Ecological Economics 106 (2014) 56–68

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

Weather conditions and outdoor recreation: A study of New England ski areas

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ARTICLE INFO

Article history:
Received 21 November 2013
Received in revised form 3 June 2014
Accepted 7 July 2014
Available online 2 August 2014

Keywords:
Discrete time survival analysis
Market structure
Climate change
Weather conditions
Tourism

ABSTRACT

We present a structural model and employ discrete time survival analysis to examine the impact of weather conditions on firms' exit decisions within the New England ski industry. Our results suggest that weather conditions can have significant direct and indirect effects on the closure of ski areas. The results also indicate that larger ski areas are more likely to engage in investment activities to help offset the effects of adverse weather conditions, which tip the odds of success in favor of these ski areas. Consequently, this study shows that climate change may have played a significant role in altering the market structure of the New England ski industry.

1. Introduction

Today climate change is a frequently discussed topic in both the media and academia. Since many industries rely on the stability of their local weather for survival, the climate change issue has become a major economic concern (Nordhaus, 2012; Stern, 2006; Tol, 2012). To have good assessments of the overall impact of climate change, it is important to first accurately evaluate how weather conditions affect individual industries (Mendelsohn et al., 2000; Tol, 2002). Industries which may be vulnerable to the damages of climate change are diverse; ranging from agricultural to insurance, healthcare to financial services, and fishing to tourism (e.g., Berrittella et al., 2006; Bosello et al., 2006; Bosello et al., 2007; Cheung et al., 2010; Gomez-Echeverri, 2013; Hajat et al., 2014; Mills, 2005; Piao et al., 2010).

In this study, we explore the potential effects of weather conditions on the ski industry. We focus on the ski industry because it relies heavily on steady and lengthy winter weather conditions. Changes in weather patterns due to global warming, such as reduced snowfall and an upward trend in winter temperature, can be devastating to the operation of a ski area.

The ski industry in the United States has been experiencing structural changes. Studying the New England ski industry, Hamilton et al. (2003), reports that there has been a significant decline in the number of operational ski areas over the past several decades. Wake (2005) shows that in New England the average annual temperature and average winter temperature have been rising over the same time period, and the number of days with snow on the ground has been declining in the period from 1970 to 2000. Because of the ski industry's reliance on particular weather conditions, the common time period in which winter temperatures have risen, snowfall has decreased, and a large number of ski areas have closed, seems to suggest that climate change might have had a significant role in affecting the fate of individual ski areas and changing the market structure of the ski industry as a whole. However, before jumping to this conclusion, it is necessary to explore all factors that can contribute to the structural changes in this industry.

Previous research has identified several factors that may influence the probability of success of a given ski area. Some studies show that physical characteristics of ski areas affect the demand for skiing, which can subsequently impact the survival of ski resorts. Morey (1984) investigates how individual characteristics and the characteristics of a ski area affect young skiers' behavior. He finds that skiing terrain may influence an individual's decision to visit a particular ski area. In a later study, Morey (1985) estimates the demand for the development of a Colorado ski area. He investigates specific characteristics of skiers and ski areas that may affect the demand for skiing, and finds that those ski areas with natural endowments and which can offer a good variety of activities are valued higher by consumers. Morey's findings can be used to partially explain why so many ski areas have closed in the past century. Specifically, some mountains were able to offer more to their skiers and were able to pull business away from their less diverse counterparts.

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http://dx.doi.org/10.1016/j.ecolecon.2014.07.011
0921-8009/

Other studies suggest that geographic locations are important as well. For example, Fukushima et al. (2002) study ski activities in Japan and find that the farther a ski resort is from the major metropolitan area, the less likely it is to draw a large crowd to its mountain. The findings of Morey (1984, 1985) and Fukushima et al. (2002) have been supported more recently by other studies examining the determinants of overall skier demands and destination choices (e.g., Dawson et al., 2013; Kaimakamis et al., 2013).

Some studies have shown connections between snowfall and number of visits to ski areas. Palm (2001) finds that 700,000 fewer skiers visited the ski areas in New Hampshire and Vermont during the years with the least snowfall, compared to those with the most. In a similar study, Hamilton et al. (2007) find that the amount of snow in the nearest metropolitan area greatly impacted the number of skiers who traveled to local ski areas on a particular day in New England. Fukushima et al. (2002) find significant correlation between number of skiers and the depth of snow at ski areas in Japan. They estimate a 30% decrease in ski activities for a 3 °C increase in temperature. Pickering (2011) examines the visitation patterns with differing snow cover at six ski areas in Australia during the 1997–2007 ski seasons. She finds that visitation declines significantly with low natural snow cover even with snowmaking; and, decreased visitation due to low natural snow cover is felt most strongly by ski areas in the lowest elevations. These studies suggest that when climate change alters the environment and weather conditions for a sustained period of time, it can cause a prolonged decrease in skier demand that can jeopardize the success of ski areas. The studies also note differences in the severity of decreased skier demand based on ski mountain characteristics and locations.

With the projection of continued, decreasing snowfall and rising winter temperatures, researchers have also studied the strategies from the supply side which allow ski areas to adapt to these changing weather patterns. Falk (2013) uses the Cox proportional hazard and competing risk models to examine the influential factors on ski areas temporary and permanent shut down decisions of 244 ski areas in Austria from 1995 to 2011. He finds that the ski areas with snowmaking capabilities at the start of the studied period (1995) have a 78% lower failure risk, equivalent to a 4% reduction in the average unconditional failure risk, than those without snowmaking in 1995. Scott et al. (2003) construct a simulation model, based on the data for the ski industry in Southern Ontario (Canada), to show the importance and effectiveness of snowmaking to battle climate variability and changes. Scott and McBoyle (2007) discuss more generally the adaptation options of climate change for ski resorts. The adaptation options can be technological, such as investing in snowmaking equipment and slope development, or operational, such as creating diversified revenue streams by offering a variety of services beyond ski related activities in all seasons. Some ski areas now provide lodging, shopping, and restaurants, as well as extend operations into all four seasons. Scott and McBoyle (2007) show that lift tickets sales are now accounting for less than half of the ski industry's overall revenue, compared to nearly 100% of the revenue from ticket sales when the ski industry first began. These studies show that abilities to adapt to changing weather patterns such as investment in snowmaking machinery and expanding operational seasons and offerings can contribute to the success and survival of ski areas.

Dawson et al. (2009) examine the projected impacts on ski areas for the 2040–2069 time period using a historic climate change analogue approach. They show that with current climate change projections, ski resorts in the USA Northeast will continue to feel the impact of shorter ski seasons, increased capital costs, and decreased profits. Steiger (2011) conducts a similar study in Tyrol, Austria and finds consistent results. He also echoes the findings of Pickering (2011) by highlighting that the projected increased winter temperatures and decreased snowfall will likely affect more severely the smaller and lower elevation ski areas.

From the literature, four categories of factors are considered to impact the success of a ski resort: resort characteristics, adaptation abilities, location, and weather conditions. The adaptation abilities refer to the abilities to invest and to adjust business operation in response to changes in the physical and business environment, such as acquiring snowmaking machines and extending operations beyond the ski season. Note that weather conditions may influence the success of a ski area through multiple channels. They can affect the revenue, therefore the survival, of a ski area directly by reducing the demand faced by the ski area. They may also impact the decisions to invest and to develop new business strategies which may increase the chances of survival. To assess the overall effects of weather conditions on the survival of ski areas, it is important to examine both the direct and indirect channels through which they can influence the success of the ski areas, as well as, to consider all other factors simultaneously to avoid misrepresentation.

In this study, we employ the discrete time survival analysis and present a structural model to study the direct and indirect effects of weather conditions on the closure of a ski area in New England. We compile a unique dataset containing information of the known ski areas that closed down between 1970 and 2007 and ski resorts that were still in operation by 2007. To our knowledge, this is the first study to estimate both the direct and indirect effects of weather conditions, along with other factors, on the exit decisions of firms in the ski industry.

In the next section, we present the history of the New England ski industry and describe the data collection process. In Section 3, we outline the strategy of our empirical analysis. The empirical model and econometric technique, as well as a summary of data, are presented. In Section 4, we discuss estimation issues and results. Based on the estimation results, a simulation of effects of key factors on the probability of closure of a ski area is also presented. Lastly, some concluding remarks are given in Section 5.

2. New England Ski Industry and Data Collection

The New England ski industry began as small privately owned hills with single rope tows in the late 1800s. During this time, the consistent snowfall supported the growth of the industry, and hundreds of diverse ski areas opened all over New England by the early 1900s. The ski industry soon became a multibillion dollar industry with significant impact on the area's economy (Wright, 2006).

However, starting in the mid-1900s, the structure of the ski industry in New England began to change. In the 1960s, many ski areas were forced to shut down because of an increase in insurance costs. Many of the mom-and-pop ski areas disappeared because they could not afford the payments (Puliafico, 2006). The industry continued to experience consistent consolidation after 1970. During this time, winter weather patterns also had noticeable changes as the temperatures rose and snowfall declined, and scientists began to voice their growing concern of global climate change (Peterson et al., 2008). A sizable ski industry, a wide variety of different weather conditions, and a changing market structure, make New England an ideal area for a case study. We focus this study on the years from 1970 to 2007 and compile data on both operational and closed ski areas during this time period.

