Forest Loss, Monetary Compensation, and Delayed Re-planting:

The Effects of Unpredictable Land Tenure 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. To conduct this analysis, we extend the literature on forestry economics when there is a risk of loss due to forest fire or pests. We (1) take account of the possibility that replanting can only resume after an interval of uncertain length (with immediate replanting as a special case); (2) investigate the effects of compensation for such losses based only on the net value of the stand of trees at the time of the loss; and (3) compare it to compensation that would leave the wealth and rotation decisions of the farmer unaffected by the presence of uncertainty.

Key Words: forest tenure risk; Faustmann model; optimal rotation period under uncertainty; full compensation for loss

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. Its aggressive policy of importing timber has led to unsustainable exploitation of the resources of neighboring countries (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 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 for the net value of the trees he was forced to relinquish. 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 the major transitions in Table 1 and describe each more fully in the Appendix. 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, pp. 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

[1] For 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).

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.

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]	1. Under the Land Reform Campaign, the government confiscated most privately owned forestlands and equally distributed them to individual rural households. 2. 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. 3. Private ownership and household management of forests were dominant throughout this period
1956–1980	Collective	4. The government terminated private ownership of forests after establishing advanced cooperatives. 5. Rural households were compensated with the value of forests. 6. Collective ownership and management of the forests were dominant. 7. 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. 8. Non-timber trees and trees planted around homesteads were once returned to individual households but were re-collectivized during the Cultural Revolution.
1981–1986	Private	9. 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. 10. Forest resources with undisputed ownership claims were to be returned to their original owners. 11. Degraded and waste forestland was to be equally allocated to individual households.
1987–2007	Collective	12. The government suspended privatization and restored a collective regime in some regions. 13. No compensation was paid in this round of collectivization. 14. No clear-cutting was reported associated with this round of collectivization.

[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.

2008–?	Private	15. The government initiated a new round of privatization in 2003 and has expanded it to a national scale in 2008. 16. This round of privatization aims at devolution of forest management to individual rural households.

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 an even-aged stand of trees 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 the stand of trees when the value of letting it 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 section 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,

[3] In 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.

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 considerable length before re-planting can occur. 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.

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] Three conclusions are particularly striking.

First, if farmers face a higher risk of transition 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 the loss is insured sufficiently based on the net value of their current stand, however, the result would change. In China, compensation is based on the size of the tree at the time the use right of the stand is taken from the farmer. Whether the increased risk of such expropriation lengthens or shortens the rotation period turns out to depend on the

[4] To the best of our knowledge, ours is the first paper to consider the behavior of a wealth-maximizer operating under a property rights regime that oscillates stochastically between two states of nature; in our application, the wealth-maximizer 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, either of which is higher than that of the secure source.

magnitude of such compensation.

Our second conclusion is that compensation based on the net value of the stand at the time of a loss, whether from a forest fire or from expropriation, does not constitute full compensation. We show what would constitute full compensation and that a farmer would be shortchanged if he received compensation based only on the net value of his current stand at the time of his loss.

Third, when properly 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 to them. To illustrate how this could be done, we compare the discounted value of timber harvested (net of harvesting and planting costs) when property rights are guaranteed with the corresponding discounted value when policy oscillates unpredictably. One effect which makes quantification particularly difficult is that farmers may find a different species to be optimal when the environment becomes more secure. For example, trees that grow fast like bamboo would no longer be appropriate when expropriation ceased to be a consideration, and the farmer might switch to species that, despite their slow start at the outset, ultimately attained a more massive volume. In our illustrative simulations, the net wealth is more than twice what nonstate forests currently generate. We also present a useful decomposition to identify the sources of this wealth gain.

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. We also show that compensation which *fully insures* farmers against expropriation risk would compensate them for more than the net value of their current stand of trees at the time of expropriation. In Section 4, we estimate the gains that would result from the elimination of policy uncertainty. Section 5 concludes.

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 assumptions. We assume that timber is the only forest product and that its price net of logging cost per unit volume is a constant, normalized to one. We assume that the biological growth of timber is deterministic and denote the volume of wood in an even-aged stand of trees of age t (and hence the net value of the stand if it were harvested then) as $f(t)$. We assume $f(t)$ satisfies the following properties: $f(0) = 0$, $f'(t) > 0$, $f''(t) < 0$, $\lim_{t \to 0} f'(t) = +\infty$, and $\lim_{t \to +\infty} f'(t) = 0$. That is, as the stand matures, the volume of marketable wood it contains (and hence its net value) increases but at a decreasing rate.[5] This implies that the growth rate of the stand ($f'(t)/f(t)$) declines monotonically as it ages. We assume that the exogenous cost of planting a stand of seedlings (denoted c) is small enough that farmers expect to make a profit growing trees.

Land use rights of an individual, which we refer to somewhat imprecisely as private property, may be given to the village at a random time. Land use rights of the village, designated imprecisely as common property, may later be returned to the farmer at a random time. We describe these stochastic transitions by an alternating

[5] As most commercial harvesting occurs before the stand of trees reaches maturity, we do not consider later phases where growth eventually ceases altogether.

renewal process. We assume that land use rights may be taken away from the farmer 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.

Reed (1984) considered an analogous process in which the random arrival of a forest fire sometimes prevents the farmer from reaping what he has sowed. But in Reed (1984), the farmer can immediately re-plant. We consider a more general case where land use rights under a common property regime may stochastically transit back to private property with an average transition rate of λ. Hence the expected time before replanting can occur after a forest fire (or after a tree-killing infestation or infection) is $1/\lambda$.[6] The Poisson parameters σ and λ are exogenous and the decision-maker is assumed to know them. These parameters reflect the magnitude of tenure uncertainty.

