Free-riding Free riders? Informal Public-Private Partnerships over Local Public Good Provision

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Abstract

Citizen science initiatives are being increasingly used in conservation and ecology research as well as policy decisions, but the economics of these programs remains understudied. One such program is avalanche forecasting conducted for public lands by Forest Service affiliate offices across the United States. Forecasters rely on snow pits and observations gathered by avalanche professionals supplemented with information submitted by backcountry users. This information acts as a public good benefiting both the government (Forest Service) and general public (backcountry users) and is provided in an informal public private partnership. This project investigates whether the government provided information crowds out privately provisioned information, or act as a complement. I use data gathered from snow reports to the Colorado Avalanche Information Center across their 10 forecasted zones to test this. An instrumental variables approach gives causal estimates supporting a dominant crowd in effect of forecaster information on private provision and of private provision of information leading to more forecaster provisioned information. This is suggestive that researchers that rely on citizen science can improve their information sets by making more of their ongoing work available in the public domain.

Keywords Public Land Management, Public goods, Citizen Science, Crowd in

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I. Purpose

Local public goods are often provided in a joint effort between public officials and private entities. One example is litter removal from roadsides. Government organizations (departments of transportation and the use of incarcerated labor) partially contribute to the supply and local civic organizations (such as adopt-a-highway programs) supply clean up as well. This paper seeks to understand how public provision and private provision of local public goods affect one another when the good in question is provided in an informal public-private partnership. To test this, I will look at a unique local public good where data on contributions at a daily level is available, field observations for avalanche forecasting.

Avalanche forecasting is provided by a US Forest Service (USFS) center, where they publish a daily bulletin with danger ratings and information about the main avalanche problems of concern. The daily avalanche forecast is non-rival in consumption. While forecasts could be made excludable by the provider, the forecasters choose not to exclude consumers and incur large costs to publicize the information at no cost to the consumer. Therefore, I will treat it as a local public good (Stiglitz, 1982).[1] Forecasters create the daily bulletin based on weather, experience, and observations from the field, which are provided jointly. Snow stability tests and field observations are conducted by employees of the avalanche centers, as well as other professionals such as guides and instructors, and unaffiliated backcountry travelers. Most USFS avalanche centers have a forum on their website where the general public can submit reports and observations in addition to the forecasters making their specific field observations available to the public. This creates a unique setting where inputs to a local public good are provided jointly in an informal public-private partnership.

This paper seeks to address how investment in the public good by the public agency (USFS forecasters) affects investment by private citizens (backcountry recreators), and vice versa. Recreational users may freeride off of reporting done by USFS Forecasters and chose not to gather or report their own snow pack assessments, thus decreasing the amount of information available for both parties to make decisions. However, it could be that USFS snow reports act as a complement

[1] While I would consider forecasting a publicly provided club good instead of a pure public good, the benefits accrue only to those that travel in avalanche terrain and the decision to not exclude access leads me to consider it a local public good.

and encourage more backcountry travel and reporting of snow conditions, increasing the aggregate amount of information available.

I expand the literature of private contributions to public goods in two ways. A large portion of the current empirical literature focuses on donations to charity (**list2011**), however people privately contribute to public goods in non-monetary ways such as volunteering time and knowledge. Non-monetary public goods contributions are also of interest and are subject to some of the same incentives that charitable donations are (**carpenter2010**).I want to test the validity of the theoretical literature in a non-monetary setting. Additionally, because the empirical literature has focused on money, it can only serve as a monotonically increasing signal and cannot vary in quality. This institutional setting allows for the investment by both the public and private agents to vary in type and quality. On a larger scale, economists are still puzzled by voluntary contributions to public goods, behavior that is observed extensively in reality, but difficult to explain with traditional economic tools. While there is much theoretical work to explain this, and a broad investigation in laboratory settings, evidence from real-world observational data is sparse.

Lessons for policy can be drawn from the avalanche forecasting process in other important areas. Publicly submitted field observations for avalanche forecasting could be considered an example of citizen science. Researchers rely on amateur enthusiasts to provide data or observations to increase the researchers information set and cover more space beyond what is attainable under the researchers budget and time constraints. Citizen science initiatives are increasingly being utilized by researchers and policy makers in growing number of areas, including but not limited to Monarch butterfly conservation, bird ecology, and plant seasonality, and black bear restoration (Dickinson and Bonney, 2012; Parsons et al., 2018; Ries and Oberhauser, 2015). For example, data on migratory waterfowl populations is largely drawn from hunters reporting the killing of banded birds, which requires the hunter to bear the cost of reporting the band much like backcountry users must bear the cost of submitting information into the public domain.

II. Background

i. History of Avalanche Forecasting

Formal avalanche forecasting began in Switzerland between the world wars.[2] Avalanches during battles in the alpine during World War One added to the hazards of war. The Swiss military started training units on avalanche safety and advising them on current danger levels. This operation eventually morphed into the Swiss Institute for Snow and Avalanche Research which began issuing bulletins for non-military users. The Swiss center has one central office which provides bulletins for zones covering the whole country. This centralized model would later influence the formation of avalanche centers in North America.

Avalanche forecasting in the United States (and arguably recreation in the alpine) started with the return of 10th Mountain Division soldiers from WWII. Monty Atwater, a 10th Mountain veteran began avalanche mitigation outside of Salt Lake City, UT in Little Cottonwood Canyon in the 1940s. There he pioneered the use of explosives and military artillery to purposefully trigger slides (Atwater, 1968). For several decades, avalanche work focused on mitigation in specific slide paths or passes to keep highway corridors, ski areas, and industry in the alpine open. The first program focused on advising backcountry recreationists started in 1973 with the US Forest Service's Colorado Avalanche Warning Program (Williams, 1998).

ii. Field Observation Reporting

Most USFS avalanche centers collect information through an online forum, which is available on the center's website on a separate page from the avalanche advisory bulletin. Public backcountry users can submit information through a portal on the center's website and it appears side by side with the field observations posted by the forecasters, though an affiliation is usually included so people can know if the source is an amateur or professional. Some of these forums appear in a more blog like style, while others are in a more formal table linking users to a separate page

[2] *Origins of the avalanche bulletin – history and background*.

containing the full report.[3] The forecasters then use these observations and other information like weather to produce their end product, the avalanche advisory bulletin.

Field observations that are reported may be of several types including snowpits,[4] general observations, avalanches, and incidents.[5] An example of a publicly submitted report is included in the appendix figure A2. Observations all have the date and source of the report, private backcountry travelers, professionals such as guides and ski patrol, or forecasters. The public has the option to submit anonymously. The example report is from an unintentionally triggered slide where one snowboarder was caught. An assessment of the weather, snowpack, and account of the incident plus photos of the fracture line and path are included. Observations that do not involve slide activity might include snowpit information either verbally, from photographs, or from an online application Snow Pilot for formally documenting snowpit tests.

