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Evaluating hurricane impacts on timber Markets in the Southeastern United States: A case of hurricane Michael

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ABSTRACT

The intensity of catastrophic weather events, such as hurricanes, are projected to increase across the Southeastern United States (US). With nearly half of the region's land covered by productive forests, periodic large-scale storms frequently disrupt timber supply and destabilize local markets. We investigate the impact of Hurricane Michael (2018) on timber markets in the Southeastern Coastal US, employing a Regression Discontinuity in Time (RDiT) design. Using bi-monthly stumpage price data from hurricane-affected and surrounding micro-markets, we estimate causal effects on market responses across stumpage products. Findings indicate that Hurricane Michael led to a 6 % decline in pine pulpwood prices across the region, and a 9 % and 77 % decrease in pine sawtimber and hardwood sawtimber prices, respectively, in severely damaged areas. In unaffected or lightly impacted regions, the price effects were more variable and product specific. The findings shed light on the timber market dynamics immediately following a catastrophic hurricane and provide nuanced perspectives to forest managers, landowners, and timber investors as they plan for future risk management in timber supply chain and forest sustainability.

1. Introduction

Major hurricanes are natural catastrophes that can cause extreme damage to developed structures and forest resources (NOAA, 2024). Due to their devastating damage to forest resources, severe natural catastrophes may have short and long-run impacts on forest products markets and economic activities by affecting forest resource product supplies (Zhai and Ning, 2022).

Hurricane intensity, as defined by the Saffir-Simpson scale, range from a category 1 (minimal or low damage) to a category 5 (catastrophic damage), based on sustained wind speeds. Since 2005, nine major hurricane events (categories 3 through 5) have made landfall in timber-growing areas within the Southeastern US (NOAA, 2024). Of those nine events, Hurricane Michael, which made landfall in the Florida Panhandle on October 10, 2018, is the only one classified as a category 5 hurricane and the fourth most powerful hurricane to strike the US, and the most powerful hurricane to strike Florida (National Weather Service, 2018). As hurricane Michael progressed northeast toward the central Florida Panhandle it dissipated to a Category 3 hurricane as sustained winds began to fall below 115 mph (Beven II et al., 2019). Finally, as hurricane Michael moved into southwest Georgia and parts of Alabama it weakened to a Category 1 hurricane and a tropical storm (Beven II et al., 2019).

Significant damage was left in hurricane Michael's path (Fig. 1), including the loss of 34 lives in Atlantic Coastal states (Breslin, 2019). Among the material losses, in Florida alone approximately 40,000 homes were destroyed (Mickelson, 2019). Additionally, $25 billion in damages were recorded in culmination of all areas impacted in the US (Beven II et al., 2019; Sweeney et al., 2022). Lastly, in terms of forest resources, hurricane Michael significantly damaged 6.17 million acres of economically important pine plantations and naturally regenerated hardwood and mix-species forests (Brandeis et al., 2022). As the threat of intense hurricanes continues to rise, forests in the Southeastern US are projected to be most vulnerable in the country, leading to substantial impacts on timber markets (Sohngen and Sedjo, 2005; Johnston et al., 2024). The recent hurricane Helene was also quite destructive, with substantial timber damage of mature forests with an estimated loss of $1.3 billion in Georgia, Florida and South Carolina, which could cause a significant disruption on future pine sawtimber supplies (Halverson and Livingston, 2025; Lang, 2025).

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The dynamics of timber markets following a catastrophic hurricane are complex. In the immediate aftermath of a hurricane event, timber prices are known to fall due to salvage harvests increasing roundwood supply (Yin and Newman, 1999; Prestemon and Holmes, 2000; Sun, 2016; Sun, 2020). As time progresses and salvage harvest operations are completed, timber prices begin to rebound until they reach pre-storm levels (Prestemon and Holmes, 1998; Yin and Newman, 1999; Prestemon and Holmes, 2004; Sun, 2016). In addition to decreasing salvage harvests, the rebound in timber prices has also been linked to rising lumber demands (Sun, 2016) as rebuilding occurs and as trade with surrounding undamaged regions rises to fulfill the repairing and reconstruction efforts (Sun, 2020). With the significance of the US South to global timber markets, understanding the dynamic impacts of hurricanes on timber markets is quite critical for forestry stakeholders to strategically plan for risk management under changing climatic conditions.

The potential implications of hurricanes on forest markets have long drawn questions from researchers, leading to a significant growth in the literature around those questions including research into major hurricane events in the US South. The first, and most studied hurricane event in the US South to date, is hurricane Hugo, which made landfall along the US East Coast in September 1989. Prestemon and Holmes (1998, 2000, 2004, 2010), Yin and Newman (1999), and Sun (2016) evaluated the impacts of hurricane Hugo on various aspects of timber markets. More specifically, Prestemon and Holmes (1998) utilized cointegration analysis to assess hurricane Hugo's impacts on South Carolina's timber markets and found that prices declined 35 % and 60 % for pine sawtimber and pulpwood, respectively. Similarly, Yin and Newman (1999) and Prestemon and Holmes (2000) employed an intervention analysis technique to evaluate hurricane Hugo's impacts on South Carolina's timber markets, and reported that hurricane Hugo induced a short-run decline in timber prices due to salvage harvests and a long-run price enhancement effect on certain products. Later, Prestemon and Holmes (2004) and Prestemon and Holmes (2010) assessed how hurricanes and the proceeding timber salvage operations affected economic welfare of various timber market stakeholders, and found that salvage harvests, particularly sawtimber, reduced timber market welfare losses and induced welfare transfers from owners of damaged timber to those of undamaged timber.

