce:

$$\lim_{r\to 0}\left[\frac{r}{1-e^{-rt}}\right] = \frac{1}{T}$$

5 = The dimension of is currency unit per volume unit (for example Rp m^{-3}), while that of is currency unit per volume unit per year (for example Rp m^{-3} year^{-1}). So, and are not comparable in this sense. However, if we think of as payment for a cubic meter of timber in a particular year and as payment for services provided by a cubic meter of timber in a particular year, then and are indeed comparable.

6 = By definition, “the distribution first-order stochastically dominates if, for every nondecreasing function, we have”. For standing stock, it can be said that the distribution of standing stock first-order stochastically