CHAPTER 9

TIMBER SALVAGE ECONOMICS

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1. INTRODUCTION

It could be argued that perhaps the most dismal sub-discipline within the dismal science of economics is salvage economics. In the wake of catastrophic events such as pest epidemics, storms, or fires, forest managers make complex and often controversial decisions about scavenging value from wounded, dead, or dying trees. For profit-maximizing landowners, salvage decisions must balance the cost of harvesting operations in difficult conditions with the revenue obtainable from damaged timber. On public forest lands, salvage decision-making is further complicated by the fact that managers need to consider trade-offs between the net value of timber extracted and the impact of salvage activities on a suite of ecosystem services that are valued by people.

Prior research has shown that, in aggregate, salvage provides short-run benefits to timber market participants (Holmes 1991, Prestemon and Holmes 2004) and helps to mitigate long-term timber value losses (Prestemon et al. 2006). Some have argued that substantial timber market benefits can be obtained while incurring only minor impacts on non-timber values (Sessions et al. 2003). Others would argue that catastrophic events are intrinsic to the normal functioning of natural systems and that salvage activity can be detrimental to biogeochemical processes and other ecosystem functions that occur after a natural disturbance (Foster and Orwig 2006, Lindenmayer and Noss 2006). Timber salvage has the potential to alter natural post-disturbance plant associations, introduce invasive species, decrease the available habitat for certain bird species, increase erosion, and reduce water quality (McIver and Starr 2001, McIver and McNeil 2006). The view that the net timber market benefits of salvage on public lands are outweighed by these and other non-timber value losses may induce organized resistance by stakeholder groups.

Previous research regarding the economics of timber salvage has occurred at two scales—the firm level and the aggregate market level. Beginning with Martell (1980) and Reed (1984), firm level models describe the salvage decision from the perspective of individual landowners in a Faustmann-type framework and address the question of optimal timber management in even-age stands subject to the risk of catastrophic loss. This modeling framework has been extended

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to include optimal rotation decisions in the presence of fire risk on multiple use forests (Englin et al. 2000) and the impact of intermediate fuel treatments and initial planting densities on salvage values if a fire occurs (Amacher et al. 2005). Timber salvage market models describe the economic impacts of aggregate, large-scale salvage operations on prices and the economic welfare of timber market participants. Beginning with Holmes (1991) these models use time series analysis and economic welfare theory to identify market impacts and transfers in economic welfare. Short-run price impacts have been identified for southern pine beetle epidemics (Holmes 1991) and hurricanes (Prestemon and Holmes 2000, Yin and Newman 1999). In addition, Prestemon and Holmes (2000, 2004) identified long-run price and welfare impacts due to substantial changes in timber inventories. Market-level analysis is aimed at governmental decision-makers whose salvage programs can affect market prices and quantities.

The goal of this chapter is to provide the reader with an overview and working knowledge of the main topics in timber salvage economics. The following section of this chapter describes how large scale natural disturbances affect timber markets and timber market participants. This is followed by a discussion of the role of timber salvage in private and public landowner decision models. To provide a concrete example of the methods described in this chapter, we include a case study of the timber market effects of a recent, large disturbance—the Biscuit Fire of 2002.

2. TIMBER MARKET IMPACTS OF SALVAGE

In the wake of a large scale forest disturbance, timber markets demonstrate a discernable price decline due to a pulse of salvaged timber entering the market and may also manifest longer run effects if timber inventory losses are large. The salvage price effect occurs immediately after the disturbance, as affected landowners rush to harvest as much damaged timber as possible in order to avoid additional decay-related losses in quality and volume (Holmes 1991, Prestemon and Holmes 2000, 2004). In contrast, the price and quantity impacts due to losses in timber inventory can last much longer than the salvage period and depend upon the growth rate of the subsequent inventory.

The effects of the salvage and inventory losses can be illustrated with a supply-demand graph. Figure 9.1 shows a demand curve (D) and three supply curves that represent the three main epochs of timber market conditions following an inventory-destroying large scale disturbance. Pre-disturbance equilibrium price (P_0) and quantity (Q_0) is located at point *a*. Consumer surplus is defined as the area bounded by the demand curve from above and the price line below. Producer surplus is defined as the area bounded by the price line from above and the supply curve S_0 from below. During the salvage period two phenomena occur. First, the "green" supply curve shifts back to $S(I_1)$ due to a smaller inventory $I_1 < I_0$ available for harvest. Second, a salvage supply curve, V_1, is introduced in the days,

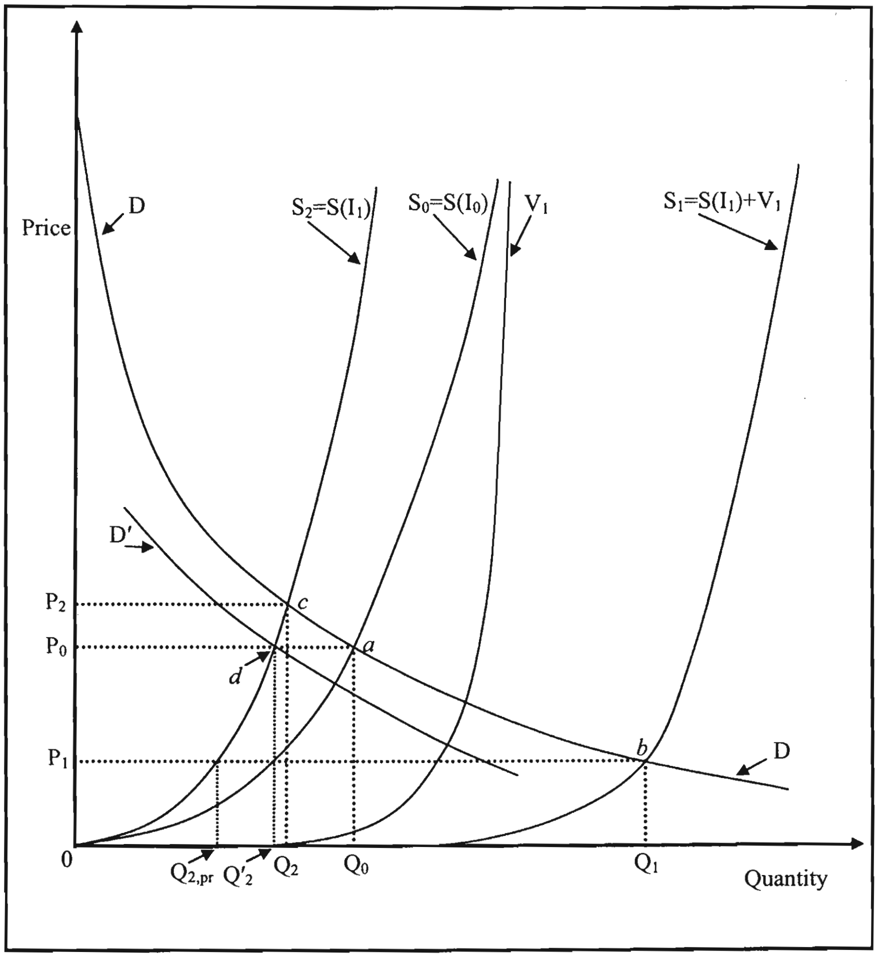

Figure 9.1. Market supply and demand shifts following a large-scale natural disturbance, including a price enhancement due to inventory loss. Point a marks the pre-disturbance supply and demand equilibrium, b marks the salvage period equilibrium, and c marks the post-salvage equilibrium.

