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Analysis

Gains from investments in snowmaking facilities

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ABSTRACT

The process of making snow requires low temperatures as well as vast quantities of water and considerable amounts of energy for the air compression. In this article the effectiveness of investment in snowmaking systems is investigated (equipment, construction works) based on data for 109 French ski resorts covering eight winter seasons (2006/2007 to 2013/2014). Both static and dynamic panel data estimations show that ski areas with large investments in snowmaking systems have a higher number of skier visits. On average a 10% higher capital stock of snowmaking infrastructure leads to an increase in the number of skier visits by 8% over the winter seasons studied. However, positive effects of snowmaking can only be observed for ski areas located at high elevations, with a magnitude deceasing by higher cumulated investments in snowmaking, indicating diminishing returns to scale. Ski areas at lower elevations, benefit effectively from snowmaking to a lower degree and only in extremely dry or snow poor winter seasons.

1. Introduction

French ski lift companies have invested heavily in snowmaking systems. Between 2006 and 2014 the 100 largest ski lift companies invested € 414 million (cumulated) or € 46 million per year on average (Source Montagne Leaders). Managers of ski lift companies argue that investment in snowmaking facilities gives a competitive advantage to the company (Trawöger, 2014). Snowmaking is commonly seen as an effective climate adaptation strategy to cope with global warming. In fact, a survey of managers of low elevation ski areas reveals that climate change is not perceived as a major challenge for the ski industry since snowmaking is the main adaptation measure (Wolfsegger et al., 2008). The goal of massive investment in snowmaking equipment is to guarantee an early start to the season and make the ski industry independent of variations in natural snowfall (Steiger and Mayer, 2008). Information on the 109 largest French ski resorts, representing 95% of the industry's total output, reveal that all but two invested in snowmaking during the period 2002 to 2014 (Source: Montagne Leaders and Table 6 in the Appendix A).

This paper presents first empirical evidence on how investments in snowmaking impact the output of French ski lift companies. Output is measured as the number of skier visits (also referred to as skier days).[1] Special attention is paid to what extent past investment in snowmaking systems leads to higher skier visits in general and how beneficial it is in winter seasons with extreme weather conditions (lack of natural snowfall or low precipitation). Since snowmaking is particularly crucial for low-altitude ski resorts we report the results for these ski areas separately. In addition to snowmaking, the model also control for new ski lift installations. Both static and dynamic panel data methods are used, where the latter makes it possible to account for the endogeneity of snowmaking investment.

This paper contributes to the growing literature on the impact of global warming on winter tourism and on possible measures to adapt (see Becken, 2013 for a review). Many studies emphasize the role of weather conditions and climate factors in the short- and long-term growth of ski lift companies. There is consensus in the literature that low-lying ski areas are considerably more affected by warm winter seasons than high-elevation areas (Bark et al., 2010; Gonseth, 2013; Hamilton et al., 2003; Pickering, 2011; Steiger, 2011). Similarly, other studies predict that climate change will have negative consequences on ski lift operations, particularly in low-elevations (Abegg et al., 2007; Dawson and Scott, 2013; Steiger and Abegg, 2013). Snowmaking is the main adaptation strategy to compensate for the lack of natural snowfall. When snowmaking is accounted for, Steiger (2012) finds that the impact of climate change on skiing demand is quite modest at least in the short and medium run. Instead, demographic changes such as stagnating and ageing population are larger threats to skiing operations.

To the best of our knowledge, this is the first study that investigates the relationship between output of ski lift companies and investment in snowmaking facilities using a longer time span and fuller data coverage (covering both warm and normal winter seasons). Previous studies investigate the link between the survival of ski lift companies and the use of snowmaking systems where snowmaking is measured as a binary variable (Falk, 2013; Beaudin and Huang, 2014), a dummy variable for a

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[1] Skier visits are defined as the number of people who buy a lift ticket or lift pass and use the ski area for one or part of the day.

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given threshold of snowmaking capacity (Gonseth, 2013) or (subjective) rating of new snowmaking systems (Tashman and Rivera, 2015). Given that almost all French ski areas in the estimation sample have been long since equipped with snowmaking systems, the amount of past investments becomes more important for output. Despite large investments in snowmaking infrastructure, little is known about their effectiveness in normal and snow poor winter seasons. Previous studies on winter tourism in the French Alps focus on winter tourism demand for ski areas belonging to the Compagnie des Alpes (CDA) group (Falk, 2015), the productivity of French ski areas (Goncalves, 2013), the productivity and greening of ski area (Goncalves et al., 2015) and the causes of stagnation (Tuppen, 2000).

A study on the returns to investment in snowmaking systems for French ski lift companies is interesting for several reasons. First, France has one of the largest ski areas in the world. Second, after a long period of increased demand and expansion the French ski market has reached a point of stagnation (Vanat, 2015; Hudson and Hudson, 2015). This holds true not only for France but for the ski industry in general. Third, the effectiveness of investment in snowmaking has been largely overlooked. Previous literature has concentrated on the relationship between winter tourism demand and weather conditions or climate variability (see Dawson et al., 2009; Holmgren and McCracken, 2014; Shih et al., 2009). An exception to this is the study by Damm et al. (2014) which investigate the costs and benefits of snowmaking under future climate change scenarios for Austrian ski areas. The authors find that costs of snowmaking will increase considerably, something that also leads to an acceleration of the increase of lift ticket prices.

Knowledge of the effectiveness of snowmaking investment is relevant for policy makers, managers, and stakeholders (e.g. investors and banks) for a number of reasons. For instance, the knowledge about the benefits of snowmaking in low elevations ski areas is important to banks and investors, since these operators pose a higher risk of failure (Trawöger, 2014).

The paper is structured as follows. Section 2 describes the theoretical background and introduces the empirical model, while Section 3 provides the data and descriptive statistics. Section 4 presents the empirical results, Section 5 discusses the results and Section 6 concludes.

2. Theoretical Background and Empirical Model

Snowmaking is the key adaptation measure to compensate for natural snow. The snow cannon was invented in 1950 and patented in 1954 (Pierce, 1954). Snow is produced by a process in which cold air and water are pumped through compressors and then sprayed on ski slopes (https://en.wikipedia.org/wiki/Snowmaking). Installations of additional snowmaking facilities increase the snow supply and can be regarded as a technological innovation, particularly a new process innovation. According to the OSLO manual, a process innovation is the introduction or implementation of a new or significantly improved production method that helps a firm to remain competitive (OECD/Eurostat, 2005). In tourism literature, snowmaking technology is included on the list of the 100 most important innovations (Hjalager, 2015). Snowmaking infrastructure not only consists of snowmaking equipment (snow towers, snow fans) but also requires the construction of new power lines and water pipelines. Often water reservoirs for snowmaking have to be constructed. Water can be drawn from a spring, river or lake. However, ski lift companies have to apply for water rights.

Expansion of snowmaking capacity can lead to an increase in the number of snow reliable days and thereby attract more visitors (Steiger and Mayer, 2008). Damm et al. (2014) show that snowmaking investments have a positive impact on revenues. However, the effects tend to be non-linear with a decrease in the positive effects as the levels of investments increase, indicating diminishing returns to snowmaking investments. For Switzerland, Gonseth (2013) finds that a ski operator that can ensure the presence of snow over 30% of ski runs (which is roughly the Swiss average) manages to considerably reduce sensitivity to natural snow conditions in relation to skier visits.