The data of the individual ski resorts no longer in operation by 2007 were collected from the New England Lost Ski Areas Project website

Table 1
The New England ski areas in the study.

Characteristic	Ski areas in operation in 2007[a]	Ski areas closed down during the period[b]		
		1970–2007	1970–1989	1990–2007
# of ski areas	31	47	31	16
Avg. # of trails	43.27	9.09	5.94	15.19
Avg. # of lifts	7.31	2.00	1.42	3.13
Avg. vertical drop	1139.99	486.49	416.26	622.56

Summarized from sources:
[a] Individual websites of ski areas.
[b] http://www.nelsap.org/.

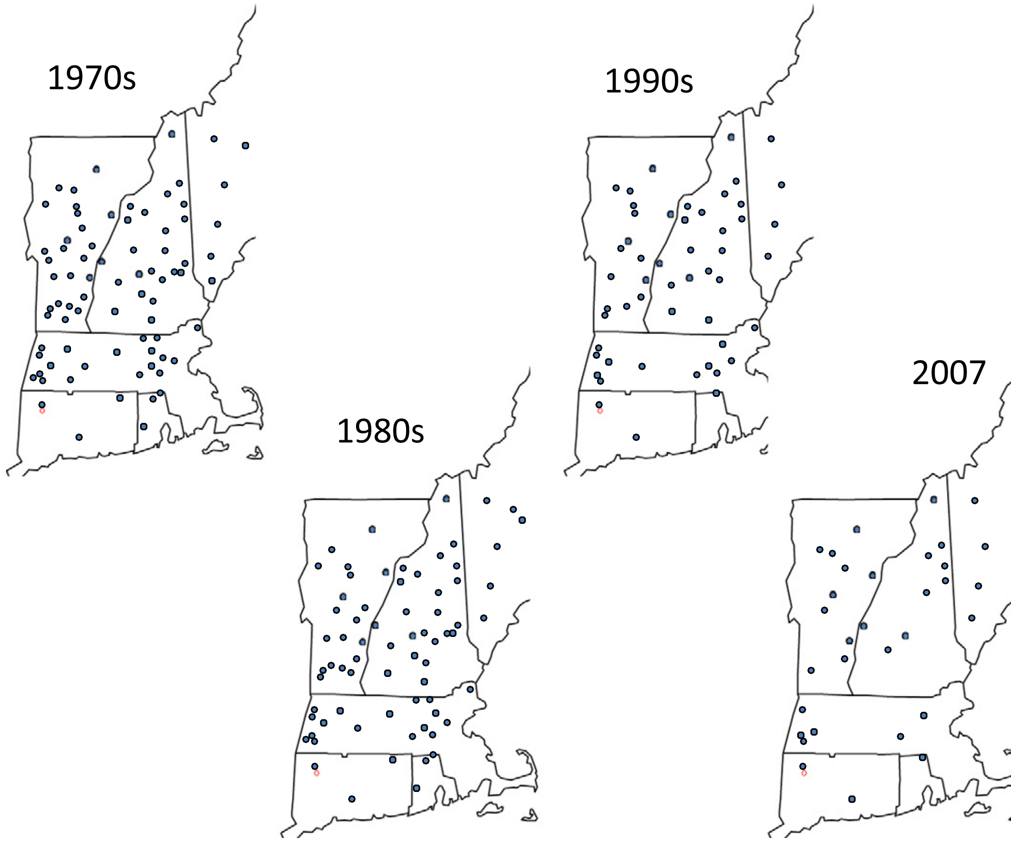


Fig. 1. Mapping of ski areas in New England over four decades.

(Davis and Gallup, 2007). This website lists the known closed ski areas of the New England states. The specific information of each closed ski area was collected from visits to the deserted mountain, interviews of former owners and patrons of the area, or ski magazines and guides from the years when the area was operational. We include all of the documented known closed ski areas in New England since 1970 that have sufficient information for our analysis. The available data of ski areas that still operated at the end of the studied year 2007 were collected from their individual websites. In total, we include 78 ski areas in this study, 31 were in operation in 2007 and 47 were closed between 1970 and 2007. The characteristics of both the operational and closed ski areas in our dataset are summarized in Table 1. Note that the average size of the closed ski areas is noticeably smaller than those still in operation by 2007. The ski areas are scattered throughout the states of Maine, New Hampshire, Vermont, Massachusetts, Connecticut, and Rhode Island. See Fig. 1 for a mapping of the studied ski areas in operation from 1970 to 2007. The continuous disappearance of ski areas in the past 4 decades is apparent. None of the closed ski areas in our study ever reopened.

The data we collected for each of the ski areas was based on the prevalent factors presented in the literature. The weather factors are the factors of interest in this study. We construct two weather condition measures: the annual average snowfall per day and average daily winter (November–February) temperature. Each ski area in our dataset is matched with the snowfall and winter temperature data from the nearest weather station. Weather stations report daily snowfall and temperature. Since our key dependent variable will be a binary variable indicating the closure of a ski area that is recorded yearly, we compute the yearly average per day snowfall and the average daily temperature during the winter months for each ski area. These are the weather condition variables used in the analysis.

The data of basic characteristics of a ski area, including number of lifts, number of trails, and the vertical drop of the mountain, are collected. We also construct two binary variables to indicate certain investment activities of a ski area. One variable indicates whether or not a ski area owns snowmaking equipment. The other denotes whether a ski area operates beyond the winter ski season and offers activities in all four seasons. Our location measures include the distance to Boston, the major metropolitan area in the region,[2] and state dummy variables to control for state fixed effects.

3. Empirical Strategy and Data Summary

3.1. Discrete Time Survival Analysis

To describe the status of a ski resort over time, during the studied period, we construct the following binary dependent variable Y_{it}.

$$\begin{aligned} Y_{it} &= 1 \text{ if the ski area is closed in year } t \\ &= 0 \text{ if it remains open in year } t. \end{aligned} \tag{1}$$

Multiple observations of Y_{it} are recorded and stacked for each ski area, from 1970 on. For example, for a ski area that was open in 1970 but closed in 1996, there are 27 observations for the ski area, one for each year between 1970 and 1996. For this resort, $Y = 0$ for the first 26 observations and $Y = 1$ for the last observation. If a ski area remained open in 2007, then there are 38 observations for this ski area with $Y = 0$

[2] We also constructed the distance variable to the nearest large urban area including New York City, Boston, Hartford (CT), Burlington (VT), Manchester (NH), and Portland (ME). The distance to the closest major metropolitan area to either New York City or Boston was also examined. The qualitative results based on these alternative location measures were the same.

for all observations. Stacking the annual observations of operational status of the ski areas enables us to conduct the discrete time survival analysis on the ski areas (Allison, 1984). No ski areas in the study were closed then reopen, so only the model of single event analysis is employed.

The discrete time duration model has been widely used in event history analysis in fields such as sociology, psychology, political science, and economics (e.g., Barber et al., 2000; Henry et al., 2009; Hiatt and Sine, 2014; Kendler et al., 1999; Louwers et al., 1999; Pennings et al., 1998; Singer and Willett, 1991; Singer and Willett, 1993; Tenfelde et al., 2012). It differs from the continuous duration model by disaggregating time into discrete time units. In contrast to the analysis of the "exact" time of an event in the continuous duration model (e.g., time of death after receiving cancer treatments), the time disaggregation for discrete time survival analysis could be due to the way events are recorded (e.g., grade of school dropout, regardless of the actual time in the year it occurs) or the natural discrete timing of an event (e.g., labor retention by annual contracts or the outcomes of presidential election). Although the nature of the data may ultimately determine the empirical modeling strategy, there are some advantages of the discrete time analysis. One advantage is that, unlike continuous hazard models, time varying covariates can be incorporated directly into the discrete time model (Allison, 1984). The other advantage is that under certain assumptions, standard binary choice models such as the logit and probit model can be used to analyze discrete time data (Jenkins, 1995). In our data, the year of the closing of a ski resort was recorded. Further, the key covariates of interest, the weather variables, are time varying. Therefore, the discrete time survival analysis is appropriate for the investigation of the impact of weather conditions on the survival of ski resorts.[3]

To describe the likelihood of failure of a ski area, let P_i be the probability that a ski area i closes as a (nonlinear) function of a set of explanatory variables X.

$$P_i = \Pr(Y_{it} = 1|X_i) = F(X_i;\beta), \tag{2}$$

where $F(.) \geq 0$, is a cumulative distribution function, and β is a set of parameters.