Expanding on Prestemon and Holmes (2004, 2010), Sun (2020) revisited the case of Hurricane Hugo and re-analyzed the effects of the hurricane on timber markets by utilizing a partial equilibrium displacement model (EDM), and revealed that the overall inventory loss, the level of salvage use, and the trade between the damaged and surrounding undamaged areas would determine the extent of timber price recovery in the post-hurricane period. In addition to hurricane Hugo, hurricane Katrina has also been used to evaluate the effects of hurricanes on timber markets. For example, Sun (2016) utilized a partial equilibrium model to assess hurricane Katrina's impacts on timber markets in heavily affected regions of Mississippi, and found similar results of hurricane Hugo that timber prices gradually recovered over time in the post-hurricane period, welfare was transferred to owners of undamaged timber, and salvage, inventory loss effects, and lumber demand increases play vital roles in the recovery of timber markets over the years (Sun, 2016).

More recently, hurricane impact studies on forest products markets focused on hurricane Michael. Henderson et al. (2022) simulated the hurricane Michael's damage to forest growing stocks and various replanting and salvage consumption scenarios, and reported that hurricane Michael induced welfare increases for pine and hardwood sawtimber producers but welfare losses for pine and hardwood sawtimber consumers. Additionally, Hernandez-Diaz et al. (2024) implemented a wavelet analysis and forecasting to assess hurricane impacts on stumpage prices in the Southeastern US, and found that hurricane Michael induced a fall in pine sawtimber, chip-n-saw, and pulpwood stumpage prices but those prices recovered quickly in the following two to four quarters (Hernandez-Diaz et al., 2024).

The aim of this study was to quantify the immediate causal effects of hurricane Michael on stumpage prices in the Southeastern US using a causal inference approach. We employed an RDiT design with a cutoff point following the landfall of hurricane Michael in parts of Florida, Georgia and Alabama. Our study contributes to the growing hurricane impact literature in that this is a study to utilize a causal inference approach to assess the impacts of a major hurricane on Southeastern US timber markets. The results provide forestry stakeholders and market participants with additional insights and nuanced perspectives on the

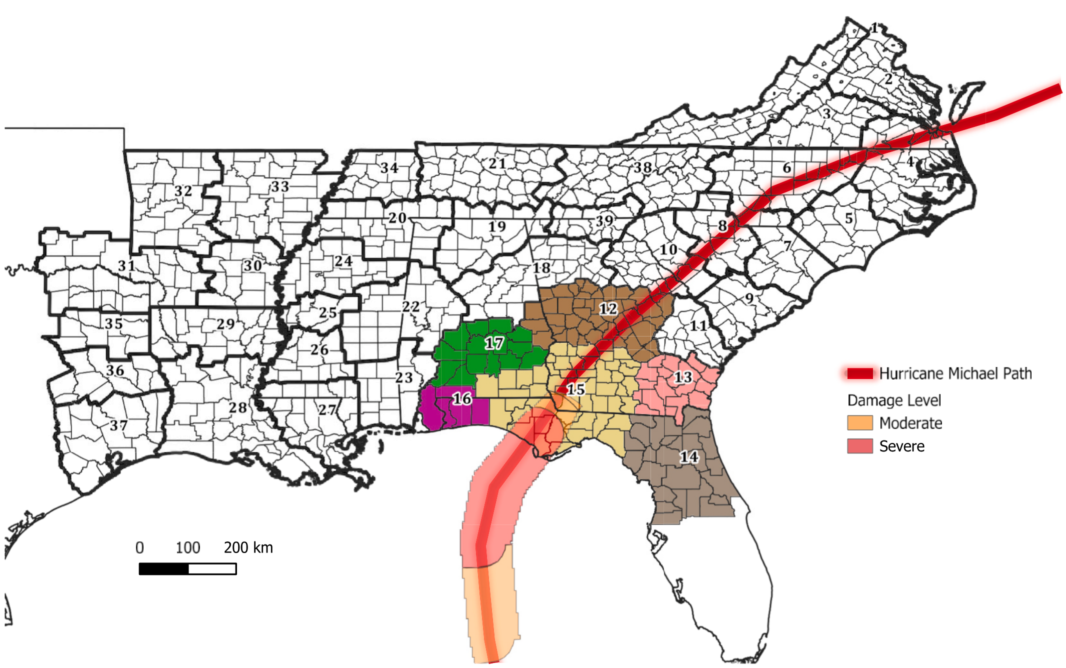

Fig. 1. Hurricane Michael path and damage zones in the various timber micro-markets delineated by ResourceWise, formerly Forest2Market. The hurricane path is obtained from the National Weather Service (National Weather Service, 2018).

impacts of hurricanes on timber markets, which may help them plan for risk management activities.

2. Methodology

2.1. Data

Data used in this analysis were collected from secondary sources. The bi-monthly price series for pine chip-n-saw, and pine and hardwood sawtimber and pulpwood stumpage were obtained from ResourceWise, formerly Forest2Market, from Jan-Feb 2012 to Mar-Apr, 2023, resulting in 67 observations. This price dataset has higher resolution with more micromarkets in the region than another commonly utilized timber price dataset from TimberMart-South. We restricted the dataset in this period to set up similar pre- and post-treatment times around hurricane Michael, which also reduces the additional noise and trends in timber price movements such as the 2008 great financial crisis. ResourceWise reports the stumpage price information by micro-markets (MMs), which are groups of counties from a single or multiple states (Fig. 1). To determine impacted regions, hurricane Michael track and intensity data were obtained from the National Oceanic Atmospheric Administration Historical (NOAA) Hurricane Tracks database (NOAA, 2024). Hurricane date, category, wind speed, pressure, and latitude and longitude coordinates, were collected at each measuring point along the hurricane's path (Fig. 1). These points were then used to match storm paths to county-level geographic locations in line with ResourceWise's MM boundaries.

Price series were obtained for the two MMs in the direct path of the hurricane, MM 15, which was affected by the highest hurricane intensity and MM 12 which experienced lower event intensity, as well as MMs 13, 14, 16, and 17, which are adjacent to the direct path of hurricane Michael (National Weather Service, 2018). Table 1 presents the summary statistics for each price series of stumpage products in each individual MM included in the analysis. Timber prices are inflation-adjusted by using the producer price index for all commodities (2019=100).

