Timber Economics of Natural Catastrophes

By
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Abstract

The United States regularly suffers losses of timber from a variety of catastrophic events, including hurricanes, wildfires, ice storms, and pest outbreaks. Such catastrophes can hurt timber producers through their effects on production, and prices if damages are widespread. These two forms of risk, production and price, have traditionally been examined independently of each other, but when damages are widespread the risks to production and price are not independent, they are joint. The joint nature of the risks substantially complicates the optimal response of landowners to such risks. Clarifying the implications of this joint risk is the central point of this paper. Fine-scaled events can cause investment losses to owners of killed timber but when catastrophes are widespread, salvage activities across a landscape depress prices and inventories, expanding the impacts to producers of timber undamaged by the event. While salvage gluts drive down prices in the near term and depress inventories, longer-term inventory effects can increase prices even higher than before. This would imply that when disasters first strike, owners of undamaged timber should delay harvesting, but some disturbance agents have temporal and spatial autocorrelations, which affect their medium-term production and price risks, complicating this simple rule of thumb. When disasters are prolonged over several years, as often happens with southern pine beetle, owners of undamaged timber must weigh the promise of future price rebounds against the increased production risks faced during those years of delay. Other agents have different temporal and spatial characteristics, this paper outlines the implications of these characteristics on the joint nature of price and production risk and their implications for optimal harvest decisions.

INTRODUCTION

Timber producers in the southern United States face a number of uncertainties in deciding whether and when to invest in timber production and in deciding when to harvest a particular stand of trees. These uncertainties include those related to production (production risk) and prices (price risk). Production risks include inaccuracies in projecting merchantable volume, quality and growth rates over time, inaccuracies in evaluating the yield effects of intermediate stand treatments, and unforeseen volume and timber quality losses caused by natural events including catastrophes. Catastrophes can be at stand and landscape scales. Stand-level catastrophes affect only small geographic areas and therefore have negligible effect on the larger timber market. Landscape scale catastrophes affect large geographic areas, and if sufficiently severe will affect market prices. Among the large scale catastrophes commonly seen in the South are southern pine beetle epidemics (Price, et al., 1998), fusiform rust (Pye, et al., 1997), hurricanes (Sheffield and Thompson, 1992), wildfires (Brenner, 1991), and ice storms (Halverson and Guldin, 1995).

Because the damages from catastrophes are non-homogeneous (Holmes, 1991), they induce wealth transfers. At least in the short run, timber consumers gain at the expense of producers. If a catastrophe causes a large enough loss in inventory that prices are increased (Prestemon and Holmes, 2000), then the remaining producers may benefit at the expense of consumers. Private and public efforts to reduce stand risks from these kinds of disasters might, in other words, have positive economic payoffs, at least for some kinds of disasters (de Steiguer et al., 1987; Hesseln, et al., 1998).

Given that natural disasters can influence both price and production risks, it is clear that price and production risks are jointly distributed, a factor that has been largely ignored in the theoretical literature on timber production. The goal of this paper is to describe the jointness of price and production risks arising from large-scale natural catastrophes such as those experienced by timber producers in the South. We begin by discussing in general terms how price and production risks affect timber production behavior. Next, we characterize the price risks that are generated by disasters, focusing on the price depression from the salvage glut and a potential price enhancement generated by inventory reductions from these disasters. We then describe how knowledge

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about the spatial and temporal autocorrelations in natural catastrophes can help timber growers make better management decisions. This is illustrated with examples of wildfire in Florida and southern pine beetle (SPB) epidemics across the South.