We define a random variable κ_i to represent the number of years that the ski area i remains open. Assume that κ_i follows a geometric distribution with a probability mass function as follows.

$$f(\kappa_i) = (1-P_i)^{\kappa_i}P_i \quad \kappa_i = 0, 1, 2, \ldots. \tag{3}$$

The above probability mass function can be rewritten to incorporate Y_{it}.

$$f(\kappa_i) = \prod_{t=1}^{\kappa_i+1}(1-P_i)^{1-Y_{it}}P_i^{Y_{it}}. \tag{4}$$

Based on Eq. (4), a likelihood function to describe the overall likelihood of observing κ_i for the n ski areas can be written as follows.

$$\begin{aligned} L &= \prod_{i=1}^{n} f(\kappa_i) = \prod_{i=1}^{n}\prod_{t=1}^{\kappa_i+1}(1-P_i)^{1-Y_{it}}P_i^{Y_{it}} \\ &= \prod_{i=1}^{n}\prod_{t=1}^{\kappa_i+1}(1-F(X_i;\beta))^{1-Y_{it}}F(X_i;\beta)^{Y_{it}}. \end{aligned} \tag{5}$$

The likelihood function in Eq. (5) can mimic a standard dichotomous choice model by rewriting κ_i into a series of Y_{it}, $t = 1, 2, \ldots, \kappa_i + 1$. Therefore, it can be conveniently estimated by standard statistical software packages. The common choices of specification for $F(X_i;\beta)$ are the cumulative distribution functions of the logistic and normal distributions.

[3] Alternatively, we may treat the number of years of a ski resort that remains open as a continuous variable and estimate continuous duration models with time varying covariates. Based on the nature of the data, we choose to proceed with discrete time analysis.

Let s_i be the number of years the ski area i was open up to 1970 and λ_i be the number of years for the ski area i to remain open after 1970, so that $s_i + \lambda_i = \kappa_i$. Then, the conditional probability distribution of κ_i, conditional on $\kappa_i \geq s_i$, can be derived as follows.

$$\begin{aligned} f(\kappa_i|\kappa_i \geq s_i) &= \frac{f(\kappa_i)}{\Pr(\kappa_i \geq s_i)} = \frac{f(\kappa_i)}{1-\Pr(\kappa_i < s_i)} \\ &= \frac{(1-P_i)^{\kappa_i}P_i}{1-\left[P_i + (1-P_i)P_i + \ldots + (1-P_i)^{s_i-1}P_i\right]} \\ &= \frac{(1-P_i)^{\kappa_i}P_i}{1-\left[1-(1-P_i)^{s_i}\right]} = (1-P_i)^{\kappa_i - s_i}P_i = (1-P_i)^{\lambda_i}P_i = f(\lambda_i). \end{aligned} \tag{6}$$

As a result, the conditional probability distribution of additional years that a ski resort will remain open does not depend on how many years the ski area stayed open in the past. Eq. (6) holds for any arbitrary s_i.[4]

3.2. Empirical Model

The probability that ski area i closes in year t may depend on various factors. The set of explanatory variables X in Eq. (2) is divided into four subcategories in our empirical model.

$$\Pr(Y_{it} = 1) = F(\boldsymbol{Z}_{it}, \boldsymbol{W}_{it}, \boldsymbol{I}_{it}, \boldsymbol{L}_{it}), \tag{7}$$

where $\boldsymbol{Z}_{it}$, $\boldsymbol{W}_{it}$, $\boldsymbol{I}_{it}$, and $\boldsymbol{L}_{it}$ represent respectively four groups of variables: characteristics of a ski area, weather, investment activities, and location. The function, $F(.)$, is a cumulative distribution function. The weather variables include snowfall and winter temperature; the main characteristics of a ski area are described by number of trails, number of lifts, and vertical drop of the mountain; two binary variables, whether to own snow making facilities and whether to operate in all four seasons, are used to signal the activities a ski area undertakes to adapt to changing physical and business environments; the distance to Boston is used to indicate the desirability of the location and the state fixed effects dummy variables are included to control for the potential general differences among the New England states. The definition of variables is given in Table 2.

As discussed in the literature review, the investment decisions may be motivated by adverse weather conditions. They can also be influenced by other characteristics related to the ski area. We define two investment activities variables for Eq. (7): $I_{1it} = 1$ if the ski area i has snowmaking equipment at time t and $I_{1it} = 0$ otherwise; $I_{2it} = 1$ if the ski area i operates four seasons at time t and $I_{2it} = 0$ otherwise. To explore the effects of weather conditions on investment decisions, two more equations are specified.

$$\Pr(I_{1it} = 1) = G(\boldsymbol{Z}_{it}, \boldsymbol{W}_{it}, \boldsymbol{M}_{it}) \tag{8}$$

$$\Pr(I_{2it} = 1) = H(\boldsymbol{Z}_{it}, \boldsymbol{W}_{it}, \boldsymbol{L}_{it}, N_{it}) \tag{9}$$

where $\boldsymbol{M}_{it}$ indicates the variables such as good sources of water (e.g., number of lakes nearby) and elevation of the mountain that can influence the decision of installing snow making facilities but do not affect the exit decision of a ski area; N_{it} represents the variables indicating the existing size of tourism related businesses surrounding a ski resort that may affect the decision to operate beyond the ski season. Both

[4] As a robustness check, we also analyze the data with alternative starting points at 1973, 1975, and 1977. Our key findings remain the same in all sets of results except that the Size variable (the size of a ski area) loses significance in the main equation of the proposed structural model but remains significant in the subsidiary equations when the starting point is set at 1973 and 1975. This suggests that the direct effect of Size may not always be significant, but the overall effect of Size on the probability of survival of a ski area remains significant.

Table 2
Variable definition and summary statistics.

Variable	Description	1970–2007		1970–1989		1990–2007	
		Mean[b]	Std[b]	Mean	Std	Mean	Std
Y_{it}[a]	=1 if the ski area i was closed in year t	2.3%		2.3%		2.3%	
Year[c]	The year in which the ski area was closed	1994.59	12.270	1980.43	4.39	2003.02	6.01
# of years a ski area remained open in the time period[c]		25.587	12.269	11.429	4.384	14.021	6.013
# of ski areas opened at the beginning of period		78		78		47	
# of ski areas closed at the end of period		47		31		16	
# of stacked observations for discrete time survival analysis		1919		1260		659	
Snow	Annual average of per-day snowfall, at nearest weather station (inches)	.178	.075	.184	.076	.171	.074
Av3Snow	Three year rolling average of per-day snowfall, at nearest weather station (inches)	.174	.067	.182	.073	.166	.062
Av5Snow	Five year rolling average of per-day snowfall, at nearest weather station (inches)	.173	.062	.179	.067	.167	.058
TempWinter	Average winter temperature (Nov.–Feb.), at nearest weather station (°F)	30.359	3.544	29.859	3.367	30.915	3.741
Av3TempWinter	Three year rolling average of winter temperature, at nearest weather station (°F)	29.428	3.590	29.085	3.478	29.772	3.703
Av5TempWinter	Five year rolling average of winter temperature, at nearest weather station (°F)	29.466	3.569	29.141	3.419	29.756	3.703
Trails	Number of trails at the ski area	33.207	31.891	27.386	29.386	39.674	34.565
Vertical	Vertical drop of the mountain (ft)	999.70	707.66	876.21	661.49	1136.91	758.96
Lifts	Number of non-rope tow lifts at the ski area	5.714	4.764	4.834	4.435	6.692	5.130
Size	The 1st principle component of Trails, Vertical and Lifts (=2.7 ∗ Trails + 0.25 ∗ Vertical + 0.05 ∗ Lifts)	339.87	257.72	293.23	240.27	391.68	277.12
I_1 (Snowmaking)	=1 if the ski area has snowmaking equipment	81.3%		71.9%		91.8%	
I_2 (FourSeason)	=1 if the ski area is open all four seasons	47.0%		39.8%		54.9%	
Boston	Distance from the ski area to Boston (miles)	127.02	49.20	121.85	48.97	132.76	49.45
Trend[d]	Time trend	1988.50	11.11	1979.50	5.92	1998.50	5.34
GDPGrowth[d]	National GDP growth	654.05	554.49	586.55	608.42	733.47	489.71
Av3GDPGrowth[d]	Three year rolling average of GDP growth	652.73	365.77	594.22	386.90	711.24	344.25
Av5GDPGrowth[d]	Five year rolling average of GDP growth	654.38	251.42	577.18	257.94	723.01	231.08
Elevation	Base elevation of the mountain (ft)	976.13	583.66	941.54	563.18	1014.57	606.40
Lakes	# of lakes in the town in which the ski area is located	1.631	1.965	1.518	1.938	1.758	1.995
Industry	Percentage of the workforce that is employed in the businesses of arts, entertainment, recreation, food services and accommodations in the town in which the mountain is located	13.986	9.496	12.978	8.971	15.106	10.078
D_NH	=1 if the ski area is located in New Hampshire	33.1%		33.2%		32.9%	
D_VT	=1 if the ski area is located in Vermont	30.2%		31.0%		29.3%	
D_ME	=1 if the ski area is located in Maine	8.7%		6.9%		10.6%	
D_MA	=1 if the ski area is located in Massachusetts	22.8%		23.7%		21.7%	

[a] See Section 3 for the detailed description of the construction of the variable Y_{it} and the compilation of the dataset. The summary statistics of Y_{it} is the mean of yearly averages. See below for further explanation.

