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Policy instruments for developing planted forests: Theory and practices in China, the U.S., Brazil, and France

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ABSTRACT

Planted forests are seen as a means to meet increasing demand for timber and environmental services and thus to achieve sustainable forest development. In this paper, we use the Faustmann–Hartman silvicultural investment model to demonstrate how policy instruments influence planted forest development and review such a development in China, the U.S., Brazil, and France. We find that planted forests emerge because of scarcity in timber and environmental services and develop in response to economic and policy and institutional instruments, including secure property rights, stumpage price policy, and efficient forestry governance and administration.

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Introduction

In 2013, we celebrated the 300th anniversary of the publication of Hans Carl von Carlowitz's Silvicultural Economics (*Sylvicultura Oeconomica oder Anweisung zur wilden Baum-Zucht*; Silvicultural Economics or the Instructions for Wild Tree Cultivation) in 1713. While managing mining on behalf of the Saxon Court in Freiberg, Germany, Carlowitz was responsible for ensuring timber supply for the mining industry. Despite the Court's forest regulations, the impact of timber shortages on Saxony's silver mining and metallurgy industries was devastating around 1700. In his work, Carlowitz formulated the idea for the "sustainable use" of the forest. He saw that only so much wood should be cut as could be regrown through planned reforestation projects. This has become an important guiding principle of modern forestry and sustainability.

Today, we are facing similar challenges that Carlowitz once had 300 years ago, namely, how to ensure adequate supply of forests that provide not only timber, but also various environmental benefits to meet societal demand. Planted forests, which included forest plantations and other forest types originating largely or wholly from tree planting (Evans, 2009), are seen as a means of achieving these goals; just like that reforestation was seen by Carlowitz as means to supply timber in a sustainable fashion. However, most studies on planted forests (e.g. de Steiguer, 1984; Keipi, 1997; Beach et al., 2005; Cubbage et al., 2007, 2010) are done in micro-level and in specific countries. The exceptions are perhaps Sedjo (1980) which is on the comparative economics of planted forests and Enters and Durst (2004) which consists of studies on the role of incentives in planted forest developments in 11 Asia-Pacific countries. Nonetheless, Sedjo (1980) does not discuss the role of policy in planted forest development and Enters and Durst (2004) does not have a theoretical foundation and is not done in a comparative fashion. As such, the results from these two studies are largely country-specific and do not present a unified theme of planted forest development.

In this paper, we attempt to provide a unified theme of planted forest development and to demonstrate its uses at a macro- or country-level through a comparative study of four countries in four continents. In particular, we present the economics of planted forest development, derive the impact of policy instruments, and look into such a development in China, the U.S., Brazil, and France, which collectively account for more than 40% of global planted forests (Carle et al., 2009). We also comment on the type of incentives useful to entice planted forest development in different contexts.

The economics of planted forest development

The economics of planted forests is about the benefit–cost calculus of tree planting and other silvicultural investments on established forests. Comparing to natural forests, planted forests represent changes in two dimensions: forest area retention/expansion and management intensity. Once a natural forest is harvested, a planted forest could develop on the same site if it could generate the highest return. In this case, forest area is retained even though the natural forest becomes a planted forest. Similarly, planted forests could develop on marginal agricultural lands or idle lands if they generated a higher return than all other land uses, and subsequently forest area expands. As for management intensity, it is change in the optimal level of silvicultural effort applied to one unit area of land. While an increase or decrease in the management intensity does not necessarily lead to any change in the area of planted forests, and vice versa, they often change simultaneously because they are both positively related to land rent, or land expectation value. These changes called shifts in the extensive (if planted forest area changes) and intensive (if intensity changes) margins of planted forests, respectively.

Fig. 1 depicts that the shift in the extensive margin of planted forests associated with the price of standing timber or the stumpage price, assuming that management intensity does not change. Suppose that the supply of timber in a region all comes from planted forests, that lands vary in productivity, and that the supply of timber increase with the stumpage price, as illustrated in the upper portion of Fig. 1. The lower portion of Fig. 1 shows, for possible change in demand and equilibrium price, how many hectares of planted forests are needed for timber production. Obviously, the most productive land will be employed in timber production at low stumpage prices, and the higher the stumpage prices progressively more and more of the less productive land will be drawn into production. Thus, as stumpage price rises from P_1 to P_2, the annual harvest increases from Q_1 to Q_2, and the amount of

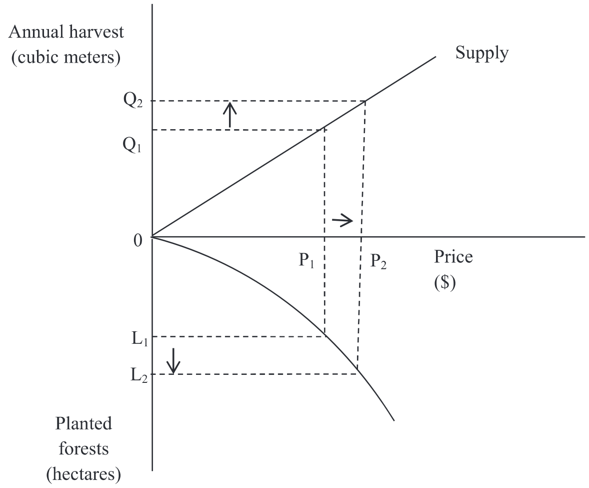

Fig. 1. Relationship among the price of timber, annual harvest, and area of planted forests.

land used as planted forests would change from L_1 to L_2. However, this direct relationship between the annual harvest and the area of planted forests is not one-to-one (not linear), because management intensity could change as well. As we noted earlier, an increase in the annual harvest often leads to simultaneous change in both area of planted forests and management intensity.