One unique feature of studying avalanche field observations as contributions to a local public good is the extremely high rate of decay of the information. Monetary local public goods contributions can be discounted with interest rates as the time value of money and can be stored by the organization or donor for future use or contribution. The constant changing state of the snowpack subject to weather and climate effects, both interday and intraday, makes the information content of field observations extremely perishable. Especially depending on the recency of major snowfall, wind, or rain, information included in an observations loses much of its value beyond a 48 to 72 hour window.[6] Thus investment in supplying information is a constant and ongoing process throughout avalanche season, as opposed to fundraising drives by a local public radio station which can achieve economies of scale by conducting fundraisers on an annual or quarterly basis.

The incentives for a backcountry user to contribute to this local public good may come from

[3]See Mount Washington Avalanche Center for an example of a more blog like forum. See CAIC or Sawtooth Avalanche Center for examples of more formal table like forums.

[4]Snowpits refer to formal investigations of cohesion in the snowpack where a person digs into the layers and performs stability tests to asses slide potential. See https://avalanche.org/avalanche-encyclopedia/stability-test/ for more information.

[5]I will refer to avalanches as naturally occurring slides or intentionally triggered by a backcountry traveler. Incidents are slides where a backcountry traveler was caught or unintentionally triggered a slide.

[6]There are some exceptions to this, like information that signals the presence of certain problem types that mya be persistent. I argue that this is an exception and not a norm. These types of persistent problems forecasters can usually detect from weather and observations just serve to confirm their inference from the weather.

two sources, which are not exclusive. The first is that they value an accurate daily avalanche bulletin, for their own use or for others, and are willing to exert effort to increase the information available to forecasters generating the bulletin. Second, a private individual may report out of some form of pro-social warm glow, not motivated by having direct input into the forecaster's information set, but instead to communicate that information directly to peers using the forum for the avalanche center. This effect may come from two sources; impure altruism or some reputational effects from peers observing your contributions (Andreoni, 1990; Bénabou and Tirole, 2006).

Beyond the direct costs of time and effort, other incentives faced by the general public may lead to under reporting. Fresh untracked snow on public land is common resource good, rivalrous in consumption but not excludable. This can create a tight lipped culture about sharing favorite locations in certain backcountry zones. Skiers can be disincentivized from sending in field reports because it could publicize private knowledge of good skiing areas, bringing others to track out fresh snow.[7] This effect does not operate through the forecast, but instead from other backcountry users looking directly at posted observations. If there is specific location information in the report then it may advertise that area to others that would not have considered going there. Just like surfers protect good surf spots, winter backcountry travelers may be wary of sending in a report that discloses their 'secret stash' to non-locals.

Additionally, incidents may be under reported because people do not want to admit mistakes. Particularly among low consequence incidents where there is not a full burial, severe injury, or death, those involved may not want to add to the public record an account possibly caused by poor decision making, inexperience, or hubris.

I do not assume all reports from the general public as perfect substitutes with reports from professional forecasters. While certain types of information, such as photographs of recent slide activity are more directly substitutable, more involved assessments such as snow pits and column tests likely vary in type depending on the source. Stability tests from the general public are not going to receive as much weight as those same assessments reported by avalanche professionals, both by the forecasters when making the daily forecast and by other backcountry users when consuming information in the observation forums.

[7]When a skier descend the mountain, she disturbs the surface of the snow. This decreases the quality of the snow for the next user.

iii. Colorado

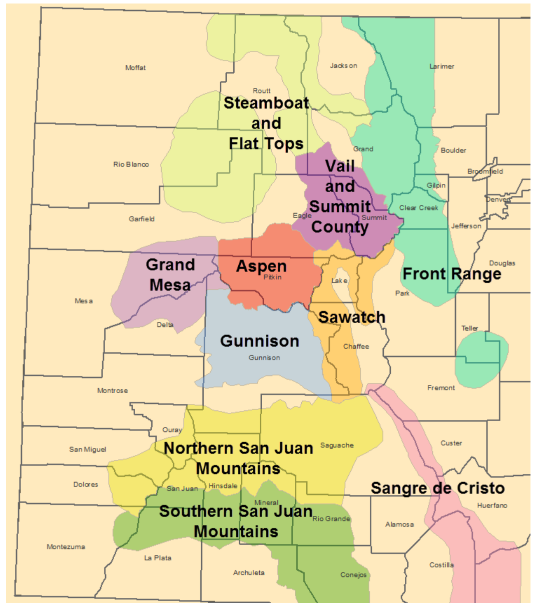
Avalanche forecasting in Colorado evolved differently from the other centers in the United States. Being one of the first centers in the United States, Colorado and the Pacific Northwest Center started based around the European model of one central office that received information from all over the forecasted zones to issue hazard ratings, as opposed the newer, more localized offices like the Gallatin National Forest Avalanche Center in Bozeman, MT. The Colorado Avalanche Information Center (CAIC), started in 1973, is not directly affiliated with the US Forest Service like the other centers across the country. It is a subsidiary of the Colorado Department of Natural Resources and the Colorado Department of Transportation. While most states with highways exposed to avalanche terrain have a DOT wing responsible for keeping the roads open, and may share information with the USFS forecasters covering public lands, no other centers formally work with their DOT counterparts like Colorado. Because of this relationship in Colorado, and because Colorado has much higher elevation avalanche-prone terrain, the CAIC contract with the State of Colorado requires them to issue daily recreational forecasts through the end of May every year. Most other USFS centers cease daily forecasting sometime in April depending on weather and funding.

The CAIC does not issue a forecast for the 10 identified zones until the end of May though. At some point in April or May, they drop back to springtime operations where the 10 zones are combined to make three regions and they issue daily forecasts for the Northern, Central, and Southern mountains. All 10 zones are still covered by a daily forecast, they are just placed into larger regions. The 10 main zones are shown in figure 1.

iv. Forecasting Process

Forecasters produce a daily advisory bulletin to advise backcountry travelers of the avalanche danger in the backcountry. A sample advisory is included in the appendix, see A1. Forecasters in North America use some variant of the 'Conceptual Model of Avalanche Hazard' to arrive at the daily bulletin (Statham et al., 2010). They will attribute a danger level to various aspects and

Figure 1: *CAIC Forecast Regions*



North American Public Avalanche Danger Scale
Avalanche danger is determined by the likelihood, size and distribution of avalanches.