months, or even years after the disturbance. This curve is drawn to be highly inelastic or nearly vertical throughout most of its range. Because the timber is no longer growing, due to severe damage or tree mortality, owners of salvage will take almost any stumpage price above zero (recall that the stumpage price is the delivered mill price of the logs obtained from the stand minus the cost of removing the timber and transporting it to the mill). Note that V_1 is the quality-adjusted volume of timber; the volume shown is adjusted downward due to defect (Holmes 1991). Added together, $S_1 = S(I_1) + V_1$ intersects with D to define the salvage epoch price, P_1 ($< P_0$), and quantity, Q_1 ($> Q_0$), at equilibrium at point *b*.

Over time, salvage is exhausted and the salvage supply curve shifts back toward the vertical axis and eventually disappears. This second epoch lasts 6–12 months in the case of hurricanes in warm and humid regions and may last several years in the case of beetle or fire killed timber in cold and dry locations.

During the third epoch, the price and quantity equilibrium is defined by the intersection of the inventory-adjusted supply curve, $S_2 = S(I_1)$, and demand, D. The equilibrium price is higher than the pre-disturbance price ($P_2 > P_0$), and the equilibrium quantity is lower than the pre-disturbance quantity ($Q_2 < Q_0$). This third epoch lasts as long as it takes timber inventories to return to pre-disturbance levels, and so will generally be shorter in high productivity locations. In the case of Hurricane Hugo in South Carolina, Prestemon and Holmes (2000) found a price enhancement of about 15 percent for southern pine timber due to inventory reductions, and Prestemon and Holmes (2004) concluded that this epoch will last 23 years for southern pine sawtimber.

The spatial extent of the timber price dynamics described above depends on the scale of the disturbance and on the costs of material transport between affected and unaffected regions. In the case of Hurricane Hugo, the use of cointegration and intervention analyses demonstrated that the salvage induced price depression was not evidenced beyond the boundaries of South Carolina, where the hurricane struck (Prestemon and Holmes 2000). This result is explained by the fact that spatial arbitrage—the equilibration of prices across space due to product movement—does not operate across great distances if the costs of product movement are high or if commodity prices are low.

The timber demand impacts following a large scale disturbance are not well understood from existing studies, and it seems as though demand may shift in either direction. On one hand, market timber price increases induced by the loss of timber inventories may force some marginally profitable sawmills out of business, thereby dampening demand to D in figure 9.1 (Prestemon and Holmes 2004). On the other hand, hurricanes which destroy or damage large numbers of homes and other structures work to increase demand for construction inputs such as lumber and panels. For example, Hurricane Katrina—the most damaging hurricane in recorded U.S. history—is projected to require the reconstruction of over 100,000 houses. This translates into a net increase in lumber consumption of 2–3 percent in 2006 and 2007 (Spelter 2005). Such outward shifts in demand in output markets translate into outward shifts in timber demand, serving to prop up timber prices. Timber price increases resulting from increases in demand for building products, however, would naturally be smaller than the effects of salvage and timber loss caused by the hurricanes. The effects of building product price increases on timber prices are likely to be dampened through spatial arbitrage in building product markets, although this is an empirical question not yet evaluated, as far as we know.

In addition to timber price impacts induced by catastrophic disturbances, transfers in economic welfare among timber market participants can be identified as well (Holmes 1991, Prestemon and Holmes 2004), and can be understood using

Figure 9.1. The supply curve S_2 represents green timber supply from producers holding undamaged timber stocks after a catastrophic event. Due to the price depressing effect of salvage (P_0–P_1), these producers reduce their harvest volume from Q_2 to $Q_{2,pr}$ during the salvage period. Consequently, they suffer a loss of economic welfare even though their stands are undamaged. After the supply of timber salvage is exhausted, supply from undamaged stands expands to Q_2 as price increases to P_2. If price P_2 exceeds the pre-disturbance equilibrium price, owners of undamaged timber enjoy a windfall. The net welfare impact on producers holding undamaged timber depends on the magnitude of these two effects and the levels of supply and demand elasticities.

During the salvage period, consumer surplus increases due to the drop in price (P_0–P_1) and higher quantity consumed (Q_1–Q_0). After the supply of salvaged timber is exhausted, consumers lose surplus as prices increase. The post-salvage price may be as high as P_2 and consumption as low as Q_2. If wood products capacity shrinks enough to drop demand back to Q'_2, then consumers lose even more surplus.

3. ALTERNATIVE SALVAGE DECISION FRAMEWORKS

Timber salvage decisions depend on the degree to which landowners or land management agencies value multiple outputs provided by post-disturbance forests. In what follows, we assume that private landowners make decisions to maximize profit or land value and public managers make decisions to maximize the value of timber and non-timber outputs. For the interested reader, private landowner decision-making is further elaborated in a technical Appendix.

3.1 Private Landowner Decision-Making

For a landowner interested in recovering timber value from a damaged stand, the value of the post-disturbance stand must exceed the cost of logging and transport to market. The decision on whether to salvage requires a comparison of the expected value of salvage versus the expected value of no salvage. If the salvage option has the greater expected value, then timber recovery should proceed.

The timber salvage problem can be embedded in a model of optimal capital management subject to risk of a catastrophic loss. The models of Martell (1980) and Reed (1984) focused attention on the optimal rotation age for timber stands prior to the onset of a catastrophic event. Either the stand attains its optimal rotation age or it is destroyed by a catastrophic event, with salvage of damaged timber a special case. These models assume that timber prices are unaffected by the catastrophic event which, as noted above, is not the case for large-scale disturbances. In order to address this gap in knowledge, we include a technical Appendix that demonstrates how governmental salvage programs (provision of subsidies for land clearing or long-term log storage, public and private road clearing to improve access to stands, enactment of temporary rules that reduce costs of log transport, etc.) can affect optimal forest management decisions. Nonetheless, these prior studies demonstrated that the risk of catastrophic loss, even when mitigated by salvage activity, shortens the optimal rotation age relative to stands facing zero risk of catastrophic loss.