In the ski industry, other major new technology consists of installations of new ski lifts. These offer a higher transport capacity, faster speed, and more comfort (heated seats, bubbles, loading carpets, etc.). Replacement of an older ski lift (e.g. a t-bar lift) with a new chairlift or a gondola can be regarded as product or process innovation. It is expected that a new ski lift attracts more passengers than older less comfortable ski lifts. However, at the aggregate ski area level the expected effect of new ski lift installations is not clear-cut. New ski lifts can take passengers from the neighbouring lifts so the output effect at the aggregate ski area level might be low.

The empirical model can be motivated by a production function where output is a function of the capital stock distinguished by the capital stock of snowmaking facilities and lift infrastructure. Due to data limitations, lift infrastructure is measured by installations of new ski lifts rather than transport capacity. The resulting production function can be specified as follows:

$$\ln Y_{it} = \alpha_i + \alpha_1 \ln K_{it} + \alpha_2 NEWLIFT_{it} + \lambda_t + \varepsilon_{it}, \quad (1)$$

where i and t denote the ski area and the year, respectively. ln denotes the natural logarithm. Y denotes the number of skier visits for winter seasons 2006/2007 to 2013/2014, K denotes cumulated past investment in snowmaking infrastructure deflated by the GDP deflator, and $NEWLIFT$ is a dummy variable of installation of a new ski lift (excluding carpet lifts and t-bar lifts) and zero otherwise. Note that K and $NEWLIFT$ refer to the calendar year (t) (e.g. 2013) whereas skier visits refer to the subsequent ski season (e.g. 2013/2014). Further, α_i denotes the fixed effects that capture all time invariant factors such as elevation and size of the ski area, different locations (e.g. Pyrénées, Jura, Massiv Central, Alps), and distance to the neighbouring ski area or to larger agglomerations. ε_{it} is the error term with mean zero and assumed i.i.d. λ_t are time effects that capture macroeconomic factors such as business cycle effects and the effects of weather conditions that are common to all ski areas.

It would be preferable to account for the economic depreciation when calculating the capital stock of snowmaking systems. However, deprecation rates differ between snowmaking equipment and structures, and are not available. Note that the economic literature shows that capital stock estimates (in case of R&D capital) are largely independent of the use or choice of depreciation rates (Hall and Mairesse, 1995).

The output equation can be estimated by the static fixed effects model for winter seasons 2006/2007 to 2013/2014. To account for the fact that ski areas are often part of a larger ski alliance, we allow the error terms of these ski areas to be correlated. Since the effectiveness of snowmaking technology is expected to differ between low and high elevation ski areas, we provide separate estimates for the two groups. Low elevation ski areas exhibit a lower number of optimal days with appropriate weather conditions to produce snow. Therefore, in warm winter seasons marked by low snowfall, output growth is expected to be lower for low-elevation ski areas than for high elevation ski areas. Output volatility can be expected to be much higher for low-elevation ski areas than for their high elevation counterparts. For Australia, Pickering (2011) finds that low natural snow cover leads to a strong decline in visitors – ranging between 52 and 86% – for the three lowest-altitude ski resorts compared to the average number of visitors from the previous nine years. Previous empirical evidence from Austrian ski areas in the province of Tyrol shows that lower-elevation resorts experienced the largest reductions in number of passenger transports during the extraordinary warm 2006/2007 winter season (Steiger, 2011). Low elevation ski areas are defined as ski areas below the weighted average elevation of ski lifts (which is 1770 m). This is done by calculating the mean of the valley and uphill lift station and then weighting the average elevation of each lift by the share of each lift in total transport capacity adjusted by the vertical meters of each lift.

Besides separate estimations for low and high elevation ski areas, we also provide separate estimates for small and large ski areas for a given elevation category. Large and small ski areas differ in a number of aspects. First, large ski areas are more profitable and thus can invest relatively higher amounts in snowmaking than their medium-sized and smaller ski areas. Second, the ski industry enters a consolidation and stagnation phase with small and medium sized ski areas having a higher failure risk than their large counterparts (Falk, 2013). Consequently, the ski market share of small and medium-sized ski areas tends to decline over time.

Furthermore, we investigate whether the effectiveness of snowmaking differs between winter seasons with extreme winter conditions such as warm temperatures or low precipitation. Lack of precipitation is a threat since snow production is very water intensive. The interaction term between cumulated past snowmaking investment and the binary year dummy makes it possible to investigate whether the output effects of the snowmaking systems differ in winters with extreme weather conditions.

$$\ln Y_{it} = \alpha_i + \alpha_1 \ln K_{it} + \alpha_2 \ln K_{it} \cdot \text{season2010t11} + \alpha_3 NEWLIFT_{it} + \lambda_t + u_{it}. \quad (2)$$

We use winter 2010/2011 as an example for extreme winter conditions. α_2 measures the difference in the effect of snowmaking investment for the season 2010/2011 as compared to the total sample period. Information obtained from Col de Porte weather station located close to Grenoble at an elevation of 1325 m shows that winter 2010/2011 was the driest winter in the last 45 years with a precipitation of 233 mm for the period December to February as compared to the average of 490 mm for the period 1970 to 2014. Note that Météo France maintains only a few weather stations in the French Alps unlike the public meteorological agencies in the neighbouring countries.[2]

The static fixed effects model has three disadvantages: First, it does not account for persistence of skier visits. It can be expected that output of ski lift companies is highly persistent over time. Second, static models neglect possible lagged reactions to expansion of snowmaking capacity. It is likely that skier visits react to new investments in the subsequent winter season rather than in the same season. Third, the fixed effects model assumes that the direction of causality goes from investment in snowmaking systems to output. However, investment in snowmaking is also likely responding to changes in output and to unobservable factors that affect both output and snowmaking themselves.

To account for endogeneity, instrumental variable (IV) estimation can be used. The IV estimator relies on external instruments. Possible instruments such as the availability of water needed for snowmaking are difficult to obtain at the ski area level. Therefore, we use the system GMM estimator developed by Arellano and Bover (1995), and Blundell and Bond (1998) which is based on internal instruments, i.e. lagged levels of the dependent and independent variables. This estimator is particularly useful for panel data with a relatively large number of cross section units and a small time dimension, as is the case here with N = 107 and T = 7. The system GMM estimator is widely used in the demand for outdoor recreation or tourism demand (e.g. Töglhofer et al., 2011).