PRODUCTION UNDER RISK

As shown by various authors (Martell 1980; Routledge 1980; Reed 1984; Reed and Errico 1985, Caulfield 1988; Valsta 1992; Yin and Newman 1996; Hesseln, et al., 1998) production risk has a uniformly negative effect on optimal harvest age, expected returns, and land value when compared to the deterministic Faustmann model. When the production risk is constant, annual risk has an effect analogous to a premium added to the discount rate that exactly equals that constant annual risk (Reed 1984). Most of the numerical examples of optimal behavior under risk-neutrality explored by Martell (1980), Routledge (1980), Reed (1984), Caulfield (1988), and Yin and Newman (1996) show reductions in optimal harvest ages of 1-5% for each absolute percent of production risk; land values were reduced by similar magnitude compared to the deterministic model. Valsta (1992) showed much larger effects for thinned Scots pine stands. Depending on the degree of positive risk aversion of an individual, however, reductions could be even larger (Caulfield 1988).

Price risk is caused by uncertainties in the short- and long-run levels and variability of prices. Prices vary over time because of changes in government policies, technology, consumer preferences, and, not inconsiderably, natural catastrophes. The effects of price risks on optimal production behavior depend on the nature of prices (e.g., Brazee and Mendelsohn, 1988; Clarke and Reed, 1989; Haight and Holmes, 1991; Thomson, 1992). Compared to the deterministic Faustmann case, stationary prices, for example, may enhance land value and extend the rotation length; nonstationary prices might do the opposite.

Most of these cited models of production and price risks have assumed that the degree of risk is constant over time or varies predictably with characteristics of the stand (e.g., stand age). The real world may be much more complicated. Analyses by Gumpertz et al. (2000) and Mercer et al.(2000) have shown that risks of broad-scale natural catastrophes are not constant over time; rather, they evolve in somewhat predictable ways. Understanding the temporal and spatial nature of natural catastrophes on timber production and how these catastrophes affect prices should help decision makers optimally prepare and respond to them. In particular, it would be useful to understand how the characteristics of various kinds of disasters affect the dynamics of timber prices and the risk horizon of individual producers. That way, producers can minimize their economic losses, consumers can plan for volatile prices and input flows, and policy makers can evaluate whether intervention into the market would have positive or negative net payoffs to society.

HOW LANDSCAPE LEVEL DISASTERS AFFECT PRICES

Case studies of southern pine beetle (Holmes, 1991) and Hurricane Hugo (Prestemon and Holmes, 2000) illustrate the price dynamics following large disasters. In the short run, prices drop precipitously, driven by the additional glut of material available to timber buyers, the lower quality of salvage material, and the added costs associated with removing material from damaged stands. Salvage material has value for a limited time after the catastrophe, depending on the catastrophe's timing and nature as well as the climate in the region. The warm humid conditions in the South make salvage periods particularly short. Holmes (1991) showed how salvage logs negatively affected prices for fifteen months after a SPB outbreak in Texas and Louisiana in 1984-1985. Prestemon and Holmes (2000) determined that Hurricane Hugo's effect on South Carolina lasted less than a year, indicating that salvage operations continued for only about nine months after the storm. Price effects from these gluts dropped timber prices in Louisiana by 25% below pre-SPB outbreak levels and about 30% below pre-hurricane levels. In the case of Hurricane Hugo, removal of a large proportion of the available inventory created a long-run enhancement of prices by around 20%, although see Yin and Newman (1999) for contrary results.

Price swings following disasters have uneven effects for producers and consumers. During the salvage periods, producers of timber that was damaged suffer either a complete loss (i.e., if no material can be profitably recovered) or a partial loss (because the price of the salvage material is lower, compared to the no-disaster counterfactual) of the potential value of the stand. However, producers of undamaged timber that is ready to harvest also suffer losses as they are forced to harvest their stands at lower value during the salvage period or forced to absorb the costs of timber storage until the salvage period ends and prices recover. During this salvage period, consumers enjoy a period of unusually low prices. If a substantial loss of inventory occurs there is a second, price enhancement phase, during which producers of undamaged timber enjoy a higher price, partially mitigating the opportunity costs of storage during the salvage period. Consumers of that undamaged timber, on the other hand, must pay higher prices, lowering profits.

