Small-scale Forestry
DOI 10.1007/s11842-015-9310-1

RESEARCH PAPER

Timber Harvesting Behaviour in Massachusetts, USA: Does Price Matter to Private Landowners?

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Accepted: 27 October 2015

Abstract Non-industrial private forest is the dominant ownership type in the eastern USA. Most of the private owners have non-consumptive, appreciative values and through surveys report little interest in the generation of timber revenue. Timber harvesting in Massachusetts was investigated for a 25-year period to compare the frequency and volume of harvests for five commercial species on private land, to species-specific stumpage prices reported on a quarterly basis. For four of the five species, there was no relationship; however, for one species a consistent effect was identified, whereby the volume harvested and number of harvest events were found to be significantly related to stumpage price, west of the Connecticut River. This effect is absent for eastern Massachusetts, and also not apparent consistently for other species. It is concluded that under some circumstances, private landowner harvest decisions are influenced by stumpage price.

Keywords Stumpage price · Private landowners · Granger causality · Red oak

Introduction

Forests as socioecological systems are influenced by a variety of natural and anthropogenic disturbances, the latter being a function of ownership, its decision-making, and resulting behaviour. Different owners, whether public or private, make decisions about their forests that have ecological consequences. Timber harvest is an excellent example. The decision to commercially harvest can alter forest

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Published online: 02 November 2015

composition, growth rate and successional trajectory. This in turn can influence habitat structure, hydrological function, carbon sequestration, future harvest potential, and other ecosystem services.

In the USA, 58 % of all forest is in some form of private ownership, two-thirds of which are in the private, non-corporate ownership category (Oswalt et al. 2014). This includes forest owned by families, individuals, trusts, and other non-profit entities. In aggregate, this private, non-corporate category [often referred to as non-industrial private forest (NIPF)] represents almost 39 % of the nation's forest, making it comparable to the proportion of forest in public hands. In many parts of the eastern USA, forested landscapes are dominated by this ownership type.

Landowners—whether public, private corporate, or private non-corporate—may harvest timber for many reasons. One obvious reason is to generate income, but others include the creation of early seral (successional) habitat conditions, rearranging the age class distribution of forests, removing low-value material to enhance the eventual production of more desirable timber, salvaging dead or dying material, reducing fire hazard and fuel loads, and the creation of views. To what extent does timber price or the stumpage market influence the decision to harvest? Can a socioeconomic circumstance such as timber price in the marketplace serve as a catalyst for ecological disturbance in forest landscapes?

Private Landowner Attitudes Towards Harvest

Decades of research have repeatedly shown that many private non-corporate or nonindustrial private forest owners place a low priority on timber management (e.g., Jones et al. 1995; Birch 1996; Butler 2008). Ownership goals tend to align more with non-consumptive, appreciative motivations, including wildlife, aesthetics, a backdrop to a residence, privacy and recreation. Landowners are generally well educated and relatively affluent, with only a small fraction of their income derived from harvest.

Most private owners do not have a management plan, or receive advice from a professional forester for a timber sale (Butler 2008). When harvest does happen on NIPF lands, it is generally done with little or no professional forestry input. Butler and Leatherberry (2004) reported that half of family forest owners have had timber harvested on their land, but only 3 % have a forest management plan. Since most private owners do not have a management plan, and, since most own their land for reasons other than timber management or the derivation of income, and since most are affluent and probably don't need the money, why do they cut?

Kittredge (2004) presented a private landowner decision cycle, whereby the land is passively providing the appreciative benefits sought by most landowners, and then an exogenous event occurs that stimulates an interest in financial income. This can be something quite unrelated to the land itself, e.g., divorce, need to distribute assets, tuition bills, uninsured medical expenses, retirement. Faced with an unexpected expense, and if there are insufficient liquid assets available, timber might be harvested to generate the required income.

Landowners and Price of Timber in the Market

Beach et al. (2005) conducted a meta-analysis of published studies investigating landowner harvest decisions and price. Owners either followed a profit-maximization or utility maximization model. The latter focused less exclusively on income generation through timber harvest, and more on maximizing the suite of appreciative and consumptive benefits from their forest. Nationally, they found 19 econometric studies of NIPF owner behaviour and harvest. Most of these were based in the southern USA, and only four were from the northeastern USA. Of those, two showed a positive, significant effect with price, and two failed to show a relationship with price. Three of four studies were from New Hampshire, the other from Connecticut, and all four were published between 1981 and 1990. One of the studies from New Hampshire was Binkley (1981) who found "The probability of timber harvest is strongly affected by stumpage price". Dennis (1989), however, found the likelihood of New Hampshire private owners selling timber was related to the acres owned and relative proportion of valuable species on a property (e.g., in this case, red oak and eastern white pine), but reported no relationship between landowners' harvest decision and price.