Agents are assumed to be risk neutral. A private owner of a land use right chooses his rotation period 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 compensation based on the net current value of the expropriated stand.[7] We also assume that a farmer anticipates that he will subsequently get his right to use the original parcel (or a parcel of equivalent value) back, devoid of trees, after it has remained common property for an unpredictable

[6] To re-produce Reed's case, let $\lambda \rightarrow +\infty$.

[7] Describing the first round of collectivization, Liu (2001, p. 243) writes: "the advanced cooperatives were required to value private forests in monetary terms and later compensate member households for the forests and trees they contributed. This policy, however, was not strictly enforced for the majority of cases." Accordingly we assume that compensation based on the net value of the stand at the time the farmer lost his use right was paid with probability θ. Hence, *the expected* compensation when a stand of trees of age x was expropriated is $\theta f(x)$.

length of time. This assumption also accords with recent practice.[8] Finally, we assume that the farmer granted the land use right anticipates that this stochastic cycle will repeat itself endlessly over time.

The expected value of the forest can be expressed as a sum of all discounted future cash flows, from either timber sales or compensations, net of harvesting and planting costs. Future values are discounted continuously at rate r. We denote as $V(y)$ the expected value to the farmer if he relinquishes to the village his right to use the parcel when trees on it have age y. We denote the expected value of the right to use a plot with no trees on it as J_0 if the farmer holds the use right. Assuming that c is not so large that growing trees is unprofitable,

$$J_0 = \max_{t\geq 0}\{[f(t) - ce^{rt} + J_0]e^{-rt}e^{-\sigma t} + \int_{x=0}^{t}[V(x) - ce^{rx}]\, e^{-rx}\sigma e^{-\sigma x}dx\} > 0 \quad (1)$$

That is, the individual will choose harvest time t to maximize his expected 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 age t, the use right will not yet have been taken away from the farmer. If so, he receives at t the net revenue from tree harvesting of $f(t)$ less the capitalized planting cost ce^{rt}. In addition, he also retains the use right to the barren land, which has expected value J_0. 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 expected value to him of common property with trees on it of age x: $V(x)$, less the cost of planting the trees he planted but could not harvest, capitalized to the date of transition: ce^{rx}. At any time x, the likelihood of

[8] 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).

such a transition is $\sigma e^{-\sigma x}$. The value of private use right to a piece of barren forest, J_0, is defined as the maximized expected value of the discounted sum, as indicated in equation (1).

When the transition to common property occurs, forest owners receive no revenue for the trees they planted. In its place, they receive expected compensation $\theta f(y)$ for $\theta \in [0,1]$. We assume that the trees are clear-cut immediately by the village, and no re-planting occurs. Farmers are then assumed to wait for the stochastic transition to return 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 expected value of the compensation plus the expected present value of its return to private property in the future:

$$V(y) = \theta f(y) + \int_{x=0}^{+\infty} \lambda e^{-\lambda x} J_0 e^{-rx} dx \tag{2}$$

which can be re-written as

$$V(y) = \theta f(y) + \frac{\lambda}{\lambda + r} J_0$$

Substituting this into equation (1), we obtain the following:

$$J_0 = \max_{t \geq 0}\{[f(t) + J_0]e^{-(r+\sigma)t} + \sigma \int_{x=0}^{t} \left[\theta f(x) + \frac{\lambda}{\lambda+r} J_0\right] e^{-(r+\sigma)x} dx - c\} \tag{3}$$

The right-hand side of equation (3) can be regarded as a mapping $M(J_0)$ from any trial value of $J_0 > 0$ into a possible different real number on the left-hand side of (3). By definition, $M(0) = \max_{t \geq 0}\{f(t)e^{-(r+\sigma)t} + \sigma \int_{x=0}^{t} \theta f(x)\, e^{-(r+\sigma)x} d\mathrm{x} - c\}$. Since we assume c is sufficiently small, $M(0) > 0$. Given any trial value of J_0, we can find a $\tilde{t}$ that maximizes the objective function. Using the envelope theorem, we conclude:

$$\frac{dM(J_0)}{dJ_0} = \left[e^{-(r+\sigma)\tilde{t}}\right] * 1 + [1 - e^{-(r+\sigma)\tilde{t}}] \frac{\lambda}{(\lambda+r)} \frac{\sigma}{(\sigma+r)} \tag{4}$$

Given the Inada condition on $f(t)$, $\tilde{t} > 0$. When $\tilde{t} > 0$, $0 < \frac{dM(J_0)}{dJ_0} < 1$, since the right-hand side of (4) is then a strictly convex combination of one and a positive fraction less than one . Since the mapping $M(J_0)$ increases from $M(0) > 0$ at a rate less than one ($M'(J_0)$), it crosses the 45 degree line at a unique, strictly positive fixed point. When we mention J_0 henceforth, we are referring to this unique fixed point (defined below by equation (5) and (6)).

The maximand in equation (3) is then a function of the cutting time t. Denote it as $H(t)$. Thus, $H'(t) = e^{-(r+\sigma)t}\left[f'(t) - (r + \sigma - \theta\sigma)f(t) - r\left(1 + \frac{\sigma}{\lambda+r}\right)J_0\right]$.

