

The Effect of Stochastic Oscillations in Property Rights Regimes on Forest Output in China

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Abstract

Over the past 65 years, forest tenure in China has oscillated unpredictably between private and common property regimes. This policy-induced uncertainty has distorted the harvesting decisions of individuals granted rights to grow trees and has lowered the value of China's forest output. We provide an analytical framework for assessing these effects quantitatively. Understanding the consequences of this policy-induced uncertainty is particularly important since China is currently engaged in an ambitious plan to increase its domestic supply of timber. We estimate that net revenue from nonstate forests would approximately double if farmers had entirely secure use rights to grow trees. Contrary to the standard result in the literature that catastrophic risk makes farmers harvest earlier, we find that they may delay harvesting if the government pays sufficient compensation for the loss.

Key Words: forest tenure risk, Faustmann model, optimal rotation period under uncertainty

JEL Classification Numbers: Q23, Q28

1. Introduction

Approximately 40% of China's rural population uses fuelwood as the major energy source. At the same time, the booming Chinese economy requires ever-increasing amounts of forest products. In 2010, China consumed the most wood-based panels, recovered paper, paper, and paperboards in the world and was the second-greatest consumer of industrial roundwood, sawnwood, and pulp for paper (FAO 2012).

Yet compared with other countries, China is poorly endowed with forests. China has only 0.145 hectare of forests per capita, barely one-fourth of the world average (FAO 2010). Moreover, forests cover 20.4% of China's surface area (SFA 2010), less than two-thirds of the world average.

Trees in China are grown in either state-owned or nonstate forests. In state-owned forests, both the land and the trees are the property of the state; these forests are controlled by state logging enterprises, state forest farms, and natural reserve agencies, and harvesting decisions are made by state-owned forest agencies. In nonstate forests, which represent 60% of the forest area nationally, the land is officially owned by village collectives (Xu et al. 2004), but the trees can be managed by the collectives, individual private households, or different private-public arrangements (Demurger et al. 2009, pp. 20).

Virtually all of China's fuelwood is grown domestically. In addition, China imports timber from neighboring subtropical countries to satisfy other demands of its growing economy. This has led to unsustainable exploitation of their resources (Xu and White 2004). In an endeavor to increase the domestic supply of forest products, China has launched the most ambitious reforestation efforts in the developing world.

These reforestation efforts have been directed toward China's nonstate forests. Historically, the state forests were China's major source of timber, as they contained most of the good-quality, old-growth forests. Since the early 1980s, however, most state-owned natural forests have suffered from serious deforestation and have been retired from harvesting. As timber output from state forests has declined, the development of nonstate forest plantations has become increasingly important (Xu et al. 2004). Over the past two decades, China has dedicated great effort to developing plantations, and it now has the largest area of forest plantation in the world (SFA 2010). It was originally expected that these nonstate reforestation projects would increase China's forested area by 10% to 20% (Bennett 2008). However, surveys show that farmers in the field have little confidence in the government's reforestation plan.

Their lack of confidence is understandable, given recent history. A farmer in the southern nonstate forest region who turned 20 in 1950 may have experienced four major tenure upheavals during his lifetime. At 20, he would have received a piece of forestland thanks to the government's policy of distributing plots of equal size to every adult farmer. Six years later, in 1956, he would have lost the use of this land because the people's commune expropriated it, although he might have been compensated with the value of trees on this land at this time. Upon celebrating his 51st birthday in 1981, he might have regained the use right of the same forestland, or a piece of land with comparable value and area, when it was returned to him as a family plot. Some trees may have been left on the plot, although they would have been badly managed. However, the land might have been taken back a second time in 1987 by the village collective when he was 57. He probably would not have received any compensation, as he may have 31 years earlier, because the land on which he had planted trees had been previously reclassified in 1956 as collective (government) property, and thus the expropriated trees on the land would not

have required compensation. If he reached the age of 78, he might have enjoyed the 2008 round of privatization, which again returned plots of equal size to individual farmers. Perhaps the farmer's one allotted child will be able to harvest the trees his father planted before the next expropriation occurs.

We summarize these major transitions in Table 1 and describe each more fully in Appendix I. Readers wishing a more detailed account of the tenure and management of nonstate forests in China since 1950 are referred to the full-length article on the subject by Liu (2001), who concludes this comprehensive history with the following observation:

Policies for forest tenure and management have changed frequently in China since 1950, causing a complete lack of confidence on the part of villagers in tenure security. ... (Liu 2001, 257)

Tenure uncertainty in China has become a major barrier to its current policy to promote domestic forest conservation and provide a sustainable supply of forest products.¹ The harm from such frequent and unpredictable policy changes, however, is hidden from view: it is the foregone net value of the trees that could have been harvested over time had the policy environment been stable. It is especially important that these opportunity costs be assessed given China's current attempts to become less dependent on imports of wood products through its reforestation efforts.

¹For further discussion of tenure uncertainty in the nonstate forests with the land use right oscillating between the collective and the household, see Demurger et al. (2009).

Table 1. Radical Transitions in Property Rights Regimes of China's Nonstate Forests

Time period	Property regime	Key features and events
1950–1955	Private ²	<ul style="list-style-type: none"> • Under the Land Reform Campaign, the government confiscated most privately owned forestlands and equally distributed them to individual rural households. • Elementary cooperatives were established in 1953, and farmers were encouraged to pool their means of production, including forestland, although they remained as the owners of land. • Private ownership and household management of forests were dominant throughout this period
1956–1980	Collective	<ul style="list-style-type: none"> • The government terminated private ownership of forests after establishing advanced cooperatives. • Rural households were compensated with the value of forests. • Collective ownership and management of the forests were dominant. • The Great Leap Forward led to excessive deforestation in forest collectives. Villages cut trees as fuel for village-based steel furnaces in an irrational attempt to match British industrial output. • Nontimber trees and trees planted around homesteads were once returned to individual households but were re-collectivized during the Cultural Reform.
1981–1986	Private	<ul style="list-style-type: none"> • The “Three Fix” policy stipulated that the right of collective forest management should be contracted to individual households, although forestland was still nominally collective property. • Forest resources with undisputed ownership claims were to be returned to their original owners. • Degraded and waste forestland was to be equally allocated to individual households.
1987–2007	Collective	<ul style="list-style-type: none"> • The government suspended privatization and restored a collective regime in some regions. • No compensation was paid in this round of collectivization. • No clear-cutting was reported associated with this round of collectivization.
2008–?	Private	<ul style="list-style-type: none"> • The government initiated a new round of privatization in 2003 and has expanded it to a national scale in 2008. • This round of privatization aims at devolution of forest management to individual rural households.

² Private property of land was abolished in China in 1956. We use the term “private property” as a shorthand to mean that the farmer was granted the legal right to use the land for a certain period for the purpose of growing trees and was granted full ownership of products on the land, the priority to renew the land-leasing contract, and even the right to re-rent his use right to others. However, unlike a full owner of private property, he was prevented from free purchase and sale of land.

To assess these opportunity costs requires a model. Yet the forestry models in the literature cannot contribute to this policy analysis without significant modification. All forestry models are descendants of the seminal article by Faustmann (1849), who examined the wealth-maximizing sequence of harvesting decisions of someone who owns a plot of land over an infinite horizon and plants a tree every time he cuts one down. Faustmann's model applies to the Chinese situation where an infinitely lived family maximizes the sum of the discounted profits earned from the trees on land to which it has use rights. Taking the stationary price as given, it is optimal to harvest trees when the value of letting a tree grow another year equals the interest lost by postponing for a year not only the sale of the wood but also the net revenue from future harvests.

Although Faustmann's original model assumes certainty, more recent contributions have abandoned that assumption and have examined the effects on rotation decisions of introducing uncertainty. The forms of uncertainty most closely related to our contribution arise from natural hazards and from expropriation.

Natural hazards such as fires, ice and windstorms, and pest attacks can destroy forest stock. Reed (1984) asked how the risk of a forest fire would affect harvesting decisions. He used a Poisson stochastic process to describe the catastrophic events and assumed they occur independently and randomly. Reed implicitly assumed that the harvester was completely uninsured and that he could immediately re-plant following the disaster. He concluded that the presence of fire risk increases the effective discount rate and shortens the optimal rotation periods. The Poisson process has been used to explain many other natural threats, such as hurricane (Haight et al. 1995) and soil degradation (Routledge 1987). These researchers all reach the same conclusion: it is optimal to cut trees at an earlier age if the risk of a natural disaster

increases. More recently, Yoder (2004) has shown that with sufficient protection efforts and a salvage value that is high enough, rotation age may be extended.