Furthermore, the estimator allows for estimation of long-run elasticities and is hence an optimal solution to the two problems mentioned above. The skier visits equation in dynamic form can be written as follows:

$$\ln Y_{it} = \tilde{\alpha}_i + \tilde{\alpha}_1 \ln Y_{it-1} + \tilde{\alpha}_2 \ln K_{it} + \tilde{\alpha}_3 NEWLIFT_{it} + \lambda_t + u_{it} \quad (3)$$

The long-run effect of snowmaking investment is obtained by $\hat{\tilde{\alpha}}_2/(1-\hat{\tilde{\alpha}}_1)$. The system GMM estimator builds on two assumptions. The first is that past changes of a variable can have an influence on its current level but not the other way around. The other is that past levels of a variable do have an impact on current changes of the variables but not vice versa. Assuming that the residuals of the level equation are serially uncorrelated, variables in levels lagged two or more periods can be used as instruments in the first-differenced equation. Variables in the equation in levels are instrumented with lags of their own first differences. As a rule-of-thumb the number of instruments should not exceed the number of groups in the regression (Roodman, 2009). The two-step estimator is used to estimate the output equation with the finite sample correction developed by Windmeijer (2005). The snowmaking capital stock is treated as endogenous (predetermined) and values lagged two years are used as instruments because data refers to the previous calendar year.

3. Data and Descriptive Statistics

Data originate from several sources: The first is the investment survey provided by *Montagne Leaders*. This source contains information on the amount of investment in snowmaking infrastructure for the period 2002 to 2014. This information is used to calculate the snowmaking capital stock by the perpetual inventory method assuming a zero depreciation method. The second data source is the TOP 100 revenue survey published by *Montagne Leaders,* containing information about sales revenues, employment, number of persons transported uphill, and skier visits for about 100 ski-lift operators in France. Skier visits (also referred to as skier days) are defined as the number of people who buy a lift ticket or lift pass and use the ski area for all or any part of the day (or night). Skier visits are available from the winter season 1999/2000 onwards. However, since there are a relatively large number of missing values in earlier years, the sample starts from 2006/2007 onwards. The third data source is lift statistics containing information on the elevation of ski lifts and vertical distance as well as new ski lift installations provided by the French Ministry of Ecology, Sustainable Development and Energy (Le ministère de l'Écologie, du Développement durable et de l'Énergie [MEDDE]; website: http://cairn.application.developpement-durable.gouv.fr/consultationInternet.do). Elevation is defined as the average of the peak and valley lift station weighted by vertical transport capacity. T-bar lifts and carpet lifts are not considered as major ski lifts and excluded from the new lift variable.

Data on snow depth, winter temperatures, and precipitation can be downloaded from the National Centre for Meteorological Research.[3] The weather station in question is located at Col de Porte (Massif de la Chartreuse-Isère) at an elevation of 1325 m above sea level. Using a definition based on deviations above and below one standard deviation from the average winter temperatures and snow depth for the period 1973 to 2013, winter seasons 2008/2009, 2009/2010, and 2011/2012 can be regarded as cold with average snow depth levels, and 2006/2007 as both warm and snow poor (see Table 5 in the Appendix A).

Table 6 in the Appendix A shows the descriptive statistics for investment in snowmaking cumulated for the period 2002 to 2014 (here in current prices) by ski area. Between 1993 and 2014 French ski lift companies invested about 1.4 billion in snowmaking systems (see Fig. 1 in the Appendix A). Years 2002, 2003, and 2005 have the highest amounts of investment in snowmaking at about 100 million or more. In addition, the ratio of average investment in snowmaking to total revenues for 2014 is provided. All but two ski areas have invested in snowmaking in any of the years between 2002 and 2014. This is consistent with Spandre et al. (2015)based on a recent survey. The authors show that 32% of the slopes were equipped with snowmaking systems for the 2014/2015 season. Our calculations show that the ski areas with the highest investment in snowmaking systems are Les Arcs, Val d'Isère, Val Thorens, La Plagne, and Auron with investment of about € 20 million or more during the period 2002 to 2014. When expressed as a ratio of average investment in snowmaking to revenues, Auron, Les Brasses, Isola 2000, La Pierre Saint Martin, and Gérardmer are the top investors in snowmaking equipment and systems with a share of 15% or more.

[2] Personal correspondence with Samuel Morin (Météo France).

[3] http://www.cnrm-game.fr/spip.php?article289&lang=en.

Table 1
Descriptive statistics.
Source: various issues of Montagne Leaders, own calculations.

	Change in skier visits in percent (means)	Change in cumulated investment in snowmaking in percent (means)	Percentage of ski areas with at least one new ski lift (excluding t-bar)
Winter season		Low elevation ski areas < 1770 m (# ski areas = 51)	
2006–2007	−26.2	n.a.	24.3
2007–2008	23.5	48.8	15.4
2008–2009	10.2	11.1	12.5
2009–2010	−11.6	32.1	9.8
2010–2011	−10.2	14.2	14.9
2011–2012	11.1	22.4	13.3
2012–2013	9.2	5.9	7.3
2013–2014	−7.1	18.9	9.5
		High elevation ski areas ≥ 1770 m (# ski areas = 58)	
2006–2007	−5.5	n.a.	33.3
2007–2008	10.0	31.7	25.9
2008–2009	2.6	24.8	18.2
2009–2010	−1.2	11.2	25.0
2010–2011	−4.4	8.4	27.8
2011–2012	−0.6	9.5	24.1
2012–2013	3.7	7.1	16.7
2013–2014	−2.9	5.6	25.0

Table 1 displays a number of descriptive statistics based on the estimation sample. For low elevation ski areas, changes in skier visits vary highly over time ranging between −26% for the winter season 2006/2007, and −11 and −12% for the winter seasons 2009/2010 and 2010/2011, respectively. For high elevation ski areas, skier visits are generally less volatile over time. In the two winters with extreme weather conditions (2006/2007 and 2010/2011) these ski areas experienced a decline in skier visits of −5.5 and −4.4%, respectively. Fig. 2 in Appendix A shows a positive association between the level of past investments in snowmaking (expressed as ratio to revenues) and skier visits. However, the relationship only holds true for high elevation ski areas.

4. Empirical Results

Table 2 shows the fixed effects estimates of the determinants of skier visits for the ski season 2006/2007 to 2013/2014 for high and low elevation ski areas. The main result is that for high elevation ski areas, cumulated investment in snowmaking has a significant and positive effect on the output of ski lift companies' measured as skier visits when controlling for time effects and time-invariant ski area effects. However, snowmaking is not significant for low elevation ski areas. A possible explanation might be that these resorts are among the first to be equipped with snowmaking systems. Another explanation is that low elevation ski areas have a lower number of days with optimal temperatures for the use of snowmaking facilities.

For high elevation ski areas the coefficient is 0.063 indicating that a 10% increase in snowmaking capital stock leads to an increase in skier visits of about 6% on average. The magnitude of the output effect of snowmaking investment is quite large given the median ratio of average snowmaking investment to total revenues of 4%. In contrast to snowmaking investment, installations of new ski lifts are never significant at conventional significance levels.

Furthermore, time dummies are highly significant. For low elevation ski areas, skier visits for the 2006/2007 and 2010/2011 winter seasons are on average 30 and 11% lower, respectively, than the benchmark season of 2009/2010.[4] For high elevation ski areas the decline of skier visits is significantly less pronounced with reductions of eight and 5% on average. This indicates that high elevation ski areas also suffer from winters marked by low snowfall or little precipitation and do not benefit from shift in demand from low elevation to high elevation ski areas. Overall, the findings show that investment in snowmaking has not completely reduced the sensitivity of skier visits to reductions in natural snowfall or lack of water due to low amounts of precipitation. For the 2008/2009 and 2012/2013 winter seasons we find that output is 10% higher than the benchmark period. This is not surprising given that both winter seasons are characterised by colder than average temperatures and excellent snow conditions in the early season (late November to mid December).