2.2. Regression discontinuity in Time (RDiT) as an empirical approach

Regression Discontinuity Design (RDD) is a popular methodology utilized in applied studies interested in estimating causal inference and treatment effects (Calonico et al., 2017; Calonico et al., 2020). The proximity to a randomized experiment is attributed to RDD being one of the most credible quasi-experimental research designs for causal inference, as well as its ease to interpret and present treatment effects (Calonico et al., 2017; Hausman and Rapson, 2018). The primary goal of RDD is to estimate the effects of an event on an outcome, where each group receives or does not receive treatment, and no group can be observed in both states at one time (Hahn et al., 2001). Treatment in the RDD setup is determined by the running variable, and treated groups have a "score" that exceeds a known cutoff value of the running variable and untreated groups have a "score" below the cutoff (Calonico et al., 2017).

A popular extension of RDD is Regression Discontinuity in Time (RDiT), which is similar to an event study analysis (Hausman and Rapson, 2018). RDiT differs from RDD as it uses time as the running variable, with the cutoff being the date the treatment occurs (Hausman and Rapson, 2018). In this context, treated and untreated groups within a region, where treated groups have dates after the cutoff and untreated groups have dates before the cutoff, are compared (Hausman and Rapson, 2018). RDiT frameworks have previously been used to assess the impacts of the COVID-19 pandemic on vegetable prices in China (Ruan et al., 2021) and timber markets in the US South (Bruck et al., 2023).

To evaluate any discontinuous changes in stumpage prices induced by hurricane Michael, we utilized the Regression Discontinuity in Time (RDiT) model. We employed an RDiT design for the pooled panel data to estimate the price impacts of the hurricane across the region. Similarly, we estimated the individual MM 15 model representing the hurricane's directly impacted zone (Fig. 1) to account for the direct effects of the hurricane on stumpage prices. Additionally, to account for spillover effects, such as unaffected surrounding markets procuring salvage from damaged markets and damaged markets procuring roundwood from undamaged markets, we estimate RDiT models for each micromarket surrounding MM 15.

Like standard RDD, RDiT designs can be sharp or fuzzy and conventional or kink (Hahn et al., 2001). Sharp designs are characterized by each unit that is assigned to the treatment group actually receiving treatment, and each unit that is assigned to the control group never receiving treatment (Cattaneo and Titiunik, 2022). Contrarily, fuzzy designs are characterized by either some units assigned to the treatment group failing to receive treatment or some control units not supposed to receive treatment becoming treated (Cattaneo and Titiunik, 2022). In this analysis we employed a sharp RDiT design due to hurricane Michael occurring at a distinct point in time (Oct 2018) which clearly separates pre- and post-treatment periods. However, because we utilize the bi-monthly data and hurricane Michael occurred in October 2018, which is the latter half of the September to October period, we set the cutoff to bi-month Nov-Dec 2018 (42). Setting the cutoff to bi-month 42 allows all storm damage to occur and be assessed, as well as for salvage harvest and repairing and rebuilding to begin in this period and forward.

Furthermore, the pre- and post-treatment slopes of the price data can define whether the RDiT design is conventional or kink. Conventional

Table 1
Descriptive statistics for each stumpage product price series and micro-market used in the analysis ($N = 68$, pooled $N = 408$; Jan 2012 -Apr 2023).

Price Series ($2019 year)	Mean	Std.Dev.	Minimum	Maximum
Micro-market 12				
Pine Sawtimber	25.47	2.19	20.32	30.28
Pine Chip-N-Saw	16.70	2.00	11.41	21.52
Pine Pulpwood	9.28	1.46	5.82	12.01
Hardwood Sawtimber	30.75	6.34	20.03	41.49
Hardwood Pulpwood	8.80	1.93	4.00	13.62
Micro-Market 13				
Pine Sawtimber	31.27	3.22	24.58	37.33
Pine Chip-N-Saw	24.96	4.07	15.81	34.04
Pine Pulpwood	18.57	3.25	11.45	28.47
Hardwood Sawtimber	24.07	4.64	18.51	38.69
Hardwood Pulpwood	8.90	1.95	5.11	12.81
Micro-Market 14				
Pine Sawtimber	31.76	3.55	22.80	40.50
Pine Chip-N-Saw	24.51	4.52	13.22	37.01
Pine Pulpwood	16.05	3.93	7.88	31.64
Hardwood Sawtimber	23.69	3.94	17.28	34.53
Hardwood Pulpwood	6.71	1.74	3.41	11.99
Micro-Market 15				
Pine Sawtimber	29.56	2.79	24.28	36.71
Pine Chip-N-Saw	21.45	3.13	15.89	27.61
Pine Pulpwood	12.88	2.83	7.22	20.27
Hardwood Sawtimber	25.19	5.16	14.92	35.68
Hardwood Pulpwood	8.13	2.03	3.24	12.24
Micro-Market 16				
Pine Sawtimber	27.08	2.81	21.50	33.45
Pine Chip-N-Saw	19.07	2.50	13.96	24.28
Pine Pulpwood	11.95	2.61	6.39	16.91
Hardwood Sawtimber	23.07	2.84	18.28	28.39
Hardwood Pulpwood	12.45	2.25	8.36	17.53
Micro-Market 17				
Pine Sawtimber	25.47	2.24	19.89	31.35
Pine Chip-N-Saw	17.41	1.82	14.30	23.15
Pine Pulpwood	10.16	2.01	6.63	15.56
Hardwood Sawtimber	27.91	5.94	18.73	39.83
Hardwood Pulpwood	11.84	2.15	7.68	17.21
Pooled average				
Pine Sawtimber	28.45	3.82	20	41
Pine Chip-N-Saw	20.68	4.55	11	37
Pine Pulpwood	13.14	4.28	6	32
Hardwood Sawtimber	25.79	5.63	15	41
Hardwood Pulpwood	9.46	2.88	3	18

