The Bamboo Cycle[1,2]

Tong Wu, David R. Just, C.-Y. Cynthia Lin Lawell, Ariel Ortiz-Bobea,
Jiancheng Zhao, Zhangjun Fei, Qiang Wei

Abstract

We develop the notion of a bamboo cycle analogous to the agricultural economics notion of a cattle cycle, which is a period of time that describes cattle producers' decisions to grow and decrease the size of their herds. The development and management of a bamboo forest are similar to the cattle cycle; and the dynamics and interdependence of bamboo forest products share characteristics with the dynamics and interdependence of cows and calves. The bamboo cycle is a dynamic ecological and economic process driven by the interactions between shoot emergence, forest structure, market factors, and environmental uncertainty.

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[1] Wu: Cornell University; tw494@cornell.edu. Just: Cornell University; drj3@cornell.edu. Lin Lawell: Cornell University; clinlawell@cornell.edu. Ortiz-Bobea: Cornell University; ao332@cornell.edu. Zhao: Zhejiang Academy of Forestry; jiancheng68@163.com. Fei: Boyce Thompson Institute and Cornell University; zf25@cornell.edu. Wei: Nanjing Forestry University; weiqiang@njfu.edu.cn.

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1. Introduction

Forests supply the world's population with timber as well as renewable non-timber forest products such as fruits, nuts, and maple syrup that can be harvested at more frequent intervals than the trees themselves. Bamboo (*Bambusoideae*) grows faster compared to other forest types (Wei et al., 2018), which is consistent with the preservation- and restoration-orientation of China's forest management policies since the 1990s (Démurger, Hou, and Yang, 2009). Moso bamboo (*Phyllostachys edulis*) is the single most important bamboo species in China, accounting for 74% of China's bamboo forest area ("China Forestry and Grassland Administration", 2018), as well as the third most important source of timber in China. Both bamboo shoots and bamboo stems are harvested as valuable products: bamboo shoots are a traditional food source, and bamboo stems are used as timber for paper making, flooring, and construction (Fu, 2001).

In this paper, we develop the notion of a bamboo cycle analogous to the agricultural economics notion of a cattle cycle, which is a period of time that describes cattle producers' decisions to grow and decrease the size of their herds (USDA, 2025; Tonsor, 2011). The cattle cycle is essentially an agricultural representation of a dynamic process that illustrates how interdependent products can affect each other, given the uncertainties of climate change and prices. The development and management of a bamboo forest are similar to the cattle cycle and cattle management; and the dynamics and interdependence of bamboo forest products share characteristics with the dynamics and interdependence of cows and calves. Like cattle producers, bamboo farmers face multiple sources of uncertainty; for bamboo farmers, the sources of uncertainty include precipitation, prices, and the possibility of bamboo shoots death. When there is both uncertainty and interdependent forest products, the interaction between these two phenomena leads to a complicated set of trade-offs (Wu et al., 2025a).

Optimal Moso bamboo management is a complex dynamic problem (Wu et al., 2025a). Moso bamboo forest management involves making decisions about the timing and quantity of bamboo stem harvests and bamboo shoot harvests. Both bamboo stems and bamboo shoots are products that are sold on the market. Bamboo shoots prices vary day to day and are hard to predict, while bamboo stem price does not vary much over the course of a year. Bamboo shoots grow annually from a bamboo plant's underground rhizomes. Owing to their tender taste and to difficulties in harvesting underground shoots, winter shoots – which are young bamboo shoots that are just beginning to grow underground during the winter months – have a higher market price than the older spring shoots that emerge above ground during the later spring months. Bamboo shoots grow into bamboo plants after the end of spring shooting (Shi et al., 2013). While winter shoots are more expensive than spring shoots, both winter shoots and spring shoots are more expensive than bamboo stem. Bamboo stems continue to grow each year until age 4-5 years (Zhang et al., 2014; Zhuang et al., 2015), while bamboo shoots only grow within a year. The harvesting of bamboo stems entails cutting down the bamboo plant, while the harvesting of bamboo shoots does not.

There are several trade-offs involved in determining the optimal shoots harvesting strategy that arise from uncertainty and the interdependence of shoots and stem. Reasons to harvest shoots sooner rather than later include: high prices, low costs, and uncertainty over survival. Reasons to delay shoots harvest, include: uncertainty over prices, and allowing shoots more time to grow. Reasons not to harvest shoots at all include: low prices, high costs; allowing shoots to grow into bamboo stem at the end of the year; and uncertainty over precipitation, which affects how many shoots will grow the following year from any stem that grow from unharvested shoots the previous year (Wu et al., 2025a).