Optimal timber management decision-making by timberland owners following a catastrophic event requires an accurate estimate of the reduction in timber price due to a loss in timber quality. We refer to this change in price as the salvage discount. The salvage discount depends on many factors, including species, climate, pre-disturbance timber quality, the degree and nature of timber damage, the effect of disturbance on harvest and transport costs, and time. Following hurricanes, for example, internal damage to wood may be extensive, whereas with fire or beetle-killed trees, damage can be limited to an outer ring of wood. In warm, humid climates, the price discount increases rapidly over time due to fungal staining and decay (Forest Products Laboratory 1999, p. 13-2). Examples of degrade losses are reported in the literature: (1) de Steiguer and others (1987) found that southern pine beetle mortality caused a 25–75 percent reduction in timber value, (2) Lowell et al. (1992) and Lowell and Cahill (1996) found a 10 percent reduction in timber value following wildfire induced mortality, and Prestemon and Holmes (2004) found a reduction value due to degrade of 80–90 percent following Hurricane Hugo. Figure 9.2 provides a general schematic of the change in timber quality degrade over time.

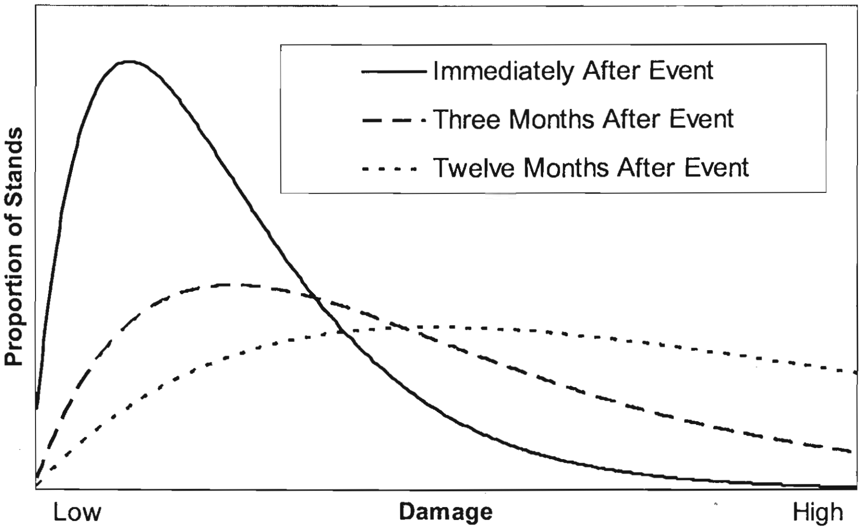

Figure 9.2. Hypothetical damage progression of stands in damage zone following a catastrophic disturbance over time.

From the perspective of profit-maximizing landowners holding stands of even-aged timber, the salvage decision depends on whether salvaging results in a decrease or an increase in profitability over the long run. In turn, this decision depends on the price of timber, the salvage discount, and the age of the stand when the damage occurred. Haight et al. (1995) evaluated the impact of varying rates of damage in young stands on the decision of whether to clear-cut and replant or to let the stand grow. They discovered that, for low disturbance frequencies (3 percent or less), stands with disturbance-caused stocking reductions that are less than 25 percent would optimally be left to grow until a rotation age is reached that is very similar to the no disturbance case. Higher disturbance frequencies call for an immediate clearing of young stands or earlier entry for a commercial thinning to remove injured trees and concentrate growth on larger ones. Because this study did not address the issue of the market effects of a large-scale disturbance on the price of timber, we can surmise that a market price drop due to aggregate salvage activities would decrease the attractiveness of timber salvage and increase the probability that a damaged stand should be left untouched following a disturbance.

The market price dynamics of a widespread disturbance such as a hurricane, catastrophic wildfire, or a large pest outbreak provide both opportunities and risks for affected and unaffected landowners. Owners of damaged timber should understand that salvage prices might be lower than the quality reductions would imply. Owners of undamaged timber may receive higher prices for several years following the exhaustion of salvage supply and may benefit from delaying their harvests. As well, owners of lightly damaged (but live) timber might do well to wait until timber is mature rather than go forward with an immediate harvest. Dunham and Bourgeois (1996), however, caution against letting leaning trees grow to maturity, as these can develop significant timber quality problems related to reaction wood as they age.

3.2 Public Landowner Decision-Making

Government land management agencies typically manage public forests to provide multiple goods and services. If the harvest of timber from public lands is a profitable activity, timber salvage on those lands following a natural disturbance can help mitigate the overall negative economic impact of the disturbance. The economic efficiency of any salvage effort is a logical objective so long as efficiency efforts do not reduce non-timber values produced from the disturbed landscape. Unfortunately, studies that precisely quantify the non-timber consequences of timber salvage are very scarce, thereby impeding a fully specified description of the trade-offs between timber and non-timber values resulting from salvage operations. Greater understanding of these effects is worthy of new research.

One approach would be to model the public decision using a modified Hartman (1976) model in which non-timber benefits flow from intact forests and where salvage potentially reduces those benefits. Generally, the Hartman decision framework reveals that non-timber values can lead to an optimal rate of timber harvesting that is lower than that deriving from a pure timber profit-maximizing decision structure. Depending upon the value of non-timber goods and services provided by disturbed forests, it is possible that salvage on public lands rarely produces positive net benefits from a social welfare perspective. Alternatively, social welfare optimizing solutions may restrict salvage to a subset of the stands that would have been economically salvaged under a timber-only (Faustmann) model. In this case, decisions on which individual stands to salvage would depend on non-timber impacts of salvage, distances to markets (affecting stumpage values), the expenses of cutting, the species mix, timber quality, and the nature of the damage. Because all of these factors vary across disturbance events, the decision calculus could vary dramatically from case to case.

Even within the narrow perspective of timber revenue maximization, several factors work together to reduce the volume of timber salvaged on public lands. First, public timber salvage can reduce market timber prices during the salvage period. Price reductions negatively affect prices received by private landowners holding undamaged timber, reducing their profits and (or) forcing them to delay harvest. Price declines also have a negative impact on private landowners holding damaged timber who are seeking to salvage some of their timber, driving down their salvage revenues. Further, such price reductions can reduce revenues obtained from regular public harvests that proceed during governmental salvage operations. To the extent that public agencies consider the impacts on other market participants from salvage-induced market price reductions, public salvage will be constrained. Although we have not seen evidence indicating that concern for these impacts explicitly influences agency decision making, it would be possible to evaluate the question empirically.