Amacher et al. (2003) also noted the consistent positive relationship between ownership area and likelihood of harvest. In a review of 28 published papers that estimated likelihood of harvest based on a variety of independent variables, Silver et al. (2015) found that the variable most often cited (i.e., from 16 papers) was ownership size, and its effect was universally positively related to harvest. Harvest price was positively related to likelihood of harvest, but only surfaced in the analysis from 7 published papers. The question of private landowner harvest may be more a matter of ownership size than price.

Markowski-Lindsay et al. (2012) studied Massachusetts landowner likelihood of having biomass harvested on their land with respect to a number of independent variables, including price per acre. They found "forest owner participation in biomass harvesting is not greatly influenced by a change in price (i.e., price per acre)". Aguilar et al. (2013) studied Missouri landowner attitudes towards biomass harvest and found owners to be rather insensitive to price.

In a literature review of econometric papers and landowner decision making, Amacher et al. (2003) cited a number of studies that showed both landowner responsiveness and indifference to price and harvest. They concluded: "Not surprisingly, there has been considerable debate regarding the role that prices play in harvesting decisions". They attribute this to different values landowners place on other benefits from their land, as well as differences in relative affluence and thus the impact of timber income. A survey of New York landowners who had sold timber revealed that only 4 % of them had consulted the state's timber price report beforehand (Rosen et al. 1989). They further concluded: "NIPF timber marketers engage in extremely limited search for information, and the sources they consult are generally poor compared with the experts' recommendations". The dynamic between price and a positive harvest decision has been described as a "reservation price", representing the minimum price an owner would need to receive in order to make the harvest decision. Gould (1984) described a New Hampshire study in 1955, whereby this reservation price appeared to guide the harvest decision of private landowners: “If prices fell below some threshold, they cut little or nothing. At the other extreme, if prices rose well above what they felt to be the fair price, they cut considerably more than normal.”

The research objective is guided by the following questions: Is the private landowner harvest decision influenced by the stumpage marketplace? Are landowners swayed to harvest (i.e., inspired to depart from their satisfied, status-quo approach of doing nothing on the land and appreciating its benefits) if they perceive the marketplace is returning a good price? If few are consulting a timber price report or other official market information, they may be indirectly hearing about price variation through informal social connections. Are landowners who generally profess indifference to timber as an ownership goal responsive to price? It is possible that landowner surveys assessing attitudes towards harvest have been conducted in times of poor prices or a weak market, thereby giving a “false signal” about attitudes. Importantly, this analysis a way to further explore landowner behaviour, and not an econometric modeling or supply-and-demand exercise.

The Study Area

In spite of being the 3rd most densely populated state in the nation (U.S. Census 2010), Massachusetts is heavily forested. Its more than 3 million acres of forest rank it as the 11th most forested state by land use nationwide (Oswalt et al. 2014). Roughly two-thirds (66.9 %) of the timberland area is privately held. The majority of this private forest (84.3 %) is in the private, non-corporate category (i.e., private lands that are not owned by corporate interests, including individuals, Native American lands, unincorporated partnerships, clubs, and lands leased by corporate interests), with the remainder being considered private corporate (i.e., forest land that is administered by entities that are legally incorporated, Smith et al. 2009). More than half the public land (57.7 %) is held by state agencies. County and municipal forest represents 36.4 % of public lands, and Federal forest makes up the small remaining balance (Oswalt et al. 2014).

In Massachusetts, private non-corporate lands are predominantly owned by families and individuals. There are an estimated 27,000 ownerships greater than 4 ha (10 acres), with the average ownership of 15.5 ha being relatively small by forest management standards (Butler et al. 2014). Landowner attitudes in Massachusetts mirror those from around the nation. Owners prefer to own forest for appreciative and non-consumptive reasons, are relatively well educated, and do not rely on timber revenues for a substantial portion of their income (Belin et al. 2005; Butler 2008; Rickenbach and Kittredge 2009).