[b] The summary statistics are computed for the expanded dataset that multiple yearly observations for each ski area are present in the expanded dataset for discrete time survival analysis. Note that the purpose of the summary statistics here is to show the average conditions every year that ski areas face. Hence, the Mean in this table is derived by first computing the yearly average for each year, then taking the mean of the yearly averages. Similarly, the standard deviation (Std) is the mean of the yearly standard deviations. The formulae to compute Mean and Std are as follows.

$$\text{Mean} = \frac{\sum_{t=1}^{T}\overline{X}_{.t}}{T} = \frac{\sum_{t=1}^{T}\frac{\sum_{i=1}^{n_t}X_{it}}{n_t}}{T} \text{Std} = \frac{\sum_{t=1}^{T}\sqrt{\left(\frac{\sum_{i=1}^{n_t}\left(X_{it}-\overline{X}_{.t}\right)^2}{n_t-1}\right)}}{T}.$$

[c] The summary statistics for this measure are computed based on the raw data of the 78 ski areas, not the expanded (stacked) data.

[d] This variable signals the temporal and/or macroeconomic effects on the ski industry. The value of this variable will be the same for all ski areas in the same year. The summary statistics for this variable is computed by averaging over the study period directly, not the summary statistics of the yearly mean as outlined in footnote b.

the decisions to install snowmaking facilities ($I_1 = 1$) and to operate four seasons ($I_2 = 1$) can be affected by the characteristics of the ski area and weather conditions. We believe that the decision to operate beyond the ski season can be affected by the location as well. The functions, $G(.)$ and $H(.)$, are cumulative distribution functions. Eqs. (7), (8), and (9) together form a structural model; $\boldsymbol{M}_{it}$ and N_{it} serve as the instruments to help identify Eqs. (8) and (9) in the structural model. Assume normality for the cumulative distribution functions $F(.)$, $G(.)$ and $H(.)$ The structural model is estimated with the simulated maximum likelihood method (Cappellari and Jenkins, 2003).[5] Note that weather variables are anticipated to enter both the main Eq. (7) and the subsidiary Eqs. (8) and (9) in the structural model. The estimation of the structural model helps us examine the direct effects and indirect effects (through decisions of investment) of weather on the survival of a ski area.

3.3. Summary of Data

All the explanatory variables, either time varying or time invariant, are stacked according to the observations of Y. Table 2 presents the definition of all variables and the summary statistics. Note that the constructed data for the discrete time survival analysis are essentially unbalanced panel data. To get the sense of variation across ski areas each year, we first compute the mean and standard deviation across ski areas each year for each variable, then average them over years.[6] For comparison, summary statistics for data from 1970 to 1989 and from 1990 to 2007 are also tabulated. Among the 47 ski areas closed by 2007, the closures appear to be more frequent in the first two

[5] In this study, the estimation of the structural model is carried out by the Stata command triprobit, written by Antoine Terracol (2002) who uses the GHK simulator to evaluate the trivariate normal distribution in the likelihood function. For a general review of simulated maximum likelihood estimation, see Stern (1997).

[6] The formulae to compute the summary statistics are given at the bottom of Table 2.

decades (1970–1989) than in the remaining years, but they do spread out in the whole studied period (of thirty-eight years). Of the 78 ski areas in our dataset, during the study period the average number of years remained open is about twenty-five years.

The three variables Trails, Vertical, and Lifts collectively determine the size of a ski area. The raw data show that the size of ski areas vary quite significantly from a few trails to over a hundred trails and from no lift to over 20 lifts.[7] Comparing the average size of ski areas in 1990–2007 and in 1970–1989, it has noticeably increased over the years, due to the closure of many smaller ski areas. Note that these size characteristic variables are (naturally) correlated. To address the potential collinearity issue, we construct a size indicator based on the first principle component of these three characteristic variables: $\text{Size} = 2.7 * \text{Trails} + 0.25 * \text{Vertical} + 0.05 * \text{Lifts}$. In the empirical analysis, we will compare results using either all the three characteristic variables or the combined Size indicator.

Comparing the average snowfall variable (Snow) and the winter temperature variable (TempWinter) over the different time periods, the slight decrease in snowfall and increase in winter temperature are detected. To examine the cumulative effects of weather conditions, we also construct the 3-year and 5-year rolling averages of the snowfall and winter temperature variables (Av3Snow, Av5Snow, Av3TempWinter, Av5TempWinter). These variables will be used to examine the effects of weather in the empirical analysis. See Fig. 2 for the plots of the snowfall and winter temperature variables (averaged across ski areas) over time. The plots of the three- and five-year rolling averages of these weather condition variables are also shown in Fig. 2. These plots show a slight upward trend in winter temperature and a noticeable downward trend in snowfall during the time of our study.

Of all the ski areas every year, on average over eighty percent of them have snowmaking equipment and close to half of them are open all four seasons. Fig. 3 presents the proportion of open ski areas that had snowmaking facilities and four season operations from 1970 to 2007. The plots show increasing percentages of open ski area with snowmaking facilities and four-season operations over time, indicating disproportional closures of ski areas that had no snowmaking capabilities and/or did not expand operations to all seasons. The average distance to Boston is 127 miles (approximately 2 h by car). Note that the average distance from a ski area to Boston has increased in the recent two decades comparing to the previous two decades, indicating that more ski areas closer to Boston have closed down. To estimate the effects of weather on the survival of ski areas, it is imperative to simultaneously consider all the other potential impact factors.

Based on the proposed structural model, we hypothesize and summarize the potential direct and indirect effects of the variables on the probability of closure of a ski area, as shown in Table 3. Note that most of the variables have potentially both direct and indirect influences on the probability that a ski area will close because they enter the structural model through both the main Eq. (7) and the subsidiary Eqs. (8) and/or (9). Primarily we believe that as the temperature warms and snowfall declines ski areas will be less likely to survive. However, if firms make strategic investment decisions, they may be able to offset (partially) the negative effects of the changing weather. We believe these decisions are also influenced by the local weather and expect to see that as the weather patterns change, ski areas will be more likely to change their production processes. This is where we may see the indirect effect of the weather factors. The overall impact of weather conditions will be determined by both the direct and indirect effects. Note that the characteristics of ski areas can also have both direct and indirect effects. First, it is likely that larger ski areas may have higher probabilities of success because of economies of scale. At the same time, they probably have larger revenue bases to make strategic investment decisions to boost a secondary increase in their probability of success. Lastly, all else equal, geographical location may also impact directly and indirectly the potential success of a ski area. For example, being close to Boston, the major central business district in New England, may be advantageous and may influence the decision to operate beyond the ski season. We test all of these hypotheses, focusing on the impact of the weather variables.[8]

4. Estimation and Results

4.1. Simplified One-Equation Model

We begin our empirical analysis with the estimation of a simple one equation model given in Eq. (7), assuming that the investment decision variables I_1 (snowmaking equipment) and I_2 (four-season operation) are exogenously determined. The dependent variable is $Y_{it} = 1$ if the ski area i is closed in year t and $Y_{it} = 0$ otherwise. Different specifications are presented for comparison. In addition to the amount of snowfall and winter temperature of the year, we employ alternatively the 3-year and 5-year rolling averages of snowfall and winter temperature to examine the potential cumulative effects of weather conditions. The three characteristic variables of a ski area (Trails, Vertical, Lifts) are either included individually or collectively as an index (Size). The estimation results of six alternative specifications of the one-equation model are presented in Table 4.

In the first three specifications, Models O1–O3, in which the three characteristics of a ski area are included, the effect of number of trails is significant with expected sign indicating that more trails decreases the probability of closure. The number of lifts has the expected sign and significant. The positive and significant coefficient estimate of the vertical drop of the mountain is somewhat unexpected when it is viewed as an indicator of the size of operation. The vertical drop may also indicate the physical environment of a mountain. A taller mountain may also be rockier and icier that makes it harder for a ski area manager to carve multiple and challenge varying trails at the top of the mountain.[9] This difficulty may limit a ski area's abilities to accommodate skiers of all levels and affects the success of the ski area.

When the characteristic variables are combined as in the Models O4–O6, the Size variable is significant. All else equal, larger ski areas are less likely to close down. The only weather variable that is significant in these estimated models is the amount of snowfall. The significant, negative coefficient estimates of the Snow variable in Models O1 and O4 indicate that the more snow, the less likely is a ski area to close down. The 3-year and 5-year rolling averages of the amount of snow as well as the winter temperature do not have significant effect. In contrast, the availability of snowmaking equipment significantly reduces the likelihood of a ski area going under. However, operating in all seasons does not show significant effect on the success of a ski area in these models. Nor does the location seem to matter. There is a significant trend of closures of ski areas over time, while the GDP growth does not seem to affect the probability of closure. Based on these models, the variables with consistent, significant effects are the size of a ski area, the amount of snowfall, and the presence of snowmaking facilities.