A second factor that can reduce government salvage is the perception by some members of the public that timber salvage is a subsidy to private sector mills who buy the damaged wood. Although such windfalls might be passed on to consumers of forest products in the form of lower prices of building and paper products, competition in the forest products industry suggests that this is unlikely and that mills receive most of the short-run gains from lower timber prices. Although we have no evidence that wood product prices do not reflect lower input prices, public perception that salvage is a giveaway to industry is evident in public communication by the environmental community. Governmental decision-makers may, in response to these kinds of communication campaigns, reduce the amount of timber offered in salvage sales or replace their green timber harvests with salvage harvests (Prestemon et al. 2006).

A third factor is that government efforts to salvage timber are limited by the potential costs of litigation by interested outside parties who oppose salvage sales and by their own institutional capacity. In the latter case, governments might have personnel capacity limitations for managing an increase in overall timber sale activity on affected public forests.

Fourth, and in recognition of the last two factors, mandated decision frameworks can lead to a reduction in salvage. As has been discussed, timber salvage can harm the provision of non-timber values such as ecosystem functions (McIver and Starr 2001), which governments are charged with protecting (Fedkiw 1997).

Fifth and finally, the decision to salvage timber from public lands must not only consider the effects of salvaging on non-timber values but also the consequences of moving economic resources within an agency to carry out a timber salvage sale. In the United States, laws require planning and public hearings, including the preparation of an environmental impact statement. The time required for planning and hearings typically will delay a timber sale, reducing the quantity and quality of salvable timber through decay. Research by Prestemon et al. (2006) quantifies how these kinds of delays may have resulted in real economic welfare losses in the timber market. These losses accrue as timber decays, reducing the net value of standing timber and hence the viability of proposed timber sales on government lands.

4. CASE STUDY: TIMBER SALVAGE FOLLOWING THE BISCUIT FIRE

In order to provide an illustrative example of the economic consequences of a public salvage project, we provide a model that describes the potential market impacts induced by the salvage of fire-killed timber in southwest Oregon. This example highlights some aspects of the decisions facing public land managers. Additionally, this example utilizes the concept of spatial equilibrium in the transport of salvaged timber to regional markets.

4.1 The Biscuit Fire

Between July 13 and November 9, 2002, the catastrophic Biscuit fire burned 499,965 acres, mainly on the Siskiyou National Forest, but also included some Bureau of Land Management land in southwestern Oregon, the Six Rivers National Forest in northern California, and some private land. Most of the Kalmiopsis Wilderness Area, contained within the boundaries of the Siskiyou National Forest, experienced the fire. Burn intensities varied greatly across the area affected, with generally low intensity within the Kalmiopsis Wilderness Area and higher intensities in other zones. Suppression expenditures for the fire exceeded $150 million (USDA Forest Service 2003a).

Four main categories of National Forest lands were burned. These were: Congressionally Reserved (CR, 152,900 acres burned), Administratively Withdrawn (AW, 64,100 acres), Late Successional Reserves (LSR, 133,700 acres), and Matrix land (33,000 acres). The CR land includes the entire Kalmiopsis Wilderness Area. By virtue of legislation and administrative rule, the CR and AW lands are off limits for salvage harvesting and do not contain inventory available to the timber market.

4.2 Model Assumptions

Our analysis provides estimates of the net impacts of the fire under a no-salvage alternative and under alternative rates of salvage, up to 1,500 million board feet (MMBF), which we model as being carried out over two years (2004, 2005). Economic impacts are disaggregated by market participants: owners of damaged timber, owners of undamaged timber, and consumers. The model structure and some underlying assumptions are based on research conducted by the authors, including Holmes (1991), Prestemon and Holmes (2000, 2004), Butry et al. (2001), and Prestemon et al. (2003, 2006), as well as methods pioneered by Samuelson (1952) and Takayama and Judge (1964).

Critical inputs to the analysis include: the pre-fire regional inventory volume and the amount of timber inventory volume killed by the fires (mentioned above), the current price of softwood (green) stumpage, the rate of degrade for fire-killed timber over time, the size of market within which salvage volumes would flow, discount rates, market price sensitivities (measured as the price elasticities of supply and demand), and the starting date of the salvage. These are discussed in turn below.

4.2.1 Timber volumes

We take as given by Sessions et al. (2003) that 40 percent of timber in the burned area was killed. Within LSR and Matrix lands, this amounts to 1,951 MMBF killed (Sessions et al. 2003, p. 22), 83 percent of which was softwood. Therefore, the total volume of softwood killed is assumed to be 0.83 x 1,951 = 1,619 MMBF.

4.2.2 Timber markets

Two markets are identified for analysis: "fire-zone" and "outside fire zone." The fire-zone market constitutes the local area within which much of the salvage volume would likely be consumed and consists of five southwest Oregon counties (Coos, Curry, Douglas, Jackson, and Josephine). In 2003, the sawtimber harvest level in these counties was estimated by the Forest Service to be about 1,441 MMBF. The regional "outside fire zone" market constitutes a larger region around the fire zone, which would be available to absorb additional volume. These counties include seven counties in California (Del Norte, Humboldt, Lassen, Modoc, Shasta, Siskiyou, and Trinity), and one in Oregon (Lane). These eight counties processed approximately 1,825 MMBF of timber in 2003, the base level used in our analysis.

Salvage is assumed to be consumed within the fire zone until the price of the salvage is low enough that it is economically optimal to ship logs from the burn area to the eight counties outside the zone. Inside the fire zone, maximum capacity of sawmills is assumed to be 50 percent above current production. Outside the fire zone, capacity constraints are never reached, because so little salvage exits the fire zone and since timber price reductions are modest, in aggregate. It is possible for some capacity to go unused even while some material exits the fire zone, due to the spatial arbitrage occurring through transport. The two sets of counties therefore have separate and differential impacts from the salvage activity. When timber is moved outside of the five fire zone counties, an additional \$60/MBF is deducted from the defect-adjusted salvage stumpage value, to cover an average of 60 miles additional transport distance to a non-fire zone mill (i.e., per unit transport costs are set at \$1/MBF/mile).

4.2.3 Standing inventory

The Biscuit fire killed approximately 0.5 percent of non-reserved standing softwood timber in the two market areas. Note that hardwood timber impacts are not addressed by this analysis. Inventory re-growth rates are obtained from tables 30 and 34 in Smith et al. (2004). Dividing the Pacific Northwest softwood inventory net growth volume by the region's softwood inventory volume yields a growth rate of 2.1 percent.

4.2.4 Timber prices

Initial equilibrium timber prices for softwood stumpage are taken as the approximate average sale price for stumpage in majority Douglas-fir sales made on National Forests in southwest Oregon in 2002. This price is \$333/MBF (USDA Forest Service 2003b).