RDiT has constant slopes of the pre- and post-treatment data, whereas slope changes direction at the cutoff point in the kink RDiT setup (Calonico et al., 2014). To determine whether the RDiT analysis is conventional or kink, we first evaluated the slopes of each price series in each MM at the bi-month 42 cutoff, which is Oct-Nov 2018. Figs. 2 and 3 present the graphical representation of the pre- and post-hurricane stumpage prices of the pooled panel data based on conditional means plots and regression discontinuity plots, respectively. Similarly graphical analyses of regression discontinuity plots of each individual MM are presented in the supplemental material (Fig. S1-S5). Therefore, the specification for our RDiT design is as follows:

$$\ln\left(y_{it}^{s}\right) = \beta_0 + \beta_1(PostStorm) + \beta_2\left(\left(lag\, y_{it}^{s}\right) + \sum_{k=3}^{n} \beta_k\left(x_{it}^{s}\right) + \varphi f(time) + x(PostStorm)^{*} f(time) + \varepsilon_{it}\right. \quad (1)$$

Where y_{it} is the stumpage price (log transformed) of timber product *s* for MM *i* at time *t*; β_1 is the parameter of interest that estimates the effect of hurricane Michael on stumpage prices; *Lag* y_{it} is the lagged log price variable that accounts for autoregressive properties (Hausman and Rapson, 2018); x_{it} represent the covariates controlling the effects of demand and supply factors of stumpage prices such as prices of related stumpage products; *PostStorm* is a dummy variable equal to one if bi-month is greater than or equal to 42 (Nov-Dec 2018) and zero otherwise; *f(time)* contains the polynomial time trend that flexibly controls for time series variation in stumpage prices that would have occurred in the absence of hurricane Michael (Ruan et al., 2021); *x(PostStorm)*f (time)* is an interaction term that allows the time trend in stumpage prices to differ on each side of the cutoff; ε is the random error. Since stumpage products are co-produced or markets of timber products are related (Newman, 1987; Parajuli et al., 2016), we included the price series of other stumpage products in each model. For instance, the related stumpage products in the pine sawtimber price model include pine chip-n-saw and pine pulpwood, whereas hardwood pulpwood is included in the hardwood sawtimber price model.

Identification using RDiT requires several strong and often untestable assumptions (Hausman and Rapson, 2018). Foremost, it is assumed that the event in question is the sole cause of discontinuity in the independent variable as argued by Ruan et al. (2021) and Bruck et al. (2023). However, due to the time series nature of RDiT designs, potential confounding variables through time may bias the estimates (Hausman and Rapson, 2018). Yet, any changes in the independent variable around the cutoff will be absorbed by the flexible polynomial time trend and not contribute to any bias (Hausman and Rapson, 2018; Ruan et al., 2021). The next major assumption of RDiT is that self-selection behavior, the ability to decide to move into or out of treatment does not occur (Ruan et al., 2021). In our application of RDiT, we can safely assume that self-selection behavior is non-existent, as hurricanes are natural occurrences. Moreover, autocorrelation could be an issue in RDiT models (Hausman and Rapson, 2018), so we included the first lag of each dependent variable in Eq. [1].

2.3. Empirical estimation

Following the methods of Calonico et al. (2014); Heckman and Vytlacil (2007); and Imbens and Wooldridge (2009), we utilize the potential outcomes framework to identify impacts of hurricane Michael on stumpage prices. Under this framework the scalar random variable for each MM is the stumpage price, and the scalar regressor, the running variable (bi-month), assigns the treatment based on the known cutoff point at bi-month 42 (Imbens and Kalyanaraman, 2012). Thus, {*[Price$_i$(0), Price$_i$(1), time$_i$]'*, $i = 1,2,\ldots,n$} is a random sample from population *{Price(0), Price(1), time}'*, where *Price(0)* and *Price(1)* are potential stumpage prices without and with the occurrence of hurricane Michael (Imbens and Kalyanaraman, 2012). Hence, the observed outcome can be defined as follows:

$$Price_i = \begin{cases} Price_i(0)\ if\ Bi - Month < 42 \\ Price_i(1)\ if\ Bi - Month \geq 42 \end{cases} \quad (2)$$

In this study, we estimated Eq.[1] for each individual stumpage product and micro-market combination separately, using bi-monthly stumpage price data from Jan-Feb to Mar-Apr 2023. Empirical estimation of the potential outcome framework for each RDiT model was conducted using the *rdrobust* command in STATA 18 software. Table 2

