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The potential for a backward-bending supply curve of non-timber forest products: An empirical case study of wild American ginseng production

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ABSTRACT

Renewable natural resources that have biological constraints on reproduction and are open-access may be subjected to intense harvest activity that limits regeneration, potentially leading to a backward-bending long-run supply curve. Empirical evidence of such supply abnormalities has been found for some open-access fish species but not yet for non-timber forest products (NTFPs). We describe the theory of the backward-bending long-run supply and how such a supply relationship could produce multiple market equilibria, affecting regulatory outcomes. An empirical example is provided to test the theory in the case of wild American ginseng (*Panax quinquefolius*), which has been subjected to habitat loss and harvest pressure since the 18th Century and now has its exports regulated. We find evidence that quantities supplied are negatively related to price in the long run, indicating that harvest pressure is restricting wild ginseng harvestable stocks. Also, we find that a federal regulation banning exports of roots from plants under five years old, in effect since 1999, coincided with a reduction of supply. This result could be due to the slow natural rate of population recovery.

1. Introduction

Renewable natural resources provide numerous products in the economy, including food, fiber, energy, and medicine. In certain cases, legal and customary rights as well as specific characteristics of the resource and its environment can create situations where access is difficult to limit and harvests are difficult to monitor and control – making them “*de facto* open-access” resources (Bulte and Engel, 2006). Status as an open-access resource has vast implications for production, markets, trade, and regulation of these resources, which in turn can influence the availability and sustainability of the resources themselves. A classic example is marine fisheries (Gordon, 1954), which are difficult to regulate and monitor because of their vast size and international nature, and hunting and trapping of certain wildlife species can also fit this paradigm.

Non-timber forest product (NTFP) markets and trade are often informal and not fully understood (Alexander et al., 2002). Since the 1970s, the harvest of certain NTFPs has been regulated in the United States, with wild American ginseng (*Panax quinquefolius*) being the foremost example (US FWS, 2017). Design of regulatory policies depends crucially on sociological and ecological research to understand harvesters and harvest impacts. However, Gordon (1954) recognized that the question of commercial exploitation (and over-exploitation) of natural resources includes an economic component. Market price, which is determined simultaneously with production and consumption, undoubtedly influences and is influenced by harvests. The position of the supply function in price-quantity space is itself determined by economic and biological factors including stocks, reproductive rates, cost of productive inputs, and policies that may constrain activities or make them more costly, while the position of the demand function is determined by numerous social, macroeconomic, and policy factors.

The present study offers insights into how supply and demand curves for NTFPs that are rivalrous, open-access, and under intense harvest pressure, could be shaped and describes how external factors, including regulations, may impact supply and demand. The objective was to develop a theoretical framework for understanding certain aspects of NTFP markets, trade, and regulation under certain conditions. We argue that, in cases where it is difficult to limit access of outsiders to products, a backward-bending supply curve is theoretically plausible at high levels of harvest intensity, particularly for NTFPs where the entire plant is harvested. We discuss the implications of this curvature on harvest and trade, well-being of harvesters, and regulation. Finally, we use data on wild American ginseng harvest and sale for export to look for evidence of the backward-bending supply and discuss implications.

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2. Theory of supply and regulation of wild-harvested non-timber forest products

2.1. Demand and supply

The Laws of Demand and Supply state that for most products, aggregate quantity demanded, the sum of individual consumption decisions, is negatively related to price, and aggregate quantity supplied is positively related to price. Supply of a wild-harvested product is affected by a combination of social and biological factors, which vary for different types of NTFPs. For many NTFPs, production inputs are dominated by individual producers' labor, which is dedicated to the search for and extraction of the product from the forest (Chamberlain et al., 2017). Each laborer has a reservation price, below which no labor is provided, which could be affected by factors such as employment status of the individual. In the aggregate, holding factors like unemployment rate constant, higher product prices would attract more labor.

The “short run” in economic modeling is defined as a time period in which some production inputs are fixed; in the “long run” none are fixed. Given constant NTFP stocks, in the short run higher prices lead to increased labor input and hence increased production. However, if harvest increases lead to stock decreases, then a negatively sloped, or “backward-bending” supply relationship with price could emerge in the long run. While short-run supply is typically expressed as a function of variable factor inputs and quasi-fixed stocks (inventories), long-run supply relaxes the fixed stock assumption, potentially leading to inverse price-quantity supply relationships.

2.2. Backward-bending long-run supply curves in natural resource literature

Forestry literature has presented models of backward-bending long-run aggregate supply curves for timber in certain situations (Binkley, 1993). The situation can occur where there is neither intensification of investment (such as planting trees, site preparation, etc.) nor conversion of land to timber production from other uses (Yin and Newman, 1997).

Evidence from fisheries highlights the pivotal role that a fixed production base, lack of clear ownership rights, and biology play in making a backward-bending long-run aggregate supply relationship possible. In the short-run, increasing fishing efforts will always increase catch – there is no backward-bending short-run supply. However, in the long run, intense fishing efforts at the aggregate level result in a decrease in catch (Bell, 1972; Clark, 2005; Copes, 1970; Nøstbakken and Bjørndal, 2003; Thuy and Flaaten, 2013; Turvey, 1964). Above a certain effort level, fish populations are depleted such that they cannot reproduce enough to meet the maximum sustainable yield (MSY) (Clark, 2005, p. 13). This “biological over-fishing” would occur in cases where the market price is relatively high, and the effort costs relatively low (Flaaten, 2011, p. 36). Maximum profits (maximum economic yield, MEY) are achieved at effort levels below that of MSY (Flaaten, 2011, p. 32; Gordon, 1954).

Copes (1970) identified two necessary conditions for a backward-bending supply curve: biological limitations on reproduction and inability to restrict access of others to harvest. Even if a resource meets these conditions, they alone are not sufficient to imply that the resource is on the backward-bending portion of the curve. Since zero harvest effort implies zero harvests, the long-run supply curve must be upward-sloping at low harvest levels before it can then bend backward at higher harvest intensities. Thus, high harvest intensity is necessary before backward-bending supply becomes an empirical reality.

With a backward-bending long-run supply, supply and demand may define multiple price-quantity equilibria. Fig. 1 shows hypothetical demand and backward-bending long-run supply curves. There are two equilibrium points in this hypothetical scenario: q_a and q_b. However, q_b is unstable. That is, if an initial price falls on the curve below q_b, it will be driven in equilibrium towards q_a, if above q_b, it would create a situation in which price and quantity are driven away from the unstable equilibrium q_b towards higher price and zero quantity produced in the long-run—i.e., extinction (Clark, 2005, pp. 133–135). Such price-quantity conditions can be initiated by a shift in the supply curve caused by natural reproductive variability, natural disasters, or policy changes (Holden and McDonald-Madden, 2017), or a shift in the demand curve caused by macroeconomic, social, or other factors.

2.3. Common-pool resources

Copes' (1970) two conditions for a backward-bending long-run supply, restated, are essentially the definition of a “common-pool resource”: limits to reproduction suggest the resource is rivalrous,[1] i.e., an individual's use of the resource reduces another's potential use; and inability to restrict access suggests that the resource is open-access[2] (Ostrom and Ostrom, 1977).

Many forest plants and fungi grow and mature slowly. Harvesting an NTFP means that someone else cannot also harvest it, so it meets the first condition of rivalry. In a legal sense, however, forest plants do not technically meet the second condition of open access. The land in the United States is owned by discrete landowners who legally own the plants on their land and control access rights. However, forests are large, and some wild NTFPs are remote and scattered over a large area, with precise locations that are not well known or that shift over time, and/or can be extracted over long periods during the year, so access is extremely difficult to monitor and control (Bulte and Engel, 2006; Everett, 2001; Love and Jones, 2001). Private lands have a large number of absentee landowners (Petrzelka et al., 2013). Even for public lands and for private lands with landowners residing nearby, land area and number of access points may be too large to effectively monitor. Furthermore, many of the NTFPs themselves are small, lightweight, and easily concealed (Everett, 2001). These factors create a “*de facto* open-access” condition for many NTFPs (Bulte and Engel, 2006). This concept is further validated by the well-known fact that many NTFP harvesters are extremely secretive about harvest methods and locations (Love and Jones, 2001; Vaughan et al., 2013); that is, there would seem to be little need to be so secretive if the resource were well monitored and controlled.

Ostrom and Ostrom (1977) recognized that there are degrees of rivalry and open access, and some NTFPs fall more into the common-pool category than others. For example, harvesting which kills the entire plant, such as harvesting the roots of ginseng or goldenseal, is more rivalrous than only removing fruits or fruiting bodies, such as with mushrooms or berries; or simply collecting dead portions of a tree, such as pine straw. Similarly, some NTFPs are more easily monitored and controlled and therefore easier to exclude outsiders. For example, a wild huckleberry patch may be geographically compact and have a relatively short harvest season.

2.4. Regulation and conservation

Since common-pool resources may have supply and demand curves that define multiple equilibria, and situations where populations are driven to extinction or simply over-harvested are possible, regulation is justified to reach a management regime closer to what is economically optimal, defined by the maximum economic yield (MEY) (Turvey, 1964). The reversal of the usual slope of the supply curve produces regulatory results that may seem counter-intuitive if the explicit economic model is not fully considered. For this reason, it is useful to consider qualitative theoretical descriptions of the potential impacts

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[1] Several synonymous terms may be used: “alternative use”, “subtractible”, “consumptive”, etc.

[2] The term “non-excludable” is a synonym.