The lower panel of Table 2 reports the fixed effects estimations including the squared term for cumulated snowmaking investment. We find that for high elevation ski areas the cumulated investment in snowmaking is significantly positive, and its squared term is significantly negative indicating a non-linear relationship. Fig. 3 in the Appendix A shows the corresponding elasticity of skier visits with respect to snowmaking investment and the 95% confidence interval. It shows that the returns to investment in snowmaking are declining with increasing investments. The turning point is log 8.8 which is equal to a cumulated investment in snowmaking of about € 6.5 million. Above the turning point, snowmaking does not lead to higher skier visits. Calculations are based on an “average” size of ski lift companies in the sample of high elevation ski areas with about 550,000 skier visits per year on average.

Table 2 also contains fixed effects estimates with an interaction dummy variable for small ski areas. The FE estimates for high elevation ski areas show that the positive effects of snowmaking investments are significantly lower for small ski areas (with an elasticity of 0.047). For low elevation ski areas no significant effect can be found for either large or small ski areas. The lower effects of snowmaking investments in small ski areas will increase the gap in profits and performance between small and large ski areas, and probably lead to an increase in the failure risks of these companies.

Having found that snowmaking is significant and positive with a decreasing non-linear form, we proceed by investigating whether the relationship between snowmaking and skier visits is different in winter seasons with extreme low amounts of precipitation.

Table 3 reports the fixed effects model with an interaction term between snowmaking investments and a dummy variable for the 2010/2011 winter season. We find that for low elevation ski areas, investment in snowmaking is significant at the 5% level for the 2010/2011 winter season. This indicates that the larger the investment in snowmaking, the lower the decline in skier visits during winters with extreme weather conditions (here low precipitation and lack of natural snow). However, the elasticity of skier visits with respect to snowmaking investments is quite low with 0.03. For high elevation ski area snowmaking investments is remain positive and significant in this winter season.

The next step is to investigate the effects of snowmaking using dynamic panel data methods, making it possible to account for the

[4] In semi-log equations, coefficient have to be converted into percentage change (Halvorsen and Palmquist, 1980).

Table 2
Impact of snowmaking investment on skier visits (fixed effects estimates).

	high elevation		low elevation	
	average ski lift elevation center>=1770m		average ski lift elevation center<1770m	
	(i)		(ii)	
	coeff.	t	coeff.	t
ln cumulated investment in snowmaking (t)	0.063***	2.53	-0.008	-0.61
new ski lifts (yes/no) (t)	-0.009	-0.86	-0.027	-0.64
season 2006/07 (reference winter season 2009/10)	-0.079**	-2.38	-0.266***	-5.53
season 2007/08	0.002	0.11	-0.065*	-1.74
season 2008/09	0.010	1.01	0.100***	4.31
season 2010/11	-0.046***	-5.38	-0.105***	-5.78
season 2011/12	-0.058***	-3.57	0.007	0.40
season 2012/13	-0.028	-1.55	0.109***	5.41
season 2013/14	-0.059***	-3.14	0.031	1.00
constant	12.639***	61.27	12.553***	133.08
number of observations	422		324	
number of ski areas	58		51	
R squared	0.21		0.42	

	high elevation		low elevation	
	average ski lift elevation center>=1770m		average ski lift elevation center<1770m	
	quadratic specification			
	(iii)		(iv)	
	coeff.	t	coeff.	t
ln cumulated investment in snowmaking (t)	0.247***	3.95	0.016	0.68
ln cumulated investment in snowmaking squared (t)	-0.013**	-2.52	-0.003	-1.00
new ski lifts (yes/no) (t)	-0.009	-0.91	-0.026	-0.62
season 2006/07 (reference winter season 2009/10)	-0.090**	-2.74	-0.273***	-5.46
season 2007/08	-0.006	-0.36	-0.068*	-1.82
season 2008/09	0.008	0.81	0.098***	4.06
season 2010/11	-0.043***	-4.88	-0.102***	-5.28
season 2011/12	-0.052***	-2.78	0.011	0.56
season 2012/13	-0.019	-0.94	0.115***	5.22
season 2013/14	-0.048**	-2.34	0.040	1.20
constant	12.056***	59.20	12.535***	151.97
number of observations	422		324	
number of ski areas	58		51	
R squared	0.21		0.42	

	high elevation		low elevation	
	average ski lift elevation center>=1770m		average ski lift elevation center<1770m	
	interaction dummy small ski areas			
	(v)		(vi)	
	coeff.	t	coeff.	t
ln cumulated investment in snowmaking (t)	0.067***	3.22	-0.017	-0.98
ln cumulated investment in snowmaking (t) × small ski areas	-0.020***	-3.82	0.009	1.48
new ski lifts (yes/no) (t)	-0.006	-0.59	-0.025	-0.61
dummy variables for winter seasons	yes		yes	
constant	12.678***	78.26	12.573***	122.56
number of observations	422		324	
number of ski areas	58		51	
R squared	0.29		0.42	

Notes: ***, ** and * denote significance at the 1, 5 and 10 percent significance levels. Standard errors are adjusted for 25 clusters (ski alliances or ski networks offering a joint ski pass). The dependent variable (skier visits) refers to the subsequent ski season, whereas the right hand variables refer to the calendar year (e.g. 2013/14 ski season data are related to 2013 data on cumulated investment in snowmaking and new ski lifts). Small ski areas are defined as ski areas with less than the median value of average skier visits across ski areas. The model is estimated by the Fixed effects (within) estimator, so that all variables are measured as deviations of the means over time.

endogeneity of snowmaking investments. Table 4 shows the results of the two-step system GMM estimator. The GMM regressions use robust standard errors and treat all explanatory variables as predetermined, except for the time dummy variables.[5]

The Hansen J-test supports the validity of the instruments in all cases (except for the total sample). The AR(2) test indicates that the residuals do not suffer from second-order serial correlation in all cases. Interpretation focuses on short-run coefficients, as the long-run coefficients are relatively high due to the high degree in persistence of skier visits. For high elevation ski areas we again find that cumulated investment in snowmaking is significantly and positively related to skier visits, with a short-run elasticity of about 0.08. The magnitude of the snowmaking investment

[5] The system GMM estimations are performed using the XTABOND2 command developed by Roodman (2009).

Table 3
Impact of snowmaking investment on skier visits with an interaction term for snow poor winter seasons (fixed effects estimates).

	High elevation		Low elevation	
	Average ski lift elevation center ≥ 1770 m		Average ski lift elevation center < 1770 m	
	Coeff.	t	Coeff.	t
ln cumulated investment in snowmaking (t)	0.064**	2.52	−0.011	−0.85
ln cumulated investment in snowmaking × dummy season 2010/2011 (t)	−0.016**	−2.10	0.030**	2.42
Dummy variables for winter seasons	Yes		Yes	
Constant	12.63***	60.82	12.57***	129.87
Number of observations	422		324	
Number of ski areas	58		51	
R squared	0.21		0.43	

Notes: ***, ** and * denote significance at the 1, 5 and 10% significance levels. Standard errors are adjusted for 25 clusters (ski alliances or ski networks offering a joint ski pass).