The Faustmann model which maximizes land expectation value on one unit area of land (Faustmann 1849) is appropriate for analyzing the change in the management intensity of planted forests. Hyde (1980), Chang (1983), Li and Zhang (2007), and Zhang and Pearse (2011, p. 259–264) have shown a prototype model for planted forest management intensity. Here we extend their results to policy variables.

As in Zhang and Pearse (2011), we assume that all additional silvilcultural investment made after the establishment of a planted forest can be discounted to year 0 or the beginning of establishing it, using the interest rate of a representative landowner. In this way, all subsequent silvicultural investments could be directly added on to the establishment costs (or costs of tree planting), formulate a new variable called total silvicultural investment, which, theoretically, only occurs in the initiation period of establishing the planted forest (year 0). This total silvicultural investment variable is further decomposed into two parts: total silvicultural effort (E), and unit cost of silvicultural effort (w). The former is a decision variable for the landowner, while the latter is often exogenous and market-driven, but may be influenced by government policies. Thus, the economics of planted forests can be demonstrated with a silvicultural investment model that starts with the Faustmann formula.

Further, only revenue from final timber harvests is considered. As it is well known that revenues from thinnings could be treated as added revenues to the revenue of final harvest in the Faustmann formula, this assumption merely makes the model more flexible in derivation. Assuming the production function for a given hectare of planted forest is

$$Q = Q(t, E) \tag{1}$$

where Q is standing timber inventory, which is a function of stand age, t, and the level of silvicultural effort, E. The land expectation value for the timber portion only (LEVT) is then

$$\text{LEVT} = \frac{PQ(t, E)\,\mathrm{e}^{-rt} - wE}{1 - \mathrm{e}^{-rt}} \tag{2}$$

where r is the discount rate for the landowner, and P is the expected stumpage price.

The first order condition of Eq. (2) with respect to E is

$$PQ_E - e^{-rt} = w \tag{3}$$

where Q_E is the partial derivative of Q with respect to E.

In economic terms, Eq. (3) means that the optimal level of silvicultural investment is reached when the marginal revenue (or the marginal revenue product of silvicultural effort) is equal to the marginal cost of the silvicultural effort, w. Obviously the optimal condition in Eq. (3) should be satisfied at the silvicultural effort, E, as well as the optimal rotation age, t. Following a change in stumpage price P, interest rate r, or the growth effect of the silvicultural effort, Q_E, both the optimal silvicultural effort, E, and the optimal rotation age, t, could change. Yet, the impact of most of the economic and biological factors on the optimal E is indeterminate unless one make additional assumptions about the growth-yield function, $Q(t, E)$ (Chang, 1983).

Nonetheless, as Chang (1983, p. 273) notes, "on the occasions when the impacts of changes in parameters are theoretically uncertain, available empirical evidence suggested that the results generally tend to be the same as those obtained when the answers are definite". Chang (1983) indicates that, silvicultural effort, E, rises with stumpage prices (p) and fall with interest rate (r) and unit silvicultural cost (w) when the answers are definite. As Q_E and p have a multiplication relationship in Eq. (3), the impact of Q_E on total silvicultural effort, E, should be positive as well. This is to say, when the responsiveness of timber growth to silvicultural effort (Q_E) increases, silvicultural effort increases. This responsiveness is mainly determined by land productivity, the genetic traits of tree species, and the silvicultural treatments chosen. If the landowner is assumed to choose the right species and appropriate silvicultural treatments for a given site, Q_E rises along with public and private research and development (R&D) investment in tree breading and silvicultural techniques.

Now, let us put the timber value aside for a moment and consider maximizing only non-timber values in our silvicultural investment model. Here non-timber values include all non-timber benefits that private landowners and the public can enjoy from a forest. The portion of these non-timber benefits that is captured mostly by the public (instead of, or in addition to, those captured by private landowners) is often called environmental services. Each of these non-timber values is related to the age of the forest, but the exact relationship varies (van Kooten and Folmer, 2004). More importantly, aggregating all these benefits at various ages may produce a complicated relationship (Robert and Stenger, 2013). However, these benefits must be positive. Otherwise, there will not be such a thing as positive externality or environmental benefits associated with a forest.

The difference between timber and non-timber benefits is that, except for commercial thinnings, timber benefits accrue only at the end of rotation when trees are harvested. Non-timber benefits, on the other hand, accrue continuously, or annually in the discrete sense. Suppose that non-timber values of a forest up to age t and silvicultural effort E are given by an accumulative function, $N(t, E)$:

$$N(t, E) = \int_0^t n(a, E)\, e^{-ra}\, da \tag{4}$$

where (a, E) is the nominal (not-discounted) non-timber value at a given age, a, and given silvicultural effort, E.

Our objective is to choose the level of silvicultural effort (and consequently the level of silvicultural investment) that maximizes the discounted stream of such benefits, recognizing that these benefits fall to zero each time the forest is cut.

$$V_n = \frac{\int_0^t n(a, E)\, e^{-ra}\, da - wE}{1 - e^{-ra}} \tag{5}$$

where V_n is capitalized, or net present value of, non-timber values.

The first order condition of Eq. (5) is

$$\frac{d \int_0^t n(a, E)\, e^{-ra}\, da}{dE} = w \tag{6}$$

Eq. (6) shows that, when only non-timber benefits are produced from a forest, the optimal level of silvicultural effort is reached when the marginal benefit of effort is equal to the marginal cost of the effort, w. Some forests are created mostly, if not exclusively, for non-timber benefits, especially environmental benefits. China's Three North Sheltbelt forests are a good example.