Danger Level	Travel Advice	Likelihood of Avalanches	Avalanche Size and Distribution
5 Extreme	Avoid all avalanche terrain.	Natural and human-triggered avalanches certain.	Large to very large avalanches in many areas.
4 High	Very dangerous avalanche conditions. Travel in avalanche terrain not recommended.	Natural avalanches likely; human-triggered avalanches very likely.	Large avalanches in many areas; or very large avalanches in specific areas.
3 Considerable	Dangerous avalanche conditions. Careful snowpack evaluation, cautious route-finding and conservative decision-making essential.	Natural avalanches possible; human-triggered avalanches likely.	Small avalanches in many areas; or large avalanches in specific areas; or very large avalanches in isolated areas.
2 Moderate	Heightened avalanche conditions on specific terrain features. Evaluate snow and terrain carefully; identify features of concern.	Natural avalanches unlikely; human-triggered avalanches possible.	Small avalanches in specific areas; or large avalanches in isolated areas.
1 Low	Generally safe avalanche conditions. Watch for unstable snow on isolated terrain features.	Natural and human-triggered avalanches unlikely.	Small avalanches in isolated areas or extreme terrain.

Safe backcountry travel requires training and experience. You control your own risk by choosing where, when and how you travel.

Figure 2: *North American Avalanche Danger Scale (Statham et al., 2010)*

elevations based on the danger scale shown in Figure 2.

$$\hat{A}_t = F(\hat{A}_{t-1}, E(W_t), Q_{F_{t-1}}, Q_{P_{t-1}}) \tag{1}$$

For the purposes of this paper I will model the advisory bulletin production function as Equation 1. The daily advisory bulletin, $\hat{A}_t$, is a function the previous bulletin which is augmented and updated by the experience and knowledge of the forecaster using current information. This current information is a set of inputs including the expectation of the day weather, $E(W_t)$, and the recent field observations gathered by the forecasters, Q_F, and submitted by the public, Q_P. I assume that forecasters objective function is to minimize the difference between their published advisory bulletin, $\hat{A}$, and the true underlying riskiness of the snowpack, A, which is unobserved.

$$Q_{F_t} = F_F(\hat{A}_t, W_t, Q_{F_{t-1}}, Q_{P_{t-1}}) \tag{2}$$

$$Q_{P_t} = F_P(\hat{A}_t, W_t, Q_{F_{t-1}}, Q_{P_{t-1}}, t) \tag{3}$$

Information is supplied by the forecasters in equation 2 and by the public according to equation 3. Both parties make travel decision based on the daily advisory, $\hat{A}_t$, and the weather on that day which both affect terrain travel decision by each party and what they can observe. Additionally, demand for current information in t is a function of the quantity and type of information gathered in $t-1$ by both parties. I include t in equation 3 because the number of backcountry travelers is greatly affected by the draw of t from the set of days in the week. There will be a lot more people in or near avalanche terrain on weekends relative to weekdays. The forecasting offices run at a relatively stable staffing level 7 days a week throughout the season so I assume the draw of t does not affect equation 2.

v. Crowd in and crowd out

Crowding out has been studied in funding for public goods in the field and in a vast array of experimental laboratory settings (Andreoni and Payne, 2003; Shang and Croson, 2009). In the environmental realm, the crowd in and out effect has been studied by Parker and Thurman

(2011) with federal land programs and private conservation investments. The estimand of public information provision on private information provision and vice versa could suggest four possible effects between the public and private parties depending on the sign.

If public information provision crowds out private information provision, then $\frac{\delta Q_{P_t}}{\delta Q_{F_{t-1}}} < 0$. This would support standard free riding behavior by the public predicted by neoclassical theory when the good in question has some qualities of a public good. However, the extreme negative consequences of being caught in an avalanche may make the demand for information collection by the general public relatively inelastic with respect to the behavior of others. This does not affect the decision by a private backcountry traveler to share the information she collects in the public domain. A backcountry traveler may have a very high marginal willingness to collect information which may be less subject to freeriding incentives, but the decision to bear the cost of relinquishing property rights over that information and share it with forecasters may be affected by free-riding incentives. It is important to note that I only observe the set of information private parties have entered into the public domain. I cannot observe the full set of privately collected information, which includes information not submitted to forecasting centers.

It is possible that the forecaster's collection of information could be crowded out by public provision, in which case $\frac{\delta Q_{F_t}}{\delta Q_{P_{t-1}}} < 0$. This may be the case if forecasters feel they have sufficient information from the public to generate the advisory bulletin and do not need to expend resources to gather their own field observations. This effect may be more prominent in smaller, more resource constrained, avalanche centers where forecaster's time in one zone carries the opportunity cost of consuming information from the other zones the center covers. The CAIC is large relative to their peers, being the largest avalanche center in the US and maintaining a staff of full time observers that are separate from the forecasters generating the advisory bulletin from the central office.[8]

While the aforementioned crowd out effects are what would be expected in a pure rational choice model, it may be that public investment crowds in private investment, meaning $\frac{\delta Q_{P_t}}{\delta Q_{F_{t-1}}} > 0$. If forecasters disseminating more of their information encourages the general public to enter more privately held observations into the public domain, then one of the best ways for forecasters to

[8]I am not implying that forecasters in the central office do not go into the field, or that CAIC zone observers do not input about the advisory bulletin. However, CAIC employees have primary duties unlike other USFS centers where forecasters must preform both duties. See https://utahavalanchecenter.org/forecast/how-we-generate for a work flow example where forecasters rotate between office and field.

improve their information sets would be to increase their transparency. Andreoni, Payne, and Smith, 2014 find evidence for crowd in of private contributions to smaller charities in the UK after receiving government grants. However, the signaling mechanism by which this crowd in effect operates (Andreoni and Payne, 2003; Vesterlund, 2003) revealing quality of charities to private parties is unlikely the mechanism here.

Public sector investment crowding in private investment may occur through a similar signaling effect, but instead of private donors freeriding off of government grantors research, information disseminated by the forecasters might signal higher levels of risk or uncertainty about the underlying snowpack danger, which would encourage more private collection of information. For example, a forecaster snow pit observation may show a specific problem which may exist in some areas and not others based on weather or climate, then a backcountry recreator might stop to dig a snow pit to confirm or refute the existence of that problem on their planned route. This would be an example of public crowding in private because in absence of that forecaster provided information the recreator would not have stopped to dig a pit. But collection does not mean provision and there must still be either some direct utility, altruism, or reputation effect to incentivize the private backcountry traveler to submit the information to the public domain. Even if the percentage of observations that are reported remains constant, if a forecaster reports increases the number of observations taken down by recreators then public investment crowding in private investment would be observed.