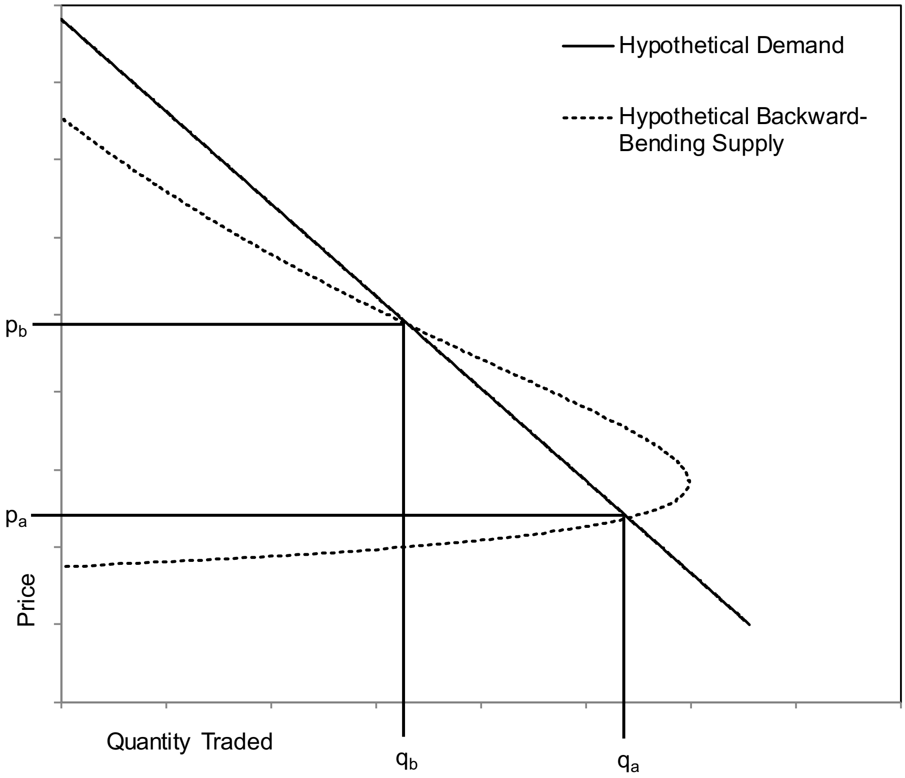


Fig. 1. Hypothetical linear demand and backward-bending supply for a common-pool non-timber forest product with slow reproduction. The point p_b, q_b is an unstable equilibrium. At initial levels of the price below p_b, market equilibrium price and quantity will be driven to p_a, q_a. At initial levels above p_b, the market will drive price higher and quantity towards zero, potentially towards extinction.

with a backward-bending supply curve. Most of the following results have been described in the fisheries literature, including mathematical formulations (Clark, 1980, 2005; Flaaten, 2011; Gordon, 1954; Turvey, 1964). Our approach here is to discuss those results in the context of NTFP harvesting. We, therefore, discuss regulations that have been implemented or proposed for NTFPs (see: Burkhart et al., 2012; Pierce and Burgener, 2010) or those that have direct parallels in the regulation of other resources. We do not take an explicitly mathematical approach; instead, we discuss implications of regulation on equilibrium price and quantity in a qualitative way.

An economic perspective on NTFP regulation is valuable, but understanding the influences of the underlying the ecological, legal, social, and tenure context is also important, and dialogue with resource users is key to policy formulation. As a first example of the limits of traditional economic models, farm-raised or artificial alternatives are assumed to be substitute products for wild-harvested products, driving down the price of the wild product, but in fact have been known to legitimize illegal trade or unsustainable practices, confuse consumers, or even make the wild product more desirable and of higher profile (Fischer, 2004). As a second example, a tax on harvest may generate socially desirable outcomes, but could still face political opposition, which would not be anticipated by certain economic models. We proceed, therefore, with a clear view of the merits and limits of an economic approach towards policy analysis.

Traditionally, literature has recognized two goals of regulation of common-pool resources: optimizing the level of biological stock of the resource and optimizing the level of harvest effort. Both factors must be optimized to achieve the socially-desirable goal of MEY (Clark, 1980; Turvey, 1964). Additionally, we briefly consider demand-side and other governance policies.

2.4.1. Optimizing biological stock: age or size restriction, total quotas, harvest seasons; stocking

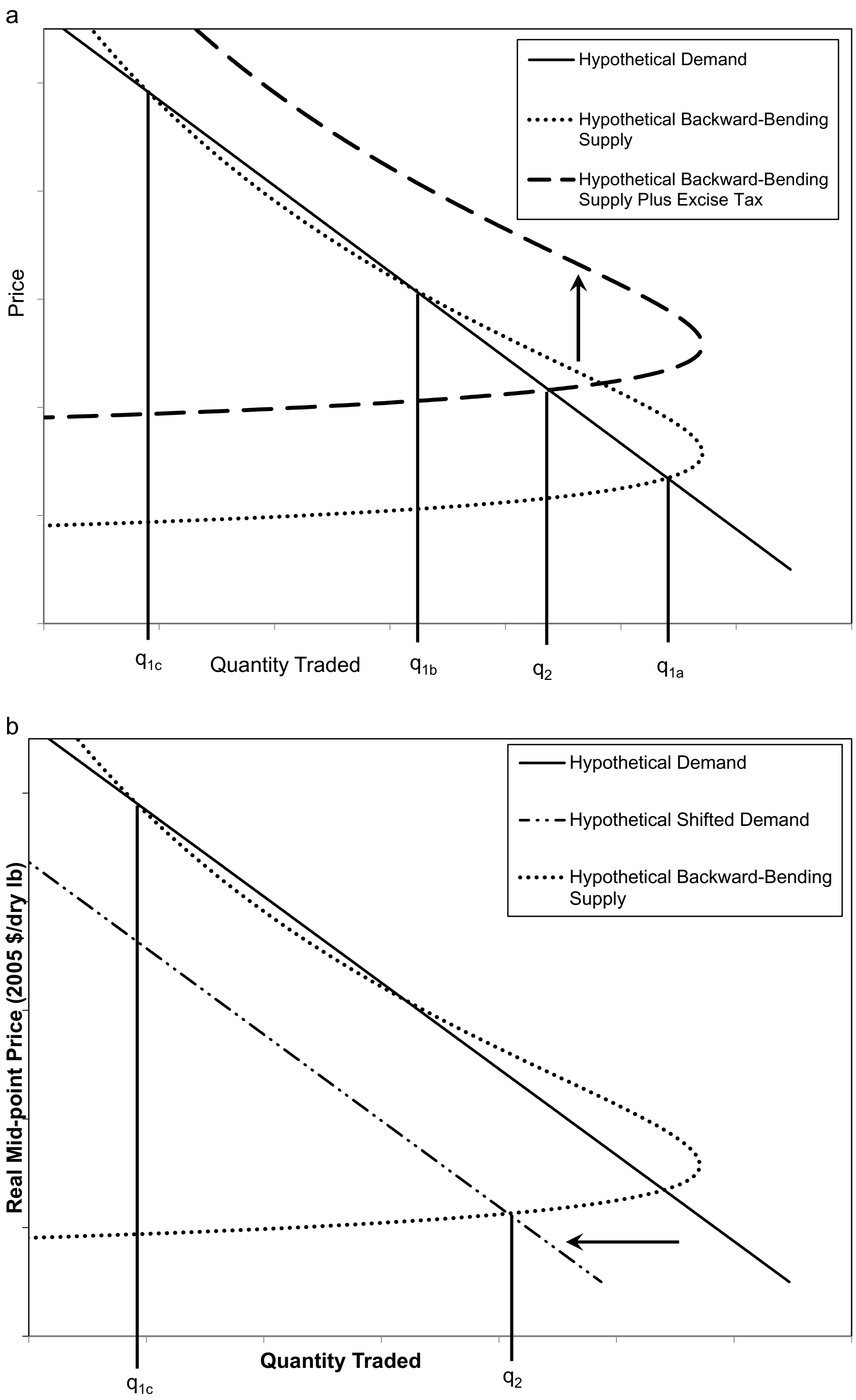
Optimizing the biological stock of NTFPs has the economic goal of maximizing the harvest at any given level of harvest effort. This is achieved by ensuring sufficient plants are physically present in the forest to reproduce. In practice, this can be achieved by several types of regulations. First, age or size restrictions limit harvest to plants above a certain age or size have been adopted in certain cases and are conceptually similar to regulations of fishing nets with larger meshes. Second, a total quota would prohibit harvest each year after a certain amount has been harvested. Third, a harvest season could be imposed and shortened or lengthened to allow the appropriate stock level. Fourth, an alternative or complement strategy which is not typically discussed in marine fisheries literature might be to “stock” forests with NTFPs, similar to stocking streams with trout.

Normally, intuition suggests that any regulation restricting harvest to only a certain quantity would reduce production at all price levels, i.e., shifting the supply curve inwards. However, since the stock level depends on reproduction, preventing harvest of some plants could increase long-run supply (Clark, 1980; Turvey, 1964), that is, increase harvest at each level of harvest effort. However, it could take years to reach this long-run equilibrium and be accompanied by decreases in catch levels at each price in the short run.

2.4.2. Optimizing harvest effort: taxes, licenses, and limits

Turvey (1964) demonstrated that optimal regulation could be achieved with mechanisms which control the stock size and harvest effort. Fig. 2a shows the effect of an excise tax on backward-bending supply, with a hypothetical demand curve. The dotted curve represents the supply without tax; a tax shifts the supply curve up to the dashed curve. Without the tax, there are three possible equilibria – q_{1a} and q_{1c} are stable equilibria, while q_{1b} is unstable. The exact effect of a tax is dependent on the shape of the demand curve with respect to supply. If we suppose that the current equilibrium is a point such as q_{1c}, a tax could shift the equilibrium to a point such as q_2. Licenses and limits for individual harvesters theoretically have a similar impact to taxes (Fig. 2a) – by raising the cost of participating in the market they force the equilibrium towards lower harvest efforts (Flaaten, 2011, p. 41).

Economically speaking, a tax, license, or limit that caused the equilibrium price from a place on the backwards-bending portion of the curve to the MEY would cause aggregate resource rents to be higher



Figs. 2. a–b.Hypothetical linear demand and backward-bending supply curves without and with policies that would affect supply or demand, demonstrating the impact of policies on equilibrium quantities traded and price. (a) Effect of a hypothetical $200/lb. excise tax, showing that the tax could potentially shift an equilibrium quantity from q_{1c} to a much higher equilibrium quantity q_2, with lower corresponding equilibrium price. Note that the supply without tax has multiple possible equilibria, with q_{1a} and q_{1c} being stable equilibria and q_{1b} unstable. (b) Effect of a hypothetical policy that reduces demand, showing a potential change in equilibrium quantity from q_{1c} to q_2.

because of higher resource yields concurrent with lower effort (costs) (Flaaten, 2011, p. 32; Gordon, 1954).