Now, considering that the landowner receives both timber and non-timber benefits, the land expectation value becomes

$$\mathrm{LEV} = \frac{PQ(t,E)\,\mathrm{e}^{-rt} + \int_0^t n(a,E)\,\mathrm{e}^{-ra}\,\mathrm{d}a - wE}{1-\mathrm{e}^{-rt}} \tag{7}$$

Eq. (7) is an extension of the Hartman formula (Hartman, 1976), with the term representing silvicultural investment being added on. The optimal condition for silvicultural effort (investment) is then

$$PQ_E\,\mathrm{e}^{-rt} + \frac{\mathrm{d}\int_0^t n(a,E)\,\mathrm{e}^{-ra}\,\mathrm{d}a}{\mathrm{d}E} = w \tag{8}$$

Comparing to Eq. (3), Eq. (8) means that, when considering both timber and non-timber benefits, the marginal revenue of silvicultural effort increases, causing an increase in silvicultural effort (investment). Further, the higher the non-timber values, the more silvicultural effort (investment) should be. This result explains where some tree planting and other silvicultural efforts on planted forests are for additional, even mainly, non-timber benefits. As private landowners often do not capture many parts of the non-timber benefits (the environmental benefits) of planted forests (or natural forests, for that matter) and as public demand for environmental services generally rise along with per-capita income and population, governments often step in by directly planting trees on public lands or by offering private landowners incentives to plant trees on private lands.

In summary, silvicultural investment is influenced by expected stumpage prices, unit silvicultural cost, interest rate, the responsiveness of tree growth to silvicultural effort, and the value of non-timber benefits. Although most of these factors are market-driven, various government policies can directly and indirectly influence them, and thus provide positive or pervasive incentive for landowners to develop planted forests. It is also this very reason—government policies influence planted forest development—that makes our country-level comparative study below relevant and illustrative.

Let us look at stumpage prices first. Stumpage prices reflect the level of timber scarcity and are mainly a market phenomenon. Nonetheless, stumpage prices are influenced by government taxes and fees, because private landowners are mostly interested in the after-tax prices and after-tax returns. Moreover, government regulations and land withdrawal from timber production could induce timber scarcity, thereby raising future stumpage price expectations.

Government economic incentives such as subsidy, either in form of direct cash payment, low interest loans, or technical assistance, lower the unit silvicultural cost of landowners. Macroeconomic and policies can affect interest rates on the market and of landowners. For example, government afforestation and reforestation tax credits (meaning that landowners could earn credits again their income tax liability), a policy used in the U.S. and other countries, reduce the interest rates of money spent in tree planting. In fact, because of the "use-it or lose-it" nature of the tax credits, if the money spent in tree planting is within the limit of the tax credits, the landowner has got "free" money and the interest rate of the money spent is effectively zero. Finally, as noted earlier, government response to rising societal demand for environmental services and investment in R&D in tree breeding and silvicultural techniques could provide positive or negative incentive for landowners to develop planted forests.

Thus, investment in planted forests is influenced by not only natural and market factors, as well as government policies. On private lands, it is firstly influenced by market factors (stumpage prices, unit silvicultural cost, and prevailing market rate of interest), and then by government fiscal policies (tax rate, tax credit, subsidy, technical assistance) and regulatory policies (regulations and land withdrawals). More importantly, because forestry is a long-term investment, institutional arrangements such as secure property rights are essential for attracting private investments in planted forests. It is though these fiscal and regulatory policies and institutional arrangements that governments affect private investment in planted forests. On public lands, government could directly invest in tree planting, or incentivize private individuals and companies who lease public lands to invest in silviculture.

In the latter case, the calculus of the lease holders in terms of investment in tree planting is similar to that of private landowners.

As we have not considered future changes in prices, forest productivity, silvicultural technique, and government policy, the above analysis is static. Nonetheless, the implications of various market and policy variables on planted forest development are applicable in dynamic settings. In the next section, we will see how these variables affect planted forest development in three of the countries with largest planted forest areas (China, the U.S., and Brazil) and one (France) whose modern planted forests were largely policy-induced. Note that we do not directly compare the economic variables such as interest rates and timber prices among these countries. Rather, we focus on how government policies have sparked, speeded up, or slowed down the pace of the respective planted forest development in these countries. In this way, other countries could learn from the experiences of these countries and design appropriate policies for their own.

A comparative study of planted forests development

China: Mostly a government initiative

China has the largest amount of planted forests in the world, with 76 million ha or 29% of the global total (FAO, 2010). For about one hundred years prior to 1949, China had had multiple foreign invasions and civil wars. In 1949, the forest cover in the country was estimated at 8.6% (Xu et al., 2004). Timber was undoubtedly very scarce, and societal demand on forest-related environmental services was hardly met ($N(t, E)$ was high in the country). Thus, since the very beginning of the People's Republic of China, the government has emphasized on afforestation for industrial timber and for soil and water conservation and other environmental services.

The government started with large afforestation and reforestation campaigns, that is, directly order and augment the silvicultural variable, E, in Eq. (7). As lands were owned by either collectives (or communities) or the central government and China had a central planning economic system before 1980, the government was able to mobilize the people and to do tree planting in a fairly large scale with little attention paid to price incentive (stumpage price, P, was fixed in the country) or the reward of the people's effort, w. Between 1949 and 1986, an average of 5 million ha was planted annually (State Forestry Administration, 2011).

However, only some 30% of areas with tree planting before 1980 actually became forests (Ministry of Forestry, 1980; Xu et al., 2004). This means that the economic efficiency of tree planting was not promising, most likely because the payment for the effort of the people (w) was inadequate, fixed stumpage prices (P) lowered the return of forestry projects, and private property rights were not encouraged. Subsequently, China changed its standard of tree planting reporting: since 1987, only these areas that have an 85% survival rate or higher after 3 years of tree planting can be reported as newly forested area instead of the 45% used before.