Lastly, if $\frac{\delta Q_{F_t}}{\delta Q_{P_{t-1}}} > 0$, then it suggests that private information provision crowds in public information. If an avalanche forecasting office had unconstrained resources this might be expected because they would want to confirm (or refute) the accuracy of public information. If a forecasting office receives information from a public backcountry traveler that is suggests serious snowpack instabilities, the forecasters may want to replicate it with their professional knowledge and experience. Additionally, on a smaller margin, private reports will mechanically increase public reports because the avalanche forecasting office is responsible for incident investigation and act as first responders for incidents in avalanche terrain. If a backcountry traveler is caught an buried by and avalanche, the forecasters are often called on to perform rescue and recovery in the event of serious injuries or fatalities. The forecasters will submit reports about the incident, but these often precede the report submitted by the public backcountry user so this should not plague my empirical analysis because of this timing.[9] Additionally, major incident reports are only (insert percentage here when I have that data) of publicly submitted observations.

III. Milestones

- The most immediate task I have remaining is to build out a matrix of control variables including the advisory bulletin for each zone/day observation, additionally the weather and snowpack variables that I can control for. Colorado and the CAIC makes weather easy because they have an in-house weather operation which includes a weather forecast for the alpine in each zone's daily advisory bulletin. If my analysis is going to be expanded to other avalanche centers then I will need to make some assumptions on how to measure weather. I do not think using the centroid of the zone, a common approach in the urban and amenity literature, would be accurate given the high variance of mountain weather across time and space in a given day. Having the advisory bulletins is an extremely important control and can add value to other possible identification strategies. Unfortunately data on users in the backcountry by zone does not exist, but to control for the group size in each zone across time, I believe web traffic serves as a good second best proxy. Web traffic for each zone's advisory bulletin is kept by the CAIC at the daily level, and the number of page hits should be highly correlated with the number of users in that zone. It is not a perfect measure; it will pick up people not in Colorado poking around the web and people from other zones reading forecasts in areas they have no intention on traveling to, but it is the best available that I have come up with to proxy for user base. This should be valid so long as the number of non-user hits does not drastically differ across zones.

- In addition to completing the set of control variables, I would like to pull more information from the reports I have scraped. Currently I treat all observations by a specific group equally, but there are several ways I can differentiate based on quality of reports. Some simple first

[9]The forecasters are unlikely to be notified about a major incident from the observation forum, instead being contacted directly by those involved or emergency personnel. They will interview the party involved and include the account in their reporting of the incident so these incidents are coded as forecaster provided in my data.

pass ways include creating variables for the number of photos included or word count, but I cannot verify the accuracy of the information (more may not always be better). I also need to subset the observations into categories for human triggered avalanches, naturally triggered avalanches, sub-surface snow observations such as snow pits, and general field observations.

- Beyond my instrumental variables approach, there are a few other causal inference strategies that I would like to consider as I improve my data quality. These are discussed in the method section. If these specifications provide useful information, the will be included in the final paper.

- Also there are some further research questions I would like to work on with this data and area, though they may be separate papers ultimately. Directly related to this question is how the information from private citizens affects the forecasters bulletin quality. This requires a way to judge the accuracy of the advisory bulletin which is no small feat. I have considered a few strategies for this, including coding the causes of avalanche incidents against the main avalanche problems mentioned in the bulletin, but this has its own issues such as the bulletin being endogenous to victim's decisions that precede an accident. One possibility which has potential but will require some serious outside resources is modern snowpack modeling. Currently snow science researchers are developing computer based meteorological models to do avalanche forecasting opposed to humans digging snow pits in potentially hazardous terrain (Bellaire and Jamieson, 2013; Côtè, Madore, and Langlois, 2017). There is potential to use these models and past weather, terrain, and snowpack data to generate condition reports to test the Forest Service predictions against. This would allow me to assess the impact privately provided information has on human forecast deviations from the algorithmic assessment.

- Last, I would like to investigate what incentivizes the private citizen to submit information. I laid out several reasons for reporting earlier in the background, including directly adding to the information set of the forecasters (which would in turn benefit the citizen with a better forecast if private information does improve forecast quality per the previous bullet), providing information directly to other backcountry users through the forum giving them some warm-glow from pro-social behavior, and some reputation effect of peers seeing the private citizen adding to reports on the forum. Testing which one of these effects is dominant would be important for policy, particularly how forecasters ask for information from the backcountry users, possibly wanting to use different nudge approaches. Beyond the avalanche community, this would be an interesting empirical test of different theories explaining pro-social behavior which is under explored beyond the laboratory.

IV. Methods

$$Obs_{izt} = X_{jt}B + \sum B_n Obs_{jz(t-n)} + \mu_t + \gamma_z + \epsilon_{izt} \tag{4}$$

I first estimate the number of observations reported by one group (forecasters or public) in response to the other groups. The unit of observation is Obs_{izt}, the number of reported observations by group $i \notin j$ in zone z on day t as a function of $Obs_{jz(t-n)}$, the number of reported observations by group $j \notin i$ in zone z on the preceding n days, $t-n$. Controls in X_{zt} include weather, climate, and information from the advisory bulletin including danger rating at each elevation in each zone day combination. Zone and day fixed effects are included with μ_t and γ_z.

The nature of the data is a count outcome. Currently my analysis present linear models for easily interpretable coefficients and simplicity's sake. However, table A1 is very suggestive that discrete nature of the dependent and independent variables means inference from linear coefficients are misspecified. I will duplicate all analysis in an appendix using count models for robustness.

i. Identification Strategies

There are a number of factors that lead to observing increases or decreases in reported observations by forecasters and backcountry users which could bias coefficients in linear models. These are largely unobservable. For example, in the Snowpack Description section of the example observation in figure A2, the reporter mentions a "whumpf", slang for feeling a collapsing snow layer underfoot, which could lead to an avalanche in steeper terrain. While I can control for weather and climate, the exact interaction of these factors that created the conditions leading to the reporter experiencing the "whumpf" is difficult to measure. Those exact conditions would typically induce further investigation into the snow layers by both forecasters and private individuals in the backcountry, which may lead to a report. There are latent variables that affect both parties in a manner I cannot control for.

However, these latent factors are likely correlated day to day. Thus I can use the same-day observations by forecasters as and instrument for their prior day's observations to get causal estimates of the impact of forecaster observations on public observations. This same strategy can be used in reverse, day-of reports by the public to measure forecaster response. I argue this meets the exclusion restriction because parties are likely not observing each other generating observations in the backcountry on the same day, only seeing the information supplied by the other party after they have returned from the field.