The risk of expropriation can also affect harvesting decisions. Yin and Newman (1997) examined empirically the impact on the forest sector of China's rural reform. They found that in regions with severe tenure insecurity, forest growth was limited. Amacher et al. (2009) show that expropriation risk creates incentives for agricultural clear-cutting and short-term harvesting. Qin et al. (2011) conducted a survey-based choice experiment with 210 Chinese farmers. The results show that reduced perceived risk of contract termination can significantly increase farmers' willingness to pay for a forest contract.³

While the introduction of uncertainty into Faustmann's tree-cutting model is a step in the right direction, this literature assumes that the farmer (1) receives no compensation from an insurance company when his crop is destroyed and (2) can immediately re-plant. Neither assumption is appropriate for many natural disasters, since farmers often receive insurance payments for their losses and some disasters (e.g., oil spills, chemical spills, or nuclear accidents) require a time interval of uncertain length before replanting can occur. Moreover, neither assumption is appropriate in the application to expropriations in China, as the government has sometimes compensated the farmers whose trees are expropriated and has restored their use rights only after uncertain time intervals of considerable length. We generalize the standard model by introducing as exogenous parameters the expected rate of compensation following a loss and the hazard rate governing the time when re-planting can occur.

³In most cases, the Chinese government granted individual farmers use rights over an equal share of the land free of charge. As the land use right came to be regarded as property, however, farmers granted use rights could rent or sell them to other farmers who wanted to expand their forestry operations. The value of a use right can be regarded as the expected discounted value a farmer would get from renting out his parcel to others wanting to grow trees whenever the right to use that parcel was granted to him plus the expected present value of compensation receipts whenever that right was taken away again.

The contribution of our paper is to characterize the harvesting decisions of individuals granted land use rights that oscillate stochastically between private and common property over infinite time and to use this characterization to clarify the consequences of the government's policy.⁴ Two conclusions are particularly striking.

First, if farmers face a higher risk of transitions from private to common property, they may extend rotation periods rather than shorten them as the literature suggests. The literature's conclusion rests on the assumption that farmers are not compensated if lightning or pests destroy their trees; if they were insured sufficiently, the result would change. In China, compensation based on the size and age of a tree is paid when privately owned trees become common property (SFA 2001). Whether the increased risk of such expropriation lengthens or shortens the rotation period turns out to depend on the magnitude of this compensation.

Second, when calibrated, our model can be used to assess the potential gains that China could secure if farmers could grow their trees without the risk of losing the use rights that were granted them. We compare the discounted value of timber harvested (net of cutting costs) when property rights are guaranteed with the corresponding discounted value when policy oscillates unpredictably. The potential net wealth is approximately *double* the net wealth currently generated by nonstate forests. Whether this would represent a net gain in overall surplus,

⁴To the best of our knowledge, ours is the first paper to consider the behavior of a wealthmaximizer operating under a property rights regime that oscillates stochastically between two states of nature; in our application, the wealthmaximizer is an individual choosing the optimal time to harvest trees (if disposition of them happens to be under his control). We are by no means the first to study optimal behavior in response to other oscillations between two states of nature. Virtually all of the other papers, however, focus on the same question: what storage behavior is optimal when a vital import (e.g., oil, natural gas) oscillates stochastically between being available and unavailable. Bergstrom et al. (1985) and Bahel (2011) assume that the imported good's price is exogenous while Creti and Villeneuve (2013) have endogenized it. The remaining paper, Gaudet and Lasserre (2011), considers optimal usage of two exhaustible resources, a secure domestic resource that can be extracted at low cost and a foreign nonrenewable resource that oscillates stochastically between two costs of extraction, each of which is higher than that of the secure source.

however, depends on the social value of the alternative uses (e.g., village steel mills) to which the land was temporarily put when the use right reverted to the village collective.

The next section introduces the model. Section 3 investigates the comparative static effects of changing the compensation rate and the hazard rates governing the transition to and from the common property regime. In Section 4, we estimate the gains that would result from the elimination of policy uncertainty. Section 5 concludes. In the text, we assume that when a village acquires the use right to a parcel of land, it immediately clear-cuts the trees and, instead of re-planting, puts the land to an alternate use (e.g., local steel mills). In Appendix II, we show how the analysis would change if the village continued to harvest and replant trees.

2. The Model

2.1. *The Optimal Age to Cut Trees*

To isolate the effects of stochastic oscillations between property rights regimes, we make a number of simplifying assumptions. We assume that timber is the only forest product and that its price is a constant, normalized to one. We assume that the biological growth of timber is deterministic and summarize the volume of wood in a tree of age t by the growth function $f(t)$, satisfying the following properties: $f(0) = 0$, $f'(t) > 0$, $f''(t) < 0$, $\lim_{t \rightarrow 0} f'(t) = \infty$, and $\lim_{t \rightarrow \infty} f'(t) = 0$. Thus, as the tree matures, the volume of marketable wood it contains increases but at a decreasing rate.⁵ Replanting is assumed to be costless, but cutting down a tree is assumed to cost c . We denote the cash flow at the time a tree is cut down, net of this harvesting cost, as $F(t) = f(t) - c$. $F(t)$ inherits its properties from $f(t)$. Thus, $F(t) < 0$, $F'(t) > 0$, $F''(t) < 0$, $\lim_{t \rightarrow 0} F'(t) = \infty$, and $\lim_{t \rightarrow \infty} F'(t) = 0$. We also assume that there exists at t_0 such

⁵ As most commercial harvests occur before the tree reaches maturity, we do not consider later phases where growth eventually ceases altogether.

that $F(t_0) = f(t_0) - c$. That is, the timber value of a tree will exceed the cutting cost if and only if the tree is older than t_0 .

Land use rights of an individual (private property) may stochastically be taken away and granted to the village (common property). Like Reed (1984), we describe the stochastic transition as a Poisson process, with an average transition rate of σ per unit time. A larger σ therefore corresponds to a shorter expected time until the transition to common property. Similarly, land use rights under a common property regime may stochastically transit back to private property, with an average transition rate of λ . The transition rates σ and λ are exogenous and the decisionmaker knows them. They reflect the magnitude of tenure uncertainty.

Agents are assumed to be risk neutral. The goal of a private owner of a land use right is to maximize the expected value of his forest over an infinite horizon. We assume that in computing his expected payoff, the owner takes into consideration that if his land use right is expropriated at a random time in the future, he will expect to be compensated (possibly only partially) based on the size of the trees he is forced to relinquish. This assumption accords with recent practice.⁶ We also assume that he anticipates that he will subsequently get his right to use the original parcel (or a parcel of equivalent value) back as barren private property after it has remained common property for an unpredictable length of time. This assumption also accords with recent practice.⁷ Finally, we assume that the person granted the land use right anticipates that this stochastic cycle will repeat itself endlessly over time.

⁶ As required in the *Decree on Forest Land Appropriation and Expropriation* (SFA 2001): any legal entity that expropriates private forestland should pay compensation that covers the value of the land and trees, as well as the cost of replacement of farmers.

⁷ After the 1956–1980 collective management of nonstate forests, China initiated a new round of forestland privatization. One of the components of the reform was to confirm the existing forest boundary and return the trees to the previous owners, if there was no dispute over the property rights (Liu 2001, pp. 247).

The expected value of the forest can be expressed as a sum of all discounted future cash flows, either from timber sales or from compensations. Future values are discounted continuously at rate r . We denote the expected value of the right to use a plot with trees on it of age y as $J(y)$ if the use right is currently privately held and $V(y)$ if the use right has just transitioned to common property. Thus, if a tree initially of age \bar{a} is managed privately, $J(\bar{a})$ is defined as

$$J(\bar{a}) = \max_{t \geq 0} \{ [F(\bar{a} + t) + J(0)] e^{-rt} e^{-\sigma t} + \int_{x=0}^t V(\bar{a} + t) e^{-rt} \sigma e^{-\sigma x} dx \} \quad (1)$$

That is, the individual will choose harvest time t to maximize his wealth, which can be decomposed into the weighted average of two parts. There is a chance of $e^{-\sigma t}$ that if cutting is planned for t , the use right has not yet transitioned to common property. If so, he retains the net earnings $F(\bar{a} + t)$ from the harvest as well as the continuation value $J(0)$ since he would retain the use right to the barren land. Alternatively, at some time $x \in [0, t]$ before his intended cutting time, a transition to the common property regime occurs. In that case, he receives the value of common property with a tree on it of age $\bar{a} + x$: $V(\bar{a} + t)$. At any time x , the likelihood of such a transition is $\sigma e^{-\sigma x}$. The private use right to land with trees of current age, $J(\bar{a})$, is defined as the maximized value of the discounted sum, as indicated in equation (1).