As China industrialized and expanded its economy between the 1950s and 1970s, natural forests in the remote regions of the country started to be harvested, and reforestation became a government policy directive. Timber shortage still existed. This was evident because soon after China began to reform its economic system and had a more open trade policy in 1978, timber imports, started from a very low base, soared. In 2010, China became the largest forest products importer of the world (FAO, 2013). Beginning in the early 1980s, China has tried to privatize its collective forests and introduced a management responsibility system to its national forests. But the efforts to privatize its collective forests were hindered by heavy taxes on timber income before 2003 (Zhang, 2003). This privatization process picked up speed and timber taxes were lowered since 2003. In 2010, China's forest cover rose to 19.6%, although the per-capita forest cover is still only 0.1 ha or 20% of the global average (FAO, 2010). Xie et al. (2014) showed that policy instruments have a positive impact on forest management intensity and the area of planted forests in China.

Fig. 2 shows the area of tree planting in China between 1949 and 2010, the total of which reached 200 million ha. As remarkable as it was, if we assume a linear distribution of survival rate and then adjust the newly forested areas prior to 1986 using the 85% survival rate, the area of tree planting is drastically reduced (Fig. 3).

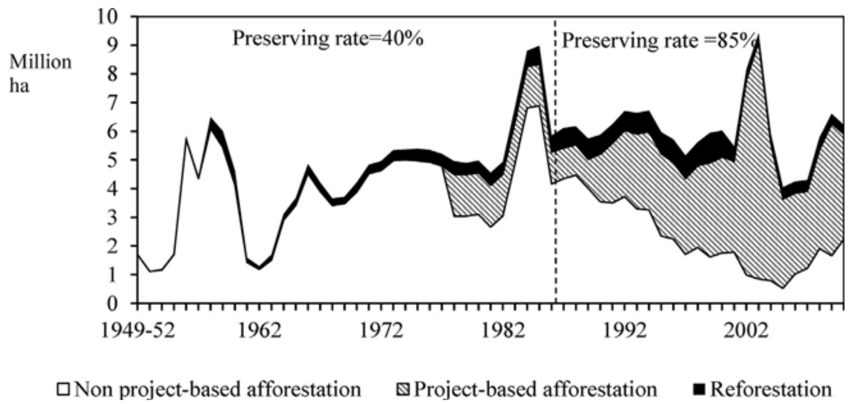

Fig. 2. Tree planting area in China: 1949–2010.
Source: State Forestry Administration (2011) and Xu et al. (2004).

Another feature in China's planted forest development is the emphasis of project-based afforestation and reforestation. China has now implemented 6 large forest projects: they are the Three North Shelterbelt Protection Forest Project, the Upper-reach Yangtze and Yellow Rivers Protection Forest Project, the Marginal Agricultural Land Conversion Project, the Planted Forest Project, the Beijing-Tianjin-Tangshan Protection Forest Project, and the Wildlife Protection Project. As most of funding from the central and provincial governments go to these projects, it is not surprising that nearly 70% of all afforestation and reforestation areas took place under these projects (Fig. 3). As five out of six of these projects focus mainly on environmental benefits, China's afforestation and reforestation activities are mainly for non-timber benefits.

The United States: A mixture of market and policy

If China's planted forest development is mainly led by the government and for environmental benefits, the planted forest development in the U.S. is rather due to a mixture of market and policy incentives, and is for both timber and environmental benefits. As of 2010, U.S. had some 26 million ha of planted forests, or 10% of the global total (FAO, 2010).

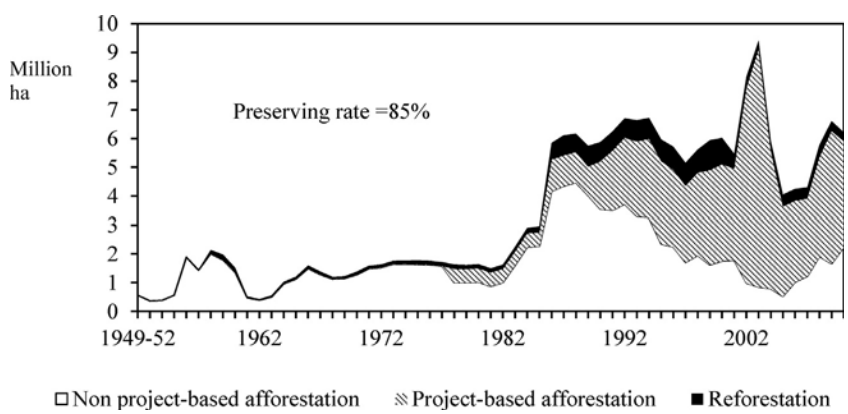

Fig. 3. Adjusted tree planting area in China: 1949–2010.
Source: State Forestry Administration (2011) and Xu et al. (2004).

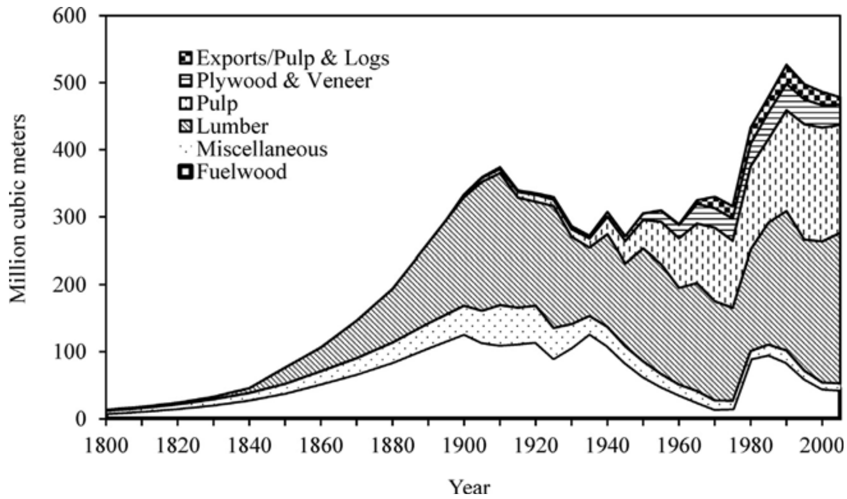

Fig. 4. Forest Products Production in the U.S.: 1800–2005.
Source: Zhang (2004) and Howard (2007).