Two unique sources of data are used to study the question of private landowner harvest decision-making with respect to timber price in the marketplace, viz. harvest data and stumpage data. In Massachusetts since 1983, the statewide Forest Cutting Practices Act (FCPA) has required a Forest Cutting Plan (FCP) be submitted for any commercial timber harvest of greater than 87 m^3 (i.e., 25 thousand board feet or

Mbf) on private or public land. Specifically this is only required for harvest with the intent of leaving the land in forest use. Any harvest with the intent of converting the land use to another (e.g., development, agriculture) is considered land clearing, and not subject to the FCPA. The FCPA is overseen by the state's Bureau of Forestry. County Foresters review submitted FCPs, make on-the-ground judgments of the proposed plan (in terms of the protection of water quality and rare species habitat), and approve, approve-with-amendments, or disapprove them. FCP data are recorded in a statewide database, thereby providing a continuous record of every commercial timber transaction >87 m^3 on public and private land, importantly not involving harvest as part of land clearing or some other non-forestry activity. These data should be viewed in light of several caveats:

1. The preparer of the FCP is required to declare the volume to be harvested by species, but the Bureau of Forestry does not verify this volume. If the proposed volume is obviously not consistent with what is observed on the ground, the landowner is informed.
2. It could be possible that some timber transactions escape regulation (i.e., are done illegally), however this is unlikely. Massachusetts is the third most densely populated state in the nation, and harvesting is difficult to hide.
3. These FCP data are captured by clerical staff in the Bureau of Forestry for purposes of administrative record keeping, but are not held to a rigorous research data protocol.

While these regulations provide a unique record of harvest transactions over multiple decades and hundreds of thousands of forested acres, they are not a perfect representation of all transactions. In this way, they need to be used with the understanding that they are a reasonable reflection of commercial harvest activity on a statewide basis. Though generated for administrative and regulatory purposes, these data have been used for several published research studies (McDonald et al. 2006, 2008; Thompson et al. 2011; Blumstein and Thompson 2015).

With regard to stumpage data, since 1988 in Massachusetts the state Extension Forester (who is also the lead author of this study) has conducted a quarterly survey of over 250 sawmills, loggers, and public and private foresters to assess the stumpage marketplace in southern New England (the tri-state region of Massachusetts, Connecticut, and Rhode Island; see: UMass Extension 2015; Fig. 1). Reporting is voluntary. Between 1988 and 2011, the total number of reported sale transactions in a quarter ranged from 39 to 155 (mean = 88; median = 95; Smith et al. 2012). In some cases the buyer of stumpage reports the price paid, and in others the seller reports, and there is no control, thereby the possibility exists for double reporting of a transaction and its price. For sawtimber, prices are reported by species in $/thousand board feet (International ¼ inch). Submitted data are summarized by species in a 1-page report available on masswoods.net that provides median, high, and low price, as well as the number of reported transactions upon which these prices are based. Results are reported on the basis of whether the transaction took place east or west of the Connecticut River that roughly bisects the region (Fig. 1).

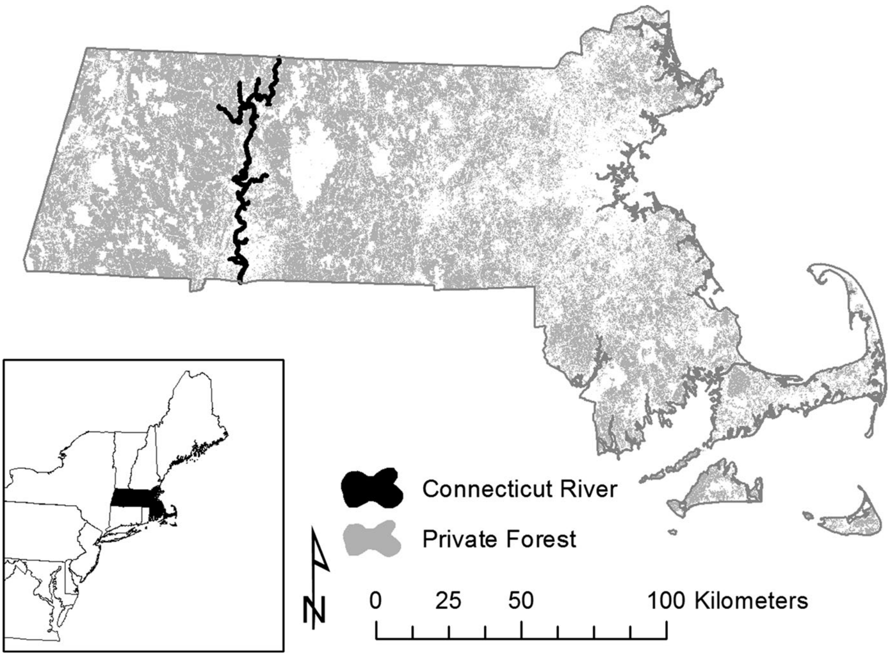

Fig. 1 The state of Massachusetts, in the northeastern USA, showing the Connecticut River