When the transition to common property occurs, forest owners receive expected compensation $\theta f(a) = \theta [F(\bar{a}) + c]$ for $\theta \in [0, 1]$, which may be partial and depends on the size of the expropriated tree. After that, trees are assumed to be clear-cut immediately by the village, and no re-planting occurs.⁸ Farmers receive no revenues for the trees they planted. All

⁸ We assume that the village clear-cuts the trees when it acquires the use right to the land even when the trees on it are so young that cutting is more expensive than the value of the harvested timber ($t < t_0$). In addition, we assume that the village does not re-plant. This need not be irrational since the land may be put to more socially valuable use. Sometimes, however, the rationality of harvesting such young trees is questionable. As Liu (2001) mentions, in the 1958 Great Leap Forward, China used harvested wood to fuel its steel furnaces in an overambitious attempt to

they can do is bide their time and wait for the stochastic transition to return to them their former use right to the land, albeit stripped of trees. Thus, a tree of age y in a common property regime is worth the value of the immediate compensation plus the expected present value of its return to private property in the future:⁹

$$V(y) = \theta[F(y) + c] + \int_{x=0}^{\infty} \lambda e^{-\lambda x} J(0) e^{-rx} dx \quad (2)$$

Given the definition in equation (2), we can write the second term in the maximand in equation (1) as

$$V(\bar{a} + x) = \theta[F(\bar{a} + x) + c] + \int_{x=0}^{\infty} \lambda e^{-\lambda x} J(0) e^{-rx} dx = \theta[F(\bar{a} + x) + c] + \frac{\lambda}{\lambda + r} J(0)$$

Substituting this into equation (1), we obtain an equation that must hold for any $\bar{a} \geq 0$.

Focusing provisionally on the case where $\bar{a} = 0$, we obtain the following:

$$J(0) = \max_{t \geq 0} \{ [F(t) + J(0)] e^{-(r+\sigma)t} + \sigma \int_{x=0}^t \left[\theta(F(x) + c) + \frac{\lambda}{\lambda + r} J(0) \right] e^{-(r+\sigma)x} dx \} \quad (3)$$

The right-hand side of equation (3) can be regarded as a mapping $M(J(0))$ from any trial value of $J(0)$ into a possibly different real number on the left-hand side of equation (3). It

expedite industrialization. To show the usefulness of our framework, we explore an alternative assumption in Appendix II.

⁹ In other applications, it might be more appropriate to assume that rational individuals, not the village, do the harvesting. In that case, the definition of $V(y)$ would be slightly different. Define t_0 as the unique root $F(t_0) = 0$ the age when the value of the wood in the tree just covers the harvesting cost. Suppose the use right to the land is expropriated when the tree is age y . If $y \geq t_0$, the expression in (2) still holds. If $y < t_0$, the compensation is paid immediately as before, but the tree is cut only when it reaches age t_0 . That is, profits are dissipated because of free access, but individuals would not cut trees at a loss. So if the random return of the private use right occurs at $x < t_0 - y$ years, the land will be handed back to the farmer with a tree on it of age $x + y$, which will then be worth $J(x+y)$. Alternatively, if the random return occurs at $x \geq t_0 - y$ years, the tree will have been cut and the use value of the land will be $J(0)$. Thus, under this alternative assumption, the expression of forest value under a common property regime is:

$$V(y) = \begin{cases} \theta[F(y) + c] + \int_{x=0}^{\infty} \lambda e^{-\lambda x} J(0) e^{-rx} dx & y \geq t_0 \\ \theta[F(y) + c] + \int_{x=0}^{t_0-y} \lambda e^{-\lambda x} J(x+y) e^{-rx} dx + \int_{x=t_0-y}^{\infty} \lambda e^{-\lambda x} J(0) e^{-rx} dx & y < t_0 \end{cases}$$

can be shown that $M(0) > 0$. Given any trial value of $J(0)$, we can find $a\bar{t}$ as the optimal harvestage that maximizes the objective function. Using the envelope theorem, we conclude:

$$\frac{dM}{dJ(0)} = \frac{\lambda}{\lambda+r} \frac{\sigma}{\sigma+r} + e^{-(r+\sigma)\bar{t}} \left[1 - \frac{\lambda}{\lambda+r} \frac{\sigma}{\sigma+r} \right] \quad (4)$$

It can be shown that $0 < \frac{dM}{dJ(0)} < 1$, as long as $a\bar{t} > 0$. Since the mapping $M(J(0))$ increases at a rate less than one ($M'(J(0))$), it has a unique fixed point. When we mention $J(0)$ henceforth, we are referring to this unique fixed point.

The maximand in equation (3) is then a function of the cutting time t . Let it be $H(t)$.

$$\text{Thus, } H'(t) = e^{-(r+\sigma)t} [F'(t) - (r + \sigma - \theta\sigma)F(t) - r \left(1 + \frac{\sigma}{\lambda+r} \right) J(0) + \sigma\theta c].$$

Since $F(0) < 0$, $F'(0) \rightarrow +\infty$, and $r \left(1 + \frac{\sigma}{\lambda+r} \right) J(0)$ and $\sigma\theta c$ are constant, $H'(t)$ is positive. $F''(0) < 0$, so as t increases, $F'(t)$ keeps decreasing and $F(t)$ keeps increasing. For some t , $H'(t)$ will be zero, and then $H'(t)$ becomes negative. That means the function of $H(t)$ is single-peaked. It achieves the unique global optimum at the solution to the following first-order condition:

$$F'(t) = (r + \sigma - \theta\sigma)F(t) + r \left(1 + \frac{\sigma}{\lambda+r} \right) J(0) - \sigma\theta c \quad (5)$$

Denote the unique solution to equation (5) as t^* . Substituting into equation (3), we obtain

$$J(0) = [F(t^*) + J(0)]e^{-(r+\sigma)t^*} + \sigma \int_{x=0}^{t^*} \left[\theta(F(x) + c) + \frac{\lambda}{\lambda+r} J(0) \right] e^{-(r+\sigma)x} dx \quad (6)$$

Since σ , λ , θ , r , c , and $F(\cdot)$ are exogenous, the two endogenous variables t^* and $J(0)$ are simultaneously determined by equations (5) and (6). Once $J(0)$ is determined, it is then

straightforward to determine $J(\bar{a})$ and the optimal time to wait before cutting a tree if it has initial age \bar{a} .¹⁰

When forest owners receive full compensation following expropriation of their use rights ($\theta = 1$), equation (5) implies that trees should be cut at a younger age in this stochastically oscillating system ($\sigma > 0$) than in the standard Faustmann model, where $\sigma = 0$. When $\sigma = 0$, the optimal age to cut each tree is the unique solution to $F'(t^*) = rF(t^*) + rJ(0)$, where $J(0) = \frac{F(t^*)e^{-rt^*}}{1-e^{-rt^*}}$. This is the case of the Faustmann model. When $\theta = 0$ and $\lambda \rightarrow +\infty$ (the length of the commons phase is zero, and every time landowners plant a tree they risk losing their forest property without compensation), equation (5) is reduced to $F'(t^*) = (r + \sigma)F(t^*) + r\hat{J}$, where $\hat{J} = \frac{(r+\sigma)F(t^*)e^{-(r+\sigma)t^*}}{r[1-e^{-(r+\sigma)t^*}]}$. This is Reed's condition.

2.2. Properties of the Stochastic Model in the Long Run

In our model, the land use right has a hazard σ of being expropriated at each instant and, given that it has been seized by the government, a hazard λ of being returned to the private sector. The behavior of such “alternating renewal processes” has been well studied in the context of equipment that fails with constant hazard σ , is immediately sent to the repair shop, and is returned to service with constant hazard λ . Cox (1967, 83, equation 4) deduces the probability $\pi(t)$ that a land use right that starts in the private property state (the analog of functioning equipment) is in the private property state at time t :

$$\pi(t) = \frac{\lambda}{\lambda + r} + \frac{\sigma}{\lambda + \sigma} e^{-(r+\sigma)t}$$

¹⁰ It turns out that if the tree is initially younger than t^* ($\bar{a} < t^*$), one should wait until it reaches age t^* to cut the tree. If the initial age weakly exceeds t^* ($\bar{a} > t^*$), one should cut the tree immediately and replant.

It follows that this probability declines from unity monotonically and approaches the limit $\pi^* = \frac{\lambda}{\lambda + \sigma}$. Intuitively, if λ is near zero so that use rights are rarely returned by the government, this limit π^* is near zero; if, on the other hand, λ is huge so that use rights are almost immediately returned by the government, this limit π^* is near unity.