Likewise, there are several trade-offs involved in determining the optimal bamboo stem harvesting strategy. Reasons to harvest stem sooner rather than later include: high prices and low costs. Reasons to delay bamboo stem harvest include: low prices, high costs; allowing bamboo stem more time to grow; allowing shoots to grow annually from the bamboo plant; and uncertainty over precipitation, which affects how many shoots will grow from the stem remaining at the beginning of the year (Wu et al., 2025a).

We contribute to and integrate the erstwhile separate literatures on cattle management and cattle cycles (Rosen, Murphy and Scheinkman, 1994; Hadley, Wolf and Harsh, 2006; Tonsor, 2011), and on optimal forest management (Faustmann, 1849; Wicksell, [1901] 1934; Samuelson, 1976; Newman, 1988; Jackson, 1980; Chang, 1983; Chang, 1981; Hall, 1983; Berck, 1981; Bowes, 1983; Calish et al., 1978; Hartman, 1976; Nguyen, 1979; Strang, 1983; Chang, 1982; Klemperer, 1979; Pearse, 1967; Rideout, 1982; Ollikainen, 1991; Bare and Waggener, 1980; Gregersen, 1975; McConnell et al., 1983; Hardie et al., 1984; Newman et al., 1985; Nautiyal and Williams, 1990; Chang, 1998; Deegen et al., 2011; Arimizu, 1958; Amidon and Akin, 1968; Kilkki and Väisänen, 1969; Hool, 1965; Hool, 1966; Amidon and Akin, 1968; Amidon and Akin, 1968; Brodie et al., 1978; Brodie and Kao, 1979; Chen et al, 1980; Ritters et al., 1982; Tyler, Macmillan, and Dutch, 1996; Ritters, 1982; Haight, 1985; Yousefpour and Hanewinkel, 2009; Buongiorno, and Gilless, 2003; Kant and Alavalapati, 2014; Wu et al., 2025a). Wu et al. (2024) provide a recent review of the literature on optimal forest management.

2. Background on Moso Bamboo

Bamboo (*Bambusoideae*) is distributed mostly in tropical areas, subtropical areas, and temperate zones in Asia. They survive even at 4000 meters elevation from sea level (Scurlock, Dayton, and Hames, 1999). There are 107 genera and 1300 species of bamboo worldwide (Zhu, 2001). Bamboo grows faster compared to other forest types (Wei et al., 2018), which is consistent with the preservation- and restoration-orientation of China's forest management policies since the 1990s (Démurger, Hou, and Yang, 2009).

China has the world's most copious bamboo forest resources, with more than 500 bamboo species in 39 genera covering 6.01 million hectares of bamboo forest. Eighty-nine percent of China's bamboo forests are located in eight provinces: Fujian, Jiangxi, Zhejiang, Hunan, Sichuan, Guangdong, Guangxi and Anhui ("China Forestry and Grassland Administration", 2018). Of the bamboo forest resources in China, 6.6% are in state forests, 51.4% are in collective forests, and 42.0% are in private forests (Démurger, Hou, and Yang, 2009). China has established pilot futures market in Fujian province, where bamboo change can be traced through market price (Wang et al., 2007).

2.1. Bamboo stem and shoot growth

Moso bamboo (*Phyllostachys pubescens*) is the single most important bamboo species in China, accounting for 74% of China's bamboo forest area ("China Forestry and Grassland Administration", 2018). Moso bamboo distributes mostly in subtropical provinces including Fujian, Hunan, Zhejiang, and Jiangxi. The mean annual temperature where Moso bamboo grows well varies from 15 to 21°C (59 to 69.8°F), and the mean temperature of the coldest month is 1 to 12°C (33.8 to 53.6°F). Annual precipitation higher than 800mm (31.5 inches) and soil fertile loam deeper than 60cm (23.5 inches) with pH of 4.5 to 7.0 are ideal for Moso bamboo growth. Extreme temperature, precipitation, and soil conditions influence bamboo shoot growth for different areas (Fu, 2001).

Bamboo shoots grow annually from a bamboo plant's rhizomes, which is an underground system of bamboo stems. As long as the rhizome has not been destroyed, bamboo shoots can still emerge from rhizomes. A bamboo plant may have rhizomes that extend massively and thus can have lots of nodes for shoots growth.

A bamboo growth year begins in September with winter shooting. The number of bamboo shoots at the beginning of the bamboo growth year is positively correlated with the number of bamboo stem: the more bamboo stem, the more rhizomes there are underground, and the more bamboo shoots that can grow (Li et al., 2016; Zhang and Ding, 1997). The number of bamboo shoots is also positively correlated with precipitation in July and August of the previous bamboo growth year, when bamboo shoots are being formed (Zhang and Ding, 1997).