The global optimum of $H(t)$ cannot occur at $t = 0$ given the Inada condition on $f(t)$. We now show that $H(t)$ is single-peaked and achieves a global optimum at the unique solution to $H'(t) = 0$. Since $f(0) = 0$, $\lim_{t\to 0} f'(t) = +\infty$, and $r\left(1 + \frac{\sigma}{\lambda+r}\right)$ is constant, $H'(0)$ is positive. The last two terms in the square brackets are negative. The first is strictly decreasing and approaches zero as $t \to \infty$. Hence, there will be some t such that $H'(t)$ is zero. Moreover, since the term in square brackets is strictly decreasing, $H'(t)$ becomes negative for larger t. That means the function of $H(t)$ is single-peaked and achieves its global optimum at the unique solution to the following equation:

$$f'(t) = (r + \sigma - \theta\sigma)f(t) + r\left(1 + \frac{\sigma}{\lambda+r}\right)J_0 \tag{5}$$

Denote this unique solution as t^*. The left-hand side of equation (5) is the marginal benefit of further delaying harvesting and the right-hand side is the marginal cost of doing so. Since $J_0 > 0$, $\frac{f'(t^*)}{f(t^*)} > r + \sigma - \theta\sigma \geq r$. Hence, it is optimal for the farmer to cut his stand when it is still growing faster than the rate of interest. It follows that if expropriation or a natural catastrophe intervenes *before* he can harvest the stand, he loses an asset that would have continued to grow faster than the rate of interest until he harvested it.

Substituting t^* into equation (3), we obtain:

$$J_0 = [f(t^*) + J_0]e^{-(r+\sigma)t^*} + \sigma \int_{x=0}^{t^*} [\theta f(x) + \frac{\lambda}{\lambda + r} J_0]\, e^{-(r+\sigma)x} dx - c$$

Solving for J_0, we obtain:

$$J_0 = \frac{f(t^*)e^{-(r+\sigma)t^*} - c + \sigma\theta \int_{x=0}^{t^*} f(x)e^{-(r+\sigma)x} dx}{[1 - e^{-(r+\sigma)t^*}][1 - \frac{\lambda}{(\lambda+r)}\frac{\sigma}{(\sigma+r)}]} \quad (6)$$

Since $\sigma, \lambda, \theta, r, c$ and $f(.)$ are exogenous, the two endogenous variables t^* and J_0 are simultaneously determined by equation (5) and (6).

When $\theta = 0$ and $\lambda \to +\infty$ (the length of the common property phase is zero, and every time landowners plant trees they risk losing their forest property without compensation), equation (5) reduces to $f'(t^*) - (r + \sigma)f(t^*) - rJ_0 = 0$, and equation (6) reduces to $J_0 = \frac{(r+\sigma)[f(t^*)e^{-(r+\sigma)t^*} - c]}{r[1 - e^{-(r+\sigma)t^*}]}$. These are Reed's conditions. If, in addition, $\sigma = 0$, the equation (5) reduces to $f'(t^*) - rf(t^*) - rJ_0 = 0$ and equation (6) reduces to $J_0 = \frac{f(t^*)e^{-rt^*} - c}{[1 - e^{-rt^*}]}$. These are Faustmann's conditions (Amacher et al., 2009, p. 20).

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:

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

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.

3. What Constitutes Full Compensation

In this section we compare the expected compensation ($\theta f(x)$) which has traditionally been paid to Chinese farmers when their use right has been expropriated temporarily to the hypothetical compensation which would have induced these farmers to behave as if no expropriation risk existed. Only the latter merits the adjective "full" compensation. As we show, compensation based entirely upon the net value of the current stand at the time of expropriation shortchanges farmers.

We proceed as follows. We first show that farmers anticipating compensation based on the net value of their current stand at the time it is expropriated will *adjust* their rotation decision in response to the uncertainty that they face; moreover, the value of the use right to cleared land will also depend upon the uncertainty parameters (σ and λ). Sensitivity to these parameters is a tipoff that farmers are not paid “full” compensation. Whether they are overcompensated or undercompensated will become clear. Second, we characterize what full compensation would entail. We verify that a farmer anticipating this form of compensation would choose the *same* rotation age as Faustmann’s farmer and would earn the *same* expected discounted net profits as Faustmann’s farmer regardless of the uncertainty parameters (σ and λ). Third, we show that such a farmer would be shortchanged if instead of the full compensation he was anticipating, he received only the net value of the stand ($\theta f(x)$ for $\theta \leq 1$) at the time of the expropriation.

3.1 Comparative Statics

Since the Chinese government compensates the owner of a land use right when it is expropriated, anticipation of such compensation would potentially affect a farmer’s rotation decision as well as the value of the use right to cleared forest land.

To determine the effect of increasing the compensation rate θ on the optimal rotation age, we differentiate (5) with respect to θ to obtain the following:

$$[f''(t^*) - (r + \sigma - \theta\sigma)f'(t^*)]\frac{\partial t^*}{\partial \theta} = -\sigma f(t^*) + r[1 + \frac{\sigma}{\lambda + r}]\frac{\partial J_0}{\partial \theta} \quad (7)$$

Since the term in the square brackets on the left-hand side of (7) is negative, $\frac{\partial t^*}{\partial \theta}$ has a sign opposite to that of the right-hand side of (7). Applying the envelope theorem to equation (6), we conclude that $\frac{\partial J_0}{\partial \theta} = \frac{\sigma \int_{x=0}^{t^*} f(x)e^{-(r+\sigma)x}dx}{[1-e^{-(r+\sigma)t^*}][1-\frac{\lambda}{(\lambda+r)}\frac{\sigma}{(\sigma+r)}]} > 0$. Plugging this expression back into (7), its right-hand side can be rewritten as $\frac{(r+\sigma)\sigma \int_{x=0}^{t^*}[f(x)-f(t^*)]e^{-(r+\sigma)x}dx}{[1-e^{-(r+\sigma)t^*}]}$. Since $f' > 0$, $f(t^*) > f(x)$ for $x \in [0, t^*)$, the right-hand side of (7) is negative. Therefore, $\frac{\partial J_0}{\partial \theta} > 0$ and $\frac{\partial t^*}{\partial \theta} > 0$.