Table 4
Impact of snowmaking investment on skier visits (system GMM estimates).

	High-elevation ski areas		High-elevation ski areas		Low-elevation ski areas	
	(i)		(ii)		(iii)	
	Coeff.	t	Coeff.	t	Coeff.	t
ln skier visits (t-1)	0.898***	23.16	0.895***	26.98	0.930***	36.16
ln snowmaking capital stock (t)	0.080**	2.25	0.056**	2.24	0.041	1.61
ln snowmaking capital stock (t) × dummy small ski lift companies			−0.011***	−3.50		
Year dummies	yes				yes	
Constant	0.660**	2.34	0.944***	3.27	0.492*	1.92
Number of observations	402		402		691	
Number of ski areas	56		56		51	
Number of instruments	35		56		35	
AB-test for AR(1) (p-value)	0.000		0.000		0.000	
AB-test for AR(2)(p-value)	0.919		0.985		0.840	
Hansen test (p-value)	0.172		0.223		0.372	

Note: ***, ** and * denote significance at the 1, 5 and 10% levels. The table reports two-step GMM results with the Windmeijer (2005) correction for small samples. Lagged skier visits and snowmaking capital stock are treated as predetermined (endogenous). The Hansen J test checks for the validity of instrumental variables. AB is the Arellano-Bond test which checks for the absence of autocorrelation in first-differenced errors (1st and 2nd order). The lag limit for the instruments is restricted to 1. The time period refers to the period 2006/2007 to 2013/2014.

elasticity is slightly higher than those obtained by the static fixed effects model. In general, however, system GMM panel data estimates are preferable to static fixed-effects estimates because the use of lagged variables as instruments reduces possible bias due to measurement errors and treat snowmaking investments as endogenous. Again, for low elevation ski areas in general, investment in snowmaking is not significantly different from zero. Column (ii) shows the results for high elevation ski areas with an interaction term for small ski areas. Consistent with the static fixed effects estimations, we find that the magnitude of snowmaking investment elasticity is higher for large ski areas at high elevations. For small ski areas at high elevations, the elasticity is slightly but significantly lower (0.045). Lagged levels of cumulated investments in snowmaking do not have an impact and are thus also not included in the final specification. Similarly, new lift installations are not significant at conventional significance levels and thus omitted from the final specification. Furthermore, there is a large degree of persistence in skier visits as indicated by the coefficient of lagged skier visits.

We conduct several robustness checks and estimated simpler specifications such as the OLS first difference model. Again, for high elevation ski areas, cumulated investment in snowmaking systems is significant at the 5% level with larger effects for large ski areas in high elevations. Furthermore, ownership changes or linking ski areas via installations of connection ski lifts – such as between La Plagne and Les Arcs in 2003 – can also affect skier visits. However, no such changes occurred during the sample period.

5. Discussion

The result that for low elevation ski areas snowmaking is not effective has several implications. Furthermore, skier visits decline strongly in extreme dry or snow poor winter seasons indicating that snow-making cannot fully offset the decline in natural snow fall. Snowmaking investments have to be evaluated from both the economic and ecological perspective. The immense amount of water needed for fabrication of snow has been the subject of environmental criticism. For France, snowmaking accounted for 19 million m3 of water use in 2007 (Badré et al., 2009) (cited in Gössling et al., 2012). Using data for two winter sport destinations in Switzerland, Rixen et al. (2011) calculate that water consumption due to snowmaking facilities accounts for 22 and 36% of total water consumption in a given winter season. Using data for the Kitzbuehel area (Austria), snowmaking water demand can account for >50% of total water demand for the winter season (Vanham et al., 2008). People living in villages in ski areas are reported to suffer from water scarcity due to the large snowmaking related water demand (De Jong, 2015). In addition, a significant share of the water used for snow production is lost through evaporation (de Jong, 2007). In some alpine villages conflicts over water demand between local residents and ski lift companies have been reported in the early winter season and in periods of intensive snowmaking (De Jong, 2007, 2015; Gross and Winiwarter, 2015; Magnier and Reynard, 2012). For a ski resort located at a high altitude, Gross and Winiwarter (2015) report that inhabitants observe a decreased hydraulic thrust on the water tap in periods of intensive usage of snowmaking systems.

Apart from demanding water requirements, energy costs represent a significant proportion of total snowmaking costs. For larger villages the share of energy costs due to snowmaking is relatively low. Although the energy costs of snow making facilities are declining through technological change, rising electricity prices could lead to a substantial increase in energy costs, resulting in lower profits (Damm et al., 2014).

Scepticism against the use of snowmaking comes not only from the scientific community but also from the population. Based on a representative survey of about 1000 skiers and non-skiers conducted in December 2014, >50% of respondents argue that, due to ecological concerns, snow making should be not used to compensate for a lack of natural snow (ZEITONLINE, 2015). About 30% are in favour of the use of snow-making facilities.

In addition to high water and energy requirements, snowmaking can have negative ecological impacts on biodiversity, vegetation and soil (de Jong, 2007; Zu Schlochtern et al., 2014). Using river water could have fertilising effects, and the additional manmade snow could delay snow-melt, leading to increased erosion of soil and a delay to the start of the flowering season (Zu Schlochtern et al., 2014). Making snow with bacterial additives is another controversial aspect of snow production, although the possible effects on plants and human health are unclear (Lagriffoul et al., 2010).

6. Conclusion

This study investigated the impact of investment in snowmaking on performance of ski areas measured as skier visits. The data covers the 109 largest ski areas in France, which account for 95% of total skier visits in the country. Descriptive analysis shows that investment in snowmaking is widespread. Only two ski areas did not invest in snowmaking facilities between 2002 and 2013. Fixed effects estimates show that cumulated past investment in snowmaking systems has a significant and positive impact on the number of skier visits. However, positive effects can only be observed for high elevation ski areas with an average ski lift elevation of about 1800 m or above. For low elevation ski areas we find that snowmaking has a much smaller and only a positive effect in winters with extreme weather conditions (low levels of precipitation and lack of natural snowfall). As expected, the positive snowmaking effect decreases with higher investment in snowmaking. Furthermore, the largest effects of snowmaking investments can be found for large ski areas at high elevations. In general the results are robust when endogeneity of snowmaking investments is accounted for.