HOW DISASTERS ARE SPATIALLY AND TEMPORALLY RELATED

The preceding text has made casual references to spatial and temporal autocorrelation, which need to be made more explicit. Three kinds of autocorrelation may exist in nature: spatial, temporal, and spatial-temporal. Referring to cross-sectional units as *i* and *j*, time as *t* and *s*, temporal autocorrelation is where $\mathrm{Cov}(y_{i,t}, y_{i,s}) \neq 0$; spatial autocorrelation is when $\mathrm{Cov}(y_{i,t}, y_{j,t}) \neq 0$; and spatial-temporal autocorrelation exists if $\mathrm{Cov}(y_{it}, y_{j,s}) \neq 0$. The distinction between small and large disasters is inherently one of spatial autocorrelation. If sufficient damages occur in a neighborhood, we may say that damages are spatially autocorrelated. Under these circumstances production damages propagate to the broader scale at which prices operate, and under these circumstances production and price risks become joint. The regular dynamics of prices following a disaster imply a temporal autocorrelation whose lag structure is determined by the dynamics of salvage and storage processes. These spatial and temporal processes interact, constrained by limitations of shipping—if salvage material could be shipped without cost, the impacts of the salvaged material would be absorbed by the broader market. Increased hauling costs will act to confine the salvage and subsequent inventory depressions to more localized markets and create more extreme but localized dynamics. Different types of disasters have characteristic patterns of spatial and temporal autocorrelation, and understanding those patterns offers landowners improved means for ameliorating risks and improving returns to timber production. Wildfire and southern pine beetle outbreaks are disasters with very different spatial and temporal patterns but which share the problem of jointness of risk.