An additional instrumental variables approach I have considered is using weekends as an instrument. The CAIC operates at a pretty constant staffing level throughout the season seven days a week. [10] However, it is a reasonable assumption that there will be more backcountry recreators on weekends and holidays opposed to weekdays, which I argue is exogenous to the forecasters. The best argument against this approach is that forecasters also know there will be higher demand on weekends, thus they put more effort into the forecast, or publish more risk averse bulletins, for weekends and holidays opposed to a random Tuesday. I think this is a relatively weak critique, evidenced by the CAIC's consistent staff schedule. If they treated weekends differently, it would likely be reflected in how they choose to deploy their resources. One drawback to this approach is that it would only allow causal estimates in one direction, from private to public. I would need to find another instrumental variable to give estimates in the other direction. Figure A4 shows a substantive increase in public observations on weekend days relative to weekdays.

One further causal identification strategy to explore is a matching estimator. A propensity score like approach using the frequency and discrete variability of the data would allow me to create near exact matches on days. For example, I could match two zone days with moderate danger

[10] This has been confirmed in conversations with the CAIC Deputy Director, Brian Lazar.

levels below and at treeline and considerable danger above treeline that are both Tuesdays in February, and minimize distance between other weather variables. If one zone day has 2 forecaster supplied observations and the other has 3, I could then measure the marginal impact of the 3rd observation on the following similarly matched danger level days. It would require assuming that the reasons for one day having an additional observation is as-good-as random, and not correlated with unobservables, which might be a heroic assumption.

In an ideal world for a quasi-natural experiment, the Colorado office would continue at full operational capacity because of the contractual obligation noted earlier, while the other offices across the country shut down. However, shortly after most other centers cease daily operations, Colorado switches to the 3 zone format. As the forecast zones are reduced from ten to three, that changes the private altruistic benefit of reporting. An individual still receives benefit from the information in making their own backcountry travel decisions, but it may not be incorporated into a daily forecast for public benefit, or into a more specific forecast so the marginal impact is dampened. This does not make this unique contractual feature useless though. I can use partial identification assumptions to back out the parameter for incentives for private reporting through directly helping peers (Tamer, 2010). Using the timing of other avalanche centers that have completely stopped daily forecasting as a treatment group, and the Colorado zones as controls, I can compare the difference in reporting rates from backcountry users after the spring closure in Utah with reporting rates in Colorado. This would allow me to estimate what portion of observations are sent in with the intent of informing peers. However it requires some assumptions because there are also changes in Colorado with the zone structure. *I still have some more thinking to do on this*

V. Data

Data on observations were obtained from the CAIC website using the Rvest package for R to crawl the web pages. I consider an observation any report that is submitted to the CAIC forum and can be placed in one of the 10 zones covered by CAIC forecasts. Reports from outside the forecasted areas are not considered in the data. I aggregated these at the daily level between CAIC employees, general public, and other snow professionals.[11] Table 1 shows the summary statistics for observations submitted by CAIC forecasters, snow professionals, and the general public. This covers the 2010/11 winter to the 2018/19 winter season across the 10 forecast zones that are covered by the CAIC. In total, 22358 individual observations comprise the data set, which are aggregated to a daily count in each zone by each group. On average CAIC-employed forecasters will post observations every other day in a given zone. The general public sends about one fewer observation a week on average and snow professionals contribute considerably less data but they are also a smaller group relative to the public and not doing observations full time like CAIC forecasters. The data set is truncated at the avalanche forecasting season running from November to May. The out of season months are not included.

Figure 3 shows the number of reported observations by each group across all zones for the

Table 1: *Summary Statistics for Observations at the Zone/Daily level for the season*

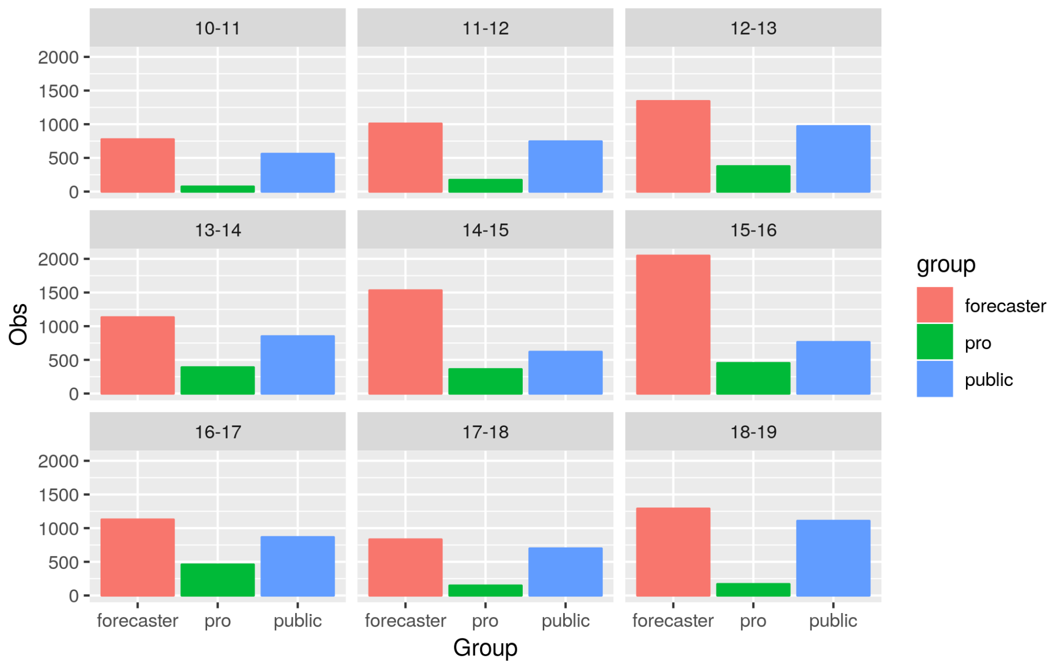
Statistic	Mean	St. Dev.	Median	Pctl(75)	Max
Forecaster	0.587	1.051	0	1	17
Public	0.383	0.815	0	1	11
Pro	0.138	0.491	0	0	7

winter seasons in the sample. Figure A3 shows the weekly observation rate across the 2017/18 season in each zone as an example of the trend across seasons.[12] The observation rate appears to be somewhat cyclic, likely because it is correlated with storm cycles, increasing the demand for observations. The daily correlation of posted observations across the three groups is reported in figure 2. The main correlation of interest is between the public and forecasters which is the

[11] Any observer who reports their name or organization (see figure A2) as part of ski patrol, a guide service, or any avalanche education courses (because these are done under the supervision of guides) as professional. I keep them separate from the public because the information likely higher quality and probably not used in the same way by forecasters. Additionally because these individuals work avalanche terrain, not just recreate, their incentive structure is different from the public.