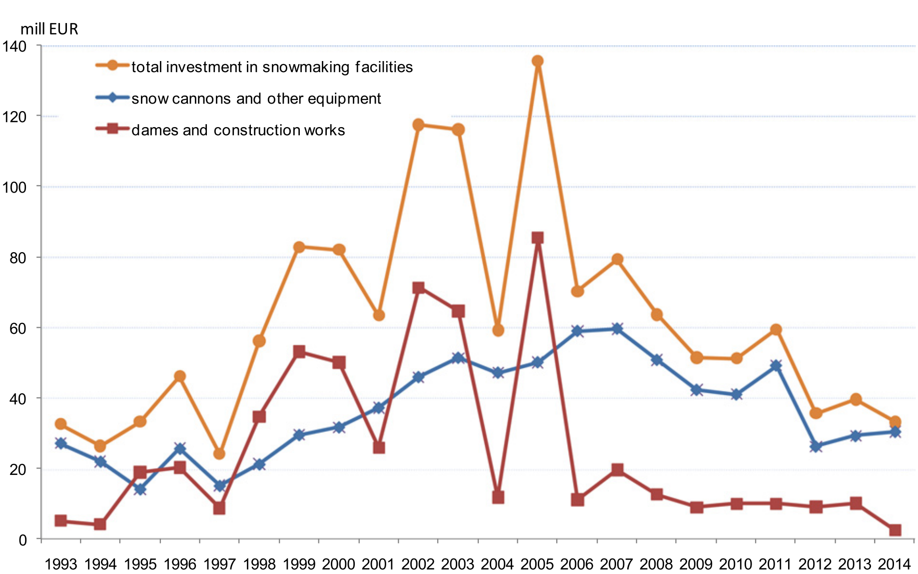
Another important result is that despite massive investments in snowmaking, skier visits are still sensitive to lack of natural snowfall or to low amounts of precipitation in a given winter season. In particular, skier visits in low elevation ski areas react strongly to a lack of natural snow and warm temperatures – as was the case in the 2006–2007 winter season – and to extreme dry seasons – such as in the 2010–2011 winter season.

The key finding that snowmaking investment has no impact on skier visits in low elevation ski areas has several implications. Snowmaking facilities are often installed because of economic considerations. The result that for low elevation ski and small ski areas high investment in snowmaking technology does not lead to more visitors also has important implications from an economic point of view. First, findings point to a widening gap in long-term performance between small ski areas in low elevations and large ski areas in high elevations. Second, the increased occurrence of green winters will lead to increased snowmaking requirements. At the same time the number of optimal snowmaking days with appropriate temperatures will decline. Note that the costs to produce snow under marginal temperature conditions are higher than under cold temperatures. Another adaptation strategy is the development of new ski terrain at higher elevations. However, this is not possible for low elevation ski areas given that uphill lift stations often reach the highest elevations. In the absence of positive returns to investment in snowmaking systems, further installation plans should be thoroughly considered.

This research is subject to some limitations. First, the very small ski-lift operators (i.e. those with one or two ski lifts) are not included in the empirical analysis due to a lack of available data. Second, this study is conducted for French ski areas and thus the results cannot generalised to ski areas located in other countries. Future work can apply the same methodology to ski areas in other countries. Third, the model fit is quite modest, so it is important to account for other time varying factors that may affect the number of visitors. These factors include investment in tourism infrastructure other than ski lifts and snowmaking, and the supply of new accommodations.

There are several avenues for future work. One idea is to distinguish by type of snowmaking investment (snowmaking equipment versus structures such as water reservoirs and ponds). Another idea for future work is to evaluate the impact of public investment subsidies for snow making facilities and new ski lifts.

Appendix A



Source: Various issues of Montagne leaders.

Fig. 1. Evolution of investment in snowmaking.
(Source: Various issues of Montagne leaders.)

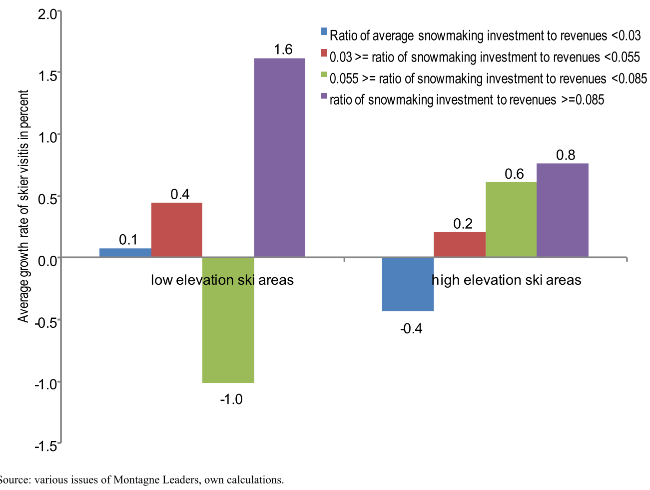


Fig. 2. Relationship between snowmaking investment and evolution of skier visits by elevation.
(Source: various issues of Montagne Leaders, own calculations.)

Table 5
Weather conditions at the weather station Col de Porte (1325 m) December to February.

Winter season	Temperature in Celsius	Snow depth in cm	Precipitation in mm	Temperature category	Snow depth category	Precipitation category
2001–2002	−0.7	38	317	Normal	Normal	Dry
2002–2003	−1.9	43	387	Normal	Normal	Normal
2003–2004	−1.0	68	449	Normal	Normal	Normal
2004–2005	−2.1	59	404	Normal	Normal	Normal
2005–2006	−2.9	77	344	Cold	Normal	Normal
2006–2007	1.5	18	443	Warm	Snow poor	Normal
2007–2008	0.7	70	504	Normal	Normal	Normal
2008–2009	−2.5	72	303	Cold	Normal	Dry
2009–2010	−3.2	51	479	Cold	Normal	Normal
2010–2011	−1.2	35	233	Normal	Snow poor	Dry
2011–2012	−2.3	71	599	Cold	Normal	Normal
2012–2013	−2.7	113	609	COLD	Snow rich	Normal
2013–2014	0.7	52	538	normal	Normal	Normal
Mean 1973–2014	−0.7	67	482			
St. dev 1973–2014	1.5	32	162			

Source: Lesaffre et al., 2012. National Centre for Meteorological Research. http://www.cnrm-game.fr/spip.php?article289&lang=en. Extreme winter seasons defined as average minus one standard deviation.

Table 6
Investment in snowmaking by ski area.
Source: Various issues of Montagne leaders.

	Cumulated investment in snowmaking in 1000 Euro 2002–2014 (current prices)	Ratio of average investment in snowmaking systems 2002–2014 to revenues in 2014 in percent
Les Arcs	24,924	3.1
Val d'Isère	22,041	4.2
Val Thorens	21,619	2.7
La Plagne	20,541	2.3
Auron	19,138	25.3
L'Alpe d'Huez	18,621	4.1
Serre-Chevallier	18,046	4.3
Courchevel-Méribel-Mottaret	17,632	2.2
Méribel Les Allues	17,430	3.7
Isola 2000	14,876	18.1
Les Ménuires	14,695	2.2
Valberg	14,216	
Valloire/Valmeinier	13,007	7.4
Châtel	12,750	4.3
Le Grand Bornand	12,309	6.3
Tignes	12,257	2.0
Montgenèvre	12,050	7.2
Vars-les-Claux Crevoux (La Forêt Blanch)	10,059	7.0
Les Orres	9909	7.0
Superdévoluy	9804	7.4
La Clusaz	9803	3.9