If a land use right is in private hands at some point in the distant future, what is the probability density of trees on it? No trees will be older than t^* since the farmer would cut them down. Trees that are t years old this year are all growing on plots that had $t - 1$ -year-old trees on them last year. But “seedlings” newly planted this year could be on plots that either had t^* -year-old trees last year or had *no* trees on them last year but were re-planted after being returned by the government. If the steady-state flow of use rights returned to the private sector increased, the number of these newly planted seedlings would increase. But in the long run, the number of trees of *every* age would increase in the same proportion. Hence, increasing the rate at which expropriated use rights are returned to the private sector (λ) will increase the number of plots that are privately held (and hence the total number of trees), but it will *not* affect the steady-state age distribution of those trees. That distribution is exponential with parameter σ truncated on the right at t^* .¹¹

¹¹ Suppose there are N plots of land. Then $\frac{\sigma}{\lambda + \sigma}$ of them are in government hands, and these are returned to the private sector at rate λ and immediately planted. Hence, there is a flow of $N \frac{\sigma}{\lambda + \sigma} \lambda$ plots just acquired by the private sector that have new seedlings on them. In addition, if X is the total number of private plots with seedlings on them in the steady state, then there is an additional flow $X e^{-\sigma t^*}$ of plots where the farmer harvested his trees and then replanted seedlings. Hence, $X = N \frac{\sigma}{\lambda + \sigma} \lambda + X e^{-\sigma t^*}$. It follows that the proportion of privately held plots with seedlings just planted is $\frac{\sigma}{1 - e^{-\sigma t^*}}$. But, as one can verify, this is the vertical intercept of the exponential density with parameter σ right-truncated at t^* .

3. Comparative Static Analysis

3.1. Effects of Changing the Compensation Level (θ)

In some regions of China, complete or partial compensation is paid to original owners of the land use right when it is expropriated (SFA 2001; Wen et al. 2010). Although this is intended primarily as restitution, anticipation of such compensation would presumably affect farmers' rotation decisions as well as the value of the use right under a private property regime. To determine the effect of changing the compensation rate θ on the optimal rotation age, we differentiate equation (5) with respect to θ to obtain equation (7):

$$\frac{[F''(t^*) - (r + \sigma - \theta\sigma)F'(t^*)] \partial t^*}{\partial \theta} = -\sigma F(t^*) + \frac{r[1 + \frac{\sigma}{\lambda + r}] \partial J(0)}{\partial \theta} - \sigma c \quad (7)$$

Because the term in square brackets on the left-hand side of (7) is negative, $\frac{dt^*}{d\theta}$ has a sign opposite that of the right-hand side of (7). Applying the envelope theorem to equation (6), we

conclude that $\frac{\partial J(0)}{\partial \theta} = \frac{\sigma \int_{x=0}^{t^*} (F(x) + c) e^{-(r+\sigma)x} dx}{[1 - e^{-(r+\sigma)t^*}] [1 - \frac{\lambda}{\lambda + r} \frac{\sigma}{\sigma + r}]} > 0$. Plugging this expression back into (7), its

right-hand side can be rewritten as $\frac{(\sigma + r)\sigma}{1 - e^{-(r+\sigma)t^*} [\int_{x=0}^{t^*} (F(x) + c) e^{-(r+\sigma)x} dx - \int_{x=0}^{t^*} (F(t^*) + c) e^{-(r+\sigma)x} dx]}$.

Since $F' > 0$, $F(t^*) > F(x)$ for x in $[0, t^*]$, the right-hand side of (7) is negative. Therefore,

$$\frac{\partial J(0)}{\partial \theta} > 0 \text{ and } \frac{dt^*}{d\theta} > 0.$$

Increasing the compensation paid for expropriated use rights of forestlands increases the value of private land use right because it would increase an owner's receipts even if he did not alter his rotation decisions at all. China's payment of compensation to farmers whose trees have been seized is like insurance that partially protects against the risk of total loss of the asset due to lightning or a pest infestation. The increase in the value of the use right equals the value of such insurance.

An increase in compensation also motivates farmers to lengthen the rotation periods. In this stochastically oscillating system, the farmer will harvest a tree when the benefit of letting it grow in value for another year just equals all the expected costs involved in postponing the sale. Now, if the tenure risk had been covered by the government's compensation mechanism, the marginal cost of postponing cutting by a year is reduced, and farmers extend the rotation period. Thus, t^* increases with θ .

3.2. *Effects of Changing the Mean Time as Common Property ($1/\lambda$)*

The level of tenure uncertainty also affects the value of private land use rights and farmers' rotation decisions. This subsection examines the effects of changes in the transition rate λ (from common to private regimes); the next subsection deals with the transition rate σ (from private to common regime).

According to equation (6), $J(0)$ can be rewritten as

$$J(0) = \frac{F(t^*)e^{-(r+\sigma)t^*} + \sigma \theta \int_{x=0}^{t^*} (F(x) + c)e^{-(r+\sigma)x} dx}{[1 - e^{-(r+\sigma)t^*}][1 - \frac{\lambda}{\lambda + r\sigma + r}]} \quad (8)$$

Substituting $J(0)$ into equation (5) with the expression of $J(0)$ in (8), we get $F'(t^*) =$

$$(r + \sigma - \theta\sigma)F(t^*) + \frac{(r+\sigma)(F(t^*)e^{-(r+\sigma)t^*} + \sigma\theta \int_{x=0}^{t^*} (F(x) + c)e^{-(r+\sigma)x} dx)}{[1 - e^{-(r+\sigma)t^*}]}.$$

Thus, t^* is independent of λ .

Since the denominator of (8) is decreasing in λ and no other terms depend on λ , $J(0)$ is increasing in λ . In other words, shortening the mean time as common property ($1/\lambda$) increases the value of the use right to the farmer but does not alter a farmer's rotation decisions.

Since changing the time (t^*) when the current crop of trees is cut affects neither the time when use of the land is returned to the farmer following a future expropriation nor its value from proceeding optimally, then a change in λ has no effect on the optimal age when the tree will be cut.

3.3. Effects of Changing the Mean Time as Private Property ($1/\sigma$)

Unlike the first two parameters, the effects of changing σ on value of private land use rights $J(0)$ and optimal rotation age t^* are indeterminate. To illustrate this, we need only consider the case where the government returns use of the land to the farmer immediately after expropriating it and clearing the land of its trees ($1/\lambda \rightarrow 0$). Reed (1984) in effect considered this case for the extreme where $\theta = 0$. His farmer incurred no harvesting costs if a natural disaster claimed his trees, just as our farmer incurs none if the government expropriates them. We then consider the opposite extreme where the gross revenue lost if a tree is expropriated by the government or destroyed by nature is fully reimbursed.

Reed (1984) showed—at least for the growth function, interest rate, and cost function assumed in his simulations—that land value and rotation age decrease with increased risk when the hazard resulting in the destruction of the trees is uncompensated ($\theta = 0$). We *prove* under the assumptions we have been making that when $\theta = 0$, both value of the land use right and the optimal rotation age strictly decrease as the loss hazard increases.

Reed's Claim

Proposition: If $\theta = 0$, $\frac{\partial J(0)}{\partial \sigma} < 0$ and $\frac{\partial t^*}{\partial \sigma} < 0$.

Proof: When $\theta = 0$ and $1/\lambda \rightarrow 0$, our equation (5) becomes $F'(t) = (r + \sigma)F(t) + rJ(0)$.

According to equation (8), $rJ(0) = F(t^*)\left\{\frac{r+\sigma}{e^{(r+\sigma)t^*}-1}\right\}$. By the envelope theorem, $r\frac{\partial J(0)}{\partial \sigma} = r\frac{\partial J(0)}{\partial \sigma}\big|_{t^*}$. To show that value of land use right strictly decreases as the hazard increases, we need merely to verify that the term in braces above is strictly decreasing in σ .¹² Substituting $rJ(0)$

¹² Let $g(\sigma) = \frac{r+\sigma}{e^{(r+\sigma)t^*}-1}$, $g'(\sigma) = \frac{[e^{(r+\sigma)t^*}-1]-(r+\sigma)t^*e^{(r+\sigma)t^*}}{[e^{(r+\sigma)t^*}-1]^2} = \frac{[e^a-1]-ae^a}{[e^a-1]^2}$, for $a = (r + \sigma)t^* \geq 0$.

into equation (5) and simplifying, we conclude that $F'(t^*) = F(t^*)\{\frac{r+\sigma}{1-e^{-(r+\sigma)t^*}}\}$. Since the objective function is locally concave at its optimum, verification that the term in braces strictly increases in the hazard completes the proof of Reed's claim that the rotation age strictly decreases in the hazard σ .¹³ ■

Having proved Reed's claim, we illustrate it below in Figure 1.