Intuitively, increasing the compensation rate θ increases the value of the use right to cleared land since it would increase an owner's receipts even if he did not alter his rotation decisions at all. The value of this compensation (that is, the maximum a farmer would be willing to pay for it) is the increase in the value of the use right (J_0) that this increased compensation rate (θ) induces.

To determine the effect of increasing the return rate (λ) on the optimal rotation age, we substitute J_0, as expressed in equation (6), into equation (5) to obtain the following: $f'(t^*) = (r + \sigma - \theta\sigma)f(t^*) + \frac{(r+\sigma)[f(t^*)e^{-(r+\sigma)t^*} - c + \sigma\theta \int_{x=0}^{t^*} f(x)e^{-(r+\sigma)x}dx]}{[1-e^{-(r+\sigma)t^*}]}$.
This equation implicitly defines t^* in terms of exogenous parameters. Since λ does not appear in this equation, the optimal rotation age is unaffected by changes in λ for any admissible θ and σ.

An exogenous increase in λ does, however, increase the value of the farmer of the use right to cleared land (J_0). Intuitively, shortening the expected time the use right is held by the village ($1/\lambda$) raises the private value of the use right to cleared land. More formally, both the numerator and denominator of equation (6) are positive. While an increase in λ has no effect on the former, it does reduce the latter. Thus, $\frac{\partial J_0}{\partial \lambda} > 0$.

Finally, we consider the effect of changing σ on the optimal rotation age. This turns out to be indeterminate. To clarify this, we first show that the optimal rotation age *strictly decreases* in σ when no compensation is paid ($\theta = 0$); then we provide an example where the optimal rotation age *strictly increases* with σ when compensation is always paid ($\theta = 1$).

Assume that $\theta = 0$, equation (5) and (6) reduce to (5') and (6') as follows:

$$f'(t^*) - (r+\sigma)f(t^*) - r\left(1+\frac{\sigma}{\lambda+r}\right)J_0 = 0 \quad (5')$$

$$J_0 = \frac{f(t^*)e^{-(r+\sigma)t^*} - c}{[1-e^{-(r+\sigma)t^*}][1-\frac{\lambda}{(\lambda+r)}\frac{\sigma}{(\sigma+r)}]} \quad (6')$$

Equation (6') can be further rewritten as $J_0 = \frac{(r+\sigma)[f(t^*)e^{-(r+\sigma)t^*}-c]}{1-e^{-(r+\sigma)t^*}}\{\frac{\lambda+r}{r(r+\sigma+\lambda)}\}$. By the envelope theorem, $\frac{dJ_0}{d\sigma} = \frac{\partial J_0}{\partial \sigma}|_{t^*}$. Clearly the factor in braces on the right of the equation defining J_0 is positive but strictly decreasing in σ. To show that value of land use right strictly decreases as the hazard increases, we need merely verify that the remaining positive factor decreases as well.[9]

To verify that the rotation age (t^*) strictly decreases in σ, substitute the expression for J_0 into equation (5') and simplify to obtain $f'(t^*) = [f(t^*) - c]\frac{r+\sigma}{1-e^{-(r+\sigma)t^*}}$. We can again interpret the left- and right-hand sides of this equation defining t^* as marginal benefit and marginal cost, respectively. It is straightforward to show that the marginal-cost curve shifts up uniformly when σ increases.[10] Since

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[9] Denote this remaining factor as $h(\sigma) = \frac{(r+\sigma)[f(t^*)e^{-(r+\sigma)t^*}-c]}{1-e^{-(r+\sigma)t^*}}$. Differentiating and simplifying , we obtain: $\frac{\partial h(\sigma)}{\partial \sigma} = \frac{[f(t^*)e^a - c][1-e^a] - [f(t^*)e^a - ce^a][-a]}{[1-e^a]^2}$, where $a = -(r+\sigma)t^* < 0$, thus $0 < e^a < 1$. Let $g(x) = 1 + x - e^x$. The function has the following properties: (1) $g(0) = 0$, and (2) $g'(x) = 1 - e^x > 0$ for $x < 0$, so $g(a) = 1 + a - e^a < 0$, i.e. $1 - e^a < -a$. It is also true that $f(t^*)e^a - c < f(t^*)e^a - ce^a$, since $e^a < 1$. Thus, the first product in the numerator of the differentiation is less than the second one, and it implies $\frac{\partial h(\sigma)}{\partial \sigma} < 0$. Hence, J_0 strictly decreases in σ for any $\sigma, \lambda > 0$.

[10] Denote the marginal-cost curve, for any t, as $[f(t) - c]m(\sigma, t)$, where $m(\sigma, t)$ is defined as $m(\sigma, t) = \frac{r+\sigma}{1-e^{-(r+\sigma)t}}$,

the marginal-benefit curve must cut the marginal-cost curve from above at t^*, we can conclude that a marginal increase in risk will result in a marginal decrease in the optimal rotation age: $\frac{dt^*}{d\sigma} < 0$.

For an example where the optimal rotation age increases with σ, assume $c = 8$, $r = 0.05$, and the net value of the stand grows according to the following:

$$f(t) = 640 * [1 - \exp(-0.0035 * t)]^{0.6} \quad (8)[11]$$

It can be verified that this growth function satisfies our assumptions: $f(0) = 0$, $f'(t) > 0$, $f"(t) < 0$, $\lim_{t\to 0} f'(t) = +\infty$, and $\lim_{t\to +\infty} f'(t) = 0$. In addition, assume that compensation based on the current net value of the expropriated stand is always paid ($\theta = 1$). In Figure 1, we plot t^* and J_0 against σ for this example (computed using MATLAB 2011a). As shown in Figure 1, the optimal rotation age (t^*) has a vertical intercept equal to the Faustmann rotation age (t_F) and strictly increases as the hazard rate σ increases. Hence, for every $\sigma > 0$, $t^* > t_F$. Thus, the conclusion of Reed (1984) that under uncertainty $t^* < t_F$ need not hold if the farmer is assumed to be *compensated* for his loss.