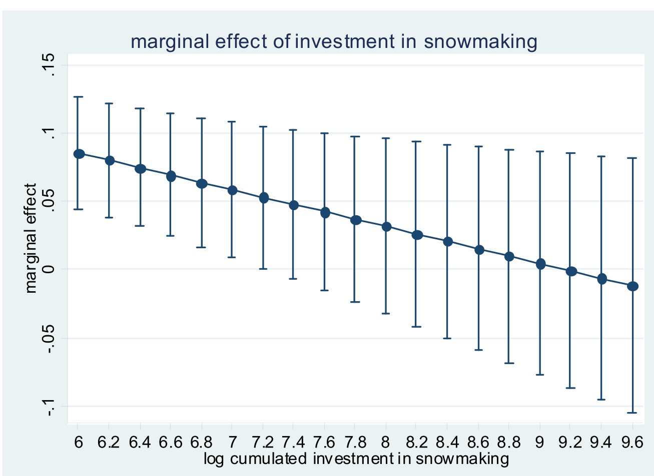
Table 6 (*continued*)

	Cumulated investment in snowmaking in 1000 Euro 2002–2014 (current prices)	Ratio of average investment in snowmaking systems 2002–2014 to revenues in 2014 in percent
Font Romeu Pyr 2000	9090	6.3
Morzine	9052	5.4
Mégève	8889	3.3
St Gervais/St Nicolas Evasion Mont-Blanc	8810	5.4
Peyragudes	8589	7.1
Flaine-Morillon-Samoens-Sixt	8384	1.8
Villard de Lans	8341	7.9
Les Saisies	7967	4.3
Avoriaz	7954	1.5
Le Tourmalet-La Mongie Le Barèges	7874	4.0
Les Contamines-Montjoie (Evasion Mont-Blanc)	7599	5.6
Les Sept.-Laux	7460	5.7
Les Deux-Alpes	7453	1.5
Valmeinier	7383	5.5
Chamonix + Les hoches	7326	0.8
Valmorel	6972	4.3
Saint-Lary-Soulan	6507	3.0
Luchon-Superbagnères	6378	11.4
Les Gêts	6266	2.7
La Pierre Saint Martin	6142	15.5
Pra Loup-La Foux	5985	6.4
Risoul 1850	5938	4.5
Super besse	5445	4.8
La Rosière	5437	4.0
Métabrief - Mont d'or	5357	
Gourette	4944	5.4
Les Rousses	4936	7.5
Orcières-Merlette	4909	3.8
La Norma	4893	11.6
La Toussuire	4784	3.7
Lioran (Le)	4751	5.9
Le Mont Dore	4258	5.8
Puy Saint Vincent	4146	4.6
Val d'Allos	4072	4.5
Ancelle	4019	
Gérardmer	3993	15.3
Les Brasses	3944	21.9
Val Cenis Vanoise	3913	2.5
Combloux Jail, La Giettaz (Evasion Mont-Blanc)	3708	3.3
Les Carroz d'Araches	3640	2.2
Les Angles	3391	2.9
Aussois	3287	7.2
Molines Queyras + Saint Véran, Abres/Avieu	3097	
Crest Voland Cohennaz Val D'Arly	3028	5.2
Saint Jean d'Aulps	2891	
Ax les Thermes	2870	2.5
Le Corbier-St Jean d'Arves Saint Collomb	2837	2.1
La Chapelle d'Abondance	2831	7.3
Valfréjus	2819	6.3
Saint Sorlin d'Arves	2635	2.3
Chamrousse	2634	2.0
Albiez-Montrond	2584	10.0
La Bresse Hohneck	2507	3.2
Oz- Vaujany	2293	2.1
Val d'Arly	2234	2.1
Les Karelis	2213	4.4
Saint Jean Montclar	2145	
Manigod Merdassier	2113	
Bellevaux-Hirmentaz	1935	8.0
Arèches-Beaufort	1882	4.2
Saint François Longchamp	1822	1.7
Luz Ardiden	1783	3.8
Piau Engaly	1726	3.0
Sainte Foy Tarentaise	1697	4.5
Notre Dame de Bellecombe Flumet/Praz sur	1570	
Alpes du Grand Serre	1317	6.2
Bernex	1300	
Val Louron	1263	7.3
Formigueres	1243	5.1
Monts D'Olmes	1210	7.5
Thollon Les Mémises	1145	6.3
Pralognan la Vanoise	1134	2.5
Le Sauze	1086	2.8

(*continued on next page*)

Table 6 (*continued*)

	Cumulated investment in snowmaking in 1000 Euro 2002–2014 (current prices)	Ratio of average investment in snowmaking systems 2002–2014 to revenues in 2014 in percent
Chaillou/Laye/Saint-Léger-Les-Mélèzes	1021	
Cauterets	996	1.0
Chalmazel	941	
Guzet	730	3.3
Monts Jura Crozet Mijoux	707	1.1
Porte puymorens	660	3.3
Collet D'Allevard	617	
Praz-sur-Arly	593	
Reallon	525	3.1
Bonneval sur Arc	478	
Praz de Lys Sommand	407	0.6
Espace Cambre D'aze	359	1.2
Ventron	359	
Artouste-Fabrèges	285	
Lans en Vercors	244	1.4
Autrans	174	1.0
Les Aillons-Margeriaz	140	0.4
Greolières les Neiges	101	
St Pierre de Chartreuse	37	
La Feclaz/Revard	15	0.1
La Grave La Meije	0	0.0
Le Semnoz	0	0.0



Source: Calculation based on the delta method based on specification displayed in table 2. The lower and upper bars represent the confidence interval. Calculations are based on the "average" ski area with about 550,000 skier visits.

Fig. 3. Marginal effect of investment in snowmaking on skier visits in high elevation ski areas.