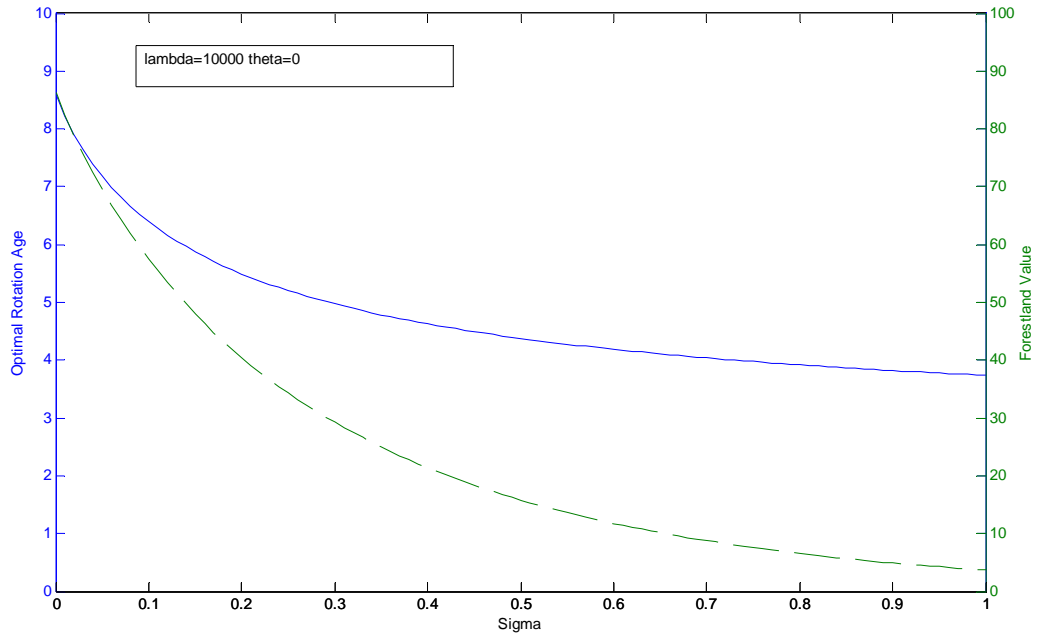


Figure 1. Optimal Rotation Age and Private Value of the Use Right with Changing σ
under Reed's Claim ($\theta = 0$)

On the contrary, with revenue reimbursement insurance or full compensation for expropriation ($\theta = 1$), the private value of the use right and the optimal rotation age may both

$Leth(a) = [e^a - 1] - ae^a$. It can be shown that $h(0) = 0$ and $h'(a) = -ae^{-a} \leq 0$. Thus, $h(a) \leq 0$ for $a \geq 0$. In particular, $h(a) < 0$ for $a > 0$. Thus, $g'(\sigma) < 0$ for $t^* > 0$ and $r + \sigma > 0$, and the term in braces is strictly decreasing in σ .

¹³ Similar to the proof in footnote 9, let $m(\sigma) = \frac{r+\sigma}{1-e^{-(r+\sigma)t^*}}$, $m'(\sigma) = \frac{[1-e^{-(r+\sigma)t^*}] - (r+\sigma)t^*e^{-(r+\sigma)t^*}}{[1-e^{-(r+\sigma)t^*}]^2} = \frac{[1-e^{-a}] - ae^{-a} - 1 - (1+a)e^{-a}}{[1-e^{-a}]^2}$, for $a = (r + \sigma)t^* \geq 0$. Let $n(a) = 1 - (1 + a)e^{-a}$. It can be shown that $n(0) = 0$ and $n'(a) = -[e^{-a} + (1 + a)e^{-a}(-1)] = ae^{-a} \geq 0$. Thus, $n(a) \geq 0$ for $a \geq 0$. Particularly, $h(a) > 0$ for $a > 0$. Thus, $m'(\sigma) > 0$ for $t^* > 0$ and $r + \sigma > 0$, and the term in braces is strictly increasing in σ .

strictly increase with the hazard (σ). To illustrate, we run a simulation with a re-planting cost (c) of 50 and an interest rate (r) of 5%. The specific tree growth function we used here is slightly modified from Mitscherlich's basic equation (Sun et al. 1999):

$$f(t) = 800 * [1 - \exp(-0.0035 * t)]^{0.6} \quad (9)$$

It can be verified that this growth function satisfies our assumptions: $f(0) = 0, f'(t) > 0$, $f''(t) < 0$, $\lim_{t \rightarrow 0} f'(t) = \infty$, and $\lim_{t \rightarrow \infty} f'(t) = 0$. Given the assumed cost of re-planting and the growth function in equation (9), a tree must be more than $t_0 = 2.85$ years old for its timber to be worth more than the cost of harvesting it. The simulation is run with MATLAB R2011a.

We plot t^* and $J(0)$ against σ , as shown in Figure 2.

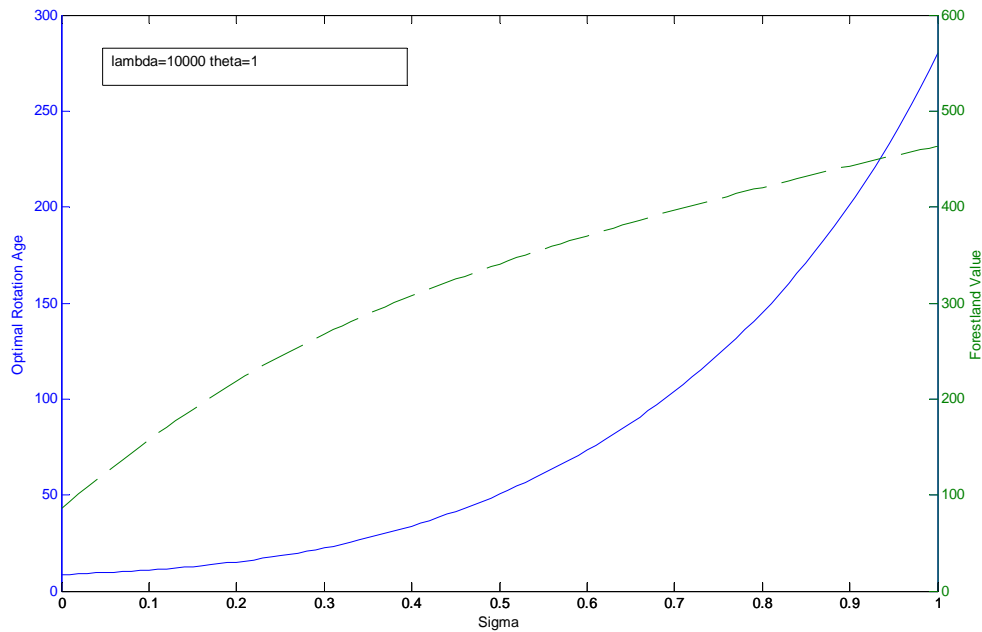


Figure 2. Optimal Rotation Age and Forestland Value with Changing σ under Revenue Reimbursement Insurance ($\theta = 1$)

As shown by the simulation, both the private value of the use right ($J(0)$) and the optimal rotation age (t^*) increase with the hazard rate of σ . This conclusion also holds if instead the

government adopted a compensation policy less preferable for farmers and paid the compensation based on the net harvest revenue (F) instead of the gross revenue ($F + c$).

When a farmer receives full compensation, he would like to extend rotation periods when the risk of losing his land use right is higher. By extending them, the farmer increases the chance that the government expropriates his use right, harvests the trees at government expense, and then pay him the full value of the harvested timber.

Why does the increased risk raise the value of the use right? If the farmer could harvest his trees at zero cost, he would harvest them almost immediately (the optimal rotation age approaches zero as the harvesting cost approaches zero) to take advantage of the fast growth that is assumed to occur when the seedling is first planted. The discounted profit from harvesting almost immediately is higher than if the farmer had to pay his own harvesting cost. Hence, when the government randomly expropriates trees before t^* , pays full compensation, and then hands the property immediately back to the farmer, it is as if the farmer is harvesting his own trees for free and then re-planting. His discounted profit is higher because of the expropriation risk and increases with that risk.

To summarize, a marginal delay in harvesting has a marginal benefit and a marginal cost (the left- and right-hand sides of equation (5)), which are equal at the optimal rotation age. How an increased hazard alters the optimal rotation age depends on whether it shifts the marginal cost of delaying harvesting up or down. The marginal cost is the sum of three terms. One involves the future value of the use right of barren land, $J(0)$, and the other two do not. Of these two remaining terms, one or the other no longer depends on σ in each polar case we examined. The other is more sensitive than the future use right value to an increase in the hazard and determines whether the marginal cost shifts up or down in response to an increase in σ .