4.2.5 Timber supply and demand elasticities and discount rate

Base estimates of the timber market supply elasticity with respect to price are obtained from Adams and Haynes (1996, p. 23), and represent the average of industry and private nonindustrial softwood timber (0.43). The elasticity of supply with respect to inventory volume is set at 1.0, consistent with Adams and Haynes (1996) and with economic theory. The elasticity of demand with respect to price is taken from Abt and Ahn (2003) (-0.5). The base discount rate is set at 4 percent.

A sensitivity analysis is conducted to evaluate the effect of changes in these model parameters on economic welfare estimates. In our simulations, the elasticity of supply and demand with respect to price were halved and doubled. The effect of the discount rate on all economic measures and prices were evaluated using alternative values of 2 percent and 7 percent.

4.2.6 Degrade factors

Salvage volume deterioration rates are weighted averages of expected annual rates by species. The rates of deterioration for one year after the fire (2003), two (2004), and three (2005) are obtained from Lowell and Cahill (1996). The rates of deterioration for years 4 (2006) and 5 (2007) are based on an analysis of the Bitterroot fires of 2000 (Prestemon et al. 2006), which show that the available volume from fire-killed timber of similar species will be about zero by year 5 (fig. 9.3). The volume proportions of fire-killed species were obtained from Sessions et al. (2003, p. 18). The weighted average net volume discount factors used in this analysis are 0.99 after 1 year, 0.89 after two years, 0.58 after three years, 0.22 after four years, and zero after five years (and later).

4.2.7 Demand sector

Salvage logs are assumed to be processed only by sawmills. Some residues from production of dimension products from these mills naturally can be diverted to other processors. The additional defect associated with salvage implies that each cubic foot of salvage sawlog produces both less lumber and less marketable residue than the typical green log of the same dimensions. In this analysis, we ignore the impacts of salvage logging on the residue-using sector. However, as demonstrated by Thurman and Easley (1992), the economic effects on the residue-using sector should be fully accounted for by examining the primary sawlog sector.

4.3 Modeling Approach

Our analysis evaluates the timber market effects—including price changes—attributable to various levels of timber salvage harvesting. The value of the salvage removed is strictly in terms of the net volume of the salvage removed times the

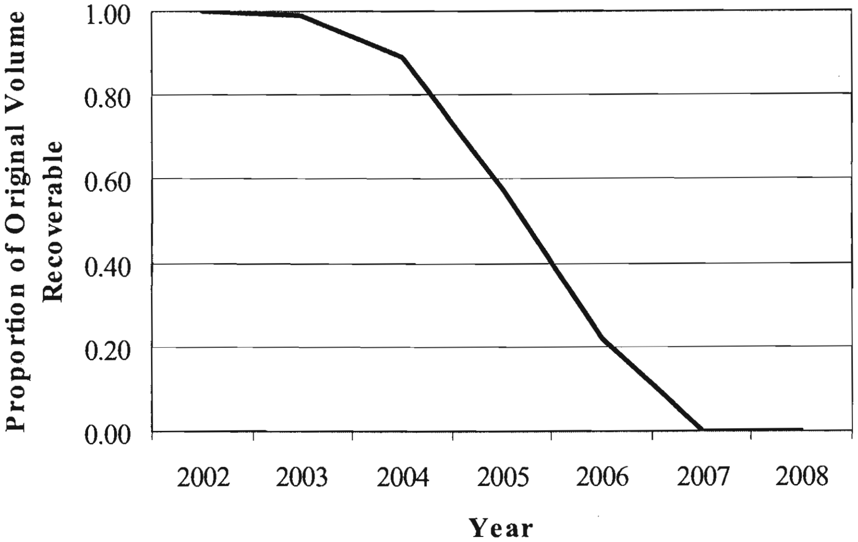

Figure 9.3. Proportion of volume recoverable from fire-killed timber, weighted by species groups (Douglas-fir, Ponderosa Pine, Sugar Pine, true firs), 2002-2008.

market-clearing price of the timber, appropriately adjusted for the fire-related defect shown in figure 9.3. The value of the timber lost from the fire and the effects of the fire on consumers and owners of undamaged timber are reported in economic surplus: consumer surplus and producer surplus. Consumer surplus is defined as the quantity times what consumers would be willing to pay for the timber, minus what they actually paid for the quantity. This can be visualized graphically in a supply-demand graph as the area above the market-clearing price (where supply intersects demand) and below the demand curve. The producer surplus is defined as the net revenues generated from timber production—in effect, the price received minus the cost of producing it. This is visualized graphically as the area above the supply curve and below the market-clearing price line. Methods applied are described in Just et al. (1982) and validated by Thurman and Easley (1992) for one resource-based market.

For non-salvage years (i.e., 2003, 2006, and later), market equilibrium prices and quantities in the two markets are determined separately. For 2004 and 2005, salvage volumes, prices, and green volumes in each subregion are jointly determined jointly using spatial equilibrium methods outlined by Takayama and Judge (1964). The joint solution is found by maximizing the sum of total net economic welfare across the two markets. That is, the combination of salvage volume in each market, green production in each subregion, and market-clearing prices in each market are determined by maximizing the two regions' sum of producer and consumer surplus minus the additional transport cost associated with moving some of salvage from the subregion in the fire zone to the subregion outside the fire zone. Hence, the price differential between the two subregions never differs by more than the cost of transport between the two regions. Net welfare impacts from salvage reported in the tables of this chapter account for the transport costs and are reported as sums across the two subregions.

4.4 Results

4.4.1 "No salvage" economic welfare estimates

The results of our market simulation show that, under a "no salvage" scenario, base case elasticities and a 4 percent discount rate, the Biscuit fire caused producer surplus to decrease for producers of damaged timber (the National Forests and Bureau of Land Management lands) on LSR and Matrix lands by $51.5 million (table 9.1). The effect of the fire on consumers (mills) is to reduce long-run consumer surplus by $79.7 million, due to the lower volumes produced on the burned-over area during the ensuing decades (inventory effect), and the higher long-run equilibrium price due to inventory loss. For owners of undamaged timber, slightly higher market prices due to the inventory reduction in the 13-county market area lead to a net benefit from the fire, amounting to about $79.2 million. Thus, a roughly equivalent economic value would be transferred from mills to producers holding undamaged timber in the long-run, under this scenario. When these three economic welfare impacts are summed, the total

Table 9.1. No Salvage Scenario, $ million changes in market welfare by group, alternative discount rates and market elasticities, for Late Successional Reserve and Matrix lands, Biscuit Fire burned area, 2002 dollars.