Even before the U.S. became an independent country, some colonial governments had implemented independent tree species protection laws that were intended to prevent timber shortage. Nonetheless, in much of the 19th century and before, the U.S. had abundant forests, its annual forest products production had risen from less than 10 million cubic meters in 1800 to 380 million cubic meters in 1913 (Fig. 4). This massive increase in timber production caused environmental problems and made the U.S. largely a net forest products importer since. Economically, this timber scarcity is reflected in the price of softwood lumber which rose against other commodities since 1800 (Fig. 5). The U.S. government then adopted a conservation policy which focused on conserving the natural forests left, forest stewardship, and an "Arbor Day" that called for voluntary tree planting. Meanwhile, private companies experimented with tree planting after 1900, and the 1924 Clarke-McNary Act called for technical assistance to farmers who do tree planting and fire suppression (Zhang,

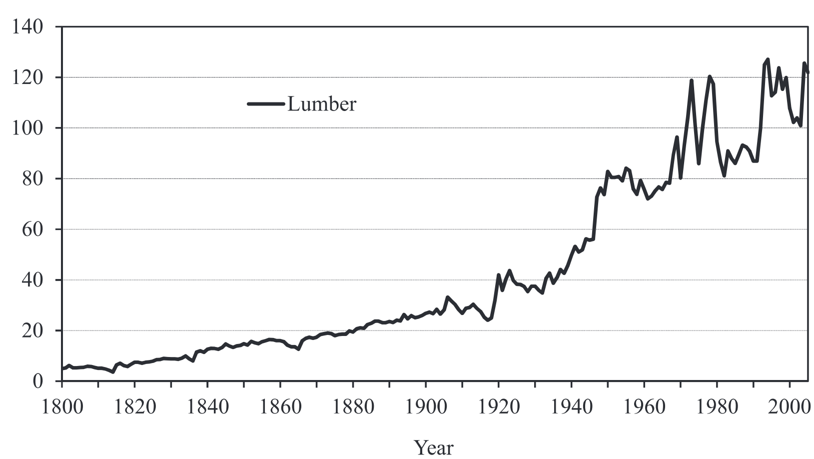

Fig. 5. Relative softwood lumber to all commodity prices, 1992 = 100.
Source: Howard (2007).

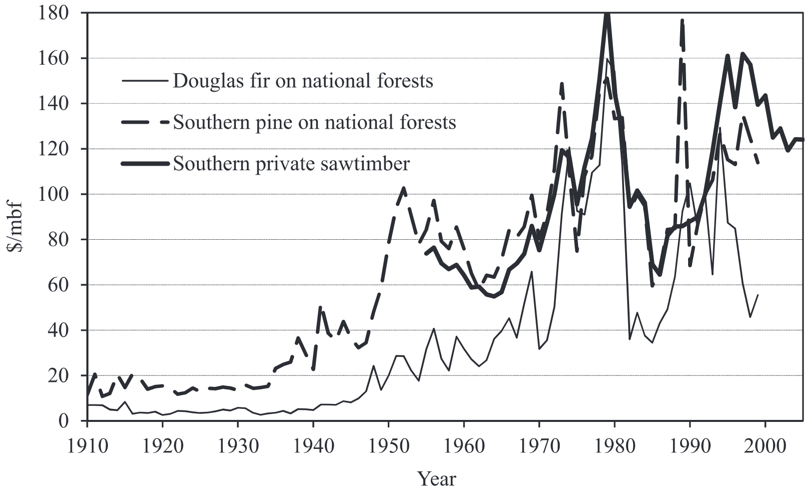

Fig. 6. Real stumpage prices in the U.S.: 1913–2005.

Source: Howard (2007).

2004). Finally, the Civilian Conservation Corps planted some trees during the depression years of the 1930s.

None of these tree planting activities was large by today's standard. Nonetheless, one of the most significant incentives for tree planting—secure property rights ("No shall private property be taken for public use without compensation")—was embodied in the U.S. Constitution in this early period. This made massive tree planting possible later when market conditions improved and public policy encouraged planted forest development.

The market conditions indeed improved shortly after the Second World War. Softwood lumber prices increased faster than price of other commodities (Fig. 5); so were stumpage prices (P) which were volatile (Fig. 6). Several public policies also favored planted forest development. First of all, timber income is given a favorable capital gains tax treatment. All else being equal, the after-tax stumpage prices rose. Second, government cost-share programs such as Soil Bank Programs in the 1960s, Forestry Incentive Programs between 1970 and 1990, and Conservation Reserve Program after the 1980 subsidized tree planting activities. These subsidies made private landowners' unit silvicultural cost (w) fall. Third, research by public universities and agencies enhanced tree growth and found better silvicultural tools. In other words, forest productivity or Q_E increased over time. Finally, some, mostly public forest lands have been set-aside for recreation, water quality, and wildlife habitats conservation purposes; reducing timber supply from these lands and further increasing the prices of timber from private lands.