2.4.3. *Demand side programs and policies*

Another set of possible programs and policies would attempt to alter the demand for wild-harvested products. If demand were reduced (shifted inward), there could be a large shift in equilibrium price and harvest effort (from q_{1c} to q_2), leading to a long-run recuperation of the species (Fig. 2b). As an (non-NTFP) example, countries have implemented import bans on rhinoceros horn, introduced substitutes, removed horn from the official list of medicines, initiated awareness campaigns, and undertaken research to demonstrate the inefficacy of horn as a remedy (Ellis, 2013).

2.4.4. *Governance of common-pool resources*

Common-pool resources were famously discussed by Hardin (1968), in which the rivalrous and open-access nature of a common-pool resource creates a situation in which additional production effort leads to overexploitation and lower overall production. However, community-based natural resource management has been shown to be effective at

Table 1
Average annual harvest (dry pounds) of wild American ginseng by state for two recent five year periods, with associated potential habitat across ownership classes. [source: data provided by the US Fish and Wildlife Service].

State	Average Annual Harvest (dry pounds)		Percent Change 2003–07 vs. 2008–12	Potential Ginseng Habitat[a] (acres)	Percent of Potential Ginseng Habitat[a] by Ownership Class			
	2003–2007	2008–2012			National Forests	Other Federal	State and Local	Private
Alabama	614.8	693.2	12.7%	7,082,722	2.9%	1.2%	2.9%	92.9%
Arkansas	1325.6	891.2	−32.8%	7,805,889	13.2%	2.4%	1.6%	79.4%
Georgia	289.7	265.7	−8.3%	6,454,236	5.4%	1.7%	3.9%	85.9%
Illinois	2501.1	2574.2	2.9%	3,472,063	5.5%	0.0%	0.2%	84.0%
Indiana	5123.1	4224.6	−17.5%	3,826,987	3.8%	3.3%	7.8%	84.7%
Iowa	621.4	758.7	22.1%	2,077,680	0.0%	3.3%	10.6%	86.0%
Kentucky	14,673.7	14,905.5	1.6%	10,588,720	6.8%	2.7%	2.0%	87.8%
Maryland	115.1	141.7	23.2%	1,640,783	0.0%	2.9%	25.5%	71.9%
Minnesota	1108.2	665.0	−40.0%	3,439,900	12.1%	1.2%	21.6%	71.6%
Missouri	1429.2	1325.0	−7.3%	12,531,879	9.5%	2.1%	5.8%	82.8%
New York	168.7	325.5	92.9%	13,643,992	0.1%	0.4%	25.0%	74.5%
North Carolina	6559.3	11,567.5	76.4%	7,278,582	8.9%	3.7%	3.8%	80.4%
Ohio	3320.2	3471.9	4.6%	6,743,017	3.4%	0.6%	9.7%	86.3%
Pennsylvania	1164.3	876.0	−24.8%	14,498,135	3.0%	0.9%	26.7%	69.4%
Tennessee	8070.2	10,619.9	31.6%	10,388,954	5.1%	4.7%	6.5%	83.3%
Vermont	93.7	148.9	58.8%	3,330,283	10.6%	1.2%	10.0%	77.5%
Virginia	3261.8	3885.0	19.1%	10,056,761	12.7%	3.2%	3.9%	78.8%
West Virginia	5279.8	5383.8	2.0%	11,111,982	8.4%	1.5%	3.1%	87.1%
Wisconsin	1895.9	1995.9	5.3%	8,211,963	7.7%	0.8%	15.4%	76.1%
TOTAL	57,615.8	64,719.2	12.3%	144,184,528	7.0%	1.9%	10.0%	80.9%

[a] Potential ginseng habitat is broadly defined as forests in the Oak-Hickory and Maple-Beech-Birch groups. (based on analysis of USFS Forest Inventory and Analysis data).

mitigating the problems in some instances (Agrawal, 2001; Ostrom, 1990). Agrawal (2001) identified critical enabling conditions within four main areas: resource system characteristics, group characteristics, institutional arrangements, and the external environment. Effective governance requires (among other things) exclusion of those outside the community, effective monitoring of the resource, and graduated sanctions for violations of norms (Ostrom, 1990), all of which serve to mitigate the open access problem. However, the ability to enact such a governance system depends crucially on the ecological and social context of the resource (Agrawal, 2001; Ostrom, 1990). To our knowledge, there are few documented examples of formal collective governance institutions specifically for NTFPs in the United States; however, informal institutions and co-management with other forest resources may occur on some tribal and public lands.

3. Case study: wild American ginseng

3.1. Background: wild American ginseng markets, trade, and regulation

We used available data on wild American ginseng harvest and exports to test for a backward-bending supply curve. American ginseng root is valued in East Asian traditional medicine, spawning widespread harvesting and vibrant international trade. American ginseng can be cultivated in the field under shade-cloth, and that segment of the industry comprises approximately 90% of U.S. exports by weight (US FWS, 2016). However, wild roots are strongly preferred by consumers and thus command a price of 10 to 25 times the field-grown price (Beyfuss, 1999; Davis and Persons, 2014, pp. 31–32). In 2013, prices for dry wild American ginseng root at the first point of sale after harvest were typically $700–800 per pound, and prices up to $1250 per pound were reported (Chamberlain et al., 2013). Ginseng root is unique among forest products in having such a wide differential between wild-harvested and cultivated prices.

Nineteen states are certified to export wild American ginseng, which together generated total estimated annual revenues for harvesters of $22 to $43 million from 2000 to 2007 (Chamberlain et al., 2013). Indiana, Kentucky, North Carolina, Tennessee, and West Virginia are the top five producers of wild-harvested American ginseng, accounting for about 70% of reported harvest (Table 1). Kentucky alone reported about 25% of the total harvest. Pennsylvania, New York, Missouri, West Virginia and Kentucky have the greatest amount of potential ginseng habitat, broadly defined as forests in the oak-hickory and maple-beech-birch groups[3]; however, New York and Missouri are on the edge of the natural range of American ginseng. Much of the prime habitat for wild American ginseng is on private lands (Table 1), yet a significant portion of ginseng harvest is on public lands (Chamberlain et al., 2013). The average annual harvest of wild American ginseng from 2003 to 2007 increased by 12% to 2008–2012 (Table 1). Over a longer time horizon, however, post-2000 harvests are significantly lower on average than 1978–2000 (Fig. 3). These changes demonstrate the need for supply modeling to control for coinciding exogenous factors such as regulation and economic downturns.

Wild American ginseng harvest is a secretive affair (Burkhart, 2011), and various factors can make existing ginseng plants difficult to detect (Bailey, 1999). Most of the habitat for ginseng is accessible in rural forested areas. Access difficult to control, and poaching is known to occur (Burkhart et al., 2012; McGraw et al., 2013). This makes *de facto* open access plausible.

NTFPs can serve as economic resources for people during difficult economic times (Pierce and Emery, 2005). Wild American ginseng has been a source of income for rural people and export-oriented firms in the United States since the 1700s (Nash, 1898). It is thought to provide an economic safety net in Appalachia and other rural areas of eastern North America. Bailey (1999, p. 24) found that coal mine layoffs and drought accounted for 72% of the variation in ginseng harvest in West Virginia. The research, however, did not account for the effect of price on harvest levels, or the interaction of supply and demand.

Biologically, American ginseng is a long-lived forest perennial that grows slowly and has low reproductive rates (Charron and Gagnon, 1991; McGraw et al., 2013; Mooney and McGraw, 2009), making it sensitive to decreases in adult survival (Van der Voort and McGraw, 2006). The root and entire plant is extracted,[4] likely decreasing long-

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[3] In reality, ginseng grows only in small niches within each of these broad forest types.

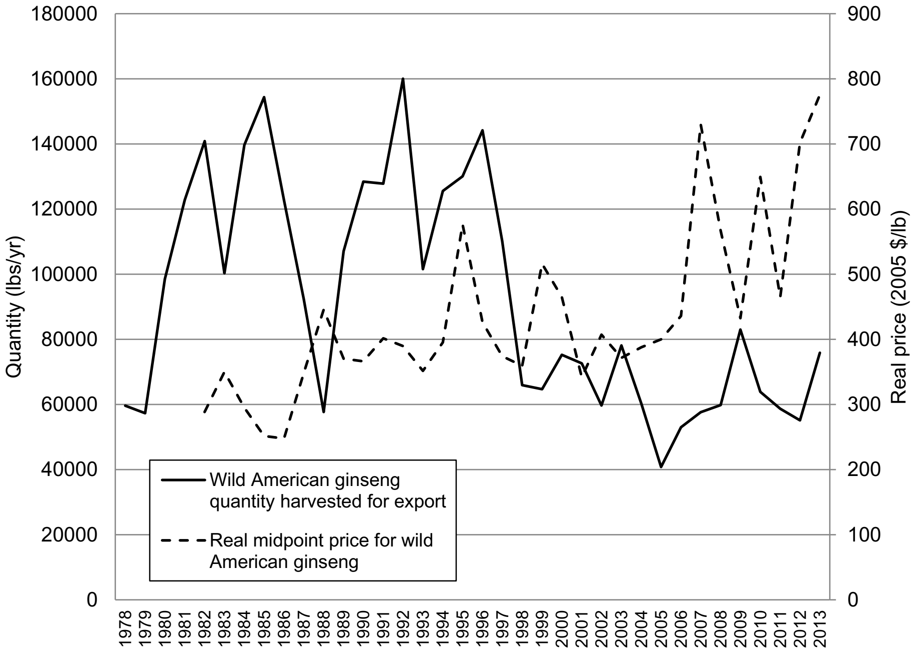

Fig. 3. Historical data for quantity of U.S. wild American ginseng harvest for export (dry pounds per year) and real midpoint price (midpoint between high and low prices for the year) (2005 $ per dry pound) from 1978 to 2013.

term population endurance (Ticktin, 2004). Demographic studies of American ginseng reveal that the plant can sustain very low levels of harvest (Van der Voort and McGraw, 2006). While harvest rates up to 8% of the existing stock of plants each year may be sustainable (Charron and Gagnon, 1991), typical harvesting practices are often not ideal (McGraw et al., 2010; Van der Voort and McGraw, 2006), leading to population declines (Souther and McGraw, 2014).