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References

Abegg, B., Agrawala, S., Crick, F., De Montfalcon, A., 2007. Climate change impacts and adaptation in winter tourism. Climate Change in the European Alps: Adapting Winter Tourism and Natural Hazards Management. Organization for Economic Cooperation and Development (OECD), Paris, pp. 25–58.
Arellano, M., Bover, O., 1995. Another look at the instrumental variable estimation of error-components models. J. Econ. 68 (1), 29–51.
Badré, M., Prime, J., Ribière, G., 2009. Neige de Culture: Etat Des Lieux et Impact Environnementeaux. Note Socio-Economique. Conseil Général de l'Environnement et du Développement Durable, Paris.
Bark, R.H., Colby, B.G., Dominguez, F., 2010. Snow days? Snowmaking adaptation and the future of low latitude, high elevation skiing in Arizona, USA. Clim. Chang. 102 (3–4), 467–491.
Beaudin, L., Huang, J.C., 2014. Weather conditions and outdoor recreation: a study of New England ski areas. Ecol. Econ. 106, 56–68.
Becken, S., 2013. A review of tourism and climate change as an evolving knowledge domain. Tour. Manag. Perspect. 6, 53–62.
Blundell, R., Bond, S., 1998. Initial conditions and moment restrictions in dynamic panel data models. J. Econ. 87 (1), 115–143.
Damm, A., Köberl, J., Prettenthaler, F., 2014. Does artificial snow production pay under future climate conditions?–a case study for a vulnerable ski area in Austria. Tour. Manag. 43, 8–21.
Dawson, J., Scott, D., 2013. Managing for climate change in the alpine ski sector. Tour. Manag. 35, 244–254.
Dawson, J., Scott, D., McBoyle, G., 2009. Climate change analogue analysis of ski tourism in the northeastern USA. Clim. Res. 39 (1), 1–9.
De Jong, C., 2007. Artificial snow drains mountain resources, EnvironmentalResearchWeb, talking point article. http://environmentalresearchweb.org/cws/article/opinion/30703 (August 2007).
De Jong, C., 2015. Challenges for mountain hydrology in the third millennium. Front. Environ. Sci. Eng. China 3 (38), 1–13.
Falk, M., 2013. A survival analysis of ski lift companies. Tour. Manag. 36, 377–390.
Falk, M., 2015. The demand for winter sports: empirical evidence for the largest French ski-lift operator. Tour. Econ. 21 (3), 561–580.
Goncalves, O., 2013. Efficiency and productivity of French ski resorts. Tour. Manag. 36, 650–657.
Goncalves, O., Robinot, E., Michel, H., 2015. Does it pay to be green? The case of French ski resorts. J. Travel Res. (in print).
Gonseth, C., 2013. Impact of snow variability on the Swiss winter tourism sector: implications in an era of climate change. Clim. Chang. 119 (2), 307–320.
Gössling, S., Peeters, P., Hall, C.M., Ceron, J.P., Dubois, G., Scott, D., 2012. Tourism and water use: supply, demand, and security. An international review. Tour. Manag. 33 (1), 1–15.
Gross, R., Winiwarter, V., 2015. Commodifying snow, taming the waters. Socio-ecological niche construction in an Alpine village. Water Hist. 7 (4), 489–509.
Hall, B.H., Mairesse, J., 1995. Exploring the relationship between R&D and productivity in French manufacturing firms. J. Econ. 65 (1), 263–293.
Halvorsen, R., Palmquist, R., 1980. The interpretation of dummy variables in semilogarithmic equations. Am. Econ. Rev. 70, 474–475.
Hamilton, L.C., Rohall, D.E., Hayward, G.F., Keim, B.D., 2003. Warming winters and New Hampshire's lost ski areas: an integrated case study. Int. J. Sociol. Soc. Pol. 23 (10), 52–73.
Hjalager, A., 2015. 100 innovations that transformed tourism. J. Travel Res. 54, 3–21.
Holmgren, M.A., McCracken, V.A., 2014. What affects demand for "the greatest snow on earth?". J. Hosp. Mark. Manag. 23 (1), 1–20.
Hudson, S., Hudson, L., 2015. Winter Sport Tourism: Working in Winter Wonderlands. Goodfellow Publishers.
Lagriffoul, A., Boudenne, J.L., Absi, R., Ballet, J.J., Berjeaud, J.M., Chevalier, S., ... Morris, C.E., 2010. Bacterial-based additives for the production of artificial snow: what are the risks to human health? Sci. Total Environ. 408 (7), 1659–1666.
Lesaffre, B., Lejeune, Y., Morin, S., Panel, J.-M., Poncet, D., 2012. Impact du changement climatique sur l'enneigement de moyenne montagne: l'exemple du site du col de Porte en Chartreuse. Actes du 25ème Colloque de l'Association Internationale de Climatologie, Grenoble, pp. 475–480 (in French).
Magnier, E., Reynard, E., 2012. Artificial snowmaking and potential water conflicts in mountain resorts. The Case of Avoriaz (Haute-Savoie, France). In EGU General Assembly Conference Abstracts 14, p. 3761.
OECD (Organization for Economic Cooperation and Development)/Eurostat, 2005t. Guidelines for Collecting and Interpreting Innovation Data — The Oslo Manual. third ed. OECD, Paris.
Pickering, C., 2011. Changes in demand for tourism with climate change: a case study of visitation patterns to six ski resorts. J. Sustain. Tour. 19 (6), 767–781.

Pierce, J. W. M. 1954. U.S. Patent No. 2,676,471. Washington, DC: U.S. Patent and Trademark Office.
Rixen, C., Teich, M., Lardelli, C., Gallati, D., Pohl, M., Pütz, M., Bebi, P., 2011. Winter tourism and climate change in the Alps: an assessment of resource consumption, snow reliability, and future snowmaking potential. Mt. Res. Dev. 31 (3), 229–236.
Roodman, D., 2009. How to do xtabond2: an introduction to difference and system GMM in Stata. Stata J. 9 (1), 86–136.
Shih, C., Nicholls, S., Holecek, D.F., 2009. Impact of weather on downhill ski lift ticket sales. J. Travel Res. 47 (3), 359–372.
Spandre, P., François, H., Morin, S., George-Marcelpoil, E., 2015. Dynamique de la neige de culture dans les Alpes Françaises. Contexte climatique et état des lieux. J. Alp. Res. 103–2, 1–18.
Steiger, R., 2011. The impact of snow scarcity on ski tourism. An analysis of the record warm season 2006/07 in Tyrol (Austria). Tour. Rev. 66, 4–13.
Steiger, R., 2012. Scenarios for skiing tourism in Austria: integrating demographics with an analysis of climate change. J. Sustain. Tour. 20 (6), 867–882.
Steiger, R., Abegg, B., 2013. The sensitivity of Austrian ski areas to climate change. Tour. Plann. Dev. 10 (4), 480–493.
Steiger, R., Mayer, M., 2008. Snowmaking and climate change: future options for snow production in Tyrolean ski resorts. Mt. Res. Dev. 28 (3), 292–298.
Tashman, P., Rivera, J., 2015. Ecological uncertainty, adaptation, and mitigation in the U.S. ski resort industry: managing resource dependence and institutional pressures. Strat. Mgmt. J. http://dx.doi.org/10.1002/smj.2384.
Töglhofer, C., Eigner, F., Prettenthaler, F., 2011. Impacts of snow conditions on tourism demand in Austrian ski areas. Clim. Res. 46 (1), 1–14.
Trawöger, L., 2014. Convinced, ambivalent or annoyed: Tyrolean ski tourism stakeholders and their perceptions of climate change. Tour. Manag. 40, 338–351.
Tuppen, J., 2000. The restructuring of winter sports resorts in the French alps: problems, processes and policies. Int. J. Tour. Res. 2, 327–344.
Vanat, L., 2015. 2015 International Report on Snow & Mountain Tourism, Geneva, Switzerland, April.
Vanham, D., Fleischhacker, E., Rauch, W., 2008. Technical note: seasonality in alpine water resources management? A regional assessment. Hydrol. Earth Syst. Sci. Discuss. 12 (1), 91–100.
Windmeijer, F., 2005. A finite sample correction for the variance of linear efficient two-step GMM estimators. J. Econ. 126 (1), 25–51.
Wolfsegger, C., Gössling, S., Scott, D., 2008. Climate change risk appraisal in the Austrian ski industry. Tour. Rev. Int. 12 (1), 13–23.
Zeitonline, 2015. http://www.zeit.de/reisen/2015-01/skigebiete-kunstschnee-yougov-umfrage (majority of Germans are against the use of snowmaking, 19.01.2015).
Zu Schlochtern, M.P.M., Rixen, C., Wipf, S., Cornelissen, J.H., 2014. Management, winter climate and plant–soil feedbacks on ski slopes: a synthesis. Ecol. Res. 29 (4), 583–592.