In short, the economics and policy worked in favor of planted forest developments in this period. Consequently, from 1945 to 1988, annual private tree planting in the U.S. increased from 16,000 ha to 1.2 million ha (Fig. 7). Between 1989 and 2012, as market for forest products stayed flat, tree planting activities in the U.S. declined slightly, but the area of tree planting remained at a high level. The other main policy incentive for private tree planting in the last two decades has been deduction of federal income taxes in reforestation expenses (which lower landowners' interest rate on capital used in reforestation).

Industrial landowners are not eligible for receiving direct government subsidies (or cost-share programs), but are eligible for tax incentives in the U.S. Yet, the fact that these landowners planted more hectares than non-industrial private forest owners show that market, in combination with tax incentives, had a bigger influence than the policy of direct subsidy. On the other hand, some 40% of non-industrial private forest landowners did not use tax incentives (Royer and Moulton, 1987).

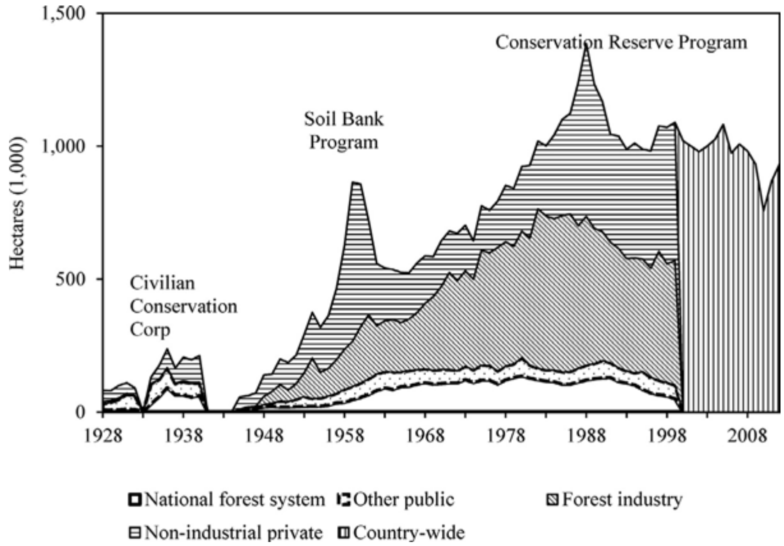

Fig. 7. Area of tree planting in the U.S.: 1928–2012.

Sources: Data before 1999 are from Moulton and Hernandez (2000). Data from 1999 and 2003 are from Georgia Forestry Commisssion (2000–2003). The 2004–2012 tree planting acres are preliminary data from the USDA Forest Service, Forest Inventory and Analysis, State and Private Forestry Programs and will be published in the near future.

Brazil: Government policy, market, and technological advance

Brazil had nearly 7 million ha of planted forests, consistent of mostly eucalyptus and pines (FAO, 2010). In 1903, Navarro de Andrade brought Eucalyptus from Australia for plantations that produce wood for railway sleepers in the State of Sao Paulo. By then, a large portion of Atlantic Forests in Brazil had already been converted to agricultural lands. In the 1940s, Eucalyptus was introduced in the State of Minas Gerais to produce charcoal for pig iron and steel production, and in 1947, pines were introduced in southern Brazil. Most of the products produced from these plantations are for wood used by state-run railway and mining companies. In 1965, Brazil only had about half million hectare of forest plantations (Viana et al., 2002).

Also in 1965, Brazil introduced its first Forest Code. In a nutshell, the Code requires landowners to set aside a portion (20–35%) of natural forests on their lands as reserves, and in the Amazon region, some 80% of natural forests are required to be reserved. This is a signal of potential timber scarcity and rising stumpage prices in the future. In the following year, the Brazilian government passed Law No. 5106 (Program of Fiscal Incentives for Reforestation, PIFIR), which allowed individuals and companies to allocate part of their income tax burden to the establishment of forest plantations. Again, this use-it-or-lose-it tax policy, in effect, reduced the interest rate (r in Eq. (7)) of the tree planting expenses, which would otherwise be paid as tax to the government, to zero. One year later, the government set up Institute of Forest Development and Research that has focused on the advancement of silvicultural techniques and tree genetics and that, along with private companies, has greatly increased the forest productivity (Q_E in the previous section) in Brazil.

PIFIR was implemented between 1966 and 1988 (Bacha, 1995). In the later 1970s, a reforestation program (PEPEMIR) targeting small and medium rural producers was introduced. Between 1985 and 1988, as a response to the drought the region has suffered in the early 1980s, a third program (Project Algarobeira) was implemented to stimulate reforestation in the Northeast of Brazil (Bacha, 1995). It was in this period (1966–1988) that planted forest area increased more than 10 fold in Brazil (Fig. 8). This increase in tree planting was accompanied by a dramatic development of Brazilian pulp and paper industry which saw its pulp and paper production rising from 1 million tons in 1965 to 9.1 million tons in 1990 and 24 million tons in 2010 (Brazilian Pulp and Paper Association, 2012). Thus, if the earlier

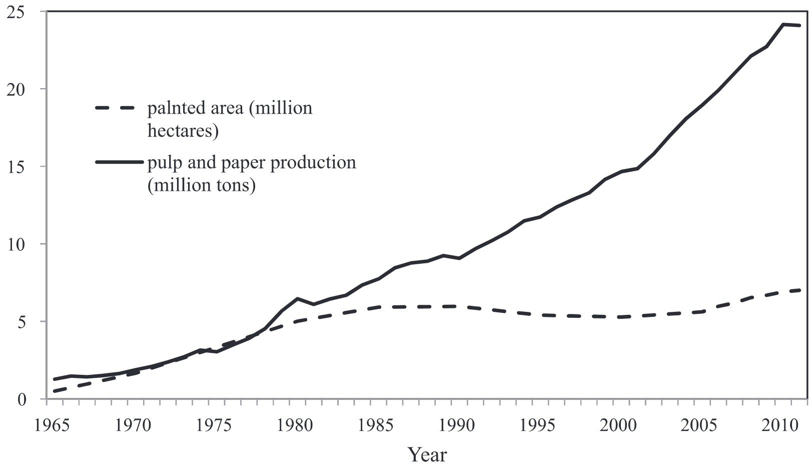

Fig. 8. Total planted area and pulp and paper production in Brazil: 1965–2011.
Sources: Brazilian Pulp and Paper Association (2012) and ABRAF (2012).

planted forests were for railway and state-owned companies, the second phase is for the development of private pulp and paper industry in Brazil.