American ginseng is a species of conservation concern, mostly due to harvest pressures, browsing by deer, the spread of invasive species, and loss of habitat[5] (McGraw et al., 2013; Mooney and McGraw, 2009; Van der Voort and McGraw, 2006). In 1975, American ginseng was listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), meaning that a country must ensure that the product is obtained legally and the export is not detrimental to the survival of the species (CITES, 2015; US FWS, 2015). The US Fish and Wildlife Service (FWS) determines if the export of wild-harvested ginseng root will be detrimental to the species survival, approves state regulation programs (see: 50 C.F.R. § 23.68, 2014), and issues permits for export. Each state that is approved to export American ginseng reports annually the amount of root wild-harvested, by county, based on reports by registered dealers who obtain information from harvesters at the first point-of-sale.

Current ginseng harvest regulations by the states include limiting the harvest season, limiting the sale of ginseng to registered dealers, and the imposition of a minimum harvest age. In 1999, the FWS determined that harvest of wild ginseng in all states should be restricted to plants five years old or older (US FWS, 2013). In 2005, the FWS additionally limited the harvest of ginseng roots for export to plants 10 years old or older. This second, more restrictive regulation was reversed, from 2006 to present, with harvest age limit reverting to five years old (P. Ford, personal communication, 14 April 2015). Age of the plant at harvest is determined first by the harvester, then verified by the registered dealer, and finally certified upon inspection by the authorized state government personnel (P. Ford, personal communication, 3 April 2015). Pre-harvest, three leaves per plant is an indicator that plants are at least five years old (McGraw et al., 2010). Post-harvest, age can be determined by counting the number of stem scars on the root neck (US FWS, 2013).

3.2. Data and methods

3.2.1. Data

We obtained ginseng harvest quantity data for 1978–2013 from FWS. High and low prices in United States dollars ($) per dry pound each year from 1982 to 2013 were obtained from Davis and Persons (2014, p. 41). While data on quantity are available at the state and even county level, price data are more limited, being only available as annual national prices. This restricts our level of analysis to the national level. We utilized the midpoint between the high and low prices. Prices were converted to real 2005 $ using the Consumer Price Index (CPI) (US BLS, 2014). Fig. 3 shows the historical quantity harvested and the real (2005 $) midpoint price of wild American ginseng. Descriptions and sources of data used for other exogenous supply and demand variables are in Table 2.

3.2.2. Statistical estimation of long-run supply

Statistical estimation of supply and demand equations involves simultaneous equation estimation methods. A traditional linear formulation of the demand equation is:

$$q_{d,t} = \beta_{d,0} + \beta_{d,p} \cdot p_t + \sum_{i=1}^{m} (\beta_{d,i} \cdot x_{d,i,t}) + \varepsilon_{d,t} \tag{1}$$

where $q_{d,t}$ and p_t are the demand quantity and market price of the good traded in time t, $x_{d,i}$ are exogenous variables affecting demand, β are coefficients, and $\varepsilon_{d,t}$ is a random error. If the Law of Demand holds, $\beta_{d,p}$ will be negative. Similarly, the linear supply equation is:

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[4] Most states provide guidelines that encourage harvesters to replant ripe seeds from extracted plants near the site of harvest.

[5] There is substantial suitable habitat that is not populated with ginseng (Chamberlain et al., 2013; McGraw et al., 2013), so loss of habitat is currently a problem that only affects localized areas, for example after a timber harvest (Chandler and McGraw, 2015). However, much of eastern North America was far more deforested in the past. Given that ginseng thrives in mature forests and that it may take time for ginseng seeds to repopulate formerly deforested areas, past deforestation might limit present populations.

Table 2
Summary statistics and sources of variables used in the regression for years 1982–2013.

Variable	Description	Source	Mean	Median	Min	Max
Wild_quantity	Annual quantity (dry pounds) of ginseng root harvested for export.	US FWS	92,722	80,558	40,796	160,035
Wild_price	Mid-point between high and low prices for wild ginseng root recorded each year converted to real 2005 $	Davis and Persons (2014)	433	397	248	775
Demand variables						
Cultivated_price	Mid-point between high and low prices for cultivated ginseng root each year, converted to real 2005 $	Davis and Persons (2014)	37.6	25.8	9.1	88.0
ln(China_GDP)	Logarithm of GDP of China, real 2005 $	World Bank (2015)	27.8	27.8	26.2	29.2
Exchange_rate	Exchange rate of Chinese Yuan to US Dollar ($)	World Bank (2015)	6.25	6.80	1.89	8.62
Supply variables						
Unemployment	Total October unemployment (thousands of unemployed) in seven states	US BLS (2016)	1248	1105	694	2265
Regulation	Ordinal variable, 0 if no age restriction on harvest (1982–1998), 1 if five-year age minimum for harvest (1999–2013, except 2005), 2 of 10-year age minimum for harvest (2005)	US FWS	0.5	0	0	2

$$q_{s,t} = \beta_{s,0} + \beta_{s,p} \bullet p_t + \sum_{j=1}^{n} (\beta_{s,j} \bullet x_{s,j,t}) + \varepsilon_{s,t} \tag{2}$$

where the s subscript indicates variables and parameters of supply and the j subscript represents the various different exogenous determinants of supply, $x_{s,j}$. If the Law of Supply holds, $\beta_{s,p}$ will be positive in the long run. A negative coefficient ($\beta_{s,p}$) on price in the long-run supply model is indicative of backward-bending supply over the range of data. Since part of the supply curve must be upward-sloping, a backward-bending supply curve implies a non-linear supply specification. To avoid forcing the data into a backwards-bending model, we first attempt to fit a traditional linear supply model to the data. If a negative slope is estimated, a nonlinear backward-bending model can be fit.

There are several exogenous explanatory variables x_s and x_d that may influence (shift) supply and demand. To avoid overfitting the model, it was necessary to select a limited number of exogenous explanatory variables, which are given in Table 2. Each of these variables has an expected sign, based on what are considered to be the usual characteristics of most goods in the marketplace. Deviations from those usual signs, however, do occur with goods that do not share those "usual" characteristics. First, we expected cultivated American ginseng to act as a substitute for wild American ginseng, that is, the coefficient is positive in both the long and short run. Second, we expected that wild American ginseng is a normal good, meaning demand increases with the higher aggregate economic output (gross domestic product) in China, where most ginseng is consumed. Third, because the prices that consumers face for imported wild American ginseng depend on the dollar-yuan exchange rate, demand in China for wild American ginseng was hypothesized to be affected by the exchange rate. Fourth, the short-run supply of wild American ginseng increases with higher unemployment, implying higher supply at any given ginseng price. Finally, long-run and short-run supply decrease with increased regulation in the United States. This normally would be understood to be the case if supply were upward-sloping, but the opposite would be expected if the supply is backward-bending.

Total stock of the resource and supply are implicitly linked (Binkley, 1993). In the short run, stocks are quasi-fixed, so a short-run model would include stock levels as an exogenous variable to control for it. In the long-run, stocks are not fixed, and stocks are affected by long-run equilibrium levels of price and quantity supplied. Including stock and price together in the statistical model would change the interpretation of the effect of price on quantity supplied. That is, by explicitly controlling for the stock in the price-quantity relationship, supply would be understood as being for a fixed level of stock, rather than an implicitly changing level of stock.

Past research has generally addressed the issue in one of two ways. The first is to estimate a model of quantity harvested as a function of stock, then make certain assumptions to impute a derived supply curve. The second is to let stock be implicitly controlled by price (or harvest effort) estimate a model of quantity harvested as a function of price (or harvest effort), after which point it is possible to make certain assumptions to impute an estimate of stock. The first approach is taken by Nøstbakken and Bjørndal (2003), and the second by Thuy and Flaaten (2013) and Bell (1972), for example. Thuy and Flaaten (2013) explicitly address the issue of modeling supply without information about stock, and develop four models to do so.

No national data exist on total stocks of ginseng in the woods, so we take Thuy and Flaaten's (2013) approach. Of the functional forms they used, we utilized Model 2 because of relative simplicity for use with aggregate empirical data, including other exogenous supply shifters (x_j), following Bell (1972):

$$q_t = \beta_{p1}\frac{1}{p_t} + \beta_{p2}\left(\frac{1}{p_t}\right)^2 + \sum_{j=1}^{n} (\beta_j \bullet x_j) + \varepsilon_{s,t} \tag{3}$$

The MSY of this curve is defined by the point where it turns from upward-sloping to backward-bending, that is, where $\frac{dq}{dp} = 0$. This MSY point can be shown to be (Thuy and Flaaten, 2013):

$$p_{MSY} = -\frac{2\beta_{p2}}{\beta_{p1}} \tag{4}$$

$$q_{MSY} = -\frac{{\beta_{p1}}^2}{4\beta_{p2}} + \sum_{j=1}^{n} (\beta_j \bullet x_j) \tag{5}$$

This MSY quantity can be parameterized at any level of the exogenous variables, x_j. Long-run equilibrium stock (X) can also be imputed by the following expression.

$$X = \frac{\beta_{p1}}{r \bullet p} \tag{6}$$

where r is the natural rate of population growth (without harvest). Evaluating the term at p_{MSY} would yield the stock at MSY (X_{MSY}).

3.2.3. Instrumental variables regression

Because Thuy and Flaaten (2013) and Bell (1972) modeled supply of small groups of fishermen, the market price can be assumed to be exogenous, that is, they are price-takers. In our model of the entire export market, however, price and quantity are endogenous due to simultaneity. The standard way to control for endogeneity is instrumental variables (IV) regression, such as two-stage least squares (2SLS).