[12] I use weekly aggregation for plots because it makes changes across the season more visible for ocular least squares.

Figure 3: *Quantity of reported observations by group and season*



strongest at 0.214. I aggregated the data to daily frequency since I do not observe the exact time that an observation is posted. This is not a hindrance because the actions in the field by one party are unlikely to be observed by another. I do not consider empirical analysis at any higher unit of aggregation because that would be arbitrarily separating the lagged impacts, for example week level empirics would have observations on Tuesday and Saturday equally affecting observations the following week. As discussed earlier, the valuable lifespan of an observation is relatively short.

Table 2: *Correlation Table*

	Forecaster	Pro	Public
Forecaster	1		
Pro	0.09	1	
Public	0.214	0.056	1

i. Panel Models

Table 3 shows panel regressions for the quantity of publicly and forecaster submitted observations on a given day as a function of the the lagged reported observations from prior days. Standard errors are clustered on the zone and season and all models include a zone and daily fixed effect. While the estimated effect of 1 day lag of forecaster observations on public observations is statistically significant, it is not economically significant such that 1 additional forecaster observation generates .03 additional public observations the next day. This low estimate is likely due to endogeniety because the previous days reported observations by any group is highly correlated with the unobservables in the error term.

These unobservables include an individuals perception of the snowpack's danger level on a given day and place, which is related to travel and information investment decisions on the next day. For example, if a forecaster suspects potential for a weak layer in the snowpack, that will cause her to make different decisions in the field. The same factors that lead forecasters to suspect a weak layer will also cause public backcountry travelers to behave differently, separately from forecasters. While I can observe some weather, climate, and advisory bulletin danger levels, the process that both forecasters and backcountry travelers make decisions under uncertainty is not. Individual actors make choices about going into the field, or where to go while in the field, around a multitude of information sources and that process is unobservable but correlated. Estimates for the effect of public observations on forecaster observations suffers from the same problem and yields meaningless coefficients. I include the same-day forecaster observation quantity in model 2 and same-day public quantity in model 4. Both show positive significant coefficients even though these decisions are being made separately and simultaneously. The forecasters decision to collect and provide information on day t is not observed by public while out in the field on day t, and the same for the public. Those coefficients are suggestive of the endogeneity concerns created by correlated decision making between the two parties.

Table 3: *Panel linear model*

	Dependent variable:			
	Public		Forecaster	
	(1)	(2)	(3)	(4)
Forecaster		0.044***		
		(0.010)		
Public				0.069***
				(0.017)
Fore_{t-1}	0.033**	0.023*	0.236***	0.234***
	(0.013)	(0.013)	(0.048)	(0.048)
Fore_{t-2}	−0.001	−0.005	0.099***	0.099***
	(0.009)	(0.009)	(0.013)	(0.013)
Fore_{t-3}	0.006	0.003	0.060***	0.060***
	(0.015)	(0.014)	(0.021)	(0.021)
Pub_{t-1}	0.155***	0.154***	0.041**	0.030
	(0.015)	(0.016)	(0.019)	(0.019)
Pub_{t-2}	0.102***	0.102***	−0.010	−0.017
	(0.016)	(0.015)	(0.018)	(0.018)
Pub_{t-3}	0.087***	0.087***	0.003	−0.003
	(0.014)	(0.014)	(0.013)	(0.012)
Pro_{t-1}	0.038	0.038	0.004	0.001
	(0.030)	(0.030)	(0.030)	(0.029)
Pro_{t-2}	0.005	0.004	0.031	0.030
	(0.012)	(0.012)	(0.028)	(0.028)
Pro_{t-3}	0.003	0.003	0.010	0.010
	(0.022)	(0.022)	(0.015)	(0.015)
Zone FEs	Y	Y	Y	Y
Daily FEs	Y	Y	Y	Y
Observations	18,700	18,700	18,700	18,700
R^2	0.345	0.347	0.376	0.378
Adjusted R^2	0.270	0.273	0.305	0.307
Residual Std. Error	0.696 (df = 16786)	0.695 (df = 16785)	0.877 (df = 16786)	0.876 (df = 16785)

Note: *p<0.1; **p<0.05; ***p<0.01

SEs clustered on Zone and Season

ii. Instrument Estimation

To solve the endogeniety problems plaguing table 3, I consider an instrument variables solution. To instrument for the effect of forecaster submitted observations on public submitted observations, I use the forecaster submitted observations on the same day. I argue this meets the exclusion restriction because the observations collected by forecasters on the same day are likely unobservable to the private backcountry traveler who will be out in the field at the same time. These observations are not posted until later when returning from the field, so the private backcountry user only knows the observations submitted by the forecasters on the day prior. However the decision by the forecaster to collect information on that day is highly correlated with all of the unobservables in the error term such as snowpack risk.[13] The results of this specification can be seen in table 4. Again, standard errors are clustered on the zone and season, as well as the inclusion of zone and daily fixed effects.

The same day observations of forecasters has an F-statistic of 27.785 and it is a strong predictor of the previous days quantity of forecaster observations. The instrumental variables strategy increases the estimate of 1 additional forecaster observation generating .03 additional public observations (OLS Column 1) to 1 additional forecaster observation causing .182 more public observations the next day (IV Column 2), which is much more economically significant.

The effect of the public observations on future forecaster observations follows an identical instrument strategy, where public observations from the same day as the forecaster observations dependent variable is used to instrument for public observations from the day prior. The first stage F-stat is greater than 70, and the instrument variable approach leads to a causal estimate of 1 additional public observation generating .39 additional forecaster observations.

iii. Instrument Strength and Robustness

If there is still concern that the observations by the other party on the same day does not meet the exclusion restriction, if for example one may argue that backcountry skiers are constantly checking the observation forums on their phone while skiing in the backcountry where cell service

[13]The snowpack risk is highly correlated day to day, as it is function of the previous days danger and weather.