As long as the shoots are underground and have not emerged above ground, they are called winter shoots. Winter shoots remain dormant during the coldest winter days in January and February, and emerge above ground as spring shoots in March when temperature rises. Due to their dormancy, the nutrient contents of winter shoots do not change by much in these two months (Su, 2012). Winter shoots can be harvested and sold on the market for a high winter shoots price until they emerge above ground and start to be called spring shoots.

Bamboo shoots either degenerate, are harvested, or are left in the ground and grow into a newly grown bamboo stem (personal communication, bamboo specialist at Zhejiang Provincial Key Laboratory of Bamboo of Zhejiang Provincial Academy of Forestry, August 2018). More than half of the shoots will degenerate and die naturally before they grow into bamboo plants (Jiang, 2007).

Bamboo shoots grow into a bamboo plant after the end of spring shooting (Shi et al., 2013). The number of newly grown bamboo is the number of surviving bamboo shoots minus number of shoots harvested. Moso bamboo stems reach their maximum biomass at age 4-5 years (Zhang et al., 2014; Zhuang et al., 2015), do not increase significantly in biomass after 4.62 years (Zhuang et al., 2015), and mature at age 5-6 years (Yen and Lee, 2011).

2.2. Bamboo management

The harvesting of bamboo shoots is a natural process of thinning since without human intervention, more than half of the shoots will degenerate and die naturally before they grow into bamboo plants. Shoots harvesting is thus a thinning activity that takes these weak shoots out before their death (Jiang, 2007). Harvesting one shoot eliminates one future bamboo plant from the beginning. Harvesting shoots does not necessarily reduce total bamboo biomass in the future, however, since thinning creates more space for other bamboo plants left in the ground to grow.

In forest management in the United States, forest thinning (silviculture) generally produces low quality logs that incur a cost due to their low market value. A unique feature of bamboo shoot thinning is that by harvesting bamboo shoots, bamboo farmers are also able to sell shoots as a by-product with a high market price.

Various management styles have been found in bamboo forests in Asia, and the decisions of bamboo farmers can be complex and hard to understand (Yen, 2015). Chinese bamboo farmers generally follow a pattern of intensively harvesting shoots when they first emerge, and then preserving the remaining shoots for later bamboo growth. In Zhejiang Province in China, bamboo forest harvest decisions and shoots harvest decisions are made according to on and off years, with guidance from biologist and forestry specialists. "On" years and "off" years are defined based on the biological growth of bamboo plants. An "on" year is a year when there is a massive emergence of bamboo shoots, and less leaf loss for a bamboo plant. An "off" year is a year with less shoots emergence and more leaf renewing, and normally comes in turn with an on year. Shoots harvest, especially winter shoots harvest, takes place during on years, when there is a massive emergence of bamboo shoots. In order to create enough growth space for shoots to emerge, and to save space for the shoots harvest before possible decaying, bamboo stem harvests take place during on years as well. Every time a stem harvest decision is made, all mature bamboo stems are clear cut for the whole field. Due to this clear-cut pattern, massive shoots emergence and the clear cutting of mature bamboo take place simultaneously in the on year. When bamboo stems are harvested during an on year, the number of shoots the following off year will be lower. During an off year, relatively fewer shoots are harvested, and little stem cutting takes place.

2.3.Bamboo market

Since fresh bamboo shoots are hard to store and transport for long distances, the majority of the fresh bamboo shoots are sold to markets in Zhejiang province, Jiangsu Province, and Shanghai. In addition, approximately 15% of the winter shoots and one third of the spring shoots are sold to local shoots processing factories (Wu et al., 2016). Consumers of bamboo shoots are from highly populated areas such as Shanghai, as well as other cites in Zhejiang and Jiangsu province including but not limited to Yongkang, Cixi, Yuyao, Dongyang, Shangyu, Fuyang, Shaoxing, Ningbo, Changzhou, Suzhou, and Hangzhou (Shen et al., 1998; Wu et al., 2016). Most of the bamboo stem are processed locally within each county to reduce transportation costs and to contribute to local economic growth (Kusters & Belcher, 2004). Consumers of bamboo stems are generally local bamboo stem processing and manufacturing factories, due to the high transportation costs and the initiatives to contribute to local economic growth (Zhang, 2003; Kusters and Belcher, 2004). Moso bamboo stem and shoots are not only produced in Zhejiang province but also in Hunan, Fujian, Jiangxi, and Sichuan provinces. Bamboo shoots, and especially winter shoots on Zhejiang market are from all these markets, and compete for the same consumers. (People.cn, 2014).