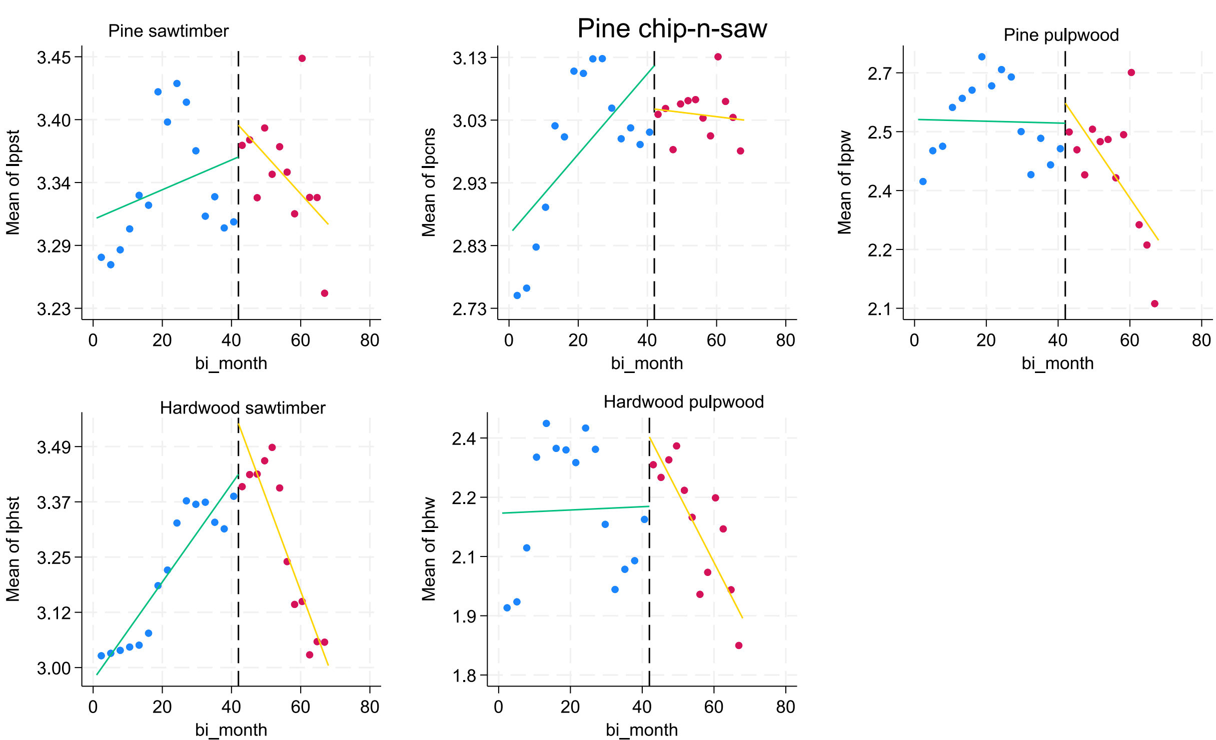

Fig. 2. Conditional mean graphs of timber stumpage products for pooled average micro-markets 12–17 with cutoff at bi-monthly period 42 (Nov-Dec 2018).

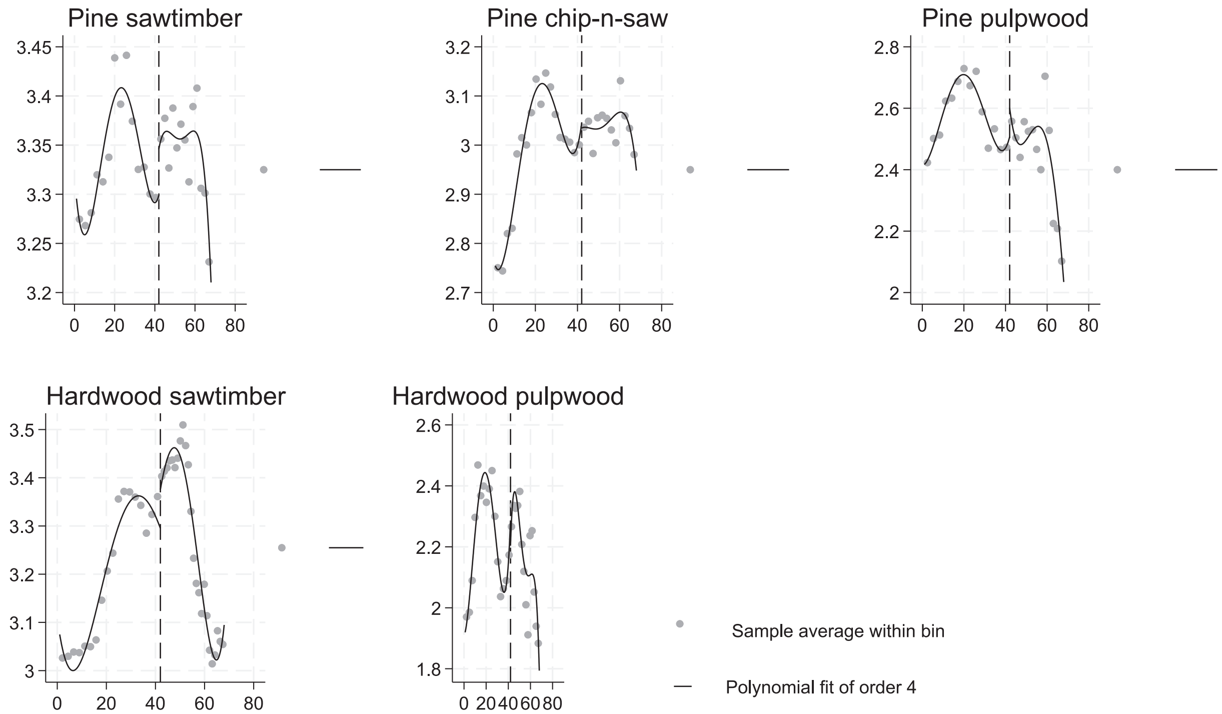

Fig. 3. Regression Discontinuity plot using a cutoff at bi-month 42 (Nov-Dec 2018) for pooled average micro-markets 12–17 stumpage prices.

Table 2
The type of RDiT design, sharp or sharp-kink, for each micro-market and stumpage products.

Micro-Market	Pine Sawtimber	Pine Chip-N-Saw	Pine Pulpwood	Hardwood Sawtimber	Hardwood Pulpwood
Pooled (average)	Sharp-kink	Sharp	Sharp-kink	Sharp-kink	Sharp
12	Sharp-kink	Sharp-Kink	Sharp	Sharp	Sharp-Kink
13	Sharp	Sharp-Kink	Sharp-Kink	Sharp-Kink	Sharp-Kink
14	Sharp-Kink	Sharp	Sharp-Kink	Sharp-Kink	Sharp
15	Sharp	Sharp	Sharp-Kink	Sharp-Kink	Sharp-Kink
16	Sharp-Kink	Sharp-Kink	Sharp	Sharp-Kink	Sharp-Kink
17	Sharp	Sharp-Kink	Sharp	Sharp-Kink	Sharp-Kink