Table 4: *Instrument Variable Regression*

	Dependent variable:			
	Public		Forecaster	
	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)
$Fore_{t-1}$	0.034**	0.182***	0.236***	0.219***
	(0.013)	(0.057)	(0.048)	(0.049)
$Fore_{t-2}$			0.099***	0.087***
			(0.013)	(0.017)
$Fore_{t-3}$			0.060***	0.056***
			(0.021)	(0.018)
Pub_{t-1}	0.155***	0.143***	0.039*	0.386***
	(0.015)	(0.018)	(0.021)	(0.111)
Pub_{t-2}	0.102***	0.094***		
	(0.016)	(0.017)		
Pub_{t-3}	0.088***	0.087***		
	(0.015)	(0.013)		
Pro_{t-1}	0.038	0.035	0.004	−0.014
	(0.031)	(0.029)	(0.029)	(0.024)
Pro_{t-2}	0.005	0.004	0.030	0.017
	(0.012)	(0.010)	(0.029)	(0.021)
Pro_{t-3}	0.003	−0.002	0.010	0.007
	(0.022)	(0.021)	(0.014)	(0.012)
First Stage Same Day reports		0.272***		0.186***
		(0.052)		(0.022)
First Stage F Stat		27.785		72.443
Zone FEs	Y	Y	Y	Y
Daily FEs	Y	Y	Y	Y
Observations	18,700	18,700	18,700	18,700
R^2	0.345	0.320	0.376	0.326
Adjusted R^2	0.270	0.243	0.305	0.249
Residual Std. Error (df = 16788)	0.696	0.710	0.877	0.911

is sparse, I use the next day observations for robustness. These are completely unobservable to the other party because they have not happened yet. Therefore they most certainly meet the exclusion restriction, yet are still highly correlated with the latent unobservables from two days prior affecting both the forecasters and public's decision to collect information. The estimates for the lead instrument strategy can be seen in appendix figure A2

VI. Conclusion

I use field observations in avalanche terrain reported to USFS avalanche forecasting centers to examine how effort from government agencies affects private effort, and in turn, how private effort affects public effort. An instrumental variables approach gives causal estimates that are suggestive of crowding in between both parties. That is, public investment induces more private investment, and private investment induces more public investment. This is an interesting case to study because the nature of the local public good requires continuous investment, reported observations have a pretty short shelf life. However, one drawback is that public and private effort are not perfect substitutes, unlike dollars in the charity fundraising literature. Thus the implications for policy are more relevant in non-monetary contributions to public goods, such as volunteer labor.

The effects of public on private provision and vice versa for avalanche forecasting observations may have more external validity in certain areas versus others. It is certainly a unique setting where there is a strong common group identity over a shared interest in recreating in avalanche terrain, that may not be as strong as the common group identity of people who enjoy litter free roadways. It also differs drastically by elasticity; recreators probably have pretty inelastic demand for being caught in an avalanche, and are willing to pay very high costs to insure against such risks.

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A. Appendix

Table A1: *Summary Statistics by Zone*

Aspen

Statistic	Mean	St. Dev.	Median	Pctl(75)	Max
Forecaster	0.845	0.962	1	1	6
Public	0.495	0.867	0	1	6
Pro	0.170	0.515	0	0	4

Front Range

Statistic	Mean	St. Dev.	Median	Pctl(75)	Max
Forecaster	1.162	1.839	0	2	17
Public	0.861	1.233	0	1	10
Pro	0.044	0.218	0	0	3

Grand Mesa

Statistic	Mean	St. Dev.	Median	Pctl(75)	Max
Forecaster	0.221	0.512	0	0	4
Public	0.040	0.204	0	0	2
Pro	0.012	0.115	0	0	2

Gunnison

Statistic	Mean	St. Dev.	Median	Pctl(75)	Max
Forecaster	0.394	0.680	0	1	5
Public	0.309	0.757	0	0	11
Pro	0.577	1.121	0	1	7

Northern San Juan

Statistic	Mean	St. Dev.	Median	Pctl(75)	Max
Forecaster	0.784	1.123	0	1	13
Public	0.488	0.863	0	1	7
Pro	0.102	0.334	0	0	3

Sangre De Cristo

Statistic	Mean	St. Dev.	Median	Pctl(75)	Max
Forecaster	0.020	0.142	0	0	1
Public	0.027	0.169	0	0	2
Pro	0.001	0.024	0	0	1

Sawatch

Statistic	Mean	St. Dev.	Median	Pctl(75)	Max
Forecaster	0.514	0.815	0	1	7
Public	0.313	0.639	0	0	5
Pro	0.014	0.117	0	0	1

Southern San Juan

Statistic	Mean	St. Dev.	Median	Pctl(75)	Max
Forecaster	1.008	1.046	1	2	15
Public	0.295	0.572	0	0	5
Pro	0.358	0.518	0	1	3

Steamboat And Flat Top

Statistic	Mean	St. Dev.	Median	Pctl(75)	Max
Forecaster	0.063	0.251	0	0	2
Public	0.252	0.601	0	0	4
Pro	0.018	0.135	0	0	2

Vail Summit County

Statistic	Mean	St. Dev.	Median	Pctl(75)	Max
Forecaster	0.808	1.187	0	1	9
Public	0.726	1.096	0	1	7
Pro	0.082	0.305	0	0	3

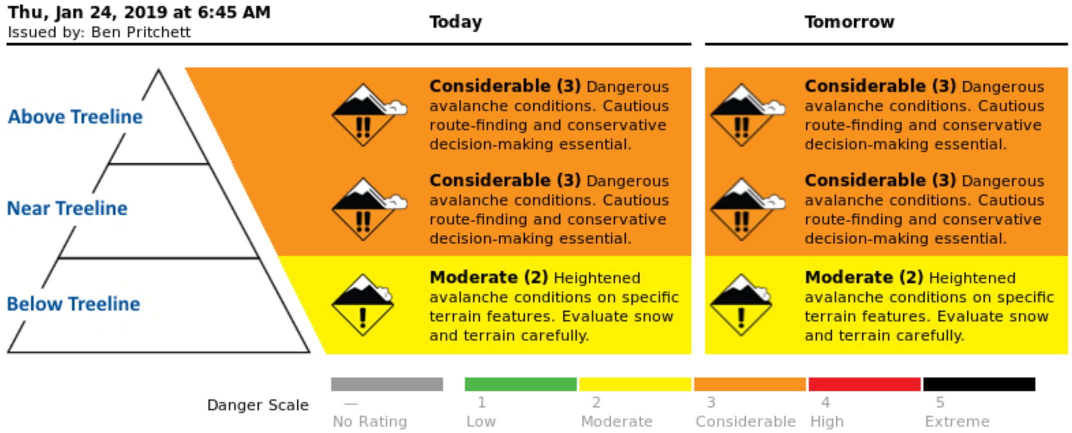
Figure A1: *An example bulletin from the CAIC*

6/13/2019 CAIC Forecast

Colorado Avalanche Information Center

Backcountry Avalanche Forecast
Sawatch Range

Thu, Jan 24, 2019 at 6:45 AM
Issued by: Ben Pritchett



Summary

Recent snowfall and steady northwest winds continue to load buried weak layers creating lingering dangerous avalanche conditions. Backcountry travelers can easily trigger large and potentially deadly avalanches on slopes below corniced ridgelines, steep rollovers in open areas, and the drifted sides of gullies. If you trigger an avalanche in the freshly drifted snow it may step down into older weak layers entraining much more snow and gathering more destructive force. Avalanches will be largest and most dangerous on northeast through east to southeast-facing aspects where the slabs are thickest.