Bamboo shoots prices vary day to day and are hard to predict, while the bamboo stem price does not vary much over the course of a year. Bamboo shoot prices also differ for spring bamboo shoots and winter bamboo shoots. Due to difficulties of locating and harvesting underground winter bamboo shoots, as well as popular preference over more tender taste, winter bamboo shoots have higher market price than spring bamboo shoots. Winter shoots can be harvested and sold on the market for a high winter shoots price until they emerge above ground and start to be called spring shoots. While winter shoots are more expensive than spring shoots, both winter shoots and spring shoots are more expensive than bamboo stem (Wu et al., 2025b).

The bamboo shoot and bamboo stem harvest cost is determined by labor costs (Wu and Cao, 2016) as well as land specific characteristics such as the slope of forest land (Wu and Cao, 2016; Dong et al., 2015). Due to decreasing profits from bamboo forests, younger workers in rural areas have left their hometown and started to find jobs in large cities such as Hangzhou and Shanghai, leaving less labor to manage bamboo forests in rural areas of Zhejiang province; this insufficient labor supply has resulted in increasing labor costs in recent years (Jiang, 2020).

For additional background information regarding China's forests and bamboo management, harvests, prices, and costs, see Wu et al. (2025b).

3. Bamboo Cycle

The U.S Department of Agriculture (USDA) defines the cattle cycle to be "a period of time that describes cattle producers' decisions to grow and decrease the size of their herds that collectively affect the size of the national cattle herd -- the total number of all cattle and calves". The cattle cycle explains the contractionary and expansionary phases of the cattle industry in the macro level, impacted by price, input costs, and climate change factors (USDA, 2025). The cattle cycle is essentially an agricultural representation of a dynamic process that illustrates how interdependent products can affect each other, given the uncertainties of climate change and prices. The total cattle inventory demenstrated cattle inventory cyles every 8-13 years from 1938 to 2011 (Tonsor, 2011).

The development and management of a bamboo forest are very similar to the cattle cycle in several ways. First, both bamboo and cattle are renewable resources, meaning that they can reproduce without human intervention. Second, managers of both bamboo forests and cattle herds face uncertainty in input prices, profitability, and weather. Third, bamboo shoots and stems are interdependent products, meaning the production and management of one product will affect the other, while at the same time they have different markets. This is also in the heart of cattle production: although calves and cow sare raised and sold on different markets, harvesting one affects the other. Fourth, both cattle herds and bamboo forests involve biological growth processes and dynamic decision-making. Although there are some differences between cattle and bamboo production, they are similar enough to make the analogy.

Since the development and management of a bamboo forest are very similar to the cattle cycle, we have developed an analogous notion of a "bamboo cycle". Figure 1 illustrates the bamboo cycle as a dynamic ecological and economic process driven by the interactions between shoot emergence, forest structure, market factors, and environmental uncertainty. This cycle applies especially to Moso bamboo (*Phyllostachys edulis*), a major bamboo species in China.

As a woody-grass plant relying on both above ground photosynthesis and its underground root system to develop, if a bamboo forest starts with more and better underground winter shoots, supported by favorable nutrition and conditions, then more high-value products can be harvested and contribute to bamboo farmers' income. The survival and quality of winter shoots depend heavily on precipitation and temperature during the shooting season, as well as the biological decay risk.

If winter shoots thrive, they lead to more and better spring shoots, which, although typically lower in market value, contribute significantly to forest regeneration and biomass growth.

These spring shoots develop into more and better stems, which, when managed well, form the structural backbone of the bamboo forest. Over time, this results in a healthier bamboo forest, increasing the forest's capacity to produce high-quality shoots in future cycles.

A healthier forest leads to higher nutrition levels and higher productivity, feeding back into the cycle with increased shoot emergence and overall ecosystem vigor.

Three forms of uncertainty disrupt this cycle, however. The first source of uncertainty is price uncertainty: volatile shoot and stem prices affect harvesting decisions, influencing shoot selection, regeneration patterns, and long-term forest structure. The second source of uncertainty is precipitation uncertainty: variable rainfall and climatic conditions impact shoot survival, especially during the sensitive shooting season. The third source of uncertainty arises from the possibility that shoots might not survive during shooting season.

The bamboo cycle is a coupled system of ecological growth and market response under uncertainty. It highlights how shoot and stem dynamics feed into long-run forest health, while economic and environmental uncertainties influence decisions at each stage. Our bamboo cycle in Figure 1 is a visual representation of the reinforcing mechanisms in bamboo production systems.

4. Conclusion

We develop the notion of a bamboo cycle analogous to the agricultural economics notion of a cattle cycle, which is a period of time that describes cattle producers' decisions to grow and decrease the size of their herds. The development and management of a bamboo forest are similar to the cattle cycle; and the dynamics and interdependence of bamboo forest products share characteristics with the dynamics and interdependence of cows and calves.

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Figure 1. Bamboo Cycle