$\frac{\partial m}{\partial \sigma} = \frac{1-(1-a)e^a}{[1-e^a]^2}$ for $a = -(r+\sigma)t < 0$. Let $n(a) = 1 - (1-a)e^a$. It can be shown that $n(0) = 0$ and $n^{'}(a) < 0$ for $a < 0$. Thus, $n(a) > 0$ for $a < 0$. Thus, the partial derivative is positive and the marginal-cost curve shifts up at every t.

[11] This function is a slight modification of Mitcherlich's basic equation (Sun et al. 1999).

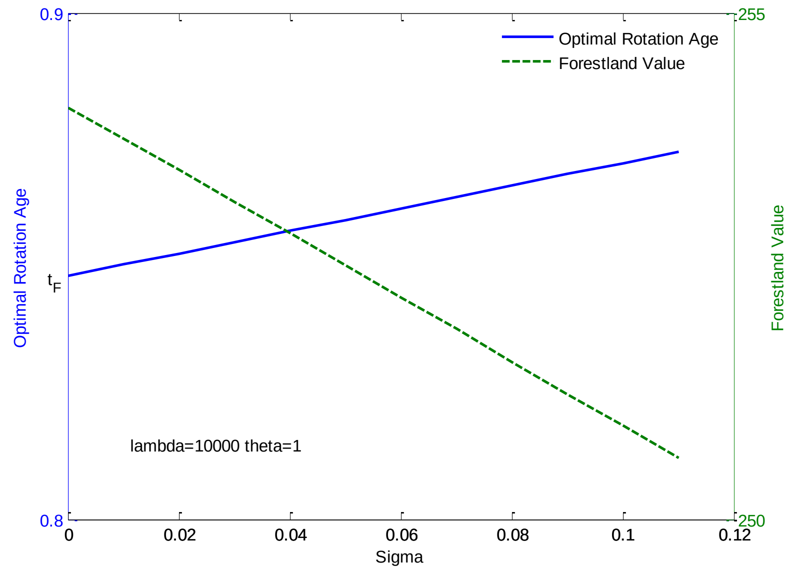

Figure 1. Optimal Rotation Age and Forestland Value with Changing σ when Compensation Based on the Current Net Value of the Stand Is Always Paid ($\theta = 1$)

Although we have focused on the extremes of unitary compensation ($\theta = 1$) and no compensation ($\theta = 0$) when determining the effect of an increased hazard rate (σ) on the optimal rotation age, similar results hold for compensation rate that are in the neighborhood of either of these two extremes since both t^* and J_0 are continuous functions of σ.

3.2 Full Compensation

What would constitute "full" compensation? Denote the wealth Faustmann's farmer would obtain in an environment without any risk of expropriations as J_F and the chosen rotation age of Faustmann's farmer as t_F.

Suppose the farmer chooses to cut his stand at some date t and registers his intention with the government. Suppose the government pays compensation if and only if the stand is expropriated prematurely (as $x < t$). Suppose in that case, the government pays the farmer $[f(t)+J_F]e^{-r(t-x)}-\frac{\lambda}{\lambda+r}J_F$ at the time of expropriation. Then, as shown below, the farmer will act as if he faces no risk: regardless of λ, σ, he will plan to cut each stand of trees when it reaches the age of t_F years and will earn over an infinite horizon the net expected present value of J_F.

To see this, note that, given the anticipated compensation, the farmer will choose t to maximize the present value of his expected profit net of costs over the infinite horizon:

$$W=\max_{t\geq 0}\{\int_{x=0}^{t}[\left((f(t)+J_F)e^{-r(t-x)}-\frac{\lambda}{\lambda+r}J_F\right)+\frac{\lambda}{\lambda+r}W]\,e^{-rx}\sigma e^{-\sigma x}dx+$$
$$[f(t)+W]e^{-rt}e^{-\sigma t}-c\} \qquad (9)$$

where W denotes the endogenous private value of forestland. The term in the larger pair of parentheses is the compensation paid at the time of expropriation. The term following this larger pair of parentheses but within the first square brackets is the expected payoff of future income the farmer expects to receive after the use right returns to him. In particular, since the chance that the farmer gets back his land after expropriation follows a Poisson process with a hazard rate of λ, the expected land value in the environment with oscillating tenure is $\frac{\lambda}{\lambda+r}W(=\int_{x=0}^{+\infty}\lambda e^{-\lambda x}We^{-rx}dx)$. Both terms must be discounted back from the date of expropriation to when the trees were planted x years earlier. The second pair of square brackets contains the present value of the payoff if expropriation does not prevent the farmer from harvesting the current crop of trees at the intended age (t). From this discounted sum must be deducted the present value cost of planting the stand of trees.

We can rewrite equation (9) as

$$W = \max_{t\geq 0}(f(t) + J_F)e^{-rt}(1 - e^{-\sigma t}) + \frac{\lambda}{\lambda+r}(W - J_F)\int_{x=0}^{t}\sigma e^{-(r+\sigma)x}dx + [f(t) + W]e^{-rt}e^{-\sigma t} - c \tag{10}$$

First note that if one sets $W = J_F$ on the right-hand side of equation (10), then the middle term drops out, and the maximand on the right-hand side reduces to $(f(t) + J_F)e^{-rt} - c$. But this is exactly the objective function of Faustmann's farmer faces and he maximizes it at t_F and earns over an infinite horizon J_F. But that would be the left-hand side of equation (10). So $W = J_F$ does solve this functional equation.