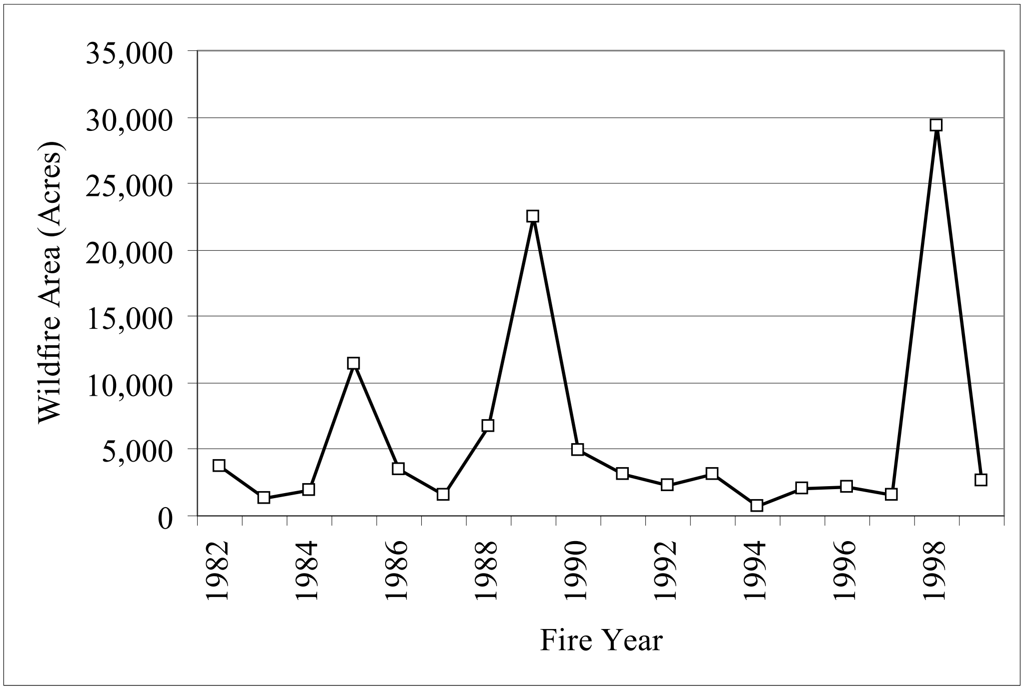
Wildfire Catastrophes

Mercer et al. (2000) examined historical forest wildfire data from Florida and found that the risk of wildfire in the current year across a given county is reduced by the amount of wildfires there in previous years, suggesting a “protective” effect. In statistical terms, wildfire has a significant negative temporal autocorrelation beginning with lag 1, in this case extending over at least 6 years, even when El Niño and urbanization measures are taken into account. At a county level, wildfire risk decreases by one quarter to one third for each of those years. Figure 1 gives a sense of the temporal variability in forest wildfire incidence over a multi-county area in Florida.

At this coarse scale, positive spatial autocorrelations were also observed, although these were reasonably explained by urbanization and other variables. The spatial autocorrelations at fine scales are of more obvious importance, as the contagious spread of fires threatens nearby landowners in a fashion easily visualized by anyone who has seen wildfires spreading through forest. A plot-level analysis in the same study confirmed the importance of neighborhood cover within ranges of a kilometer or two. In short, wildfires are subject to spatial autocorrelations at both fine and coarse scales. Such autocorrelations imply that landowners can improve their estimates of fire risk by tuning their estimates to local conditions. For example, the Mercer et al. (2000) study found that annual county-level risks of wildfire for forested lands varied from 0.02 to 6.9 percent.

More interesting for this analysis however are the implications for the landowner of temporal patterns of risk. While prescribed burning is a widely recognized tool for reducing risk of wildfires, prescribed burning is often not possible during a bad fire season, restricting landowners to a smaller set of risk reduction strategies such as herbicide and firebreaks. If widespread fires spare a given forest, its owner now has two reasons to delay harvest: 1) to avoid the depressed prices associated with salvage on nearby lands, and 2) to benefit from any subsequent price increases arising from inventory effects of the fires. Because fire risks to the spared forests will remain lower for several years, the forest will face reduced risks from fire during that delay period, an extra benefit.

Figure 1. Ecological section 232C wildfire area in Florida, 1981-1999, acres per year.



Southern Pine Beetle Catastrophes

Like wildfire, southern pine beetle (SPB) also exhibits patchiness and cyclical swings in its damage. Price et al. (1998) provide information that reveals both the temporal and spatial patterns of southern pine beetle outbreaks over broad scales. We'll use these data to show how outbreaks cycle between low outbreak years and high outbreak years, with damages severe enough in particular years to have real effects on timber markets but with dynamics which require extra considerations by forest landowners beyond those associated with fire.

Figures 2 and 3, based on Price et al. (1998), show the amount of pine sawtimber and pine pulpwood salvage entering the market for Alabama, a state heavily affected by southern pine beetle. The figures graph the annual SPB salvage relative to the average harvests in the state, and show the amount of timber killed relative to the measured inventory of timber. The amount of damage during the worst years is very substantial, although the proportion of the inventory reported killed by outbreaks is small, usually much less than 1 percent per year.

The effects of outbreaks vary greatly by product and by state, as well. Table 1 outlines the average annual salvage relative to harvests and the average annual SPB-killed volume relative to inventory by state. The maximum share of pine sawtimber killed in a state is 1.7% (Louisiana), the minimum 0.3% (Arkansas). However, there is much variability around the average, with the standard deviation of this ratio always greater than the mean. A similar pattern is observed for pulpwood. We note that pulpwood losses and salvage relative to inventory are always less than the analogous sawtimber losses and salvage, an expected result of SPB's preference for older, less vigorous trees. As disruptive as these outbreaks are to timber production of individual landowners, how large must they be to affect prices as well? The southern pine beetle outbreak of 1984-1985 killed approximately 18% of Louisiana's sawtimber inventory and 13% of sawtimber inventory in Texas. Prices decreased by 1.5% for each percentage point of inventory killed (Holmes, 1991), a price depression similar to that seen in South Carolina in 1989 when Hurricane Hugo killed nearly 20% of standing sawtimber inventory. In the case of Hurricane Hugo, we know that the loss of inventory ultimately created a long-run price enhancement of around 0.5 to 1.0% for each percent of inventory lost.