The underlying bedrock geology of the region is defined by more nutrient-rich limestone to the west, which has given rise to more fertile soil parent material than that found east of the River (Hall et al. 2002). Site quality is correspondingly higher, and this is reflected in the quality of hardwood timber (e.g., red oak, sugar maple, black cherry). For this reason, stumpage prices are summarized on the basis of east or west of the River, rather than by state. An earlier study with these data showed no significant differences within the region by state (Kittredge et al. 1999). These summarized regional stumpage transaction data represent a reliable estimate of the marketplace in Massachusetts, though they include data from adjacent Connecticut and Rhode Island, as well. Like the FCPA harvest data captured for administrative and regulatory purposes, these stumpage data are not gathered for research purposes, but for outreach purposes of providing private woodland owners, foresters, and others with an indication of the marketplace. They are also used annually by the Commonwealth of Massachusetts to set the property tax values of timberland enrolled in the state's current-use property tax program.

The FCPA data for timber harvest on private land in Massachusetts between 1988 and the second quarter of 2013 were used. Overall, this represented 16,221 harvest operations, and averaged 624 (SD = 90) annually. The data were binned by location east or west of the Connecticut River, to coincide with reported stumpage prices. In review of the data, what appeared to be some outlier values of exceedingly large volume for individual operations were encountered. These may have been due to errors in data entry or misinterpretation of directions on the FCP form (e.g.,

Table 1 Summary of harvest activity on private lands, Massachusetts, 1988 to the 2nd quarter of 2013 (i.e., 25.5 years)

Timber harvest characteristics	East of the Connecticut River			West of the Connecticut River		
	Min	Max	Mean	Min	Max	Mean
Total harvest volume (m^3/year)	58,523	290,764	164,892	25,115	155,622	82,399
Frequency of harvest events (no./year)	210	421	328	131	267	193

entering bf rather than Mbf). Based on experience and expert opinion, the harvest data were reviewed and observations removed from the records after 2003 that were >30 % above the max value seen in the in the pre-2003 data. Overall, this process of data review resulted in the removal of 90 observations (39 Oak, 25 Pine, 17 Hemlock, 5 Cherry, 4 Sugar Maple) due to unreasonably high reported volumes. A summary of the private timber sales used in the analysis is represented in Table 1.

From reported quarterly stumpage summaries, the median and reported high price for red oak, white pine, eastern hemlock, black cherry, and sugar maple were extracted for transactions that occurred east and west of the Connecticut River in southern New England, between 1988 and 2013 (second quarter). These five commercial species represent approximately 50 % of the total basal area/hectare, and almost 55 % of the growing stock volume on timberland in Massachusetts (Butler and Barnet 2014; Fig. 2).

Categories for data collection changed in 1994, allowing for data for black cherry and sugar maple to be used from this date forward. The reported maximum price for

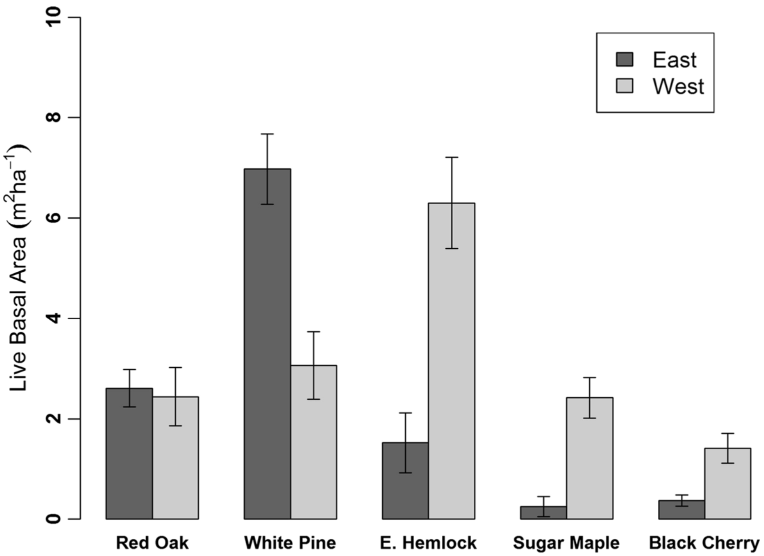

Fig. 2 Average basal area (m^2/ha) for the tree species examined in this study. Estimated from U.S. Forest Service Forest Inventory and Analysis (FIA) plots located on Massachusetts' private forestland east and west of the Connecticut River. *Error bars* indicate standard errors around the mean