indicates the type of RDiT design (sharp or sharp-kink) estimated for each stumpage product and MM combination, based on the *rdplot* graphs. The empirical difference between sharp and sharp-kink RDiT designs is that the regression function derivative is set to one in the sharp-kink design (Calonico et al., 2014). The local polynomial estimator derived from the kernel estimates the polynomial regressions around a local neighborhood of the cutoff, which is responsible for estimating hurricane Michael's causal effects on timber prices. We estimated the models with various polynomial time trends (linear, quadratic, and cubic) to construct the point estimator, but the estimated coefficient of hurricane impacts, β_1 in eq. 1, remained relatively robust, so we presented the results with a linear polynomial trend in Table 3. Results with quadratic polynomial trends are presented in Table S1 in the supplemental material. Lastly, the choice of bandwidth selection around the cutoff is critical in any RDD approaches. We estimated individual models using one common mean square error (MSE)-optimal bandwidth selector (*mserd*) which minimizes point estimate MSE using a single MSE-optimal selector around the cutoff (Calonico et al., 2017). Since results are sensitive to the bandwidth, we also estimated models using two different MSE-optimal bandwidth selectors (*msetwo*) for the RDiT treatment effect estimator, which utilizes two distinct common bandwidths on either side of the cutoff to compute the MSE-optimal point estimates (Calonico et al., 2017). Results from the *msetwo* bandwidth are presented in Table S2.

3. Results

Table 3 reports the results of the RDiT design evaluating hurricane Michael's causal impact on pine and hardwood stumpage prices in micro-markets 12 to 17. The coefficient estimates are based on the one common mean squared error (MSE)-optimal bandwidth selector (mserd) with a cutoff point at November–December 2018. MM 15 was the directly affected region by hurricane Michael, and MM 12 was also in the path with the declining effects of the extreme weather event. Two different treatment effects are presented: the bias corrected scenario with a conventional variance estimator (Imbens and Kalyanaraman, 2012); and the bias corrected scenario with a robust variance estimator (Ludwig and Miller, 2007). All scenarios have consistent and asymptotically efficient estimators as the sample size grows (Calonico et al., 2014), but we focus our results on the robust scenario estimates, given the limited sample size of 68 observations for each individual micro-market model.

RDiT results indicated that the impacts of hurricane Michael on timber prices vary by stumpage products with spatial heterogeneity (Table 3). In a pooled panel model with an average of all micro-markets, the estimated hurricane impact was statistically significant only for pine pulpwood stumpage prices, which suggests that pine pulpwood prices across the region were down about 6 % immediately after hurricane Michael. In the direct hurricane hit zone of MM 15, while the prices of pine sawtimber and hardwood sawtimber were estimated to be negatively affected by the hurricane with statistically significant effects, the

Table 3
Causal effects of hurricane Michael on stumpage prices in various micro-markets in Florida, Georgia and Alabama. RDiT results are based on the MSE-optimal bandwidth selector (mserd) and a cutoff point at November–December 2018. The local polynomial order of degree 1 (linear) is considered. Triangular Kernel is selected for the sharp design, and Uniform Kernel is specified for the sharp-kink design.

	Micro-Market						
	Panel (pooled)	12	13	14	15	16	17
Pine Sawtimber							
Bias-Corrected estimate	−0.01	−0.13***	0.03	−0.37	−0.09***	−0.07***	0.17*
	(0.01)	(0.04)	(0.08)	(0.31)	(0.03)	(0.03)	(0.10)
Robust estimate	−0.01	−0.13**	0.03	−0.37	−0.09**	−0.07*	0.17
	(0.01)	(0.06)	(0.10)	(0.35)	(0.03)	(0.04)	(0.12)
Pine Chip-N-Saw							
Bias-Corrected estimate	−0.03	−0.95***	−0.01	−0.09**	−0.06	−0.28**	−0.15***
	(0.03)	(0.33)	(0.01)	(0.04)	(0.06)	(0.13)	(0.02)
Robust estimate	−0.03	−0.95**	−0.01	−0.09	−0.06	−0.28	−0.15***
	(0.04)	(0.44)	(0.01)	(0.05)	(0.07)	(0.18)	(0.04)
Pine Pulpwood							
Bias-Corrected estimate	−0.06***	−0.13***	−0.16***	−0.04**	−0.05	0.19	0.12
	(0.02)	(0.04)	(0.05)	(0.02)	(0.04)	(0.15)	(0.09)
Robust estimate	−0.06**	−0.13**	−0.16**	−0.04	−0.05	0.19	0.12
	(0.03)	(0.05)	(0.07)	(0.04)	(0.07)	(0.19)	(0.12)
Hardwood Sawtimber							
Bias-Corrected estimate	−0.01	−0.03	−0.08**	−0.10***	−0.77***	0.04***	−0.15***
	(0.01)	(0.05)	(0.03)	(0.03)	(0.29)	(0.01)	(0.03)
Robust estimate	−0.01	−0.03	−0.08	−0.10**	−0.77**	0.04***	−0.15***
	(0.02)	(0.06)	(0.05)	(0.05)	(0.36)	(0.01)	(0.06)
Hardwood Pulpwood							
Bias-Corrected estimate	−0.09	0.11***	−0.17**	−0.12	−0.31**	−0.02	0.11**
	(0.06)	(0.03)	(0.08)	(0.19)	(0.14)	(0.04)	(0.05)
Robust estimate	−0.09	0.11	−0.17*	−0.12	−0.31	−0.02	0.11*
	(0.07)	(0.07)	(0.10)	(0.23)	(0.19)	(0.05)	(0.06)
Observations on left of cutoff	240	40	40	40	40	40	40
Observations on right of cutoff	162	27	27	27	27	27	27

*10 % significance; ** 5 % significance, ***1 % significance; values in parentheses represent standard errors.

estimated effects of the hurricane on pine chip-n-saw, pine pulpwood, and hardwood pulpwood prices were statistically insignificant. The estimated robust coefficient of −0.09 associated with pine sawtimber stumpage prices in MM 15, indicated that the hurricane led to about 9 % decline in pine sawtimber prices in the directly affected region in Florida and Georgia. Similarly, the estimated causal effect of hurricane Michael on hardwood sawtimber prices was about −77 % in MM 15.