Table 1. Average annual southern pine beetle-salvage volume relative to average annual removals, and average annual inventory killed by southern pine beetle, and their standard deviations, 1975-1996.

State		Salvage/Removals		Killed/Inventory	
		Pulpwood	Sawtimber	Pulpwood	Sawtimber
AL	Average	0.065	0.080	0.005	0.006
	Standard Deviation	0.087	0.088	0.007	0.007
AR	Average	0.009	0.065	0.000	0.003
	Standard Deviation	0.015	0.105	0.001	0.005
FL	Average	0.001	0.055	0.000	0.004
	Standard Deviation	0.002	0.183	0.000	0.012
GA	Average	0.058	0.086	0.003	0.004
	Standard Deviation	0.095	0.152	0.004	0.006
LA	Average	0.042	0.272	0.004	0.017
	Standard Deviation	0.103	0.666	0.011	0.042
MS	Average	0.015	0.102	0.002	0.006
	Standard Deviation	0.025	0.127	0.002	0.007
NC	Average	0.034	0.180	0.001	0.006
	Standard Deviation	0.067	0.357	0.002	0.010
SC	Average	0.060	0.040	0.003	0.011
	Standard Deviation	0.071	0.056	0.004	0.022
TN	Average	0.014	0.108	0.002	0.011
	Standard Deviation	0.039	0.167	0.009	0.033
TX	Average	0.033	0.366	0.002	0.015
	Standard Deviation	0.059	0.753	0.004	0.030
VA	Average	0.061	0.527	0.001	0.010
	Standard Deviation	0.172	1.119	0.004	0.019

Data sources: Price, et al., (1998) and USDA-Forest Service, Forest Inventory and Analysis surveys.

Figure 2. Alabama southern pine beetle-killed pulpwood salvaged and losses relative to annual average removals and total inventory, 1972-1996.