[7] Note that only the non-rope-tow lifts are included for analysis. If a ski area only operates a rope-tow lift, it is recorded as having 0 lift.

[8] We face a data limitation due to the unavailability of the historical data of the ski areas. Variables, including the characteristics of a ski area, availability of snowmaking facilities and operation beyond ski season, have to be constructed based on the data at the end of the studied period. Note that it is reasonable to think that the survival of a ski area depends on continuing improvements. The measurement errors in these explanatory variables tend to occur in the earlier years and bias toward the same direction – in favor of survival, which is likely to dampen the effects of the variables. Although the general conclusion of the findings remains the same, we caution that our estimated effects are likely to be more conservative due to the measurement errors in the variables.

[9] Skiing fatality reports support the statement that steeper slopes are often icier. This is mainly due to the fact that it is harder to groom these steep slopes. If appropriate grooming is unattainable, area managers may not be able to develop these slopes (New York Department of Health. Fatality Assessment and Evaluation, 2012).

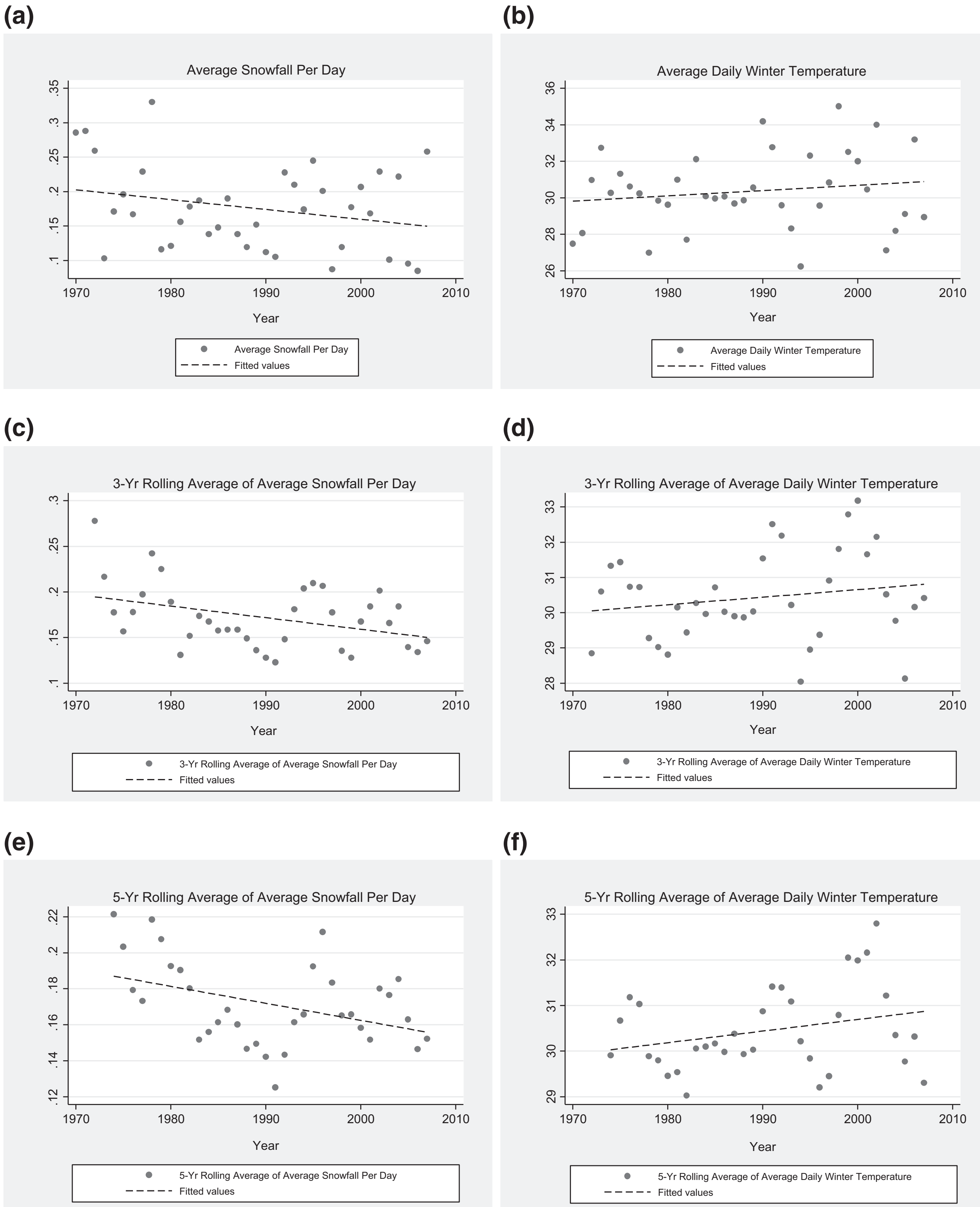
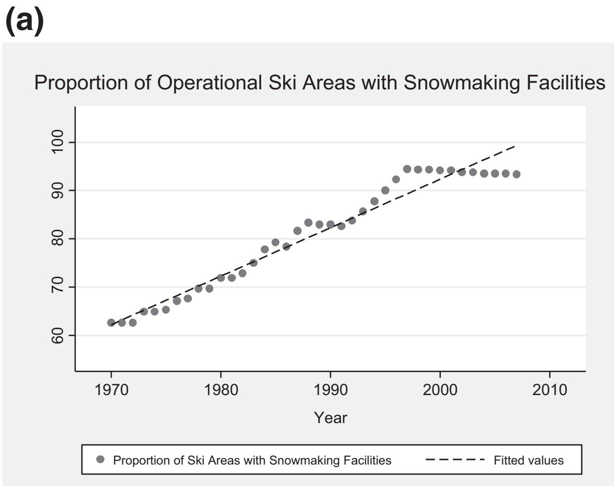


Fig. 2. Snowfall per day and daily winter temperature of ski areas in New England, 1970–2007. (a) Average snowfall per day. Data points in this graph represent the average of the average snowfall per day (Snow) at all operational ski areas within our dataset in a particular year. (b) Average daily winter temperature. Data points in this graph represent the average of the average daily winter temperature (TempWinter) at all operational ski areas within our dataset in a particular year. (c) 3-Yr rolling average of average snowfall per day. Data points in this graph represent the average of the three year rolling average (Av3Snow) at all operational ski areas within our dataset in a particular year. (d) 3-yr rolling average of average daily winter temperature. Data points in this graph represent the average of the three year rolling average of the daily winter temperature (Av3TempWinter) at all operational ski areas within our dataset in a particular year. (e) 5-yr rolling average of average snowfall per day. Data points in this graph represent the average of the five year rolling average of the snowfall per day (Av5Snow) for all operational ski areas within our dataset in a particular year. (f) 5-yr rolling average of average daily winter temperature. Data points in this graph represent the average of the five year rolling average of the daily winter temperature (Av5TempWinter) for all operational ski areas within our dataset in a particular year.



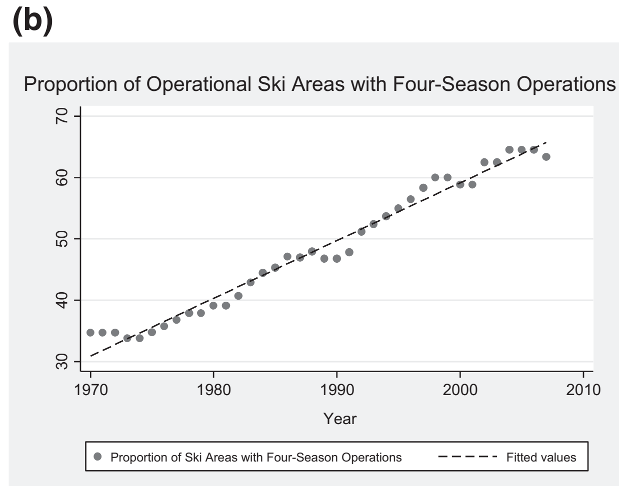


Fig. 3. Proportion of operational ski areas with snowmaking facilities and four-season operations, 1970–2007. (a) Ski areas with snowmaking facilities. Data points in this graph represent the proportion of operational ski areas within our dataset which have snowmaking facilities in a particular year. (b) Ski areas with four-season operations. Data points in this graph represent the proportion of operational ski areas within our dataset which operate during all four seasons in a particular year.

4.2. Structural 3-Equation Model

The above one-equation model does not address the issue of potentially endogenous investment activities. In Section 3, we proposed a structural 3-equation model. In addition to the main Eq. (7) to examine the likelihood of the closure of a ski area, we explicitly model the decisions to invest in snowmaking equipment – Eq. (8) and to operate in all four seasons – Eq. (9) as two subsidiary equations to the main equation. To identify Eq. (8), we include two instrumental variables; the number of lakes in the surrounding town (Lakes)[10] and the base elevation of the mountain (Elevation). The Lakes factor should influence positively the probability that a ski area invests in snowmaking since snowmaking requires a large amount of water; Elevation should influence it negatively since mountains at higher elevations should be benefitting from more natural snow. To identify Eq. (9), we include an instrumental variable called Industry that is the percentage of the workforce employed in the tourism related businesses such as arts, entertainment, recreation, food services, or accommodations in the surrounding town of the ski resort (www.city-data.com). It indicates whether the surrounding town has sufficient activities that attract tourists to help support a four-season resort. Similar to the simplified one-equation model, for comparison and robustness check, we present six alternative specifications (Models S1–S6). They differ in the ways that weather conditions and characteristics of ski areas are measured. The estimation results of the structural model are shown in Table 5.