With substantial timber damages in the hurricane-impacted region, results suggest that the spill-over effects of hurricane Michael on some surrounding timber markets were statistically significant. The estimate causal impacts of the hurricane on timber prices in the adjacent micro-markets were mostly negative, when the effects were statistically significant at 10 %, except on hardwood sawtimber prices in MM 16 and hardwood pulpwood prices in MM 17 where the estimates were found to be statistically significant with a positive sign. In terms of pine sawtimber markets, the estimated treatment effect was negative and statistically significant in MM 12 (−13 %) and MM 16 (−7 %), but the estimates were statistically insignificant in MM 13, MM 14, and MM 17. Similarly, in the case of pine chip-n-saw markets, hurricane Michael was found to induce statistically significant negative price impacts with robust standard errors in MM 12 (−95 %) and MM 17 (−15 %) only. Because of hurricane Michael, the pine pulpwood prices in MM 12 and MM 13 were down, with statistically significant effects of −13 % and −16 %, respectively.

The estimated robust effects of hurricane Michael on hardwood sawtimber and hardwood pulpwood prices in the surrounding regions were mixed. The price impacts on hardwood sawtimber were estimated to be statistically significant with negative magnitudes in MM 14 (−10 %) and MM 17 (−15 %), but it was positive in MM 16 (4 %). Likewise, due to hurricane Michael, hardwood pulpwood prices were estimated to be down 17 % in MM 13, but were up 11 % in MM 17.

4. Discussion

The Southeastern US has experienced more extreme weather events in the last few decades, which are projected to increase in terms of the intensity driven by extreme heat and precipitation (Gao et al., 2012; Masukwedza et al., 2025). The increasing risk of extreme weather events in the US South, such as catastrophic hurricanes, make forestry and associated markets in the region some of the most susceptible to climate change (Sohngen and Sedjo, 2005). Although several studies have assessed hurricane impacts on US Southeastern timber markets, this is the first study to apply a causal inference method to analyze effects of catastrophic hurricanes on stumpage prices. This study utilizes bi-monthly stumpage price data to investigate the discontinuities in stumpage prices following hurricane Michael in late 2018.

Hurricane Michael caused significant damage to forest resources in the coastal region in Florida, Georgia and Alabama. Brandeis et al. (2022) estimated that about 6.17 million acres of timberland were moderately to substantially damaged by hurricane Michael. This damage reduced remaining live pine (*Pinus spp.*) inventories to 70 % in the moderate damage zone to 22.7 % in the severely damaged zone, compared to the pre-hurricane Michael inventories (Brandeis et al., 2022). The significant timberland area damaged by hurricane Michael and the resulting decrease in the volume of live, standing pine inventories left after the storm indicates that standing timber stock significantly decreased in the hurricane affected region (MM 15) in the post-hurricane Michael period.

With significant disruptions in timber supply, inventory and additional wood product demand for recovery and reconstruction, Hurricane Michael was found to cause significant price changes in standing timber markets on average in a pooled model, in MM 15, and the surrounding markets. The hurricane effects on prices were found to be mostly negative in the main damage zone. In the directly affected region (MM 15), pine sawtimber and hardwood sawtimber prices were found to significantly decline due to hurricane Michael, whereas the hurricane effects on pine chip-n-saw and pine pulpwood and hardwood pulpwood markets were statistically insignificant with negative magnitudes. Our results are in line with most of the related literature such as Prestemon and Holmes (2004), Sun (2016), Henderson et al. (2022), and Hernandez-Diaz et al. (2024), which also reported that timber prices in hurricane affected zones decline in the immediate post-hurricane period.

The price movement dynamics consistent with supply and demand principles can explain the hurricane impacts on timber prices. The laws of demand and supply state that a commodity's price decreases when its supply increases, demand decreases, or both occur simultaneously. The supply side of timber is primarily driven by the available timber inventory and the markets for end use products such as lumber and pulp and paper products are the main determinant of timber demand (Newman, 1987; Parajuli and Chang, 2015).

In MM 15, the increase in pine sawtimber harvests was evident through wood utilization rates, the amount of pre-storm live volume used after the storm, following hurricane Michael. Across Florida, Georgia, and Alabama, pine was the most utilized species (Brandeis et al., 2022). As damage severity increased, the amount of pine utilization as salvage harvests increased, with as much as 50.5 % of the remaining pre-storm live pine volume being utilized in the catastrophic damage zone (Brandeis et al., 2022). The significant volume of utilized pine following hurricane Michael indicates a significant increase in pine stumpage product, leading to oversupply in the local wood basin. Therefore, it makes sense that the stumpage price of pine sawtimber in the most affected region decreases in the period immediately following hurricane Michael were triggered by higher supply of salvage stumpage. Additionally, most of the mills might get directly affected by the hurricane and halt or curtail their production temporarily, which would also lower the timber demand resulting in lower prices. The similar argument could explain the downward movement in prices of hardwood sawtimber in MM 15 where the estimated price effect was −77 %. Even though the salvage utilization of hardwood stumpage was relatively low (Brandeis et al., 2022), the demand side of the hardwood stumpage might have been affected severely leading to the significant drop in hardwood sawtimber prices. According to the Primary Forest Products Network database (Forestproductslocator, 2024), there were only 10 primary small-scale sawmills using hardwood stumpage across the hurricane damaged areas in Florida, Georgia, and Alabama. The price impacts may be short-lived, the timberland recovery efforts may induce replanting extensively, specifically in the case of pine plantations (Henderson et al., 2022).