We conclude by showing that it is the *unique* solution to this equation. To show this, think of equation (10) as a mapping from W on the right to $\mathrm{N}(W)$ on the left. We seek to show that $\frac{dN}{dW} \in (0,1)$.

Differentiating the right-hand side of (10) and using the envelope theorem, we get

$$\frac{dN}{dW} = e^{-(r+\sigma)t} \cdot 1 + \frac{\lambda}{\lambda + r}\int_{x=0}^{t}\sigma e^{-(r+\sigma)x}dx$$

$$= e^{-(r+\sigma)t} \cdot 1 + (1 - e^{-(r+\sigma)t})\frac{\lambda}{(\lambda + r)}\frac{\sigma}{(\sigma + r)}$$

Given the assumed Inada condition on $f(.)$, $t > 0$. Hence, $\frac{dN}{dW} \in (0,1)$ since it is a strictly convex combination of two strictly position numbers, the larger of which is 1.

Graphically, the function $N(W)$ crosses the 45 degree line at $W = J_F$ with a strictly positive slope strictly less than 1. If there were a second crossing, the slope would have be at least 1, which we have shown cannot occur.

Hence, for any λ and σ, a farmer anticipating the receipt of this compensation would maintain the rotation age t_F and would expect to earn in net discounted value over the infinite horizon J_F.

3.3 A Comparison of Full Compensation to Compensation Based on the Net Value of the Current Stand

Suppose the farmer receives the full compensation instead of $\theta f(x)$. Then, regardless of $\sigma, \lambda, \theta > 0$ and $\theta \leq 1$, the farmer will always be paid more than he would have been paid if compensation was instead $\theta f(x)$. To verify this, consider first the case where $\theta = 1$. The present value of the full compensation we proposed is $[f(t) + J_F]e^{-rt} - \frac{\lambda}{\lambda+r} J_F e^{-rx}$.[12] This exceeds the present value of what the Chinese government pays ($f(x)e^{-rx}$) by $g(x)$ where

$$g(x) = [f(t) + J_F]e^{-rt} - \frac{\lambda}{\lambda + r} J_F e^{-rx} - f(x)e^{-rx}$$

$$= [f(t)e^{-rt} - f(x)e^{-rx}] + J_F[e^{-rt} - \frac{\lambda}{\lambda+r} e^{-rx}].$$

It is easy to show that $g(t) \geq 0$ and

$$g'(x) = e^{-rx}[rf(x) + \frac{\lambda}{\lambda + r} rJ_F - f'(x)] < 0.$$

[12]In Reed's special case, the present value of full compensation reduces to $[f(t) + J_F]e^{-rt} - J_F e^{-rx}$.

The final inequality holds since the farmer will choose rotation age $t = t_F$ and will receive expropriation only if $x \leq t$. Since $g(t) \geq 0$ and $g'(x) < 0$ for $x \leq t_F$, $g(x) > 0$. That is $[f(t) + J_F]e^{-rt} - \frac{\lambda}{\lambda+r} J_F e^{-rx}$ is strictly greater than $f(x)e^{-rx}$, and farmers are under-compensated when $\theta = 1$. Intuitively, the government would be compensating the farmer for taking his stand of trees with its net current value; although this may *sound* appropriate, these funds will grow more slowly than the asset that has been taken from him would have grown. We now relax our assumption that $\theta = 1$. When $\theta < 1$, the farmer would be shortchanged *even more*. Formally, the last term defining $g(x)$ would be replaced by $\theta f(x)e^{-rx}$ and the resulting $g(x)$ would be even larger.

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

In this section we show how our model can be used to estimate the net gain in forest value that China could potentially achieve if it eliminates altogether the frequent transfers of use rights and instead secures for every farmer the right to grow trees on his parcel in perpetuity. Under the tree growth function we have hypothesized the net value of China's forest output would more than double. This overall change can in turn be decomposed into four parts. If use rights were secure, (1) parcels would no longer remain barren for extended intervals; (2) trees would no longer be harvested by the village following the expropriation before the age that would have maximized expected wealth in the insecure environment; and instead (3) each tree would be harvested at an age that would maximize net wealth in a secure environment. Collectively, these three changes (almost entirely due to the first) would cause forest output to approximately double. In addition, it seems likely that (4) farmers would switch from fast growing trees which attain their full volume rapidly (like bamboo) to trees which initially grow slowly but eventually reach a much larger size. Trees of the former type might be best suited for an environment with insecure use rights and trees of the latter type might be best suited for a secure environment. That is why we say that in our example net forest output would *more than* double.

We do not know what tree type would be chosen if use rights were secure. However, for the purpose of illustrating this last effect, we hypothesize a tree type with the following growth function:

$$\hat{f}(t) = \begin{cases} 0 & 0 \leq t \leq 3 \\ 1780 * \left[1 - \exp\left(-0.0035 * (t-3)\right)\right]^{0.6} & t > 3 \end{cases}$$

In the insecure environment ($\sigma = 0.105, \lambda = 0.043$)[13], farmers would strictly prefer trees with growth function $f(t)$, but in a secure environment ($\sigma = 0, \lambda \rightarrow +\infty$) they would strictly prefer trees with growth function $\hat{f}(t)$.[14]

In order to evaluate the net gain in forest value that China could potentially achieve if it eliminated altogether the frequent transfers of use rights, we compare the net discounted forest value (denoted J_U) in our model to the net discounted value in the Faustmann model (denoted J_F if the same tree type is utilized and $\hat{J}_F$ if farmers switch to the new tree type).

[13] 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=0.105 and 2/46=0.043. This yields expected lengths of the private and common phases of 9.5 years and 23 years, respectively.