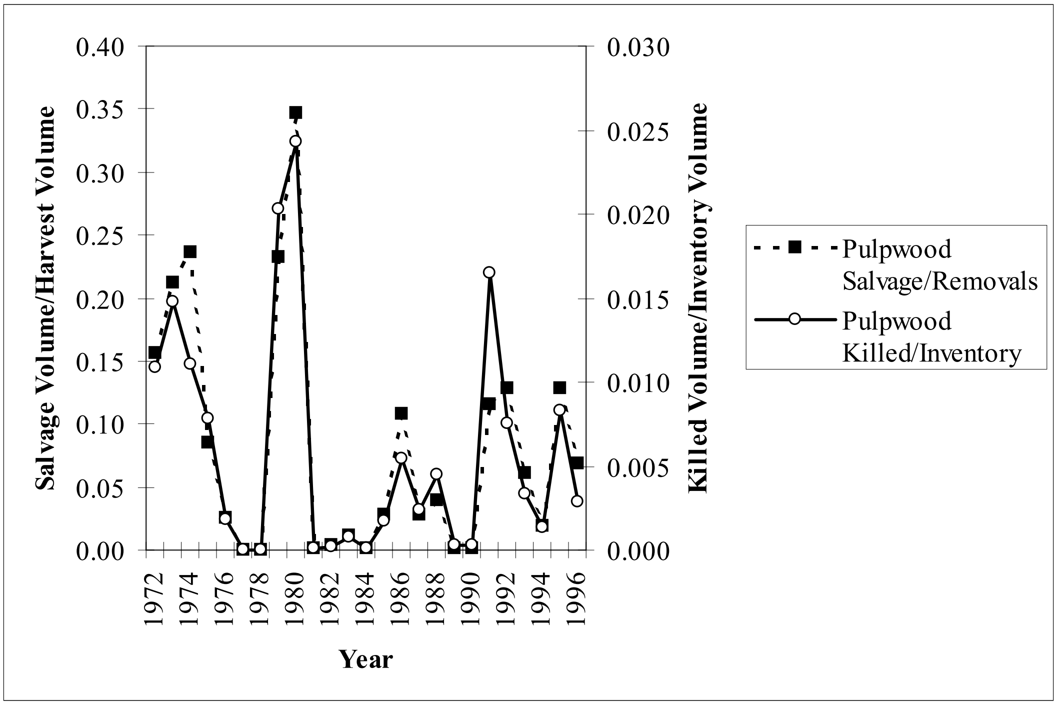
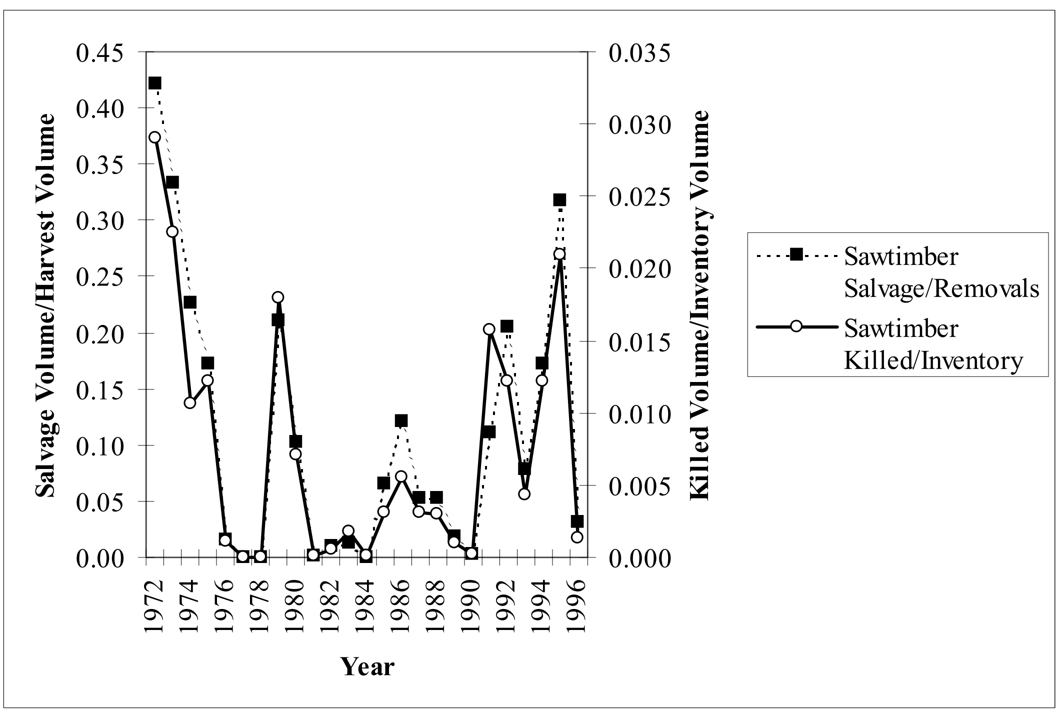


Figure 3. Alabama southern pine beetle-killed sawtimber salvaged and losses relative to annual average removals and total inventory, 1972-1996.



Disasters this large are rare in the South. For southern pine beetle, for example, we could identify only 19 times out of 314 state-years (13 states times an average of 24 years of outbreak data) when more than 2.5% of the state's inventory was killed by SPB, seven times when 5% or more was killed, five times when 10% or more was killed, and twice when 15% or more was killed.[2] We can compare these damages with those of wildfire in Florida. In 1998, the worst of nineteen years of data analyzed by Mercer et al. (2000), northern Florida lost approximately 15% of pine inventory. Such a fire probably had significant short-run effects on timber prices, but fires have been a constant feature of the Florida landscape and, one might guess, timber markets. Based on wildfire area, fires presumably consume an average of less than 1% of that state's southern pine inventory annually, but this figure varies widely by county.