Table 3
Potential effects on the probability of closure of a ski area.

Variable	Variable category	Effect	Anticipated direction of effect on closure
Snow	Weather	Direct Indirect via I_1 and I_2	− +
TempWinter	Weather	Direct Indirect via I_1 and I_2	+ −
Trails	Firm characteristics	Direct Indirect via I_1 and I_2	− −
Vertical	Firm characteristics	Direct Indirect via I_1 and I_2	− −
Lifts	Firm characteristics	Direct Indirect via I_1 and I_2	− −
Size	Firm characteristics (combined)	Direct Indirect via I_1 and I_2	− −
I_1 (Snowmaking)	Investment activities	Direct	−
I_2 (FourSeason)	Investment activities	Direct	−
Trend	Time trend	Direct	+
GDPGrowth	Macroeconomic indicator	Direct	−
Boston	Location	Direct Indirect via I_2	+ +

The results of the main equation in the 3-equation model are similar to those in the one-equation model. Larger ski areas are more likely to remain open. A good amount of snow and whether a ski area is equipped with snowmaking facilities directly affect the survival of the ski area. Winter temperature does not seem to have a direct effect on the probability of a ski area closing down. The coefficient of I_2 is (expectedly) negative but insignificant, that operating beyond the ski season does not seem to have a significant effect on reducing the probability of closure of a ski area. The trend of closure is again significant. Similar to the one-equation model, location continues to show no significant direct effect on the survival of a ski area.

Turning to the two subsidiary equations regarding adaptation abilities through investment activities of a ski area in the structural model, I_1 (snowmaking) and I_2 (four season operation), it is seen in the results of the I_1 equation that the installation of snowmaking facilities is significantly influenced by the characteristics of a ski resort. The larger the ski resort, the more likely it is to own snowmaking equipment. It is also seen that weather conditions have significant effects. More natural snow and lower winter temperature make it less likely to have snowmaking equipment. As expected, lower elevation of the mountain and more lakes nearby will increase the probability of owning snowmaking equipment.

[10] Note that it is common for ski areas to build their own lakes for snowmaking purposes on their properties. To avoid the potential endogeneity issue in our lakes variable, we include only non-man-made lakes in this measure. Our lakes variable is an instrumental variable to assist estimation of the proposed structural model. Natural lakes are not the only water sources to support snowmaking operations.

Table 4
The estimated simple one-equation models.

Dependent variable: Y_{it} (=1 if the ski area i is closed in year t)						
Model	O1	O2	O3	O4	O5	O6
Intercept	−75.6189***	−69.1368***	−62.5666***	−43.3219***	−37.9646***	−31.2711*
	(14.0754)	(13.4143)	(15.6353)	(12.3785)	(12.3206)	(15.0883)
Trails	−0.0497**	−0.0474**	−0.0472**			
	(0.0208)	(0.0214)	(0.0233)			
Vertical	0.0010***	0.0010***	0.0010**			
	(0.0004)	(0.0004)	(0.0004)			
Lifts	−0.1575**	−0.1447*	−0.1517*			
	(0.0761)	(0.0793)	(0.0821)			
Size				−0.0017**	−0.0016**	−0.0015**
				(0.0007)	(0.0007)	(0.0007)
Snow	−1.5029*			−1.3665*		
	(0.8966)			(0.8253)		
TempWinter	−0.0036			0.0061		
	(0.0213)			(0.0211)		
Av3Snow		0.1316			0.0549	
		(1.3942)			(1.3808)	
Av3TempWinter		0.0239			0.0386	
		(0.0262)			(0.0271)	
Av5Snow			−1.0778			−1.1126
			(1.4387)			(1.4728)
Av5TempWinter			0.0057			0.0219
			(0.0314)			(0.0319)
I_1 (Snowmaking)	−0.3741*	−0.3526*	−0.3655*	−0.5493***	−0.5318***	−0.5403***
	(0.1938)	(0.1954)	(0.2052)	(0.1854)	(0.1879)	(0.1939)
I_2 (FourSeason)	−0.1277	−0.0781	−0.1929	−0.1837	−0.1344	−0.2252
	(0.2856)	(0.2840)	(0.3015)	(0.2516)	(0.2484)	(0.2577)
Boston	−0.0012	−0.0007	−0.0015	−0.0002	0.0005	−0.0004
	(0.0022)	(0.0022)	(0.0023)	(0.0020)	(0.0020)	(0.0021)
Trend	0.0378***	0.0340***	0.0311***	0.0211***	0.0178***	0.0149*
	(0.0073)	(0.0069)	(0.0081)	(0.0064)	(0.0063)	(0.0078)
GDPGrowth	0.0000			0.0000		
	(0.0001)			(0.0001)		
Av3GDPGrowth		−0.0003			−0.0003	
		(0.0002)			(0.0002)	
Av5GDPGrowth			−0.0004			−0.0004
			(0.0004)			(0.0004)
D_NH	−0.1082	−0.0861	−0.0992	0.1942	0.2446	0.2269
	(0.3674)	(0.3715)	(0.3736)	(0.3273)	(0.3310)	(0.3323)
D_VT	−0.0473	−0.0713	−0.0038	0.2251	0.2296	0.309
	(0.4431)	(0.4436)	(0.4579)	(0.3766)	(0.3778)	(0.3845)
D_ME	0.5802	0.4881	0.681	0.4137	0.3144	0.4872
	(0.6271)	(0.5749)	(0.6720)	(0.5393)	(0.4768)	(0.5261)
D_MA	0.1029	0.0891	0.1083	0.1288	0.1406	0.1393
	(0.3362)	(0.3490)	(0.3467)	(0.3299)	(0.3393)	(0.3398)
Log pseudo likelihood	−173.5203	−172.1186	−165.7080	−186.0134	−183.4085	−176.9962

Note: ***, **, and * denote statistical significance at the .01, 0.5, and .1 levels, respectively.

As for the I_2 equation, larger ski areas are more likely to open all four seasons. It is less likely to open all seasons when there is more snow to support the winter ski activities. The significant, negative coefficient of the winter temperature variable is unexpected with no good explanation, though. The industry variable is positive and significant indicating that the higher percent of workforce in the tourism related businesses near a ski area, the more likely is the ski area to operate all seasons. The location variables (distance to Boston and state dummy variables) are mostly significant. The positive coefficient of Boston seems counterintuitive that within each state the further away from Boston of a ski area, the more likely it operates in all four seasons. A possible explanation is that with the continuing improvement of infrastructure and road conditions over time, it becomes easier to travel a longer distance to a ski area with better services. All else equal, the New England ski areas farther away from Boston might be more likely to operate beyond the ski season to be the all-season, vacation get-away places.

The 3-year and 5-year rolling averages of the weather variables do not appear to impact directly the survival of a ski area in the main equation. However, they are significant in the subsidiary equations, indicating that cumulative weather changes can influence the investment activities; therefore they influence indirectly the survival of a ski area.

We also estimate the reduced form model that excludes the potentially endogenous I_1 and I_2, and include the instruments from the I_1 and I_2 equations. The results can be found in Table A.1 in the Appendix. It is clear that the size of a ski area and the amount of snow play significant roles in the success of a ski area. The instrumental variables are mostly insignificant in the estimated reduced form models. Note that when the characteristic variables are combined into the Size variable in the reduced form model, all the instrumental variables are significant in the subsidiary equations in the 3-equation structural model but insignificant in the reduced form model, as expected from reasonably good instruments.

In sum, the estimation results of the structural models show that reduced snowfall, during the studied time period, has contributed directly to the closing of ski resorts in New England. The results also suggest that there have been indirect effects of the weather variables through their impact on investment decisions that improve the probability of survival and offset part of the negative direct effects. Further, we find that larger resorts not only have a higher chance of survival in the industry, but are also more likely to make strategic investment decisions to ward off the negative effects of a changing climate. Consequently, our results suggest that weather conditions have contributed significantly to the decrease in competitiveness in the New England ski industry.

Table 5
The estimated structural three-equation models.