In our case, the IVs for the price can be the exogenous variables x_d from (1) and x_s from (2). The first stage regression in the 2SLS approach is estimated to generate predicted values of the price, $\widehat{p}_t$.

$$\widehat{p}_t = \widehat{\gamma}_0 + \sum_{j=1}^{n} (\widehat{\gamma}_{s,j} \bullet x_{s,j,t}) + \sum_{i=1}^{m} (\widehat{\gamma}_{d,i} \bullet x_{d,i,t}) \tag{7}$$

The predicted values of price from the first stage regression are used as explanatory variables in the second stage regression:

$$q_{st} = \beta_{s,0} + \beta_{s,p}\bullet\widehat{p}_t + \sum_{j=1}^{n}(\beta_{s,j}\bullet x_{s,j,t}) + \varepsilon_{s,t} \tag{8}$$

We used heteroscedastic-consistent (robust) standard errors to account for potential heteroscedasticity in the second-stage equation.

3.2.4. Non-stationarity and cointegration

OLS regression with non-stationary variables can lead to spurious, biased results (Granger and Newbold, 1974), which may be tested with an Augmented Dickey-Fuller test (ADF) (Dickey and Fuller, 1979; Said and Dickey, 1984). If some or all of the variables are found to be potentially non-stationary, then a few estimation options remain. If the variables are all integrated of the first order (I(1)) but are not cointegrated, then a regression involving the first-differences of each variable can be used. On the other hand, if the variables are integrated of the same order and share one or more cointegrating relations, a vector error correction model (VECM) would allow consistent estimation of both long- and short-run effects (Engle and Granger, 1987). If variables are integrated of different orders, an option is to use an autoregressive distributed lag (ARDL) model, also known as an unconstrained VECM (Hassler and Wolters, 2006) (note we have dropped the "*s*" subscripts in the following supply specification):

$$\Delta q_t = \alpha_0 + \left[\theta_q\bullet q_{t-1} + \theta_p\bullet p_{t-1} + \sum_{j=1}^{n}\theta_j\bullet x_{j,t-1}\right] + \sum_{k=1}^{\pi}(\alpha_{q,k}\bullet\Delta q_{t-k}) + \sum_{l=0}^{\rho}(\alpha_{p,l}\bullet\Delta p_{t-l}) + \sum_{j=1}^{n}\sum_{m=0}^{\sigma}(\alpha_{j,m}\bullet\Delta x_{j,t-m}) + \varepsilon_t \tag{9}$$

where Δ is the first-difference operator, π, ρ, and σ are lag orders, and other variables are as previously defined. In this model, long-run equilibrium effects can be derived from the θs. Combining the ARDL (9) with the 2SLS second-step (8) yields:

$$\Delta q_t = \alpha_0 + \left[\theta_q\bullet q_{t-1} + \theta_p\bullet\widehat{p}_{t-1} + \sum_{j=1}^{n}\theta_j\bullet x_{j,t-1}\right] + \sum_{k=1}^{\pi}(\alpha_{q,k}\bullet\Delta q_{t-k}) + \sum_{l=0}^{\rho}(\alpha_{p,l}\bullet\Delta\widehat{p}_{t-l}) + \sum_{j=1}^{n}\sum_{m=0}^{\sigma}(\alpha_{j,\mathrm{m}}\bullet\Delta x_{j,t-m}) + \varepsilon_t \tag{10}$$

and in the case of the backward-bending model,

$$\Delta q_t = \alpha_0 + \left[\theta_q\bullet q_{t-1} + \theta_{p1}\bullet\frac{1}{\widehat{p}_{t-1}} + \theta_{p2}\bullet\left(\frac{1}{\widehat{p}_{t-1}}\right)^2 + \sum_{j=1}^{n}\theta_j\bullet x_{j,t-1}\right] + \sum_{k=1}^{\pi}(\alpha_{q,k}\bullet\Delta q_{t-k}) + \sum_{l=0}^{\rho}(\alpha_{p1,l}\bullet\Delta\widehat{p}_{t-l}) + \sum_{j=1}^{n}\sum_{m=0}^{\sigma}(\alpha_{j,m}\bullet\Delta x_{j,t-m}) + \varepsilon_t \tag{11}$$

In these models, the portion of the equation in square brackets is the error-correction mechanism, and coefficients θ determine the coefficients of the long-run cointegrating equilibrium ("levels") relation between the dependent and explanatory variables, such that (Hassler and Wolters, 2006):

$$q_t = \beta_0 + \beta_p\bullet p_t + \sum_{j=1}^{m}\beta_j\bullet x_{j,t} \tag{12}$$

where

$$\beta_j = -\frac{\theta_j}{\theta_q} \tag{13}$$

Estimates of β, which are super-consistent but potentially biased in small sample sizes, can be obtained from the direct regression of the levels of q on p and x, but the coefficient estimate from the ARDL approach will be less biased, and the t-statistic will reject the null hypothesis approximately correctly for alpha = 0.05 (Banerjee et al., 1986; Hassler and Wolters, 2006).

The remaining coefficients α represent short-run effects. The lag orders (π, ρ, σ) of each first difference in Eqs. (10) and (11) are atheoretic. In principle, one could use an information criterion to determine the optimal lag order for each variable to obtain the best fit and to eliminate autocorrelation. Given our small sample size and lack of residual autocorrelation, we decided not to include any lags to avoid overfitting the model. In this case, the short-term effects on quantity harvested are limited to only the most recent change in explanatory variables.

Diagnostic tests were done to test the validity of the ARDL structure and for significances of hypothesized cointegrating relations. ARDL structure validity was examined with a Breusch-Godfrey (Lagrange multiplier) test, which tested for significant residual autocorrelation. The existence of significant cointegrating relations was evaluated with a Pesaran et al. (2001) bounds test.

3.3. Results and discussion

3.3.1. Summary statistics

Table 2 presents summary statistics for the variables used in the regressions. Over the time period (1982–2013), total U.S. wild ginseng harvest for export ranged from about 40,000 to about 160,000 dry pounds per year, with a median of about 80,000 dry pounds per year. The years with the greatest harvest for export (> 100,000 dry pounds per year) were 1981 to 1986 and 1989 to 1997. From 1998 to 2013, the harvest was consistently < 80,000 dry pounds per year. Similarly, the wild American ginseng midpoint price (in real 2005 $) ranged from $248 to $775 from 1982 to 2013. There was a less clear delineation between high and low prices than there was with quantity, but the four years with real 2005 midpoint prices above $600/dry pound were all since 2007, and the four years with midpoint prices below $300/dry pound were 1982 to 1986. Therefore, over time, the trend has been a shift from higher quantities and lower prices to lower quantities and higher prices.

Augmented Dickey-Fuller tests (available from the authors) indicated that most of the variables were non-stationary I(1). The only variable that was potentially I(2) was the gross domestic product (GDP) of China (in billions of 2005 $). However, the natural log of the GDP of China was I(1), which was the variable used in the modeling.

3.3.2. Linear demand and supply models

The endogenous variable, price, was regressed on the full set of exogenous supply and demand variables in a first-stage regression. Results of this first-stage regression are presented in Table 3.

While there are numerous factors involved in a traditional model that follows the laws of supply and demand, a shift from higher quantities and lower prices to lower quantities and higher prices, as described by the summary statistics, is consistent with a decrease in supply, that is, a shift in the short-run supply curve upwards and inwards. This could have been caused by a change in unemployment, a change in regulation, or some other factor that shifted the supply curve inwards. Using the ARDL & 2SLS model with the exogenous explanatory variables can control for these factors. We generated linear demand and supply models using real midpoint wild ginseng prices. The linear demand and supply models are in Tables 4–5.

The results of the linear demand function estimation were largely inconclusive (Table 4). The overall fit seemed relatively good, with an F-statistic rejecting the null hypothesis of no relation between the explanatory variables and the dependent variable at alpha = 0.05, an R-squared of 0.45, and a Breusch-Godfrey test indicating no autocorrelation. However, the bounds tests fail to reject the lack of a cointegrating relationship, so estimates of the long-run relationship may be spurious. Also, very few of the explanatory variables were statistically significant at the alpha = 0.1 level or stronger.

Table 3
First stage regression of the two-stage least squares procedure. The real mid-point price is regressed on exogenous factors to obtain predicted values. The predicted values of price are then used in the second stage.

	Coefficient	Std. error	t-stat	*p*-value
Constant	−6203	1168	−5.31	0.000
Unemployment	−0.098	0.057	−1.71	0.099
Regulation	−71.2	44.3	−1.61	0.120
Cultivated_Price	2.68	1.43	1.88	0.072
ln(China_GDP)	245	45	5.51	0.000
Exchange_Rate	−18.4	16.8	−1.09	0.285
R-squared	0.675			
F (7,23)	10.78			0.000

Table 4
Estimates of a linear demand function with real mid-point prices, using the autoregressive distributed lag and two-stage least squares approaches. The dependent variable is the change in quantity (dry pounds) of ginseng root harvested for export (Δ Wild_Quantity). The model has unrestricted intercept, and no trend.

	Coefficient	Robust std. error	t-stat	p-value
Constant	562838	778052	0.72	0.477
Adjustment term				
Wild_Quantity $_{t-1}$	−0.557	0.188	−2.96	0.007
Long-run equilibrium				
Wild_Price $_{t-1}$[a]	115	173	0.66	0.515
Cultivated_Price $_{t-1}$	77.8	624.6	0.12	0.902
ln(China_GDP) $_{t-1}$	−20543	30078	−0.68	0.502
Exchange_Rate $_{t-1}$	517	3896	0.13	0.896
Short-run effects				
Δ Wild_Price[a]	6.20	177.61	0.04	0.972
Δ Cultivated_Price	−548	622	−0.88	0.388
Δ ln(China_GDP)	−9960	208,572	−0.05	0.962
Δ Exchange_Rate	9448	5923	1.60	0.126
R-squared	0.447			
F (9,21)	7.83			0.000
Bounds test F (k = 4)	3.05			[b]
Bounds test t (k = 4)	−2.96			[b]
Breusch-Godfrey chi-sq	0.005			0.945

[a] Price was instrumented using predicted values from the first stage regression (Table 3).