Table 2 Summary of quarterly stumpage price data ($/Mbf), 1988 to 2013 (2nd quarter)

	East of the Connecticut River					West of the Connecticut River				
	n[a]	Min	Max	Mean (sd)	Median	n[a]	Min	Max	Mean (sd)	Median
Red oak	102	100	450	236 (66)	250	102	125	600	305 (83)	300
White pine	102	45	130	76 (19)	75	102	37	103	64 (15)	63
Hemlock	102	10	60	30 (9)	30	102	10	55	28 (8)	30
Sugar maple	78	40	300	149 (73)	150	78	40	450	256 (84)	238
Black cherry	78	40	400	162 (82)	150	78	150	600	308 (105)	300

The number of observations (n), minimum, maximum, mean, and median are for the median quarterly stumpage prices, east and west of the Connecticut River

[a] The n reflects the number of quarters used in the analysis. These summary stats are all derived from the median quarterly data

each of these quarters, as well as the number of transactions upon which the median and high are based was also recorded. A summary of the stumpage prices used in the analysis is presented in Table 2.

Research Method

The relationship between harvest activity and price was analyzed using the notion of Granger causality, which attempts to identify causal relationships between two or more time series (Granger 1969). Granger (1969, p. 430) defines causality as follows: "if some other series y_t contains information in past terms that helps in the prediction of x_t and if this information is contained in no other series used in the predictor, then y_t is said to cause x_t." In this study, to say that stumpage price "Granger causes" harvest activity is to say that past values of stumpage price contain information useful for predicting harvest activity, beyond the information contained within past values of harvest activity alone. Granger causality was developed within econometrics (and garnered the 2003 Nobel Prize in Economics for Granger) and has been widely applied in the natural sciences, including geosciences (Smirnov and Mokhov 2009), hydrology (Salvucci et al. 2002), and ecology (Detto et al. 2012).

To avoid pre-test bias associated with the cointegration tests that are part of the conventional Granger-causality test (Zapata and Rambaldi 1997), a modified procedure introduced by Toda and Yamamoto (TY; Toda and Yamamoto 1995) was used. The TY procedure tests for Granger causality but does not require pre-testing for cointegration, thus enabling feedback effects through several lags (Zapata and Rambaldi 1997). The TY procedure is a modified Wald test that is to test restrictions on the parameters of a vector autoregressive model (VAR(k)), where k is the optimum lag length. The statistic follows an asymptotic χ^2 distribution with k degrees of freedom ($\chi^2(k)$). The procedure requires augmenting the VAR(k) in levels with the maximum order of integration, m. Then a Wald test is conducted on the first k parameters. If the first k parameters are found to be statistically significant, then the null hypothesis of non-causality is rejected.

To implement the TY procedure, the following steps were followed: First, the maximum order of integration (m) in the harvest variables (total harvest volume and number of events) and price variables (median and max) was determined using an Augmented Dickey–Fuller Test, for which the null hypothesis is non-stationarity. The Schwarz Bayesian criterion (Schwarz 1978) was used to determine the optimal lag length, k, for each VAR model, but the maximum lag length was set to four quarters to better identify any relationship between recent price and behaviour and it was not expected that price information that was more than a year old would affect landowner decision-making. The Portmanteau statistic was calculated for the selected VAR model to test for residual serial correlation. Finally, a standard Wald test was used to test the hypothesis that the coefficients of the first k lagged values of price are zero in a VAR model of harvest.

Mathematically, VAR models of the form below were fit:

$$Harv = a_0 + a_1 Harv_{t-1} + \cdots + a_k Harv_{t-k} + b_1 Price_{t-1} + \cdots + b_k Price_{t-k} + \varepsilon_t$$

The regression coefficients were then tested simultaneously H_0: $b_1 = b_2 = \cdots = b_k = 0$, that *Price does not* Granger-cause *Harvest.* A rejection of the null implies there is Granger causality.

Importantly, individual landowner response to a specific offered price for their timber was not tested. Instead, relationships are compared between: (1) aggregate data that reflect reported regional quarterly median and maximum stumpage price by species (east and west of the Connecticut River); and (2) (a) aggregate volume of timber reported by the MA Bureau of Forestry regulatory FCP data to be harvested quarterly from private land, by species, and (b) the number of harvest transactions, by species, from private land east and west of the Connecticut River.