Model	S1	S2	S3	S4	S5	S6
Dependent variable: Y_{it} (=1 if the ski area i is closed in year t)						
Intercept	−75.8750***	−70.3090***	−63.3531***	−42.7733***	−37.3432***	−31.2872**
	(14.0719)	(13.3447)	(15.4884)	(12.3546)	(12.2749)	(15.1021)
Trails	−0.0498**	−0.0484**	−0.0486**			
	(0.0206)	(0.0209)	(0.0229)			
Vertical	0.0011***	0.0011***	0.0012***			
	(0.0004)	(0.0004)	(0.0004)			
Lifts	−0.1415*	−0.1099	−0.1276			
	(0.0769)	(0.0746)	(0.0800)			
Size				−0.0014**	−0.0013**	−0.0015**
				(0.0007)	(0.0006)	(0.0007)
Snow	−1.5436*			−1.3889*		
	(0.8975)			(0.8269)		
TempWinter	−0.0013			0.0101		
	(0.0213)			(0.0215)		
Av3Snow		−0.1589			−0.1178	
		(1.4339)			(1.3868)	
Av3TempWinter		0.0281			0.0421	
		(0.0264)			(0.0275)	
Av5Snow			−1.4856			−1.1003
			(1.4738)			(1.4794)
Av5TempWinter			0.0095			0.0215
			(0.0318)			(0.0327)
I_1 (Snowmaking)	−0.5014**	−0.6557***	−0.5988**	−0.6726***	−0.6649***	−0.5322**
	(0.2454)	(0.2403)	(0.2669)	(0.2115)	(0.2073)	(0.2201)
I_2 (FourSeason)	−0.0844	−0.1467	−0.2327	−0.1736	−0.2376	−0.2309
	(0.3180)	(0.3007)	(0.3404)	(0.2943)	(0.2672)	(0.3044)
Boston	−0.0014	−0.0011	−0.0019	−0.0002	0.0006	−0.0003
	(0.0022)	(0.0022)	(0.0023)	(0.0020)	(0.0020)	(0.0022)
Trend	0.0379***	0.0346***	0.0316***	0.0209***	0.0175***	0.0149*
	(0.0073)	(0.0069)	(0.0080)	(0.0064)	(0.0063)	(0.0078)
GDPGrowth	0.0000			0.0000		
	(0.0001)			(0.0001)		
Av3GDPGrowth		−0.0003			−0.0003	
		(0.0002)			(0.0002)	
Av5GDPGrowth			−0.0004			−0.0004
			(0.0003)			(0.0004)
D_NH	−0.1279	−0.1396	−0.1334	0.1687	0.2218	0.2267
	(0.3663)	(0.3688)	(0.3759)	(0.3275)	(0.3293)	(0.3317)
D_VT	−0.0684	−0.1451	−0.0401	0.1579	0.15	0.3022
	(0.4440)	(0.4471)	(0.4657)	(0.3819)	(0.3818)	(0.3910)
D_ME	0.5818	0.4985	0.7065	0.4052	0.3058	0.4883
	(0.6260)	(0.5685)	(0.6704)	(0.5406)	(0.4709)	(0.5271)
D_MA	0.0825	0.0363	0.0756	0.101	0.1131	0.1398
	(0.3355)	(0.3429)	(0.3459)	(0.3299)	(0.3366)	(0.3390)
Dependent variable: I_1 (=1 if the ski area has snowmaking equipment)						
Intercept	−3.5281***	−3.3097***	−2.9510***	−3.0455***	−2.6709***	−2.2520**
	(0.4935)	(0.6774)	(0.8269)	(0.5964)	(0.8472)	(1.0283)
Trails	0.1011***	0.1151***	0.1166***			
	(0.0161)	(0.0181)	(0.0202)			
Vertical	0.0002	0.0005*	0.0008***			
	(0.0003)	(0.0003)	(0.0003)			
Lifts	0.3788***	0.3396***	0.3317***			
	(0.0483)	(0.0525)	(0.0563)			
Size				0.0086***	0.0093***	0.0100***
				(0.0005)	(0.0006)	(0.0007)
Snow	−2.5163***			−1.8835***		
	(0.4245)			(0.4683)		
TempWinter	0.0883***			0.0998***		
	(0.0145)			(0.0177)		
Av3Snow		−6.0592***			−5.1453***	
		(0.8376)			(0.7963)	
Av3TempWinter		0.0974***			0.1045***	
		(0.0190)			(0.0243)	
Av5Snow			−9.6268***			−8.1308***
			(1.1195)			(1.0301)
Av5TempWinter			0.1021***			0.1071***
			(0.0229)			(0.0295)
Elevation	−0.0009***	−0.0009***	−0.0008***	−0.0010***	−0.0010***	−0.0010***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Lakes	0.1654***	0.1517***	0.1232***	0.1117***	0.0989***	0.0781**
	(0.0208)	(0.0231)	(0.0252)	(0.0212)	(0.0235)	(0.0262)

(continued on next page)

Table 5 *(continued)*

Model	S1	S2	S3	S4	S5	S6
Dependent variable: I_2 (=1 if the ski area operates in all four seasons)						
Intercept	−0.0106	2.4949***	4.3906***	−0.4055	1.5536*	2.9945***
	(0.6303)	(0.8673)	(0.9815)	(0.6074)	(0.8063)	(0.9159)
Trails	0.0159***	0.0144***	0.0132**			
	(0.0048)	(0.0051)	(0.0054)			
Vertical	0.0006***	0.0006***	0.0006***			
	(0.0002)	(0.0002)	(0.0002)			
Lifts	0.1316***	0.1480***	0.1555***			
	(0.0214)	(0.0236)	(0.0257)			
Size				0.0052***	0.0051***	0.0051***
				(0.0002)	(0.0002)	(0.0003)
Snow	−0.5564			−0.5050		
	(0.4161)			(0.4097)		
TempWinter	−0.0663***			−0.0469**		
	(0.0171)			(0.0162)		
Av3Snow		−1.9986*			−1.9440**	
		(0.7879)			(0.7407)	
Av3TempWinter		−0.1333***			−0.0970***	
		(0.0234)			(0.0213)	
Av5Snow			−3.6249***			−3.4480***
			(0.9294)			(0.8783)
Av5TempWinter			−0.1786***			−0.1290***
			(0.0267)			(0.0244)
Boston	0.0057***	0.0045***	0.0037***	0.0052***	0.0040***	0.0033***
	(0.0009)	(0.0010)	(0.0011)	(0.0008)	(0.0009)	(0.0010)
Industry	0.0176**	0.0240***	0.0271***	0.0192***	0.0261***	0.0300***
	(0.0075)	(0.0081)	(0.0088)	(0.0072)	(0.0078)	(0.0085)
D_NH	0.0246	−0.1558	−0.3547	−0.1012	−0.2018	−0.3527*
	(0.1706)	(0.1748)	(0.1826)	(0.1644)	(0.1681)	(0.1743)
D_VT	−1.9036***	−2.0501***	−2.1700***	−2.0710***	−2.1402***	−2.2354***
	(0.1868)	(0.1947)	(0.2032)	(0.1822)	(0.1894)	(0.1965)
D_ME	0.8651***	0.9412***	1.2193***	0.6488***	0.7881***	1.0571***
	(0.2269)	(0.2768)	(0.3807)	(0.2252)	(0.2695)	(0.3486)
D_MA	−0.2579	−0.3767**	−0.5556***	−0.2063	−0.2840*	−0.4439**
	(0.1709)	(0.1766)	(0.1879)	(0.1625)	(0.1653)	(0.1733)
Log pseudo likelihood	−1220.3933	−1100.7686	−985.1468	−1398.7127	−1253.9812	−1116.9167

Note: ***, **, and * denote statistical significance at the .01, 0.5, and .1 levels, respectively.

4.3. Direct and Indirect Effects of Weather Conditions on Closure of Ski Areas

As seen from the estimation results of the structural model in Table 5, the three variables that are consistently significant in the main equation are Size, Snow, and I_1 (snowmaking). These variables impact the probability of closure of a ski area directly. Note that TempWinter (winter temperature) and I_2 (four season operation) are consistently insignificant in the main equation, indicating no significant direct impact from these variables. Further, both the Size and the weather variables are significant in the subsidiary I_1 equation. Along with the significance of I_1 in the main equation, we see significant, indirect effects of Size, Snow, and TempWinter on the probability of closure of ski areas through their influences on the decision to invest in snowmaking equipment. Table 6 presents the estimated marginal direct and marginal overall effects of Size, Snow, and TempWinter on the probability of closure based on the estimated structural Model S4 in Table 5.[11] As hypothesized in Section 3, the larger a ski area, the better chance it is to survive (direct effect); and the larger the ski area, the better chance it is to be able to engage in investment activities such as installing snowmaking equipment (indirect effect). The indirect effect of Size reinforces its direct effect. Our empirical results confirm the hypothesis. As for the weather variables, decreased amount of snow increases the probability of closure (direct effect), but the decreased amount of snow also increases the probability of installing snowmaking equipment (indirect effect). The indirect effect offsets part of the direct effect resulting in the overall effect of Snow being smaller than the direct effect itself. TempWinter is insignificant in the main equation (no direct effect), but it significantly increases the probability of installing snowmaking equipment (indirect effect), so all else equal, the warmer winter temperature has actually reduced the probability of closure of a ski area.