[b] Fails to reject lack of cointegration.

Table 5
Estimates of a linear supply function with real mid-point prices, using the autoregressive distributed lag and two-stage least squares approaches. The dependent variable is the change in quantity (dry pounds) of ginseng root harvested for export (Δ Wild_Quantity). The model has unrestricted intercept, and no trend.

	Coefficient	Robust std. error	t-stat	p-value
Constant	95126	37027	2.57	0.017
Adjustment term				
Wild_quantity $_{t-1}$	−0.783	0.207	−3.78	0.001
Long-run equilibrium				
Wild_price $_{t-1}$[a]	−30.1	63.5	−0.47	0.639
Unemployment $_{t-1}$	8.75	10.46	0.84	0.412
Regulation $_{t-1}$	−32368	12328	−2.63	0.015
Short-run effects				
Δ Wild_price [a]	−314	119	−2.65	0.014
Δ Unemployment	3.94	12.08	0.33	0.748
Δ Regulation	−52340	7117	−7.35	0.000
R-squared	0.540			
F (7,23)	21.68			0.000
Bounds test F (k = 3)	4.92			< 0.025
Bounds test t (k = 3)	−3.78			0.050
Breusch-Godfrey chi-sq	0.077			0.782

[a] Price was instrumented using predicted values from the first stage regression (Table 3)

Despite the lack of fit, values of the coefficients were estimated, and the best estimate of the long-run equilibrium demand was (see Eqs. (10), (12), (13) and variable definitions in Table 2):

$$\text{Wild\_Quantity} = 1{,}009{,}889 + 206*\text{Wild\_Price} + 140*\text{Cultivated\_Price} - 36{,}861*\ln(\text{China\_GDP}) - 928*\text{Exchange\_Rate}$$

Because the cointegrating relationship was not supported, and the coefficients were not statistically significant, our tests of hypotheses related to demand were inconclusive. Still, some of the signs of the coefficients were unexpected, such as the long-run coefficients on price (positive) and income (negative).

The linear supply model had more significant results than the demand model (Table 5). The overall F-statistic rejected the null hypothesis of no significance of the model at alpha = 0.05, and the R-squared value was 0.54. The Breusch-Godfrey test indicated no autocorrelation. The bounds tests rejected lack of cointegration, so the long-run cointegration relationship is valid.

The long-run equilibrium supply equation was estimated to be (see Eqs. (10), (12), (13) and variable definitions in Table 2):

$$\text{Wild\_Quantity} = 121{,}422 - 38.5*\text{Wild\_Price} + 11.2*\text{Unemployment} - 41{,}316*\text{Regulation}$$

The negative sign on the price coefficient in the long-run supply equilibrium was the opposite of the expected sign given the Law of Supply, indicative of a backward-bending supply curve. The coefficient was not statistically significant, so more evidence would be needed to say this conclusively. Short-run effects also should follow the law of supply, yet for the same-period, these effects were negative and statistically significant. Unemployment had no statistically significant effect on supply. Increased regulation (as measured by minimum age for harvest) had a negative long-run effect and short-run effect (alpha = 0.05). Each five-year increase in minimum harvest age (from zero to five or from five to ten) decreased ginseng harvest by about 41,000 pounds per year in the long-run. The short-run same-period effect of regulation on supply was the same direction as the long-run effect and equivalent to a decrease of about 52,000 pounds per year in the short-run.

3.3.3. *Backward-bending supply*

The linear long-run supply model indicated the potential for a negative slope with respect to price. Therefore, testing a backward-bending model was a logical next step. This nonlinear model of supply (Table 6) appeared to be a slightly better fit than the linear model (Table 5). The overall F-statistic for the model was significant and R-squared 0.56. The bounds tests supported the long-run cointegration relationship. Fig. 4 shows a plot of the actual versus predicted values of the dependent variable, change in quantity supplied, from the backward-bending supply model.

The long-run equilibrium backward-bending supply was estimated to be (see Eqs. (11)–(13) and variable definitions in Table 2):

$$\text{Wild\_Quantity} = 6.55 \times 10^{7}*(1/\text{Wild\_Price}) - 1.03 \times 10^{10}*(1/\text{Wild\_Price})^{2} + 18.6*\text{Unemployment} - 40{,}204*\text{Regulation}.$$

When considering the long-run equilibrium coefficients on $1/p_t$ and $1/p_t^2$, the model showed a supply curve that has a positive slope at lower harvest levels, which bends back to a negative slope at higher harvest levels. The short-run same period effects were in the same direction. In this model, unemployment was found to have a positive effect on supply in the long-run equilibrium. Increased regulation had a negative effect on the long-run supply, with each additional five-year increment in regulation decreasing supply by about 40,000 pounds per year. The magnitude of the estimated long-run effect was very similar to that measured in the linear supply model.

Fig. 4 compares the linear and backward-bending supply models, with and without the five-year harvest restriction. All models in Fig. 5 use the mean unemployment and are graphed with (1999–2005 and

Table 6
Estimates of a backward-bending supply function with real mid-point prices, using the autoregressive distributed lag and two-stage least squares approaches. The dependent variable is the change in quantity (dry pounds) of ginseng root harvested for export (Δ Wild_Quantity). This model has no intercept, and no trend.

	Coefficient	Robust std. error	t-stat	p-value
Adjustment term				
Wild_Quantity $_{t-1}$	−0.819	0.207	−3.96	0.001
Long-run equilibrium				
1/Wild_Price $_{t-1}$[a]	5.37e + 07	1.69e + 07	3.18	0.004
1/(Wild_Price $_{t-1}$)^{2}[a]	−8.47e + 09	3.47e + 09	−2.44	0.023
Unemployment $_{t-1}$	15.270	7.368	2.07	0.050
Regulation $_{t-1}$	−32946.64	13217.62	−2.49	0.020
Short-run effects				
Δ Wild_Price [a]	−311.624	126.113	−2.47	0.021
Δ Unemployment	7.523	12.167	0.62	0.542
Δ Regulation	−51004.53	7401.95	−6.89	0.000
R-squared	0.555			
F (8,23)	33.79			0.000
Bounds test F (k = 4)	5.92			< 0.01
Bounds test t (k = 4)	−3.96			< 0.025
Breusch-Godfrey chi-sq	0.008			0.931

[a] Price was instrumented using predicted values from the first stage regression (Table 3).

2007–2013) and without (1982–1998) the regulation restricting harvest to plants five-years or older. The graphs show the models only over the range of prices represented in the data. Over that area, the slopes of the curves are similar.

The overall results support a model that does not follow the Law of Supply; rather, the supply curve appears to slope backwards., Using the mean unemployment level and regulation of ginseng harvest age set to a five-year minimum, we estimated (Eqs. 4 and 5) the long-run maximum sustainable yield (MSY) of ginseng to be 88,929 pounds per year at a midpoint price of (2005 $) $315 per pound. Every year since 1999 has had lower quantities harvested and higher prices, which implies that ginseng supply is on the backward-bending part of the curve. This is indicative of over-exploited resource from biological and economic standpoints (Flaaten, 2011).

Based on our statistical model, it is possible to impute an estimate of the total stock of ginseng (Eq. 6) in terms of total dry pounds of root available for harvest. If we assume an average natural population growth rate of 4% (Charron and Gagnon, 1991; Van der Voort and McGraw, 2006) and recent midpoint prices of $700 per pound, the total stock of ginseng root would be approximately 1.9 million pounds, compared to an MSY stock of about 4.3 million pounds. It is important to note, however, that there is a high degree of uncertainty in these estimates.

Our findings do not provide evidence that ginseng populations are necessarily endangered, but support some of the underlying economic conditions that could make it possible (Clark, 2005, pp. 16–18; Courchamp et al., 2006). Populations could cross a critical threshold if the supply curve is backward-bending and the demand curve crosses in such a way that demand has a more vertical slope (less elastic) at that point and does not re-cross the supply curve at some higher price. This threshold would be an unstable equilibrium, whereby a shock into that region potentially could drive the species to extinction (Holden and McDonald-Madden, 2017). However, our research was unable to determine the existence or exact price and quantity of that threshold.

We found evidence that greater unemployment increases harvest in the long-run equilibrium, as suggested by Bailey (1999, p. 26). However, we expected this result to manifest itself in the short-run relationship, which was not the case. One counter-intuitive result of the backward-bending supply is that if harvesters were to exert less total effort, then, in aggregate, more could be produced. If such a decrease in harvest efforts from the open-access equilibrium to MSY were achieved, it would indicate lower costs of production (mostly labor), such that economic rents (profits) would increase until harvest efforts were

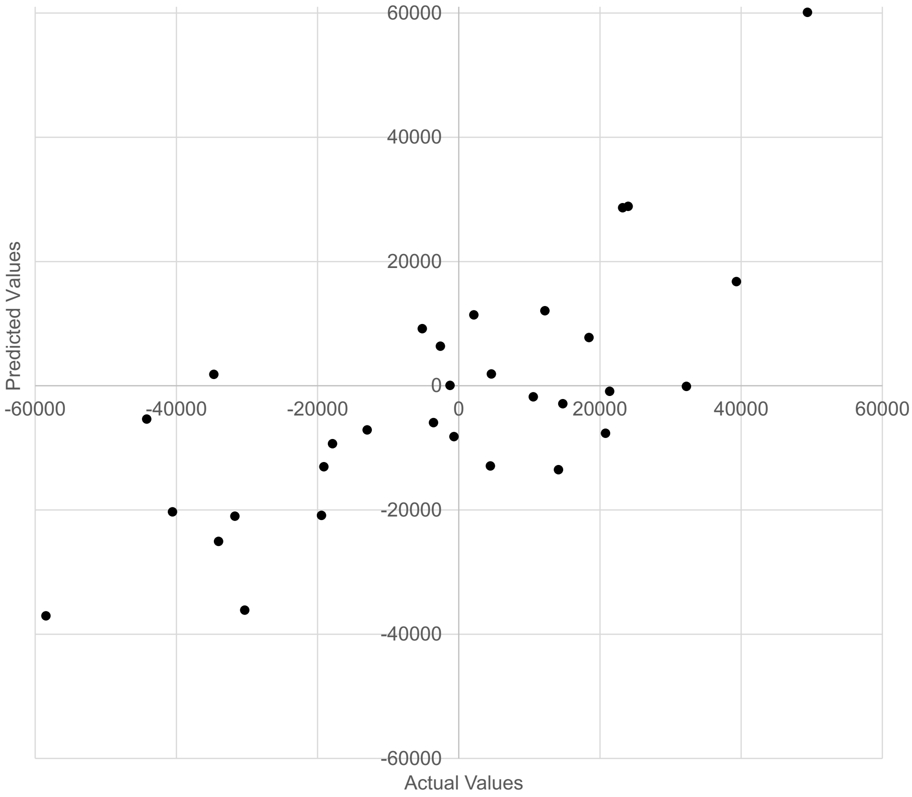

Fig. 4. Plot of the actual versus predicted values of the dependent variable, change in quantity supplied, from the backward-bending supply model.