The Granger causality test is a statistical hypothesis test for determining whether one time series is useful in forecasting another. To say that one variable, *X,* "Granger-causes" another variable, *Y,* is to say that predictions of Y based on past values of X and Y are better than predictions of Y based on past values of Y alone. Just as with more familiar statistical hypothesis tests (e.g., ANOVA, *t* test), the Granger causality test makes inference about a population distribution based on the properties of a sample and deems a relationship "significant" if the probability of realizing that relationship under a null hypothesis is below a specified threshold. We calculated a *P* value and used a conventional threshold of <0.05 for rejecting the null-hypothesis that X Granger-causes Y. In practice, the *P* value reflects both the intensity of the predictive relationship and the size of the sample. Therefore, for two tests with the same sample size, the lower the *P* value the stronger the predictive relationship.

Results

All the series examined are integrated at order one and hence the size of all VAR models was equal to the number of the lags used in the model plus one ($k + 1$). The lag often reached the maximum allowed length of four quarters; nonetheless Portmanteau statistics indicated no residual serial correlation in the error terms.

There were few examples where median or maximum stumpage price Granger-caused harvesting (8 of 44 Granger tests, where the resulting P value was less than the 0.10 threshold; Table 3).

The most consistent example of a relationship was for red oak harvesting within the western reporting zone, where oak harvest volume and the number of oak harvest events were Granger-caused by both measures of price, though, the maximum price showed stronger evidence. The number of harvest events with hemlock and black cherry in the eastern reporting zone were Granger-caused by median (but not maximum) price. White pine volume in the eastern zone was

Table 3 Granger analysis results comparing volume harvest and number of harvest plans with stumpage price, by species

Harvest activity by species	East of the Connecticut River				West of the Connecticut River			
	Lag (p)	Port[a]	P > VX^2	P value	Lag (p)	Port[a]	P > VX^2	P value
(a) Volume harvested, median price								
Red oak	4	0.58	3.1	0.52	4	0.16	8.67	0.06
White pine	3	0.289	12.8	0.23	4	0.74	6.05	0.19
Hemlock	4	0.97	6.18	0.18	4	0.43	2.85	0.58
Sugar maple	3	0.89	0.8	0.84	4	0.79	2.42	0.65
Black cherry	4	0.47	4.7	0.30	1	0.17	3.5	0.47
(b) Volume harvested, max price								
Red oak	4	0.54	1.8	0.76	4	0.35	10.72	0.02
White pine	3	0.13	19.46	<0.01	4	0.48	2.60	0.62
Hemlock	4	0.99	2.1	0.71	4	0.26	3.10	0.54
Sugar maple	3	0.3	1.6	0.64	4	0.32	1.32	0.85
Black cherry	4	0.89	4.1	0.38	1	0.22	3.68	0.44
(c) Number of plans, median price								
Red oak	3	0.6	5.19	0.15	4	0.39	10.10	0.04
White pine	4	0.33	2.4	0.64	4	0.34	19.45	0.00
Hemlock	4	0.29	12.07	0.02	4	0.24	4.42	0.35
Sugar maple	2	0.91	2.1	0.34	4	0.65	5.10	0.27
Black cherry	3	0.67	9.5	0.02	2	0.16	3.72	0.16
(d) Number of plans, maximum price								
Red oak	4	0.61	4.1	0.38	4	0.66	12.6	0.01
White pine	4	0.149	6.07	0.19	4	0.18	7.01	0.13
Hemlock	1	0.177	3.14	0.36	3	0.65	1.8	0.60
Sugar maple	2	0.8	3.6	0.46	4	0.46	7.8	0.10
Black cherry	4	0.88	3.1	0.53	4	0.24	7.5	0.11
(e) Total harvest volume								
Red oak median price	4	0.22	3.7	0.30	4	0.15	4.42	0.35
Red oak maximum price	3	0.21	2.57	0.46	4	0.52	1.55	0.81

[a] Here Port represents the portmanteau statistic for the selected VAR model to test for residual serial correlation, and Lag (p) is the number of lagged quarters

Granger-caused by the maximum price and the number of pine harvesting events in the western zone was Granger-caused by the median pine stumpage. Finally, there was no evidence to support the notion that red oak price (median or maximum) Granger-caused overall harvest volume (from 1994 to 2013, second quarter).

Discussion

Harvest Activity by Median and Maximum Stumpage Price

In only three circumstances of the 20 tested (i.e., red oak, white pine, hemlock, sugar maple, and black cherry; east and west of the Connecticut River; for both median and maximum stumpage price) was there evidence of price Granger causing regional harvest volume. Interestingly, the median and maximum price of red oak west of the Connecticut River Granger causes harvest volume. This relationship between price and volume harvested is absent for red oak east of the Connecticut River. The maximum price of eastern white pine was found to Granger cause harvest volume east of the Connecticut River.