The trade between damaged and surrounding undamaged markets affects the timber market dynamics and the recovery after hurricanes in the surrounding regions (Sun, 2016; Henderson et al., 2022). Trade between damaged and undamaged markets may provide an explanation for the significant impacts of hurricane Michael in other wood basins adjacent to MM 15. The damaged area of hurricane Michael might be within the procurement region of several primary mills located in the surrounding micro-markets. Additionally, as mills have varying distances they will travel to procure wood, depending on transportation costs (Forest2-Market, 2014), the lower value of salvage wood residues may enable mills to increase their procurement radii due to cost reductions, leading to price impacts in surrounding wood basins. It is estimated that about 1.66 billion cubic feet (about 16 % of the total tree volume) of salvage wood was utilized from the damage zones after the hurricane (Brandeis et al., 2022). With the abundance of salvage wood available in the damage area, the surrounding mills might have procured the relatively cheaper salvaged stumpage from MM 15, which might lead to decline in timber prices in their local wood basins. Both micro-markets 12 and 16, which are very next to MM 15 (Fig. 1), realized a significant decline in pine sawtimber prices, because mills from these surrounding markets might have utilized more salvage wood from MM 15. Similarly, pine chip-n-saw prices in micro-markets 12 and 17 and pine pulpwood prices in MM 12 and 13 were significantly down, mainly due to the additional salvage supply of wood from the hurricane damaged area.

Similar arguments and rationales based on supply, demand, and trade principles could explain the varying effects of hurricane Michael on stumpage prices of hardwood sawtimber and hardwood pulpwood in the surrounding wood markets. The additional salvage supply and limited mills' operations in the wake the hurricane and its aftermath could explain the downward pressure on hardwood sawtimber and pulpwood prices in surrounding markets such as MM 14 and MM 17 for hardwood sawtimber and MM 13 for hardwood pulpwood markets.

Some surrounding markets are found to realize positive price impacts from hurricane Michael, specifically in the case of hardwood sawtimber in MM 16 and hardwood pulpwood in MM 17. Similarly, while not statistically significant, coefficients associated with pine sawtimber prices in MMs 13 and 17, and pine pulpwood prices in MMs 16 and 17 were also positive. Timber market dynamics following a hurricane are partially linked to rising wood product demand (Sun, 2016) as rebuilding and repairing efforts require additional wood products. Particularly, after the recovery efforts begin, the demand for lumber and composite products such as oriented strand board is expected to significantly rise (Sun, 2016). Thus, some markets with larger mills might have picked up additional demand for reconstruction efforts in the post-hurricane period, which might push the stumpage prices higher in some isolated markets. On the other hand, while more damaged woody residues are available right after the hurricane, the salvage wood is often less accessible with wet soils and damaged road networks, indicating the less impact of salvage supply. For instance, about 1.5 billion cubic feet of wood were estimated to be standing dead in the damage zone after hurricane Michael (Brandeis et al., 2022).

5. Conclusion

Natural catastrophes have been increasing in intensity globally as a result of climate change (Kirchberger, 2017; Zhai and Ning, 2022). Due to potential short- and long-run effects on natural resources product supplies, natural catastrophes may have significant implications for natural resources markets (Zhai and Ning, 2022). With the significant role of the US South in regional and global timber markets, understanding the market impacts of catastrophic hurricane events in the timber supply basins may play a vital role in risk management decisions and better planning for both timber producers and consumers along the supply chain. Previous research related to hurricane impacts on timber markets have reported immediate price decreases after the storm, but the markets improved over the long run. The goal of this paper was to examine the immediate discontinuities in the stumpage prices following a catastrophic hurricane in the Coastal Plains region in the Southeastern United States, based on a case study of hurricane Michael.

Results from RDiT models suggest that the stumpage price impacts of hurricane Michael were mostly negative, partly varied by the stumpage products and local timber markets in the directly affected and surrounding regions. Timber markets are local, and various demand, supply and trade factors in surrounding regions could cause varying impacts on timber markets. While the higher availability of salvage wood as well as mills' limited operations in the wake of the extreme weather event could drive the timber prices downward, the issues of accessibility due to wet soils and damaged roads and increased demand for wood products in reconstruction and repairing efforts might sway the local timber prices in either direction. Moreover, due to substantial distortion in timber supply in the hurricane affected region, it is clear that hurricane Michael had spill-over effects, with statistically significant impacts on timber stumpage prices in surrounding regions.

A couple of study caveats are worth mentioning. First, our study is limited to one catastrophic hurricane event. However, an overwhelming majority of similar studies analyze a single event (Prestemon and Holmes, 1998, 2000, 2004, 2010; Yin and Newman, 1999; Sun, 2016; Henderson et al., 2022; Hernandez-Diaz et al., 2024). Second, it is worth noting that this study only assesses the immediate effects of hurricanes on stumpage prices and does not distinguish the short- and long-term price impacts. Nevertheless, our results provide useful insights into the immediate dynamics of timber price fluctuations after a major hurricane, which may help forestry stakeholders and timber market participants make more informed management decisions pertaining to feedstock supply and market dynamics.

This study presents opportunities for future research. First, assessing both the short- and long-run impacts of a major hurricane event using causal inference techniques may be useful with the known heterogenous recovery of timber markets after a hurricane. Next, with continuing advancements in causal inference methodologies, such as difference-in-difference with heterogeneous treatment timing and intensity, this study opens the door for further hurricane impact research using various newly developed casual inference approaches. Lastly, as methodologies continue to advance, assessing the impacts of hurricanes on timber markets using multiple major storm events may be an interesting endeavor.

CRediT authorship contribution statement

Austin Lamica: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rajan Parajuli:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Consuelo Brandeis:** Writing – review & editing, Validation, Funding acquisition, Formal analysis, Conceptualization.

Consent for publication

All authors agree and have full consent to publish this work in Forest Policy and Economics.

Ethics approval and consent to participate

This research doesn't contain any studies with human or animal participants performed by any of the authors.

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Declaration of competing interest

The authors have no relevant financial or non-financial interests to disclose.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.forpol.2025.103590.

Data availability

The timber price data used in this study are proprietary purchased from Resource Wise (formerly Forest2Market), so sharing the entire dataset publicly could be problematic.

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