The above analysis describes state-level damages, but outbreaks rarely span entire states. Gumpertz et al. (2000) examined long-term county-level outbreak patterns in three southeastern States and found a spatial autocorrelation range of 77 km. While price effects have been demonstrated at broader scales, it is not clear whether damages of more limited area would have similar, more local effects on prices, or whether they would be statistically detectable even if they did. For example, in a univariate time series analysis of price behavior, a price shock would have to be at least two standard deviations larger than the mean shock in order for it to be significant statistically from background "noise" in prices.

Although the Gumpertz et al. (2000) analysis explicitly addressed the spatial autocorrelation in southern pine beetle (SPB) outbreaks in the U.S. South, their analysis did not address the temporal autocorrelation present of those outbreaks. To explicitly test for the temporal predictability present in the SPB data assembled by Price et al. (1998), we performed statistical analyses at two scales: state-level and county-level. No information on spatial autocorrelation of these outbreaks was done; rather each county and state was evaluated individually in a binary choice (probit) model of outbreak.

At the state level, outbreak (y_t, below) was defined as existing when the amount of timber killed by SPB in the calendar year was more than one standard deviation greater than the average level of timber killed by SPB over the entire 36 years of outbreak data. For counties, outbreak was defined as more than one SPB spot per thousand acres of susceptible forest type. The model was:

$$PR(y_t = 1 \mid x_t) = \Phi(x_t'\beta) \qquad (1)$$

where

$$y_t = \begin{cases} 1 & \text{if in outbreak} \\ 0 & \text{otherwise} \end{cases} \qquad (2)$$

In equation (1) explanatory variables $\mathbf{x}_t$ are constants and lags of y_t. Two equations were estimated at both the state and the county level: a six-year lag model of outbreaks, with $\mathbf{x}_t=(1, y_{t-1},...,y_{t-6})$, and a single-year lag model, with $\mathbf{x}_t=(1, y_{t-1})$. The reasoning here is that six-year lags could not be estimated for some county-level regressions, while single-year lags were estimable. Although six-year lag models could be estimated for every southern state, in order to make the estimates comparable between county and state-level regressions, a single-year lag model was estimated. Equations were estimated as probits, using maximum likelihood techniques and assuming a heteroscedastic variance of residuals, where the variance was defined as an exponential linear function of the right hand side variables (Greene 1990, p. 685-686).

Table 2 shows likelihood ratio tests of six-lag and single-lag models of state regressions for three states: Texas, Alabama, and North Carolina. Outbreaks were defined for both pulpwood and sawtimber. Model equation estimates showed substantial statistical significance for the six-lag state-level regressions. Texas, a state whose counties are in outbreak more often than not, showed less predictability in the one-year lag model—indicating that outbreaks were difficult to predict given only information on outbreak in the previous year. Overall, however, the state-level temporal analysis confirms that price depression pressures from SPB salvage are likely to last for more than a single year.

[2] These volume losses are for each year in question. Some of these disasters covered more than one year, however. In those cases, each year was treated as a separate disaster in this tally of "state-years."

While price pressures are likely prolonged, what about production risks at finer scales? Table 3 shows the number of counties whose models were significantly better than a null model at explaining outbreaks. Only about 38%, or 434, of the 1,144 counties in the South could be tested, due to either models that did not converge in maximum likelihood estimation or because the tested county never recorded an outbreak. Of those, half showed significance at 5% for the one-lag model. Of the 322 that were testable in the six-lag framework, nearly all were significant at 10% and nine out of ten were significant at 5%, confirming a temporal predictability to outbreaks at this relatively fine scale.