Harvest activity could also be expressed in terms of the number of Forest Cutting Plans. In five circumstances of the 20 tested evidence of price Granger causing the regional number of Forest Cutting Plans was found. Both the maximum and median price of red oak west of the Connecticut River Granger caused the number of Forest Cutting Plans. Again, this influence was not detected for red oak east of the River. White pine median price west of the River, as well as hemlock and black cherry prices east of the River Granger caused the number of Forest Cutting Plans.

Of the eight circumstances where price Granger caused harvest activity, four of them were red oak west of the Connecticut River. The fact that this relationship was consistently absent for red oak east of the River, and present west of the River for this species suggests that price is importantly related to the amount of harvest activity in this latter region. There were several other significant relationships, but none were consistent by region or species, and could be more the result of unknown effects.

If Some Timber Entering the Marketplace is Granger-Caused by Price, How Can this be Explained?

Decades of research on landowner attitudes indicates landowner disinterest in harvest and generating income as ownership goals. Kittredge (2004) suggests that if harvest happens on private land, it is in response to or coincident with exogenous stimuli (e.g., retirement, divorce, college tuition, need for cash) and thus occurs randomly in the landscape, varying from landowner to landowner based on their personal and individual circumstances (i.e., level of affluence and need), and hence not induced by marketplace price signals. What explains the consistent Granger-causality of red oak price west of the Connecticut River influencing both the volume of red oak sold, and the number of red oak sales? It is possible that this is the result of proactive contact by sawmills, loggers, and private consulting foresters. As the marketplace heats up for oak, the activity of purchasers of standing timber increases, resulting in an increasing number of contacts experienced by private landowners. Increased contact, in turn, results in a higher likelihood of coinciding with landowner need for cash. Red oak is special in this case, because it is consistently the most valuable commercial species in the southern New England forest. Its wood is prized for furniture, flooring, cabinets, veneer, and other interior uses. It is understandable that the region's most valuable timber commodity would be most reactive to market fluctuations. What is interesting is that this market reaction occurs west of the Connecticut River, with the higher site quality and corresponding timber quality, but not east of the Connecticut River.

These increased contacts can also be between other landowners functioning within social networks of peers communicating informally with one another (e.g., Kittredge et al. 2013; Sagor and Becker 2014). Thus, most landowners themselves are not directly watching the market and timing their harvest, but are more prone or susceptible to increased contact by purchasers of standing timber when prices are higher. In particular the reported maximum red oak price expresses more Granger causality of red oak volume and the number of transactions west of the Connecticut River than the median price (indicated by more significant *P* values; Table 3). The maximum price probably attracts more attention and stimulates conversations about what a landowner could receive for their standing red oak. Interestingly, the efforts of timber purchasers appear successful resulting in more timber sold, in spite of the general indifference or apathy of landowner to the sale of timber.

Importantly, these results do not suggest that the median or maximum price of red oak Granger causes total timber harvest volume west of the Connecticut River (Table 3(e). The Granger-causality effect detected west of the River appears specific to red oak, and not a stimulant to the overall timber marketplace. In light of the mixed species compositions of most stands (e.g., FIA for Massachusetts estimates that red oak comprises 12.5 % of timber volume of the average acre of forest; Butler and Barnett 2014; Fig. 2), it is somewhat surprising that red oak price does not Granger-cause more harvest in general. Most timber sales would end up harvesting a variety of commercial species from a given ownership, and not focus exclusively on red oak. Furthermore, these results are interesting in their regional specificity. There was no case where the price of red oak Granger-caused harvest activity east of the Connecticut River. This result suggests a certain sub-regional concentration of stumpage purchasers west of the Connecticut River who are particularly effective at appealing to landowners. It also is probably related to the generally higher timber quality and prices for red oak found west of the River (e.g., median price of red oak west of the River for the observation period was $305/Mbf, vs. $236/Mbf east of the River; Table 2).