	Discounted Consumer Surplus Change	Discounted Value of Timber Lost	Effects on Undamaged Producers	Total Discounted Surplus
Base Case Values	-79.7	-51.5	79.2	-52.1
Low Discount Rate	-101.2	-65.4	100.5	-66.1
High Discount Rate	-59.5	-38.5	59.1	-38.8
Low Supply Elasticity	-84.8	-49.5	84.2	-50.1
High Supply Elasticity	-44.5	-32.3	44.2	-32.6
Low Demand Elasticity	-89.3	-42.1	88.7	-42.7
High Demand Elasticity	-42.3	-42.1	42.0	-42.3

Note: the Total Discounted Surplus column does always exactly equal the sum across the other three columns, due to rounding error.

market impact of the fires is a loss of $52.1 million. Using alternative market parameters, total impacts on economic welfare ranged from a $32.6 million loss under a high supply elasticity, to a $66.1 million loss when a low discount rate (2 percent) and base case values for other parameters are assumed.

4.4.2 Price impacts

Timber salvage reduces average market prices for both salvage and green timber, particularly in the fire zone (fig. 9.4). As stated above, a small price increase would occur in the fire zone if no timber is salvaged (about 1 percent in 2004 and 2005). From this initial equilibrium point, the price depressing effects of timber salvage would strengthen monotonically along with salvage volume. For the maximum salvage volume we considered, 1,500 MMBF out of the estimated 1,619 MMBF loss of softwood inventory, timber prices within the fire zone would decrease by 28.7 percent in 2004 and 22.3 percent in 2005. In the regional market outside the fire zone, the stumpage price reductions are 10.7 and 4.3 percent for 2004 and 2005, respectively for the maximum salvage volume. Outside the fire zone, detectable price effects are not registered until salvage volumes reach or exceed 700 MMBF. The effect in 2004 would be larger than the effect in 2005, other variables held constant, due to the decay and greater quality discount applied to salvage timber as time progresses.

4.4.3 Economic impacts of timber salvage

Salvage revenues range from about $24 million for 100 MMBF of salvage up to $265.2 million for maximum salvage effort (table 9.2). Mills are positively affected by salvage because market prices drop and they purchase greater timber volumes (salvage as well as non-salvage) at lower prices during the two years

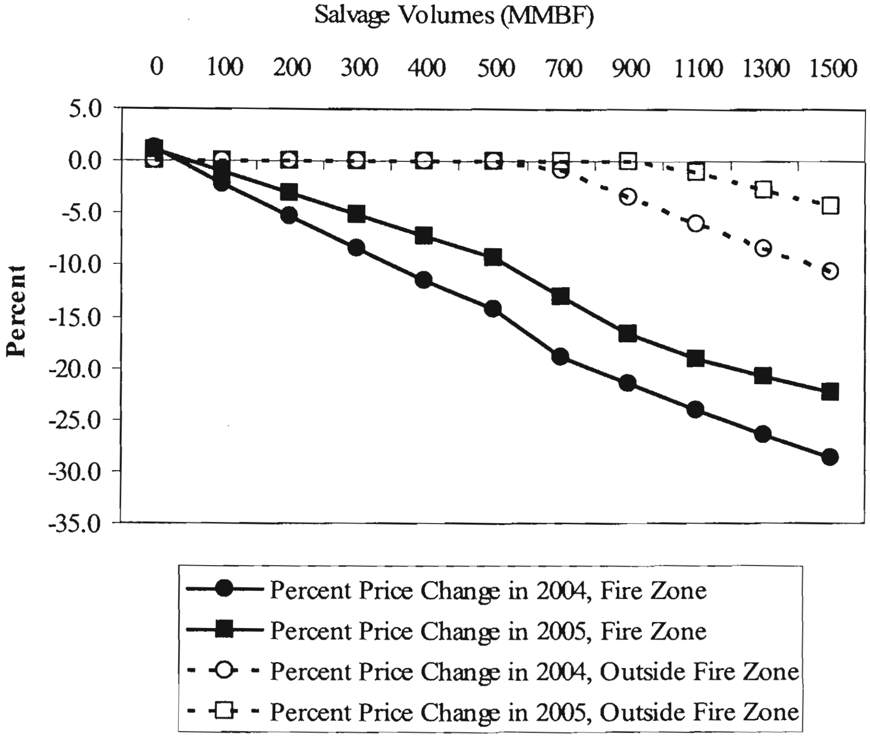

Figure 9.4. Price impacts (percent price changes) in the five-county region of southwest Oregon ("Fire Zone") and an eight-county region outside of that ("Outside Fire Zone"), from alternative salvage volumes removed from some parts of Late Successional Reserve and Matrix lands in the Biscuit Fire burn area, under base case assumptions of the discount rate and market sensitivities to prices and inventory.

of salvage activity. At a salvage volume of just over 300 MMBF, the benefits to mills from salvaging operations are approximately equal to the loss of consumer surplus due to the long-run inventory effect. At greater salvage amounts, mills would be better off in the long run than they would have been if the Biscuit fire had not occurred.

Timber salvage reduces producer surplus for forest owners holding undamaged timber, net of the windfall benefits they enjoy as a result of the elimination of inventory from the regional market (the $79.2 million benefit, mentioned above). At low salvage volumes, these producers still receive net benefits from the fire. If salvage volume exceeds about 330 MMBF, however, net windfall benefits become net losses in producer surplus. These owners are worse off with salvage because they harvest less timber during the salvage period and because they receive a lower price for their timber. Relative to the "no salvage" scenario, producers lose $24.4 million for 100 MMBF of salvage, and $308.4 million if

Table 9.2. Changes in welfare effects ($ million) resulting from alternative salvage plans, by producer and consumer group. The no salvage scenario is the point of comparison.

Volume Salvaged, MMBF, Total over 2004 & 2005	Discounted Consumer Surplus Change	Effects on Undamaged Producers	Value of Salvage Removed	Total Discounted Surplus	Percent Price Change in 2004, Fire Zone	Percent Price Change in 2005, Fire Zone	Percent Price Change in 2004, Outside Fire Zone	Percent Price Change in 2005, Outside Fire Zone
0	0.0	0.0	0.0	0.0	1.2	1.1	0.0	0.0
100	24.7	-24.4	24.0	24.2	-2.2	-1.0	0.0	0.0
200	49.1	-47.8	46.6	47.7	-5.4	-3.1	0.0	0.0
300	73.0	-70.1	67.9	70.5	-8.5	-5.2	0.0	0.0
400	96.5	-91.5	88.0	92.6	-11.4	-7.2	0.0	0.0
500	119.6	-112.0	107.0	114.1	-14.3	-9.2	0.0	0.0
700	165.2	-151.8	142.4	155.1	-18.9	-13.0	-0.9	0.0
900	210.9	-192.0	176.2	194.2	-21.5	-16.6	-3.4	0.0
1100	256.2	-231.6	207.7	231.2	-24.0	-19.0	-5.9	-1.0
1300	301.3	-270.8	237.4	266.6	-26.4	-20.7	-8.4	-2.7
1500	345.6	-308.4	265.2	300.9	-28.7	-22.3	-10.7	-4.3

Note: the Total Discounted Surplus column does always exactly equal the sum across the other three columns, due to rounding error.