Given this observation, the following simpler problem may be useful in gaining insight into the effect of increased risk on the optimal harvesting age. This simpler problem has no future rounds once the first round ends in harvesting or expropriation. To obtain the objective function for this simpler problem, we need simply to set $J(0)=0$ in equation (3). If we make the same change to equation (5), we obtain the first-order condition for the simpler problem: $F'(t) = [r + \sigma(1 - \theta)]F(t) - \sigma\theta c$. Note that the right-hand side is strictly increasing in σ when $\theta = 0$ and strictly decreasing when $\theta = 1$. Hence, an increased hazard has the same effect on the optimal age to cut as in our more complicated problem with its infinite rounds of tree growth.

Although we have focused on the extremes of complete compensation and no compensation when determining the effect of an increased hazard on the value of the use right and on the optimal rotation age, there are no discontinuities here. Similar results hold for compensation rates that are in the neighborhood of either of these extremes.

4. Loss of Forest Value Due to the Uncertain Tenure Policy

In order to evaluate the net gain in forest value that China could potentially achieve if it eliminated altogether the frequent tenure switches and granted a secure property right to any farmer growing trees on his parcel, we compare the forest value under our model to the value under the Faustmann rotation (R_F). According to Faustmann's assumption, R_F is the discounted value of trees that are optimally harvested and endlessly re-planted.

$$R_F = \frac{F(t_F)e^{-rt_F}}{1 - e^{-rt_F}}.$$

Where t_F is the optimal rotation age under Faustmann's condition, implicitly defined as the solution to $F'(t_F) = rF(t_F) + rR_F$.

We define the forest value in our model as R_U . It equals (i) the forestland value $J(0)$ minus the expected present value of the compensation payments from the government over time plus (ii) the expected present value of the trees expropriated over time (net of harvesting costs). Compensation payments should be deducted from the farmer's payoff since, while a benefit to him, they are merely a transfer from others elsewhere in society.¹⁴ The value of the trees surrendered to the village (net of the cost of harvesting them) should be *added back* because it represents the part of the value of the forest that was not included in the farmer's payoff $J(0)$.

R_U can be calculated with equation (10) below, which is the sum of two terms. The first term (corresponding to (i) above) is the value of $J(0)$ minus the value of government compensation; the second term (corresponding to (ii) above) is the value of trees surrendered to the government (net of harvesting costs) when it collectivizes the land:

$$R_U = \frac{F(t^*)e^{-(r+\sigma)t^*}}{[1-e^{-(r+\sigma)t^*}][1-\frac{\lambda}{\lambda+r\sigma+r}]} + \frac{\sigma \int_{x=0}^{t^*} F(x)e^{-(r+\sigma)x} dx}{[1-e^{-(r+\sigma)t^*}][1-\frac{\lambda}{\lambda+r\sigma+r}]} \quad (10)$$

The two terms have different numerators but the same denominator. The numerator of the first term is strictly positive. However, the numerator of the second term may be negative. This is a consequence of our assumption that when the use right switches from the farmer to the village, all the trees are cut down. The cost of harvesting trees will exceed the revenue that can be obtained from them whenever they are younger than t_0 . When $R_U < 0$, the overall gain from replacing the oscillating system with secure tenure rights is particularly attractive since $R_F - R_U > R_F$.

¹⁴ Although we deduct compensation to the farmer because it is a transfer payment, we continue to assume that the farmer takes compensation into account when choosing the optimal age to cut his trees.

This gain can be usefully decomposed by dividing it into a series of steps in moving from the original situation of policy oscillation depicted in our model to the final situation of complete security depicted in the Faustmann model.

In the first step, we assume that farmers would still harvest trees at t^* , as determined in the insecure policy situation, but we assume that the moment the villages acquire the use right and chop down the trees, the use right is returned to the farmers. That is, we assume that the time interval during which the village is granted the use right shrinks to zero ($\lambda \rightarrow +\infty$). We define R_S as the discounted expected revenue from forestry under this situation:

$$R_S = \frac{F(t^*)e^{-(r+\sigma)t^*}}{[1 - e^{-(r+\sigma)t^*}] \frac{r}{\sigma+r}} + \frac{\sigma \int_{x=0}^{t^*} F(x) e^{-(r+\sigma)x} dx}{[1 - e^{-(r+\sigma)t^*}] \frac{r}{\sigma+r}}$$

As before, the numerator of the second term may be negative, and consequently $R_S < 0$ is possible. Indeed, because the time interval is eliminated when the village holds the land without growing trees on it, future village losses would occur earlier and, because of discounting, will receive greater weight. As a result, we may have $R_S < R_U < 0$.

In the second step, we assume that the village does not clear-cut the trees but immediately relinquishes its use right to the plot. The corresponding forestry value is R_N :

$$R_N = \frac{F(t^*)e^{-rt^*}}{1 - e^{-rt^*}}$$

In the third step, we assume that the farmer adjusts his rotation period from the one appropriate in the oscillating situation to Faustmann's rotation period. That is, we break the overall gain $(R_F - R_U)$ into three components:

$$R_F - R_U = (R_S - R_U) + (R_N - R_S) + (R_F - R_N)$$

We now divide the overall gain from securing the property right into components adding to 100%:

$$G_1 + G_2 + G_3 = \frac{R_S - R_U}{R_F - R_U} * 100 + \frac{R_N - R_S}{R_F - R_U} * 100 + \frac{R_F - R_N}{R_F - R_U} * 100$$

This permits us to determine what portion of the overall gain arises because (1) the time intervals during which no trees grow on the plot are eliminated, (2) the clear-cutting by the villagers is eliminated, and (3) the cutting time is adjusted because land tenure has become secure.

We use the illustrative tree growth function as described in Section 3.3 to estimate these three sources of gains. We still assume the interest rate as 5% and set $\lambda = 1/23$, which corresponds to the average lengths of the common phases as suggested by our examination of China's forest tenure history.¹⁵ We examine how the component gains change with the hazard rate σ with no compensation ($\theta = 0$) and with full compensation ($\theta = 1$), respectively.

The simulation results show that securing forestry property rights would approximately double the net value of China's discounted profits from its nonstate forests compared with the current situation, where a farmer can expect to retain the use right to grow trees for only 9.5 years. That is, $R_F/R_U \approx 2$.

Figures 3 and 4 plot against the expropriation rate (σ) the decomposition of the predicted percentage gain in forest value from securing the farmer's use right. As shown in the figures, most of the gain could be secured if the Chinese government could eliminate clear-cutting of forests under a common property regime (see the line of G_2 in blue). This accounts for more than 60% of the total gain. Compared with that, the gains from eliminating forestland retirement and correcting rotation age are only marginally important in terms of their weight in the overall gain of forest value (see the lines of G_1 and G_3 in black and red, respectively).

¹⁵ In the past 65 years, China has undergone three phases of private property regimes (1950–1955, 1981–1986, and the still ongoing one starting from 2008) and two phases of common property regimes (1956–1980 and 1987–2007). Thus, the maximum likelihood estimates for the two hazard rates are 2/19 and 2/46. This yields expected lengths of the private and common phases of 9.5 years and 23 years, respectively.

As the hazard rate of expropriation increases, the gains from eliminating tree clear-cutting in a common property regime and premature harvesting in a private property regime become more significant(see the lines of G_2 and G_3). However, the weight of gains from eliminating forestland retirement decreases (see the line of G_1).

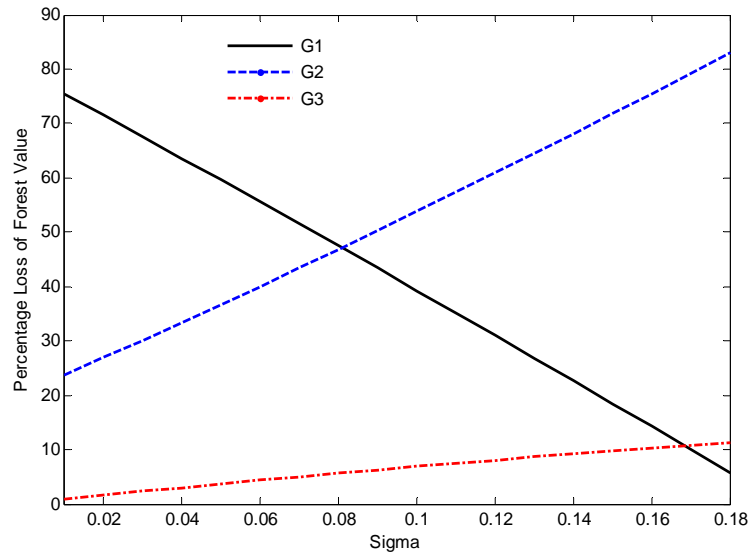


Figure 3. Percentage Decomposition of Gain in Forest Value from Securing Use Right
($\theta = 0$)