[14] According to our simulation, when no compensation is involved, the forest value farmers would derive by planting eventually bigger trees under a secure environment (280.3) is higher than that from planting initially fast-growing trees (254.1). However, with forest tenure insecurity, the value derived from planting eventually bigger trees (83.3) is lower than that from planting initially fast-growing trees (106.6). Qualitatively similar results hold if the government always compensates losses based on the net value of the expropriated stand.

J_U 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 costs). Compensation payment should be deducted from the farmer's payoff since, while a benefit to him, they are merely a transfer from others elsewhere in society.[15] 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 but is earned by the village.

J_U can be calculated with equation (11) 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:

$$J_U = \frac{f(t^*)e^{-(r+\sigma)t^*} - c}{\left[1-e^{-(r+\sigma)t^*}\right]\left[1-\frac{\lambda}{(\lambda+r)}\frac{\sigma}{(\sigma+r)}\right]} + \frac{\sigma\int_{x=0}^{t^*} f(x)e^{-(r+\sigma)x}dx}{\left[1-e^{-(r+\sigma)t^*}\right]\left[1-\frac{\lambda}{(\lambda+r)}\frac{\sigma}{(\sigma+r)}\right]} \tag{11}$$

The two terms have different numerators but the same denominator. The numerator of the first term is strictly positive, since the farmer would at least secure a positive cash flow from forestry operation when he cuts the trees at the optimal age. The numerator of the second term is at least non-negative, since we assumed $f(t) \geq 0$ for any $t \geq 0$. Overall, we estimate that $J_F/J_U \approx 2$ and $\hat{J}_F/J_U \approx 2.5$.

This overall gain can be usefully decomposed by dividing it into a series of partial gains in moving from the original situation of policy oscillation depicted in our

[15] 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.

model to the final situation with complete security and a more suitable tree type 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 parcel is barren shrinks to zero ($\lambda \to +\infty$). We define J_S as the discounted expected revenue from forestry under this situation:

$$J_S = \frac{f(t^*)e^{-(r+\sigma)t^*} - c}{\left[1-e^{-(r+\sigma)t^*}\right]\frac{\sigma}{\sigma+r}} + \frac{\sigma \int_{x=0}^{t^*} f(x)e^{-(r+\sigma)x}dx}{\left[1-e^{-(r+\sigma)t^*}\right]\frac{\sigma}{\sigma+r}} \quad (12)$$

J_S has the same numerator as J_U, but its denominator is smaller than that of J_U. Thus, J_S is always greater than J_U.

In the second step, we assume that the village does not clear-cut the trees but immediately relinquishes its use right to the plot. It is as if the farmer never relinquishes the parcel but does not adjust the rotation period. The corresponding forestry value is

$$J_N = \frac{f(t^*)e^{-rt^*} - c}{1-e^{-rt^*}} \quad (13)$$

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, but still sticks to the old tree type:

$$J_F = \frac{f(t_F)e^{-rt_F} - c}{1-e^{-rt_F}} \quad (14)$$ [16]

[16] Faustmann's model is a special case of ours. Hence, J_F in equation (14) is a special case of J_0 defined in equation (6) and is obtained by setting $\sigma = 0$ and $\lambda \to +\infty$. Similarly, t_F in equation (12) is the special case of t^* defined in equation (5) and is obtained by setting $\sigma = 0$ and $\lambda \to +\infty$.

Finally, we assume that, when farmers realize that the property right to use the forestland will henceforth be secure, they will switch to the type of tree best suited to that environment and adjusting the rotation period appropriately, generating maximized net wealth of

$$\hat{J}_F = \frac{\hat{f}(\hat{t}_F)e^{-r\hat{t}_F} - c}{1 - e^{-r\hat{t}_F}} \tag{15}$$

where $\hat{t}_F$ is the optimal rotation age under Faustmann's condition, with regard to the new tree type. We break the overall gain $\hat{J}_F - J_U$ into four components: $\hat{J}_F - J_U = (J_S - J_U) + (J_N - J_S) + (J_F - J_N) + (\hat{J}_F - J_F)$ and express each component as a percentage of the overall gain. That is $G_1 = \frac{J_S - J_U}{\hat{J}_F - J_U} * 100$, $G_2 = \frac{J_N - J_S}{\hat{J}_F - J_U} * 100$, $G_3 = \frac{J_F - J_N}{\hat{J}_F - J_U} * 100$, $G_4 = \frac{\hat{J}_F - J_F}{\hat{J}_F - J_U} * 100$. Note that $G_1 + G_2 + G_3 + G_4 = 100$.

This decomposition helps determine the importance to the overall gain of each of the four sources of change. G_1 represents the percentage of the overall gain that would occur *ceteris paribus* if the land was returned to the farmer immediately after the village cleared it of trees. G_2 represents the percentage of the overall gain that would occur *ceteris paribus* if in addition the village did not clear cut the trees (or equivalently, the farmer never relinquished the use right). G_3 represents the percentage of the overall gain that would occur *ceteris paribus* if in addition the farmer adjusted his cutting time because land tenure has become secure. G_4 represents the percentage of the overall gain that would occur *ceteris paribus* if in addition farmers switched to a new tree type that is more suitable under secure land tenure and then adjusted the harvesting age optimally.

We use the illustrative tree growth function $f(t)$ described in Section 3.1 to estimate the first three sources of gain and the growth function $\hat{f}(t)$ to illustrate the last source of gain. We will 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. We examine how the component gains change as the hazard rate σ varies with no compensation ($\theta = 0$) and with a unitary compensation rate ($\theta = 1$), respectively.