1,500 MMBF are salvaged over the two years from the Biscuit Fire burn area. The larger the salvage program, the larger the negative impact on these producers.

These ideas are further illustrated in figure 9.5, which shows the production volume during the year of the fire and in subsequent years, including salvage years, in the five counties of the fire zone. The figure shows the production volume of owners of undamaged timber as well as the volume of salvage removed, under a 400 MMBF salvage program. Owners of undamaged timber would produce about 6 percent less in 2004 and 4 percent less in 2005, due to the lower prices. The entire five county fire zone market, however, would produce about 7 percent more timber than usual in 2004 and 4 percent more than usual in 2005, adding together the volumes of green and defect-adjusted salvage.

Economic analysis of this type can help decision-makers evaluate the economic impacts of alternative timber salvage programs. For example, at maximum timber salvage effort, net economic welfare in the market would increase by about $300 million, compared to not salvaging at all. A salvage program of 1,000 MMBF would approximately compensate for the combined timber market surplus losses and the fire suppression expenditures on the Biscuit fire. A timber salvage program of roughly 300 MMBF would reduce the non-timber impacts of salvage relative to the maximum salvage program, maintain timber consumer (mills)

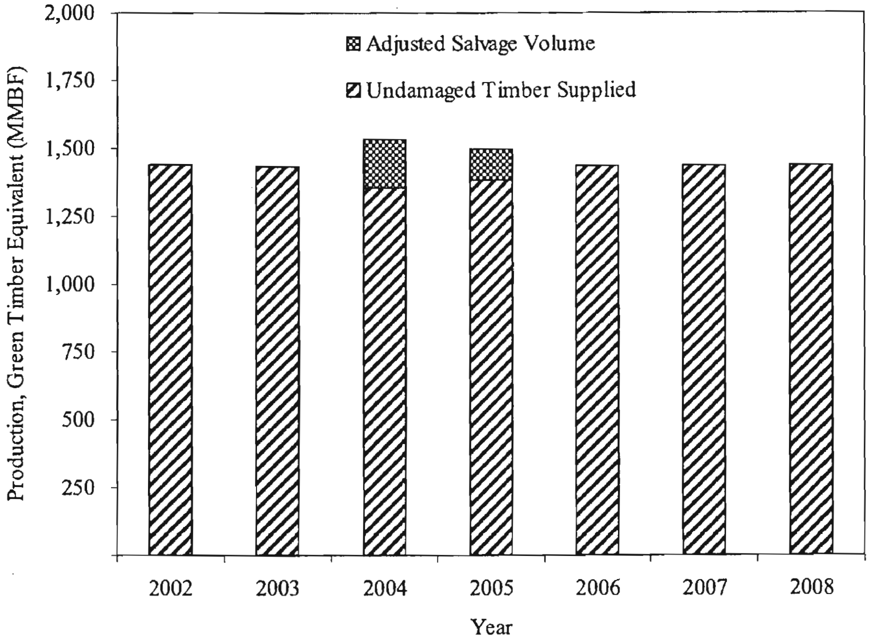

Figure 9.5. Market volume of timber produced, 2002-2008, including 200 MMBF of salvage (adjusted for degrade) occurring in each of 2004 and 2005, in the five counties of Southwest Oregon contained in the Fire Zone.

and undamaged producer surplus at roughly the pre-disturbance level, and yield timber market revenues of nearly $68 million for the suppliers of salvaged timber (the government).

5. CONCLUSIONS

Timber salvage, like other kinds of salvage, provides benefits that can help to mitigate the overall economic impacts arising from a catastrophic event. Salvaging timber, like the natural disturbance preceding it, often induces a rearrangement of economic wealth. Private forest owners holding damaged and undamaged timber need to understand the implications of price changes that occur during the aftermath of a catastrophic forest disturbance and alter their timber harvest plans accordingly. Public decision-makers need to be aware that governmental programs supporting large-scale salvage operations can accentuate timber price and welfare impacts.

Perhaps the greatest challenge facing public decision-makers is managing the suite of trade-offs between timber and non-timber economic benefits deriving from a salvage program. Unfortunately, very little is known about the value of post-disturbance ecosystem goods and services that are impacted by salvage operations. However, if public sentiment regarding governmental salvage activities is an accurate barometer of these values, we would suggest that their omission from a full economic analysis may provide biased policies. Incorporating public values in timber salvage analysis presents an urgent challenge for forest economists.

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APPENDIX

Salvage decisions faced by private landowners can be modeled within the framework of optimal capital management. In the presence of the risk of a catastrophic loss, the profit maximizing forest landowner seeks the optimal rotation age T that maximizes $L(T)$, the land rent (Reed 1984). In this Appendix, we show how the optimal capital management model can be modified to account for a short-run market price decline during the salvage period, due to a pulse of salvaged timber, as reported by Holmes (1991), Yin and Newman (1999), and Prestemon and Holmes (2000). Then we discuss how governmental interventions during the salvage period might affect landowner decisions.

We begin by modifying equation (20) in Reed (1984) by the addition of two new variables: (1) g, the relative price decline for *green* timber due to a supply pulse of salvaged timber, and (2) $\tilde{\kappa}(t)$, the volume-weighted salvage price discount ratio which reflects the price decline for *salvaged* timber, relative to green timber, due to a loss in quality. The value of an infinite series of rotations in an even-aged stand potentially subject to salvage can then be written:

$$\begin{aligned} L(T) &= \frac{[h+r]\{[V(T)-c_1]e^{-(h+r)T}+\Phi(T)\}}{r(1-e^{-(h+r)T})}-\frac{h}{r}c_2-c_1, \\ \Phi(T) &= \int_0^T hgV(t)\tilde{\kappa}(t)e^{-(h+r)t}\,dt \end{aligned} \tag{9.1}$$

where $L(T)$ is the land expectation value at the optimal rotation age $t = T$; $V(t)$ is the value of the stand at age t; h is the constant annual probability of a damage-inducing forest disturbance (described here as an independent probability, implying that the landowner's decisions have no effect on the probability); r is the discount rate; c_1 is the reforestation plus site preparation costs without a pre-harvest disturbance; c_2 is the reforestation plus site preparation costs with a pre-harvest disturbance; e is the exponential function; $\Phi(T)$ is the expected present value of salvage in the presence of a constant annual disturbance risk. The volume-weighted salvage price discount ratio obtained in year t, $\tilde{\kappa}(t)=\sum_{j=1}^{J}s_j(t)[\kappa_j(t)-d_j(\kappa_j)]$ where $s_j(t)$ is the value share at green prices of the timber in the stand year t with damage level j; $\kappa_j(t)$ ~ [0, 1] is a measure of the timber quality discount (i.e., the ratio of the value of timber with damage level j to undamaged timber); $d_j(\kappa_j)$ ~ [0, 1] measures the extra removal and transport cost (proportional loss of stumpage value) for trees with a κ_j level of damage following a disturbance.