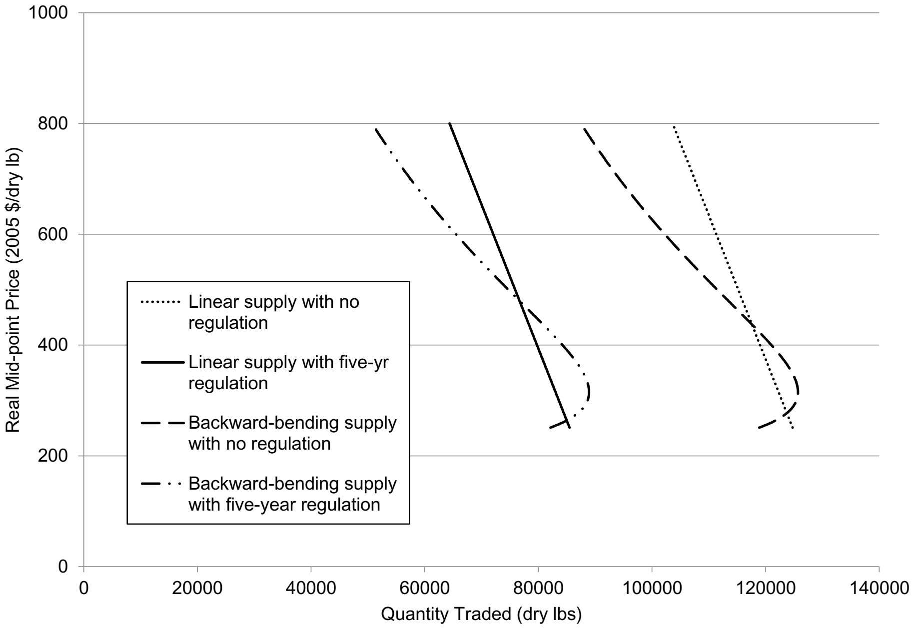

Fig. 5. Plots of the estimated linear and backward-bending long-run aggregate supply functions, with and without the regulation limiting harvest for export to plants five-years-old and older, as estimated by our statistical models, over the range of prices observed in the data.

lowered to MEY, which is below MSY (Flaaten, 2011, p. 32; Gordon, 1954). Although harvesters' net profits would increase, a decrease in harvest effort to MSY or MEY would result in lower prices and could reduce total revenues, which could be seen as negative by some harvesters. Depending on the position of the demand curve, the net effect on the total revenue generated (summed across all harvesters) is ambiguous. For instance, the data point for the year 2010 (63,889 pounds, $649/pound midpoint price) lies very close to the supply curve, assuming the five-year restriction. This data point would equate to gross revenues of about $41 million. A drop in price and increase in quantity to the MSY would bring about $28 million - although this would be shared among fewer harvesters and/or harvesters who invest less effort.

In both the linear and backward-bending supply equations, we find that supply decreased when the harvest was restricted to plants five-years-old or older. The single year that harvest was restricted to 10-years-old or older also coincided with a sharp inward shift in the supply curve. These effects were found in the long run and the short run in our models. There are several possible reasons why the regulation may have had the opposite of the expected outcome in a backward-bending supply model. First, it is possible that the implementation of the regulation in 1999 coincided with some other factor, of which we are not aware, that shifted supply inwards. Possibilities might be increased deer browse or climate change, but either of these would probably precipitate a slow decline rather than a shift in the supply curve based on the entire range specifically in 1999. Second, perhaps juvenile roots are still being harvested. If this occurred, the beneficial effect of the regulation – allowing more plants to reach reproductive maturity and increase the population – might not have happened. McGraw et al. (2010) did find that harvesters frequently harvested at least some plants with one or two leaves, contravening the regulation in those states, although they were unable to determine if those plants were actually five years old (presumably the harvesters would not have known either). Harvest of juvenile ginseng could occur if (a) the regulation is not enforced consistently and juvenile roots are still being exported, (b) juvenile roots are being traded in domestic markets (not subject to CITES), or (c) harvesters are unaware of the regulation and harvest roots that they subsequently cannot sell and must discard. If (a) were true, we would not expect to see a large impact of the regulation on supply in either direction; and domestic markets are not believed to be large, so (b) seems unlikely.

Third, the supply may not have reached a long-run equilibrium with the regulation. Ginseng populations may not have reached equilibrium with the policy because it is a long-lived, slow-growing forest herb that takes five or more years to produce seed (Mooney and McGraw, 2009), and seed dispersal is limited, so population recovery is slow (Van der Voort et al., 2003). By contrast, the majority of marine fish species reach reproductive maturity in less than two years (O'Brien et al., 1993), and can produce more eggs than ginseng can produce seed.

Fourth, it is possible that there is a dynamic effect due to multiple equilibria. For example, in the first years after the regulation, short-run supply would be restricted because the plants have not yet had a chance to increase reproduction as a result. In response to this short-run supply restriction, prices increase. The increased prices then drive stronger harvest efforts, putting greater pressure on the resource. Instead of reaching a higher long-run quantity equilibrium, the greater harvest pressure creates a lower long-run equilibrium.

Which explanation of these four we identified or other alternate explanation is true cannot be determined by our model. At most, we can say that the regulation has not had the desired effect, but this trend may be reversed in the future.

4. Conclusions

Our statistical modeling suggests that one NTFP, wild American ginseng, has a backward-bending long-run supply curve, a finding that is consistent with other common-pool resources. While ginseng is relatively unique in having a large price differential between its wild and cultivated forms, other NTFPs with similar biological characteristics, difficulty of exclusion, and high harvest pressures may react similarly. Statistical modeling of the markets of those NTFPs could advance our understanding of the long-run consequences of their common-pool vulnerabilities. However, not all NTFPs are alike, and some are less rivalrous, less open-access, or have lower harvest pressure, making them less likely to have a backward-bending long-run supply curve or less likely for equilibrium to fall on the backward-bending portion of such a curve.

Our study revealed some of the effects of regulations on a common-pool NTFP. In the 14 years that ginseng harvest has been restricted to plants five-years-old or older, the long-run supply of wild ginseng has decreased, which is the opposite of what is expected based on bioeconomic models. It is possible that ginseng will take > 14 years to equilibrate to a new, higher long-run equilibrium. As more data becomes available, it will be important to monitor price and quantity traded.

The strength of our findings was constrained by a lack of data, which limited the statistical power of our models. While ginseng harvest quantity data are available at smaller spatial scales (county level), we were unable to obtain price data at a finer spatial scale, or for either quantity or price at a finer temporal scale. Price information at first point of sale is not collected by any agency, and many dealers may be reluctant to share this information. Additionally, we could not obtain historical data on quantity or price of wild and cultivated Asian ginseng, to see whether wild American ginseng demand responds to Asian ginseng as a complement or substitute. Also, data on the quantity of American ginseng cultivated in Asia would help to understand the interlinkages.

Relatively recent trends in wild American ginseng markets not explicitly modeled, may also affect ginseng supply and would be interesting subjects for future research. First, from 2014 (our data ended in 2013) through the date of this writing, two cable television series related to ginseng harvest have been airing in the U.S. Did this publicity increase awareness of ginseng and brought additional harvesters into the forest? Second, with longer and more granular data, it may be of interest to see how other social trends, such as the opioid crisis currently affecting parts of Appalachia, might affect wild-harvesting. Third, the over-population of deer may affect ginseng reproduction (McGraw and Furedi, 2005).

Conservation of and investment in American ginseng face barriers due to difficulty in limiting access, which makes it similar to an open-access resource. Enforcement of property rights, community action, and investment in forest farming may be long term ways to resolve this situation, but these strategies are difficult to implement, given the characteristics of ginseng and its habitat. Therefore, alternative regulations may be considered. When contemplating these regulations, the ecological and economic characteristics will impact efficacy.