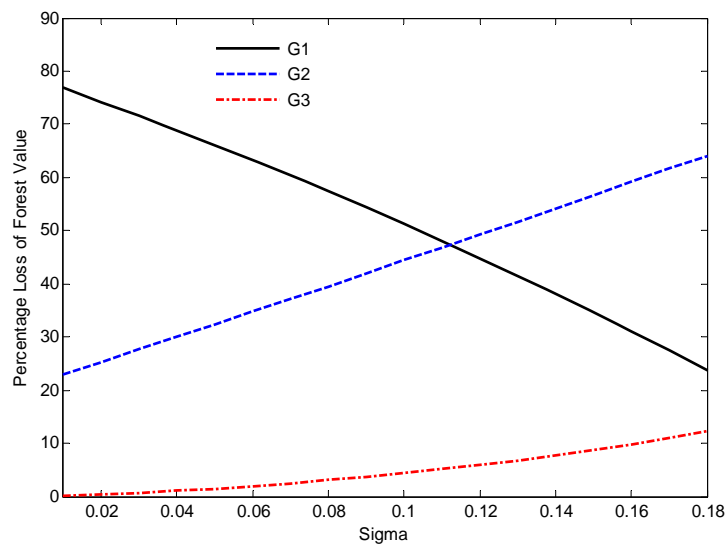


Figure 4. Percentage Decomposition of Gain in Forest Value from Securing Use Right

$$(\theta = 1)$$

5. Conclusion

This paper provides a framework for assessing the effects on forest output of the stochastic oscillations between private and common property regimes that have occurred in China during the last 65 years. The induced policy uncertainty distorts the harvesting decisions of farmers holding use rights to the land. By our reckoning, the losses in forest output resulting from this uncertainty appear large. Understanding the consequences of this policy-induced uncertainty is particularly important at a time when China is engaged in the most ambitious reforestation efforts in the developing world in the hope of significantly increasing its domestic supply of timber.

In the special case where the expected time spent in the common property regime approaches zero, our model can be interpreted as one where harvesting occurs under the threat of a catastrophic event like a forest fire and where the government compensation is reinterpreted as the payout from insurance against the catastrophe. As we show, the conclusion of Reed (1984) and others that increased risk of forest fire inevitably motivates farmers to harvest earlier fails to hold if the insurance payout is sufficiently large.

Appendix I

During the last 65 years, tenure of nonstate forests has oscillated between the two regimes of private and common property. There have been at least four radical transitions, with no regime lasting more than 25 years.

I. Private landownership resulting from the Land Reform Campaign (1950–1955)

Before 1950, feudal landownership dominated most of China. Forestland was either commons or was owned by landlords or rich peasants. The 1950 Land Reform Campaign radically changed the ownership structure. The newly founded government confiscated most private forestland, nationalized some of it, and distributed the rest to rural households in equal shares (Xu et al. 2004). Private ownership lasted for about three years before China's socialism process began to erode it. The erosion started during 1953–1955, when elementary cooperatives were established and rural households were encouraged to pool their forestland and other means of production. Yet this challenge was relatively insignificant, since less than 60% of rural households joined elementary cooperatives, and even the participating households still maintained private ownership of their land (Liu 2001). Thus, before 1955, China's nonstate forests were governed by a newly established, unstable private regime.

II. Collectivization with the socialism campaign (1956–1980)

As the socialism campaign proceeded to the advanced cooperative period in 1956, private ownership of forestland was terminated. Under this new regime, forestland, like other means of production, was expropriated. It became the collective property of advanced cooperatives (Walker 1966; Liu 2001). Whether Chairman Mao coerced or stimulated farmers to join the collectivization campaign is unclear, but by the end of 1956, 96% of rural households

were incorporated in advanced cooperatives. Although a collective regime dominated this period, there still remained some respect for farmers' ownership of land. First, when rural households joined an advanced cooperative, they were compensated in monetary terms for the value of their forests.¹⁶ Second, they continued to own nontimber trees on small spots of land (Liu 2001).

Collectivization of property rights over land peaked during the people's commune period, starting in early 1958. While previously an elementary cooperative had typically consisted of 25 rural households and an advanced cooperative 500 households, the average size of a people's commune sharply increased to 4,800 households. In addition, the collective regime further expanded to cover the nontimber trees that had been privately owned in the advanced cooperative period (Xu et al. 2004).

Accompanying this overambitious collectivization was a fanatical social campaign, the Great Leap Forward. Around the end of 1957, China resolved to catch up to Britain in terms of its industrialization level, with the production of steel as a core symbol. Beginning in early 1958, collective communes clear-cut forests regardless of age in an overzealous attempt to fuel laggard steel furnaces. Little consideration was given to the ecological and economic costs of tree cutting (Wang et al. 2007). As a result, in Hubei Province, to name one example, forest area and volume decreased by 30% during this period (Liu 2001). The Great Leap Forward campaign, along with the radical ownership transformation in the people's communes, has been blamed as the major cause of large-scale deforestation that occurred around 1960.

¹⁶ The value of forests was determined in various ways in different regions of China. China was a planning economy in the 1950s and had no concept of the market value of trees. The government set timber prices and compensation standards based on political, and sometimes economic, considerations. For example, in GuizhouJinping, compensation for a tree of 1 meter diameter at breast height (dbh) was 0.4renminbi (RMB) in some cooperatives and 0.8RMB in others (Luo 2008). In Shaanxi Zizhou, compensation for seedlings and young stands was the equivalent of the planting costs, while compensation for timber forests was based on affixed standard that was not recorded and is unknown today (Dong 2011). In other cases, farmers' trees were expropriated without any compensation (Zhao 2002).

An even more serious consequence of the Great Leap Forward was the Great Famine from 1959 to 1961, which resulted in more than 15 million deaths and great social instability (Peng 1987).¹⁷ In response to this tragedy, the government readjusted the distribution of landownership in rural China in the early 1960s. It returned land property rights and management to lower-level collectives, including both elementary and advanced cooperatives. Nontimber trees and trees planted by households around their homesteads were even returned to individual households (Xu et al. 2004; Liu 2001).

However, the Cultural Revolution (1966–1976) put an end to this short-lived backsliding toward decentralization. This movement asserted on ideological grounds that all properties in a socialist society should be collectively owned. Hence, forestland, including the land that had been returned to individual households, was once again expropriated—this time without proper compensation (Ho 2006).

Overall, the period from 1956 to the early 1980s saw the emergence and dominance of a collective property regime in the forestry sector, with various levels of centralization. This paralleled the trials of land institution design in the early stage of the People’s Republic of China (PRC) and involved both rational and irrational policy elements.

III. Privatization following the “Three Fix” policy (1981–1986)

After 25 years of inefficient forest operations, the Forestry Department modified the collective regime, beginning with the release of the Decision on the Issues of Forest Conservation and Forestry Development by the State Council in March 1981. This document “marked the beginning of a long legislative and policy process aimed at encouraging private sector participation by providing increasingly secure resource rights” (Xu et al. 2004, 67). The

¹⁷This death toll is a conservative estimate as indicated by government statistics. Unofficial estimates by scholars vary from 20 million to 76 million (Dikötter 2010; Yang 2013).

document stipulated that (1) forest resources with clear and nondisputable ownership should be returned to their original owners; (2) plots of forestland, including waste hillsides, riverbanks, and beaches, should be allocated with an egalitarian principle to farmers for long-term sustainable operation; and (3) trees planted on individual homesteads and family plots should be private property. In Chinese, this policy is called *linye sanding*, or “Three Fix” in forestry.

Under this system, nonstate forestland was still collectively owned, but rural households were entitled to full property rights of forest resources as well as the right to use the land. In addition, as with privatization in the 1950s, the new round of privatization in the 1980s also emphasized the principle of equal distribution of forestland. Given that the registered rural population had *remained stable* from the 1950s to the 1980s, farmers got back roughly an equal share of forestland, although not always their original land or land of exactly the same value.

IV. Recurrence of a collective property regime (1987–2007)

The purpose of establishing a private property regime in forestry was to improve the management of existing forests and to encourage private investment in new plantations. However, such goals had hardly been realized previously, especially in the southern regions of nonstate forest. Farmers were therefore skeptical that the privatization policy would last. So instead of expanding activities of reforestation and forest management, the farmers exploited the forest resources they had been given (Liu 2001).

The resulting deforestation once again undermined the government’s confidence in the effectiveness of the private regime in governing the forestry sector (Yin and Newman 1997). So in 1987, the central government terminated the privatization reform. Accordingly, many local governments in the southern regions restored collective management of forestland that had been contracted to households (Liu 2001). Unlike the first round of collectivization in 1956, this time

the collectivization did not involve redistribution of property rights, at least nominally, but only centralization of decisionmaking rights over the forestland that had already been collective property. Although the government did not pay out direct compensation, it did promise to share forestry revenues in village collectives with participating households. In addition, the 1987 collectivization occurred in a relatively stable political environment without significant influence from irrational social campaigns, and thus no serious clear-cutting accompanied this round of collectivization.