Comparison with Previously Published Results

These results indicate red oak stumpage price west of the Connecticut River Granger causes red oak timber harvest. Interestingly, these results align with those of Binkley (1981) in the adjacent New England state of New Hampshire: "The probability of timber harvest is strongly affected by stumpage price.". The Binkley study was based on data from 1947 to 1973. However, in this study there was no relationship east of the Connecticut River (running contrary to the Binkley (1981) results), implying a regional sensitivity below the scale of a rather small state. These model results and relationships are relevant for red oak stumpage price ($/Mbf) ranging from 125 to a maximum of 600 (Table 2). It is probably not safe to extrapolate them beyond this price range. It is thus impossible to say what landowners might do if the prices were double or triple those observed and used in the models reported. Also, the analysis is based on data representing harvest decisions in Massachusetts between 1983 and 2013 in a landscape dominated by small, non-industrial ownerships. Care should be taken in extrapolating these results, or the lack of a relationship between timber price and harvest behaviour, to areas with larger ownerships and owners who may have more interest in harvest and timber management. It is worth noting, however, that family forest owners in Massachusetts are not that dissimilar to family owners nationwide when it comes to attitudes towards their land (Butler 2008).

Harvest Sensitivity to Price and Ownership Size

It is not known if there is a price threshold, beyond which the probability of harvest increases. These results show that red oak prices west of the River Granger-cause more red oak timber to be sold. At what red oak price do purchasers of standing timber become more proactive, creating more landowner contact and market activity? This question is relevant for red oak east of the River, where price appears to have no Granger effect on harvest.

Amacher et al. (2003) reported a positive relationship between harvest and the size of ownership, as did Dennis (1989). Kittredge et al. (2008) studied private ownership size variation in Massachusetts and noted that in the central part of the state (east of the Connecticut River), mean ownership was 8.2 ha (SE = 0.2), compared to 9.9 ha (SE = 0.1) west of the River. Larger ownerships could be related to greater likelihood to harvest west of the River however this was not seen consistently for other species besides red oak.

Conclusions and Policy Implications

In Massachusetts, between 1988 and 2013, private landowner timber harvest decision making, estimated by volume and the number of transactions of red oak west of the Connecticut River, was related to the price of red oak in the marketplace. This phenomenon is not consistently observed for other species. Since the analysis used aggregate regional data over time, it was not possible to explore this relationship at the social scale of the individual owner. The general disinterest in timber income and management revealed through decades of landowner research likely remains relevant, but these results suggest the apathy or indifference is not universally true, and under some circumstances can be overcome for the region's most valuable species. In particular, these results suggest that fluctuations in red oak price can result in more harvest activity of that species. This is important, since

Canham et al. (2013) observe: "Logging is a larger cause of adult tree mortality in northeastern U.S. forests than all other causes of mortality combined.". Other commercial species are still harvested, but this harvest is unrelated to price, further substantiating the belief and research results that point to private landowner apathy and disinterest in timber management and harvest income. Something else triggers private owners to harvest, but it is not related to the price of these species in the marketplace.

This influence of price and the marketplace is neither uniform nor consistent, and instead surfaces in areas where the timber quality is relatively high, and the market infrastructure of timber buyers is effective at reaching private owners. The influence of timber price manifests itself differentially and sporadically through the region, and in general supports previous research that landowners are largely indifferent to price, and when they do harvest, it is for other reasons besides direct market influence. It remains to be seen whether or not this indifference will continue in the future, as market prices for timber rise due to scarcity and heightened demand. Timber market price is not static, as cultural taste and preference for various species can change. For example, Flagg (1890) observed: "The Red Oak is the largest of the genus belonging to American woods, and the least useful for any purpose except those of shade and ornament". Historically, there was a time when red oak had little or no market value, and it is uncertain what the future holds for timber price and its potential effect on harvest.

The results show that under some circumstances, private forest owners may shift from their typically indifferent attitude towards harvest, to harvesting in a species-specific way in response to price. It may thus be important for forestry agencies to monitor stumpage price, since it can be an indicator of heightened, species-specific harvest activity. Increases in harvest activity could have effects on wildlife habitat, biodiversity, and water quality, especially in states that have little or no harvest regulation for environmental protection. Monitoring price allows agencies to keep a finger on the pulse of harvest activity in a rather inexpensive administrative way. Under elevated price conditions, increased outreach and education to private landowners may also be initiated.

Acknowledgments We would like to thank: Jennifer Fish, Massachusetts Department of Conservation and Recreation, for access to the Forest Cutting Practices Act timber harvest data; Liza Nicoll and Luca Moreale of Harvard Forest for data management; Dave Giles for advice regarding Granger analysis; University of Massachusetts Extension Forestry program and Masswoods.net for stumpage data. Sincere thanks to Brett Butler for his help developing the Memorandum of Understanding that allowed us access to the Forest Inventory and Analysis (MOU 14-MU-11242305-025). Funding support from a National Science Foundation Long Term Ecological Research grant to Harvard Forest (DEB-1237491).

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