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References

Agrawal, A., 2001. Common property institutions and sustainable governance of resources. World Dev. 29, 1649–1672.
Alexander, S.J., Weigand, J., Blatner, K.A., 2002. Nontimber forest product commerce. In: Jones, E.T., McLain, R.J., Weigand, J. (Eds.), Nontimber forest products in the United States. The University Press of Kansas, Lawrence, KS, pp. 115–150.
Bailey, B., 1999. Social and Economic Impacts of Wild Harvested Products. PhD Thesis. West Virginia University, Morgantown, WV, pp. 103.
Banerjee, A., Dolado, J.J., Hendry, D.F., Smith, G.W., 1986. Exploring equilibrium relationships in econometrics through static models: Some Monte Carlo evidence. Oxf. Bull. Econ. Stat. 48, 253–277.
Bell, F.W., 1972. Technological externalities and common-property resources: An empirical study of the US northern lobster fishery. J. Polit. Econ. 80, 148–158.
Beyfuss, R.L., 1999. Economics and marketing of ginseng. US Department of Agriculture Forest Service and Natural Resources Conservation Service. National Agroforestry Center, Lincoln, NE.
Binkley, C.S., 1993. Long-run timber supply: Price elasticity, inventory elasticity, and the use of capital in timber production. Nat. Resour. Model. 7, 163–181.
Bulte, E., Engel, S., 2006. Conservation of tropical forests: Addressing market failure. In: López, R., Toman, M.A. (Eds.), Economic Development and Environmental Sustainability: New Policy Options. Oxford University Press, pp. 412–453.
Burkhart, E.P., 2011. Conservation through Cultivation: Economic, Socio-political and Ecological Considerations Regarding the Adoption of Ginseng Forest Farming in Pennsylvania. Phd Thesis. The Pennsylvania State University, State College, PA, pp. 312.
Burkhart, E.P., Jacobson, M.G., Finley, J., 2012. A case study of stakeholder perspective and experience with wild American ginseng (Panax quinquefolius) conservation efforts in Pennsylvania, USA: Limitations to a CITES driven, top-down regulatory approach. Biodivers. Conserv. 21, 3657–3679.
Chamberlain, J.L., Prisley, S., McGuffin, M., 2013. Understanding the relationships between American ginseng harvest and hardwood forests inventory and timber harvest to improve co-management of the forests of eastern United States. J. Sustain. For. 32, 605–624.
Chamberlain, J.L., Frey, G.E., Ingram, C.D., Jacobson, M.G., Downes, C.M.S., 2017. Forest ecosystem services: Provisioning of non-timber forest products. In: Sills, E.O., Moore, S.E., Cubbage, F.W., McCarter, K.D., Holmes, T.P., Mercer, D.E. (Eds.), Trees at work: Economic accounting for forest ecosystem services in the U.S. South. U.S. Department of Agriculture Forest Service, Southern Research Station, Asheville, NC, pp. 65–93.
Chandler, J.L., McGraw, J., 2015. Variable effects of timber harvest on the survival, growth, and reproduction of American ginseng (Panax quinquefolius l.). For. Ecol. Manag. 344, 1–9.
Charron, D., Gagnon, D., 1991. The demography of northern populations of Panax quinquefolium (American ginseng). J. Ecol. 79 (2), 431–445.
CITES, 2015. How CITES Works. Convention on International Trade in Endangered Species of Wild Fauna and Flora, Geneva.
Clark, C.W., 1980. Towards a predictive model for the economic regulation of commercial fisheries. Can. J. Fish. Aquat. Sci. 37, 1111–1129.
Clark, C.W., 2005. Mathematical Bioeconomics: Optimal Management of Renewable Resources, 2nd ed. Wiley, Hoboken, NJ, pp. 386.
Copes, P., 1970. The backward-bending supply curve of the fishing industry. Scottish J. Political Econ. 17, 69–77.
Courchamp, F., Angulo, E., Rivalan, P., Hall, R.J., Signoret, L., Bull, L., Meinard, Y., 2006. Rarity value and species extinction: The anthropogenic allee effect. PLoS Biol. 4, 2405–2410.
Davis, J.M., Persons, W.S., 2014. Growing and marketing ginseng, goldenseal and other woodland medicinals, 2nd ed. New Society Publishers, British Columbia, Canada.
Dickey, D.A., Fuller, W.A., 1979. Distribution of the estimators for autoregressive time series with a unit root. J. Am. Stat. Assoc. 74, 427–431.
Ellis, K., 2013. Can we tackle the demand for rhino horn? In: The Horn. Save the Rhino, London, pp. 24–25.
Engle, R.F., Granger, C.W., 1987. Co-integration and error correction: Representation, estimation, and testing. Econometrica 55 (2), 251–276.
Everett, Y., 2001. Participatory research for adaptive ecosystem management: A case of nontimber forest products. J. Sustain. For. 13, 335–357.
Fischer, C., 2004. The complex interactions of markets for endangered species products. J. Environ. Econ. Manag. 48, 926–953.
Flaaten, O., 2011. Fisheries economics and management. University of Tromsø, Norwegian College of Fishery Science, pp. 172.
Gordon, H.S., 1954. The economic theory of a common-property resource: The fishery. J. Polit. Econ. 62, 124–142.
Granger, C.W., Newbold, P., 1974. Spurious regressions in econometrics. J. Econ. 2, 111–120.
Hardin, G., 1968. The tragedy of the commons. Science 162, 1243–1248.
Hassler, U., Wolters, J., 2006. Autoregressive distributed lag models and cointegration. Allg. Stat. Arch. 90, 59–74.
Holden, M.H., McDonald-Madden, E., 2017. High prices for rare species can drive large populations extinct: The anthropogenic allee effect revisited. J. Theor. Biol. 429, 170–180.
Love, T., Jones, E.T., 2001. Why is non-timber forest product harvesting an “issue”? Excluding local knowledge and the paradigm crisis of temperate forestry. J. Sustain. For. 13, 105–121.
McGraw, J.B., Furedi, M.A., 2005. Deer browsing and population viability of a forest understory plant. Science 307, 920–922.
McGraw, J.B., Souther, S., Lubbers, A.E., 2010. Rates of harvest and compliance with regulations in natural populations of American ginseng (Panax quinquefolius l.). Nat. Areas J. 30, 202–210.
McGraw, J.B., Lubbers, A.E., Van der Voort, M., Mooney, E.H., Furedi, M.A., Souther, S., Turner, J.B., Chandler, J., 2013. Ecology and conservation of ginseng (Panax quinquefolius) in a changing world. Ann. N. Y. Acad. Sci. 1286, 62–91.
Mooney, E.H., McGraw, J.B., 2009. Relationship between age, size, and reproduction in populations of American ginseng, Panax quinquefolius (Araliaceae), across a range of harvest pressures. Ecoscience 16, 84–94.
Nash, G.V., 1898. American ginseng: Its commercial history, protection, and cultivation. U.S. Department of Agriculture, Division of Botany.
Nøstbakken, L., Bjørndal, T., 2003. Supply functions for North Sea herring. Mar. Resour. Econ. 18 (4), 345–361.
O'Brien, L., Burnett, J., Mayo, R.K., 1993. Maturation of Nineteen Species of Finfish off the Northeast Coast of the United States, 1985–1990. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.
Ostrom, E., 1990. Governing the commons: The evolution of institutions for collective action. Cambridge University Press.
Ostrom, V., Ostrom, E., 1977. Public goods and public choices. In: Savas, E.S. (Ed.), Alternatives for Delivering Public Services Toward Improved Performance. Westview Press, Boulder, CO, pp. 7–49.
Pesaran, M.H., Shin, Y., Smith, R.J., 2001. Bounds testing approaches to the analysis of level relationships. J. Appl. Econ. 16, 289–326.
Petrzelka, P., Ma, Z., Malin, S., 2013. The elephant in the room: Absentee landowner issues in conservation and land management. Land Use Policy 30, 157–166.
Pierce, A., Burgener, M., 2010. Laws and Policies Impacting Trade in NTFPs. In: Laird, S.A., McLain, R.J., Wynberg, R.P. (Eds.), Wild product governance: finding policies

that work for non-timber forest products. Earthscan, London, pp. 327–342.

Pierce, A.R., Emery, M.R., 2005. The use of forests in times of crisis: Ecological literacy as a safety net. Forests, Trees Livelihoods 15, 249–252.

Said, S.E., Dickey, D.A., 1984. Testing for unit roots in autoregressive-moving average models of unknown order. Biometrika 71, 599–607.

Souther, S., McGraw, J.B., 2014. Synergistic effects of climate change and harvest on extinction risk of American ginseng. Ecol. Appl. 24, 1463–1477.

Thuy, P.T.T., Flaaten, O., 2013. The backward-bending supply curve in fisheries-revisited. J. Sustain. Develop. 6, 15–33.

Ticktin, T., 2004. The ecological implications of harvesting non-timber forest products. J. Appl. Ecol. 41, 11–21.

Turvey, R., 1964. Optimization and suboptimization in fishery regulation. Am. Econ. Rev. 54 (2), 64–76.

US BLS, 2014. Consumer price index – all urban consumers, not seasonally adjusted, annual average. U.S. Bureau of Labor Statistics, Washington, DC.

US BLS, 2016. Databases, tables & calculators by subject. U.S. Bureau of Labor Statistics, Washington, DC.

US FWS, 2013. General advice for the export of roots of wild and wild-simulated American ginseng (*Panax quinquefolius*) legally harvested during the 2013 harvest season. U.S. Department of the Interior, Fish and Wildlife Service, Division of Scientific Authority, Falls Church, VA.

US FWS, 2015. Wild American ginseng: Information for dealers and exporters. In: International Affairs. U.S. Department of the Interior, Fish and Wildlife Service, Falls Church, VA.

US FWS, 2016. U.S. Exports of American ginseng: 1998–2015. U.S. Department of the Interior, Fish and Wildlife Service, Division of Management Authority, Falls Church, VA.

US FWS, 2017. CITES. U.S. Department of the Interior, Fish and Wildlife Service, International Affairs. Washington, DC.

50 C.F.R. § 23.68, 2014. How Can I Trade Internationally in Roots of American Ginseng?.

Van der Voort, M.E., McGraw, J.B., 2006. Effects of harvester behavior on population growth rate affects sustainability of ginseng trade. Biol. Conserv. 130, 505–516.

Van der Voort, M.E., Bailey, B., Samuel, D.E., McGraw, J.B., 2003. Recovery of populations of goldenseal (hydrastis canadensis l.) and American ginseng (Panax quinquefolius l.) following harvest. Am. Midl. Nat. 149, 282–292.

Vaughan, R.C., Munsell, J.F., Chamberlain, J.L., 2013. Opportunities for enhancing nontimber forest products management in the United States. J. For. 111, 26–33.

World Bank, 2015. China - World Development Indicators. World Bank, Washington, DC.

Yin, R., Newman, D.H., 1997. Long-run timber supply and the economics of timber production. For. Sci. 43, 113–120.