While the financial incentives that provided the impetus to planted forests in the 1970s were perhaps overgenerous and inefficient (Bacha, 1995), the economic impact of these planted forests attracted important foreign investments to Brazil's pulp and paper industry. Over the long-run, these incentives might be justified based on the infant industry theory.

Since 1988, the Brazilian government has eliminated PIFIR. Nonetheless, the annual reforested area has remained steady; so has the total planted area each year between 1989 and 2010. This means that market forces have taken over and served as the primary driver of planted forest development in Brazil in the last two decades. Finally, Brazilian planted forest development has a lot to do with the increase in the growth rates of Eucalyptus and pines, which have tripled in the last 40 years (Fig. 9). Thus, despite of the massive increase (nearly 3-fold) in pulp and paper production from the 1980 to

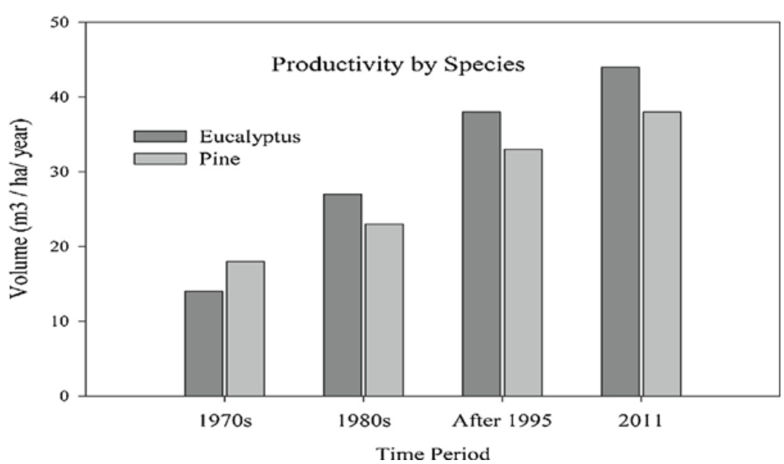

Fig. 9. Tree growth rate doubled and trippled in Brazil in 40 years.
Source: ABRAF (2004) and BRACELPA (2012).

2010, planted forest areas have only increased from 5 million ha to nearly 7 million ha. Technological advance in planted forests is more dramatic in Brazil than other three countries.

France: Heavily policy-driven and limited by soils and climate

France is the smallest country of the four and only had 1.6 million ha of planted forests in 2010 (FAO, 2010). Nonetheless, planted forests account for some 9% of its total forest area, which is higher than both the U.S. and Brazil. Further, the case of planted forest development in France shows the potentials and geographical limits of planted forests.

France had its first Forest Law in 1827, which was a policy for seed trees, sustained yield, and forest management of large landowners. This law was a response to the perception of future timber shortage. The development in planted forests in France really took off after 1857, when a law called for the cultivation of lands in the Region of Aquitaine was enacted. This law (loi relative à l'assainissement et de mise en culture des lands de Gascogne) intended to cultivate lands in Aquitaine, which had been largely sandy wetlands and used for raising sheep before. The law required draining the wetlands to make them productive. To facilitate the cultivation of these lands, communities that owned most of these lands there were required to sell them to private individuals or companies, if they could not cultivate them.

The title of the 1857 law did not even mention forestry or afforestation. However, the sandy lands could not be used for agriculture at the time, and experiments that used maritime pines to fix sands in the early 1800s were largely successful. Thus, afforestation and forestry became a de facto choice for cultivation. It also happened that the American Civil War had made the price of resin (a non-timber product) jump several fold in the early 1860s, and maritime pines were a main source for resin, which was used in shipping industry. Between 1857 and the end of the First World War, planted forests (mainly maritime pines) reached 1 million ha in Aquitaine. The remaining 620,000 ha of planted forests in France today are mainly Douglas fir and Poplar.

After the Second World War, the development of planted forests in France has relied on two policies. One is low taxes, which raise landowners' after-tax income. Landowners in France pay the least amount of tax on timber income than landowners in other three countries included in this study. The second is subsidy. Between 1947 and 1999, French government, through its "National Forest Fund" (Fond Forestier National), provided low interest loans to landowners (lowering the interest rate in Eq. (7)). In this period, some 2.2 million ha of planted forests are supported by this National Forest Fund annually (Rosenbaum and Lindasy, 2001). After the termination of the National Forest Fund since 1997, planted areas in France declined (Fig. 10). The peaks in the 1980s can be explained by modifications in both the data base and the sample as well as windstorms in 1982 and 1987. More importantly, this graph shows afforestation and reforestation before 1997 and only afforestation afterwards.

While planted forests have helped France to double its forest area from 10 million ha in the 1850s to 19 million ha in 2010, it should be recognized that due to its climate, conifer tree species and Eucalyptus do not grow well in France, and natural regeneration of other broadleaf species such as oak are far more efficient than planting. Thus, it is not expected that area of planted forests will significantly increase in France. Rather, the increase in forest area in the country in the last two centuries perhaps had more to do with conversion of marginal agricultural lands to forestry use and natural regeneration of forests. So, in contrast to Brazil, planted forests in France ceased to expand and could not even maintain its area of the 1990s when government subsidies ended in 1997, partly because the comparative advantage of planted forests vs. natural forests in France is not as great as in Brazil.