To better understand the effects of the variables Size, Snow, and TempWinter, we conduct a simulation of both the direct and overall effects for some incremental changes of these variables, again based on the estimated Model S4. The predicted probability of closure at the means of all variables is 0.01080 that for a "prototypical" ski area, the estimated probability of closure each year is approximately 1 in 100.[12] This estimated average probability of closure serves as the base to evaluate the effects of changes in variables. The direct effect of an incremental change is computed as the difference between the average probability and the new, updated probability of closure evaluated at the new value(s) of the changed variable(s). In contrast, the overall effect of an incremental change has to be computed in two steps. First, compute the updated probability of I_1 (snowmaking) due to the incremental

[11] The marginal effects of any variable X on the probability of closure can be expressed generally based on the Eqs. (7), (8), and (9).

$$\text{Direct marginal effect}: \frac{\partial P(Y=1)}{\partial X} = \frac{\partial F}{\partial X}.$$

$$\text{Overall marginal effect}: \frac{\partial P(Y=1)}{\partial X} = \frac{\partial F}{\partial X} + \frac{\partial F}{\partial G}\cdot\frac{\partial G}{\partial X} + \frac{\partial F}{\partial H}\cdot\frac{\partial H}{\partial X}.$$

[12] On average the actual annual rate of closure during the studied period is roughly 1 to 1.3 per 100 ski areas. The estimated probability of closure at means of all variables based on Model S4 is close to the actual average rate of closure.

Table 6
Estimated marginal effects of size and weather variables on the probability of closure of a ski area.

Variable	Direct effect	Overall effect
Size	−0.000040	−0.000053
Snow (inch/day)	−0.039581	−0.036616
TempWinter (°F)	No significant direct effect	−0.000157

Note: The effects are computed based on the estimates of the structural model S4 in Table 5.

change(s) in the variable(s). Then plug in the updated I_1 probability along with the updated value(s) of the changed variable(s) into the main equation of the structural model to compute the new probability of closure, to be compared with the average probability of closure that is evaluated at the mean of all variables. Note that I_2 (four seasons) is insignificant in the main equation that no indirect effect of I_2 is included in the calculation of the overall effect. The simulation results are presented in Table 7.

Compared to the average, a slightly larger ski area with 5 more trails, 1 more lift, and 50 ft taller vertical drop will have an estimated 0.00100 less chance to close down every year, as the direct effect of being slightly larger. Once we take into account the indirect effect of larger ski areas being more likely to install snowmaking equipment, the overall effect of the larger Size reduces the probability of closing down by 0.00126. The overall effect is slightly higher than the direct effect since the larger ski areas have significantly higher probabilities to own snowmaking equipment, which reinforces the chances of survival. The effects may seem small. However, given that the estimated average probability of closure is 0.01080, the estimated change in probability of 0.00126 translates into 11.7% decrease in the probability of closure.

If we examine some incremental changes in weather variables, as the amount of natural snow goes down slightly by 0.01 in. a day (3.65 in. a year), the direct effect shows an increase in the probability of closure by 0.00040, but it is partially offset by the increased probability of installing snowmaking equipment. At the end, the overall effect of the decreased snowfall will increase the probability of closure by 0.00031, a 2.9% increase from the average probability of closure. When the amount of snowfall decreases significantly, 0.1 in. a day (36.5 in. a year), the overall effect will increase the probability of closure by 0.00431, which is equivalent to 39.9% increase from the estimated average probability of closure. Regarding the winter temperature, the direct effect of winter temperature is not significant, but the indirect effect through I_1 is. If the winter temperature rises up by 0.5 °F, the indirect effect through the slight increase in the probability of having snowmaking equipment will lower the probability of closure by 0.00008. If the winter temperature is up 3 °F, the probability of closure will go down by 0.00036. The indirect effects of warmer winter temperature are significant but minimal.

Global warming may simultaneously reduce the amount of snow and increase the winter temperature. Our last simulation is to invoke simultaneous changes in Snow and TempWinter. Since TempWinter is insignificant in the main equation, the direct, combined effects of changes in Snow and TempWinter are viewed as the same as the direct effects of the changes in Snow alone. The simultaneous decrease in Snow and increase in TempWinter work together to increase the probability of installing snowmaking facilities that offsets partially the direct effect of Snow on the probability of closure. An averaged 0.03 in. decrease in snowfall a day (10.95 in. a year) accompanied by a 1 °F increase in winter temperature will raise the probability of closure by 0.00101, close to 9.4% increase from the estimated average probability of closure. If winter temperature rises by 3 °F and snowfall decreases by 0.1 in. a day (36.5 in. a year), the probability of closure goes up by 0.00398, close to 37% increase from the average probability of closure. The overall effects of decreased snowfall coupled with increased winter temperature are actually slightly smaller than the overall effects of decreased snowfall alone. This is because according to the estimation results, rising temperature increases the probability of having snowmaking equipment that can lower the probability of closure of a ski area.

5. Concluding Remarks

By applying the discrete time survival analysis to the data on both closed and operational ski areas, the results suggest that weather conditions have had a significant impact on the survival of New England ski areas in the past four decades. The effects of weather can be direct, or indirect through its influences on the investment activities of a ski area. In fact, the direct detrimental effects of increasing winter temperatures and decreasing snowfall can be partially offset by the installation of snowmaking facilities, as advocated by Scott et al. (2003) and other researchers. In this study, we confirm and quantify the direct effects of weather on the closure of ski areas and the effects of weather on investment activities of ski areas including installing snowmaking facilities and operating four seasons. Simulations are conducted to demonstrate the estimated effects of changes in weather conditions on the closure of ski areas. The empirical results also suggest that the changing climate may have tipped the scales in favor of the larger ski resorts that are more likely to invest in snowmaking equipment. The average size of ski areas in New England has become larger and the ski industry has become less competitive in nature, and our results indicate that climate change has played a significant role in altering the market structure. To our knowledge, this is the first study to investigate both direct and indirect effects of weather conditions, along with other key factors, on the survival of ski areas, and to show through survival analysis the connection between climate change and the change in the market structure of the ski industry.

Note that in the current analysis we assume independence of closure decisions across ski areas. There could be some form of spatial correlation on the closure decisions due to local competition. For future research, the analysis of exit decisions may be extended to allow spatial correlation.

In this study, we employ the discrete time survival analysis. It will be beneficial to compare the results with the continuous time survival analysis such as the Cox proportional hazard analysis. Also, we focus on the effects of weather conditions on firm's exit decisions — the impact of weather on the supply side of the market. An extension is to investigate the effects of weather conditions on the demand side of the ski industry and to derive the welfare changes of skiers when taking into account the market structure being altered by climate change.

One limitation to our analysis is the availability of instruments for the structural model. While we are able to estimate the structural model using three instrumental variables, the quality of one instrumental variable (Industry) is questionable. Further investigation of alternative instruments is needed.

The weather condition variables currently used in the analysis were manually constructed for each ski area based on data from the nearest weather station. As an extension, we may reconstruct the weather condition variables based on data from multiple weather stations through more sophisticated meteorological models to better describe the weather conditions faced by each ski area.

A better understanding of the links between weather conditions and individual industries can help better depict the overall economic impact of climate change. The proposed structural model of discrete time survival analysis can be used to study the direct and indirect effects of weather conditions on firms in other industries such as horticulture and fishing industries that can be vulnerable to climate change.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ecolecon.2014.07.011.

Table 7
Simulated effects of some incremental changes in size and weather variables on the probability of closure of a ski area.

Variable	Changes	Direct effect on P (Y = 1)	Overall effect on P (Y = 1)
Size	5.4 (2 trails, 0 lift, 0 ft)	−0.00021 [2.0%↓]	−0.00028 [2.6%↓]
	26.05 (5 trails, 1 lift, 50 ft)	−0.00100 [9.2%↓]	−0.00126 [11.7%↓]
	52.1 (10 trails, 2 lift, 100 ft)	−0.00191 [−17.7%↓]	−0.00230 [21.3%↓]
Snow	↓ 0.01 in./day	0.00040 [3.7%↑]	0.00031 [2.9%↑]
	↓ 0.03 in./day	0.00125 [11.5%↑]	0.00115 [10.7%↑]
	↓ 0.1 in./day	0.00465 [43.0%↑]	0.00431 [39.9%↑]
TempWinter	↑ 0.5 °F	No significant direct effect	−0.00008 [0.7%↓]
	↑ 1 °F	No significant direct effect	−0.00014 [1.3%↓]
	↑ 3 °F	No significant direct effect	−0.00036 [3.3%↓]
Snow & TempWinter	↓ 0.01 in./day & ↑ 0.5 °F	0.00040 [3.7%↑]	0.00030 [2.8%↑]
	↓ 0.03 in./day & ↑ 1 °F	0.00125 [11.5%↑]	0.00101 [9.4%↑]
	↓ 0.1 in./day & ↑ 3 °F	0.00465 [43.0%↑]	0.00398 [36.9%↑]

Note: The effects, the changes in probability of closure, are computed based on the estimates of the structural model S4 in Table 5. The estimated average probability of closure is 0.01080 that serves as the base probability for comparison. The effects are converted into percentage changes in the probability of closure, given in the square brackets.

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