V. The new round of privatization (2008–?)

For the next 16 years, a relatively stable common property regime dominated the nonstate forest sector, until privatization reform was initiated once again in some regions in 2003 (Xu et al. 2008). With the aim of increasing forestry productivity, the government once again decided to allocate use rights of forestland to individual households. Like the previous privatization reforms, this newest round of privatization also emphasizes farmers' equal rights of contracting forestland. In addition, it addresses farmers' concern about uncertainty regarding future forestry policy by stipulating that forestland contracts last for 70 years and that the contracts are renewable, inheritable, and transferrable (SFA 2008). This privatization reform was expanded to a national scale in 2008 and is still ongoing. Its effects on nonstate forest operation await further evaluation.

Appendix II

Our assumptions in the text reflect our reading of Chinese forestry policy since 1950. Most villages seem to have cut trees immediately when the farmer relinquished his use rights and did not replant. However, some villages may have waited to harvest trees acquired from the farmers, and if those villages retained the use rights when the trees reached exogenous a_{et_c} , they may have harvested the trees and then re-planted. In this appendix, we show how this alternate assumption can be analyzed within the framework in the text. To emphasize further its flexibility, we conduct the analysis in discrete time.

Assumptions

We assume that the tree changes age and the use right changes hands at the beginning of a period. Only the holder of the use right can cut. We assume that, if it holds the right, the collective chops the tree down when it first becomes t_c years old, where t_c is exogenous. We assume t_c can be 0,1,2, etc. If $t_c = 0$, then the village will chop down the tree the moment that it gets the use right.

Here, unlike the text, we permit $t_c > 0$. Moreover, we assume that the village—like the farmer—plants immediately after cutting. Since each party re-plants immediately, if the use right reverts to the other party in the very next period, the trees on that parcel will be 1 year old.

The Calculation of J_s in Discrete Time (Given the V_s)

If a farmer has the use right to the land and it contains a tree of age a , then he can cut it immediately, when it is a ; one period later, when it is $a + 1$ years old (assuming he still has the use right after that one potential transition); two periods later, when it is $a + 2$ years old (assuming he still has the use right after the two potential transitions); What is the expected payoff if he chooses to cut any tree age t^* or older and replant (if he has the right to do so)?

As before, there are two possibilities: either he retains the use right $t = \max(0, t^* - a)$ years later, or he loses it before then. In the former case, he cuts the tree and re-plants immediately. He thus gets $F(a + t)$ immediately and, in expectation, $\frac{(1-\sigma)J_1 + \sigma V_1}{1+r}$ from the next period onward; hence, in present value terms, he gets $\left[f(a + t) + \frac{(1-\sigma)J_1 + \sigma V_1}{1+r} \right] / (1 + r)^t$. This happens with probability $(1 - \sigma)^t$. If, however, the use right has transited to the village collective at x ($x = 1, 2, \dots, t_1$), then he gets $V_{a+x} / (1 + r)^x$. The probability of this happening is $\sigma(1 - \sigma)^{x-1}$. Putting this all together, we get the following equation:

$$J_a = \max_{t=0,1,\dots,T} \left[\frac{(1-\sigma)J_1 + \sigma V_1}{1+r} \right] \left(\frac{1-\sigma}{1+r} \right)^t + \sum_{x=1}^t V_{a+x} \sigma \frac{(1-\sigma)^{x-1}}{(1+r)^x}, \text{ where } a = 1, \dots, t_c \quad (1.1)$$

When the farmer gets the use right back from the village, the parcel will never have on it a tree strictly older than t_c , since any strictly older tree would have been cut down. Hence, in evaluating J_a , we need consider only $a = 1, \dots, t_c$.

The Calculation of V_s (Given the J_s) When Villages Are Assumed to Cut Trees Reaching an Exogenous Age and Immediately Replant

The formula for calculating J_a involves V . We have to evaluate V_1, \dots, V_{t^*} . It is here that the analysis veers sharply away from what we have done so far.

Suppose that the transition to collective property occurs when the trees turn k years old. What is the expected value to the farmer discounted to the time of that transition? We denote it V_k . He immediately gets $\theta[F(k) + c]$ in compensation, but he also gets the expected discounted payoff from proceeding optimally.

If $k \geq t_c$, then the village cuts the trees down immediately. If the farmer succeeds in getting the use right back at the first opportunity, he would receive in current value terms $J_1 / (1 + r)$. This would occur with probability σ . If he were unsuccessful in the first year, he

might be successful in the second, in which case he would acquire the 1-year-old tree planted by the villagers, which would be worth $J_2/(1+r)^2$. This would occur with probability $(1-\sigma)^1\sigma$. It is possible that the farmer would not get the parcel back until the year when the villagers would have cut the tree. In that case, the expected discounted value would be $J_{t_c}\sigma(1-\sigma)^{t_c-1}/(1+r)^{t_c}$. It is, however, also possible that the villagers would retain the use right and would then harvest the tree they planted and immediately re-plant. If the use right returned to the farmer on the next period, he would find a parcel with 1-year-old trees on it. The value to the farmer of the use right would be J_1 at the time it was returned to him.

Notice that he would get a parcel with a 1-year-old tree on it if the collective had planted 1 year ago for the n^{th} time ($n = 1, 2, \dots$). Similarly, the farmer would get back a parcel with 2-year-old trees on it if the collective had planted 2 years ago for the n^{th} time ($n = 1, 2, \dots$)... We can express V_k for $k \geq t_c$ compactly as the scalar product of two vectors. The first reflects the value to the farmer at the time the use right is returned to him. Since the land can have on it trees of age $1, \dots, t_c$, this will be a vector with t_c components. We denote it as $\vec{J}(1)$, with the 1 indicating that the first component of the vector is J_1

$$\vec{J}(1) = (J_1 \ J_2 \ J_3 \ \dots \ J_{t_c})$$

The second vector is a t_c component vector that reflects discounting and probability weights. Define $A = \sum_{i=1}^{\infty} \frac{(1-\lambda)^{0+(i-1)t_c}}{(1+r)^{1+(i-1)t_c}}$ and $B = \frac{1-\lambda}{1+r}$. Then the second vector is

$$\vec{D} = (A \ AB \ AB^2 \ \dots \ AB^{t_c})$$

We can then use the scalar product of these two vectors to determine the expected discounted value to the farmer if the collective gains the use right to the parcel when the trees on it are age $k \geq t_c$: $V_k = \theta[F(k) + c] + \vec{D} \cdot \vec{J}(1)$.

The second term is independent of k because, as long as the tree is no younger than t_c , the village will cut the tree immediately. Hence, V_k depends on k only because the farmer would get a larger compensation for an older tree.

No matter when the village gets back from the farmer the right to use the parcel, it will never contain trees older than t^* , since the farmer would have cut any older tree. We assume that $t^* > t_c$.

Suppose now that the village gains the use right to the parcel when the trees on it are age $k < t_c$. The farmer may succeed in regaining the use right in the next period. The discounted value of regaining the use right would then be worth $J_{k+1}/(1+r)$, and this would happen with probability σ . Or if the farmer failed to get the use right back then, he might be successful in the following period, when the trees were $k+2$ years old. The use right then would be worth in discounted terms $J_{k+2}/(1+r)^2$, and this would happen with probability $\sigma(1-\sigma)$. If the trees turned t_c years old, however, and the village still retained the use right, then villagers would cut down the trees and replant immediately; if the farmer regained the use right in the next period, it would then be worth J_1 .

We can once again express V_k for $k < t_c$ compactly as the scalar product of two vectors. The first reflects the value to the farmer at the time the use right is returned to him. Since the land can have on it trees of age $k+1, k+2, \dots, t_c, 1, \dots, k$, this will be a vector with t_c components with first component J_{k+1} . We denote it $\vec{J}(k+1)$:

$$\vec{J}(k+1) = (J_{k+1} J_{k+2} \dots J_{t_c} J_1 \dots J_k)$$

We can then write the expected value to the farmer if the village grants the use right to the parcel when it contains trees of age $k < t_c$ as $V_k = \theta[F(k) + c] + \vec{D} \cdot \vec{J}(k+1)$.

Solution Algorithm to Determine Js and Vs

Given t_c , we can solve the model as follows:

1. Given the parameters, calculate the scalar A and the vector \vec{D}
2. Pick a trial set of t_c values: J_1, \dots, J_{t_c} .
3. Calculate V_k for $k = 1, \dots, T$.
4. Use these values and equation (1.1) to calculate a revised set of t_c values, J_1, \dots, J_{t_c} , and return to step 3.
5. Iterate until convergence occurs.

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