Coefficients in the six-year model changed from positive to negative within four years, usually sooner. Coupled with the positive coefficient in the more broadly applicable one-lag model, we can conclude that, even at the scale of individual counties, outbreaks tend to last for several years.

Taken together, the two temporal analyses show that forest landowners faced with an emerging outbreak face a complex set of risks. Harvesting immediately eliminates the risk of production losses from the outbreak but may have the owner selling timber in a market where prices are depressed by salvage. Delaying harvest until prices recover subjects the owner to increased production risks not just for the current year but for one or two years beyond. This contrasts with the case of wildfire, where once the landowner has escaped immediate production risks he or she can look forward to reduced production risks while waiting for price risks to decline or even possibly turn beneficial.

Table 2. Probit regressions likelihood ratio test statistics of models of southern pine beetle outbreaks for three states: Texas, Alabama, and North Carolina. Models regressed current outbreak on previous years' outbreak, 1961-1996. Outbreaks were defined by pulpwood or sawtimber volumes killed for the year.

	One-year Lag Model			Six-year Lag Model	
	Log Ratio Statistic	Probability		Log Ratio Statistic	Probability
Pulpwood Definition					
Alabama	3.04	0.08		17.95	0.00
North Carolina	3.12	0.08		3.70	0.05
Texas	4.14	0.04		15.89	0.00
Sawtimber Definition					
Alabama	5.64	0.02		14.07	0.00
North Carolina	2.20	0.14		13.33	0.00
Texas	1.28	0.26		9.23	0.00

Table 3. Probit regressions likelihood ratio test statistics summary for county-level models of Southern Pine Beetle outbreaks for the entire United States South.

Significance Level	One-year Lag Model (434 counties)	Six-year Lag Model (322 counties)
1%	164	212
5%	250	297
10%	270	314

CONCLUSIONS

The preceding discussion described how natural disasters are predictably common in the South and that such disasters carry with them both price and yield risks. Viewed in isolation, production risk lowers the value of timber relative to other enterprises or the no-risk case, and it tends to shorten rotation lengths. However, we have shown that such production risks are often accompanied by price risks, and production risks in the presence of price risks can, relative to the deterministic Faustmann case, either decrease or increase optimal rotation length, land value, and optimal harvest period. To date, no theoretical development of production under jointly distributed production and price risk has been done. Empirical evidence presented in this paper suggests that such joint risks are significant for some kinds of disasters.

Further, we described how aspects of this jointness may be predictable, meaning that strategic behavior that accounts for joint risks and spatial and temporal autocorrelation in catastrophes may enable higher profits and land values than are produced under a myopic, constant-risk approach. What remains, however, is a clear theoretical development of such a model and accompanying simulations and empirical testing. Development of a model to simulate optimal behavior under joint price and production risks in the presence of realistic spatially- and temporally-autocorrelated production and price risks should be tractable. Indeed, we may even be able to empirically show that informal models of this type are already in use.

More proximally, our paper outlined strategies for landowners. First, with respect to fires, hurricanes, and other intense storms, the optimal strategy for a landowner whose timber is approaching saleable age and has been spared from the catastrophic damage is to wait a year or more for local timber markets to recover before selling timber. Second, landowners in or near a severe outbreak of southern pine beetle face a more complicated decision requiring careful consideration of their stand's composition and other risk factors. Owners of stands with low risk factors (e.g., slash or longleaf pine, young, lightly stocked with vigorous growth) would do well to delay harvesting until prices recover. Those whose stands are at higher risk (shortleaf or loblolly pine, old, highly stocked and slow growing) must either harvest their stands immediately and suffer reduced prices, or closely monitor their stands and its surroundings for early signs of attack and be prepared to respond quickly with suppression cutting should an infestation be discovered. Severe outbreaks can overtax the capacity of local loggers, so prearrangements may be necessary, but rapid suppression response is crucial to keeping spots contained and protecting as much of the remaining stand as possible.

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