The economic significance and variability of the timber quality discount is indicated by noting that de Steiguer et al. (1987) determined $\kappa(t)$ ranged from 0.50 to 0.75 for southern pine-beetle damaged wood. Lowell et al. (1992) and

Lowell and Cahill (1996) found $\kappa(t)$ to be at or above 0.9 in fire-killed timber for two years following tree mortality in Oregon. Prestemon and Holmes (2004) showed that the volume-weighted salvage price discount ratio $\tilde{\kappa}(t)$ aver-averaged 0.22 for sawtimber and 0.11 for pulpwood in the year following Hurricane Hugo.

Optimal decisions regarding salvage in stands damaged by a disturbance where $L(T) \leq 0$ are somewhat simpler. Here, a landowner must ask whether the following inequality holds (ignoring discounting, as salvage usually proceeds within a year of the disturbance):

$$gV(t)\tilde{\kappa}(t) - (c_2 - c_1) > 0 \tag{9.2}$$

where $c_2 - c_1$ is the extra cost of harvesting the stand following a disturbance compared to a harvest of an undamaged stand. If (9.2) holds, then salvage can take place profitably for non-timber-managing forestland owners.

The above decision framework applies to stands with older trees, where salvage can yield damage mitigating revenues. Following Haight et al. (1995) and Reed (1984), the probability of a catastrophic event can be defined by a Poisson process, whereby the cumulative probability that a disturbance will have occurred by year t is given by $\Pr[X(t)] = 1-e^{-ht}$, where X is the time between successive stand damaging events or clearcuts. The cumulative distribution is then $\Pr[X<t] = 1-e^{-ht}$ if $t < T$ equal to 1 if $t=T$. Hence, the probability that either the rotation age (T) or the disturbance has occurred by year t is given by $1-e^{-ht}$ if $t < T$ and 1 if $t \geq T$. The expected present value of managing a young stand without salvable wood but with the ongoing risk of stand damage is modeled as in Reed (1984, equation (3)):

$$J = [V(T) + L]e^{-(h+r)T} + \frac{h(L-c)[1-e^{-(h+r)T}]}{h+r} \tag{9.3}$$

where c is the simple land clearing cost following a disturbance.

When disturbances are widespread, post-disturbance market prices will be different from the pre-disturbance market prices, even after accounting for the reduced quality of some timber entering the market. Holmes (1991), Yin and Newman (1999), and Prestemon and Holmes (2000) all noted substantial market price declines. The studies of Hugo found green-timber price reductions averaged about 30 percent during the salvage period, or a value of g in equation (9.2) equal to 0.7 for both southern pine pulpwood and southern pine sawtimber. Holmes' (1991) study of southern pine beetle found green-timber price reductions that averaged about 20-30 percent ($g = 0.7$ to 0.8). A market price drop would tend to decrease the attractiveness of timber salvage while simultaneously increasing the probability that a damaged stand should be left untouched following a disturbance.

Evaluation of the equations (9.1), (9.2), and (9.3) offers the opportunity to identify ways in which government interventions could change the optimal decision-making calculus for private landowners, and they offer insights into potentially optimal strategies for landowners generally. For example, the effect of post-disturbance subsidies of land clearing or planting costs on land value could be assessed by evaluating how incremental changes in subsidies affect long run profits from the land use. At a 6 percent discount rate and an annual disturbance probability of 3 percent, each dollar of subsidy to clearing plus replanting cost following disturbance would yield about $0.50 in land value increase. More generally, given a clearing plus planting cost of $400 per acre and a land value of $1,000 per acre, each 1 percent increase in the land value subsidy would increase land value by 0.2 percent. In other words, if governments want to encourage timber growing, maintenance of land in forest, and timber salvage in the event of a disturbance, then provision of a post-disturbance subsidy to affected landowners can help.

Part of the salvage discount is the extra cost of removal and transport of wood from disturbance-damaged stands. Therefore, another way for government to intervene is in the facilitation of transport. In South Carolina following Hugo, for example, the State relaxed weight limits on roads temporarily to allow for larger log loads. The State also invested generally in road clearing, which likely aided the salvage effort. Unfortunately, it is unclear how much harvest costs and transport costs are directly affected by disturbance events.

Another consideration is how governments can act to increase the level of market demand, which will enhance prices offered to all landowners in the months or years immediately following a catastrophe. To the extent that demand capacity can be expanded, the ratio of damaged to undamaged timber prices will be higher, which will encourage salvage, increase land values, and raise the economic incentive to reestablish stands. For example, assume that the volume of pre-event timber on a stand is 1,700 ft^3, the value is $976/acre, the discount rate is 6 percent, the annual rate of disturbance is 3 percent, and the optimal harvest age is 25 years with a salvage value per unit volume that is 30 percent lower than for an undamaged stand. Now, assume government intervention to encourage a demand expansion following the disturbance event such that there is only a 20 percent loss in stand value immediately following the storm, then land values would increase by about 7 percent. The value of salvage would rise by exactly the proportional rise in the salvage period price, about 14 percent in this case. Although these numbers are somewhat arbitrary, they are reasonable and therefore informative. If government efforts to facilitate log storage achieve this kind of dampening of the salvage price glut, then widespread benefits could be experienced by affected landowners by enhancing their salvage revenues and land rents.

In this last case, where government could intervene by subsidizing temporary log storage capacity expansion begs an important question: Would government spending on private capacity be economically efficient? If market decision makers possess all of the same, correct information about probabilities of timber-damaging natural disturbances as the government, then we might expect an optimal distribution of production inputs devoted to storage capacity to exist in the market. In this context, government provision of a storage subsidy would be inefficient. Presumably, mills make decisions about log storage capacity by balancing the cost of the last unit of capacity with the additional expected long run stream of extra revenues gained by creating it. The capacity decision should therefore incorporate the probability that disturbances will occasionally offer gluts of raw materials. One possibility justifying such subsidies would be that some firms have under-invested in capacity because of capital (credit) constraints or because poor decisions were made (e.g., the firm underestimated the actual frequency of such disturbances). Alternatively, the sector might have under-invested in capital in anticipation of government intervention; if such intervention does not happen, then capital would have been misallocated.

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