Summary and discussion

In this paper, we use the Faustmann–Hartman silvicultural investment model to develop a unified theme of planted forest development and demonstrate the role of various market and policy instruments in such a development. The unified theme is that scarcity in timber and forest-related environmental services causes private landowners and governments to respond, and appropriate government policies facilitate planted forest development. Thus, investment in planted forests is made in favorable market conditions and high demand for environmental services. Government fiscal,

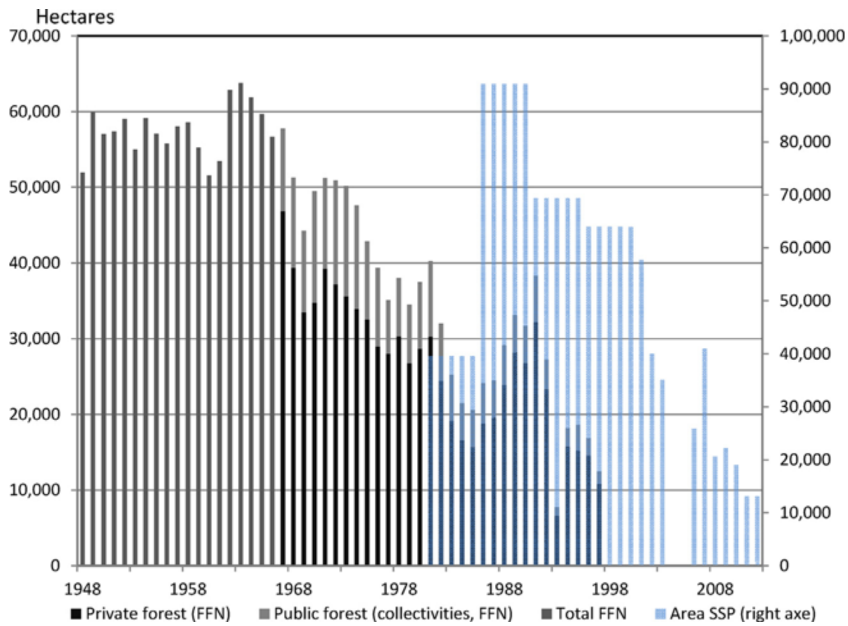

Fig. 10. Area of tree planting in France: 1947–2010.
Notes: FFN means Fonds Forestier Français. From 1948 to 1966: public and private planted areas with subventions from FFN include afforestation and reforestation; from 1967 to 1997, private and public areas with subventions are distinguished and again include afforestation and reforestation; from 1981 to 1997, data both from FFN and Teruti. From 1981 to now (in blue, only afforestation) Teruti data base (*Source*: first mean afforested areas every 5 years; integrated economic and environmental account for forest – France – based on Teruti and IFEN data, 1995) and then from 2006 more precised data from Teruti-Lucas (annual report). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)
Source: Niedzwiedz (2013) who used data from SSP (Services Statistiques du Ministère de l'Agriculture) and IFEN (Institut Français de l'Environnement).

monetary, and regulatory policies affect market variables. Governments could use fiscal policies such as tax incentives and cost-share (subsidy) to facilitate planted forest development, even though the primary goals of cost-share programs may not be forestry or planted forest development.

Governments could also use other policy that indirectly influence planted forest development. Fire suppression and research in tree breeding, pest and disease control, and silvicultural techniques can enhance economic returns of planted forests. Environmental regulations, too, can indirectly signal timber scarcity and raise the expectation of future timber prices, and thus facilitate the development of planted forests. However, as we focus on the economic, policy, and especially comparative aspects of planted forest development, we have not explicitly considered other factors such as site productivity, declining forest productivity (Fox, 2000), and actual technologies of planted forest management (Halbritter and Deegen, 2011).

As for the four countries included in this study, all respond to the apparent scarcity in timber and environmental services with a mix of market and policy instruments. China, the least forested country of the four on per-capita basis, perhaps relies on government programs the most in its planted forest development. The logging ban implemented since 1999 is one of the most recent government actions in response to scarcity in forest-related environmental services, and China has recently reduced its timber taxes and intended to rely on private sectors do tree planting in recent years. The U.S. has used a mixture of market and policy instruments, and in some periods, one plays a bigger role than the other. Brazil and France started with policy instruments and then relied more on market in recent decades. In contrast to Brazil, planted forests in France ceased to expand or could not even maintain its area of the 1990s when government subsidies disappeared in 1997, partly because the comparative advantage of planted forests vs. natural forests in France is not as great as in Brazil. This illustrates the role of a policy instrument (subsidy) and the geographical limits of planted forest development without it.

Although the most appropriate mixture of market and policy instruments depends on natural and socio-economic conditions of particular countries, it is evident that both are needed for planted forest development. As growing trees are a long-term business, sound institutional arrangements such as secure property rights, a well-function stumpage market, and a good forestry governance mechanism could reduce the transaction costs of landowners in growing trees. The experience and lessons learned from these four countries are consistent with these found in Chile, India, and Indonesia (FAO, 2001) and might be useful for other countries to develop their respective planted forests. To the extent that planted forests can enhance natural forest conservation and provide certain environmental benefits, positive policy incentives toward the development of planted forests are needed in some parts of the world. Finally, we should point out that, planted forest development on marginal agricultural lands are beneficial and can help conserving natural forests, conversion of natural forests to planted forests may cause environmental problems and should be avoided through appropriate policy instruments.

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