Figure 2 and 3 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, when the government either does not pay compensation when expropriating forestland or compensates that loss based on the net value of the expropriated stand, the orders of importance of these partial gains are quite similar. Most of the gain (almost 80%) could be secured if the government could return the land to the farmers immediately after clear-cutting (see the line of G_1 evaluated at $\sigma = 0.105$). Compared with that, the gain from switching to a tree type more suitable to an environment with secure property rights is less important. This accounts for approximately 20% (see the line of G_4 evaluated at $\sigma = 0.105$). The gains resulted from eliminating clear-cutting of forests under a common property regime (see the line of G_2 evaluated at $\sigma = 0.105$) and correcting the rotation age (see the line of G_3 evaluated at $\sigma = 0.105$) are quite minor, and almost negligible.

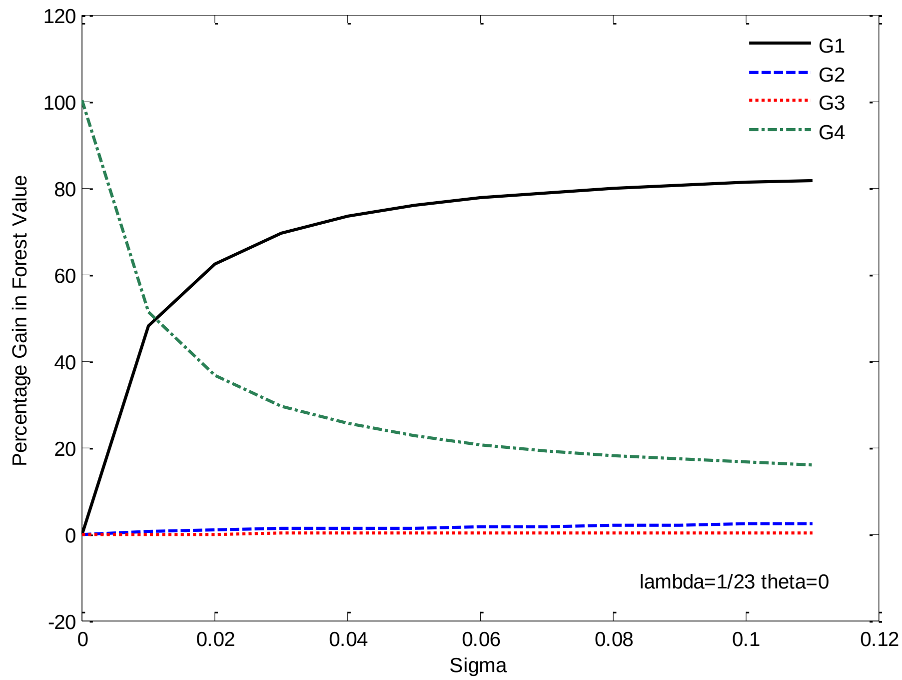

Figure 2. Percentage Decomposition of Gain in Forest Value from Securing Use Right ($\theta = 0$)

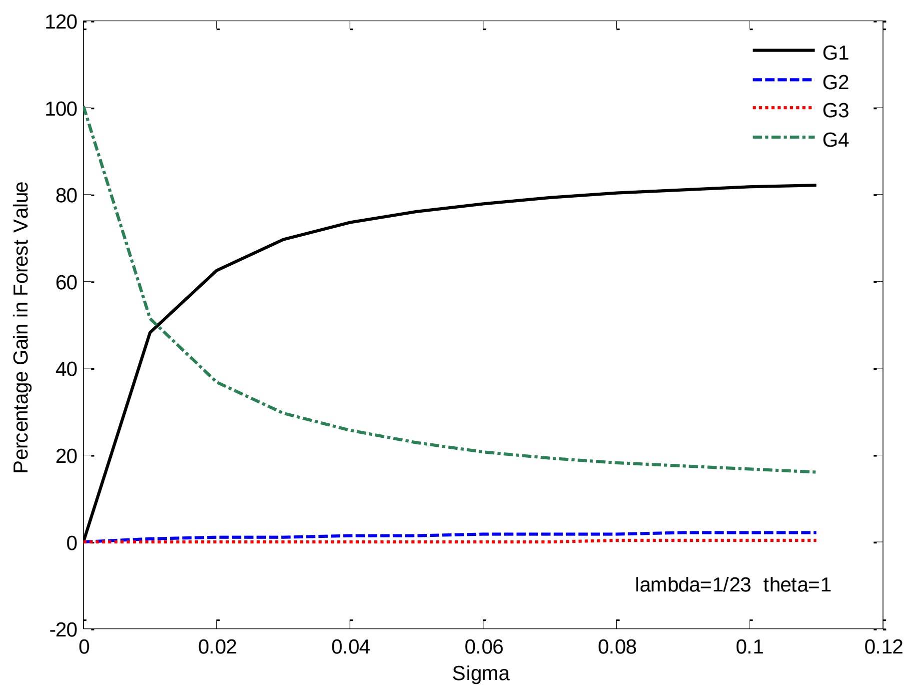

Figure 3. Percentage Decomposition of Gain in Forest Value from Securing Use Right ($\theta = 1$)

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 past 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. 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 compensation is based only on the net value of the current stand at the time of the loss. We show, however, that this would not fully compensate farmers for their loss. If farmers were fully compensated for the uncertainty that they faced, they would behave like Faustmann's foresters in a riskless environment.

Appendix

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. Second, they continued to own non-timber 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 non-timber trees that had been privately owned in the advanced cooperative period (Xu et al. 2004).

Accompanying this over ambitious 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 over zealous 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.

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). In response to this tragedy, the government re-adjusted 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. Non-timber 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, pp.67). The document stipulated that (1) forest resources with clear and non-disputable 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 decision-making 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.

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