Even in wind-sheltered terrain, consider that you can trigger avalanches remotely, or from far away. A group of skiers triggered two large avalanches breaking a couple feet deep near Cottonwood Pass on Wednesday on northerly terrain near treeline. The simplest approach right now is to stick to slopes less than about 30 degrees, without steeper terrain overhead.

Weather Forecast for 11,000ft Issued Thursday, Jan 24, 2019 at 6:45 AM by Ben Pritchett

	Thursday	Thursday Night	Friday
Temperature (ºF)	28 to 33	15 to 20	32 to 37
Wind Speed (mph)	15 to 25	7 to 17	12 to 22
Wind Direction	WSW	WSW	WSW
Sky Cover	Mostly Cloudy	Partly Cloudy	Mostly Cloudy
Snow (in)	2 to 4	0 to 1	0 to 1

Avalanche conditions can change rapidly during snow storms, wind storms, or rapid temperature change. For the most current information, go to www.colorado.gov/avalanche.

https://www.avalanche.state.co.us/caic/pub_bc_avo_fx_print.php?bc_avo_fx_id=10678 1/1

Figure A2: *A sample (high quality) publicly submitted field report to the CAIC website*

6/12/2019 CAIC

CAIC Colorado Avalanche Information Center

BC Zone Observation Report

Wednesday, May 1, 2019 at 12:00 AM
Vail & Summit County

Details

- Date: 2019/05/01
- Observer: Patrick Gephart
- Organization: Public

Location

- BC Zone: Vail & Summit County
- Area Description: N/NW facing couloir off east ridge of Pacific Peak
- Route Description: Spruce Creek trailhead to Mohawk Lakes to base of couloir

Weather

- Weather Description: Calm below 11,500. High winds above 12,000 ft. to base of couloir. Seemed like wind was consistently S/SW. Overcast to broken cloud cover with short windows of sun.

Snowpack

- Snowpack Description: High SWE in new snow was noticed from the trailhead and throughout the day. New snow ranged from 6 inches to what seemed like 1-2 feet in couloir proper. Whumpf was noted in snow pack below treeline in flat but was concluded to be weak freezing in lower elevations. Wind slab was the key issue we were looking for during they day.

Avalanches

- Avalanche Description: Myself and 1 partner (splitboarder) switched over to crampons in a safe zone from both wind and the slop itself below a large rock face. From the start of the boot back it was clear that the snow was deep but no weak layers were evident, including wind slab. The new snow appeared to be well bonded and had came in entirely right side up. Once we got above 13,000 ft. and toward the top of the couloir we noticed a small slab, but it seemed very well bonded and showed no signs of propagation when breaking through this. Towards the top out this wind slab became thicker, but again manageable due to its structure, or so we thought (heuristic in hindsight). A small but notable convexity right before the top out was noted which would be key later. We transitioned and set up for the descent. I was dropping first. Upon gaining speed and making the first turn I noted the wind slab was a bit ticker where I was riding then where we booted. As I turned by the small convexity the wind slab broke, flowing skier's left and propagating a bit towards the skier's left, eastern aspect of the apron below the sheltered choke. I was able to turn hard skier's right and drive my hands in the consolidated snow in the bed surface, arresting myself and getting out of the slide path. I would say I was caught for 20-30 feet before exiting the slide (GoPro video that I will submit later may be helpful here). The avalanche ran to the bottom of the couloir through the apron. Small debris pile and the wind slab portion that slid seemed to be isolated only to where we noted it, upon inspection of the flanks. If we had booted up the climber's

https://avalanche.state.co.us/caic/obs/obs_report.php?obs_id=56531&display=printerfriendly 1/4

6/12/2019 CAIC

right, most eastern facing aspect I think we would have noted this as more of a weak layer much quicker and turned around. I would classify the avalanche as a R1-2 D1.5. If I had been taken by it I would have gotten take over a few rocks, but would not have been buried. Heuristics certainly played a big part here. Both myself and partner consider ourselves conservative backcountry snowboarders with advanced snow science knowledge, safe practices, constant discussion, continuing observations, etc. We have safely navigated isolated pockets of wind slab before in isothermic, spring snow packs, and managed them safely. We deemed what we found on the climb up "safe" due to its structure and noted resistance to propagate when punching through, although it was still a wind slab. The classic "I've been in these conditions before and we managed them safely" was at play here. It only took one turn to find the shallow weak spot that propagated to a thicker slab to skier's left to create a wind slab avalanche. Luckily I was able to exit it quickly. Spatial variability of the slab's thickness was also a factor, as we were climbing in the thinner part on climber's left, but the thicker and more dangerous part was to our climber's right and out of observation on the way up. This was a good wake up and will keep our heads on more of a swivel in the future. Upon reading the avalanche forecast again for 4/30/19 we deemed it spot on and exactly what we encountered. Great reporting and a user error on our end.

Date	Location/Path	#	Elev	Asp	Type	Trig	SizeR	SizeD
2019/05/01 †	10-mile Range	1	>TL	E	SS	AR	R1	D1.5

- Date: 2019/05/01 (Estimated)
- Observer: Patrick Gephart
- Organization: Public
- Area Description: Pacific Peak
- Landmark: 10-mile Range

Media

Images

https://avalanche.state.co.us/caic/obs/obs_report.php?obs_id=56531&display=printerfriendly 2/4

6/12/2019 CAIC

Figure 1: Crown looking towards skiers left. I triggered skier's right

Figure 2: Avalanche propagation, flank and bed surface in first apron before second choke

https://avalanche.state.co.us/caic/obs/obs_report.php?obs_id=56531&display=printerfriendly 3/4

6/12/2019 CAIC

Figure 3: Avalanche propagation and flank

Figure 4: Looking up at avalanche propagation and flank from towards the bottom of the couloir. Note the few rocks that would cause injury if taken over. Couloir goes looker's left past view.

https://avalanche.state.co.us/caic/obs/obs_report.php?obs_id=56531&display=printerfriendly 4/4

Figure A3: *Weekly observation rate by group in each zone for the 17/18 season*

Figure A4: *Group reporting averages by weekday*

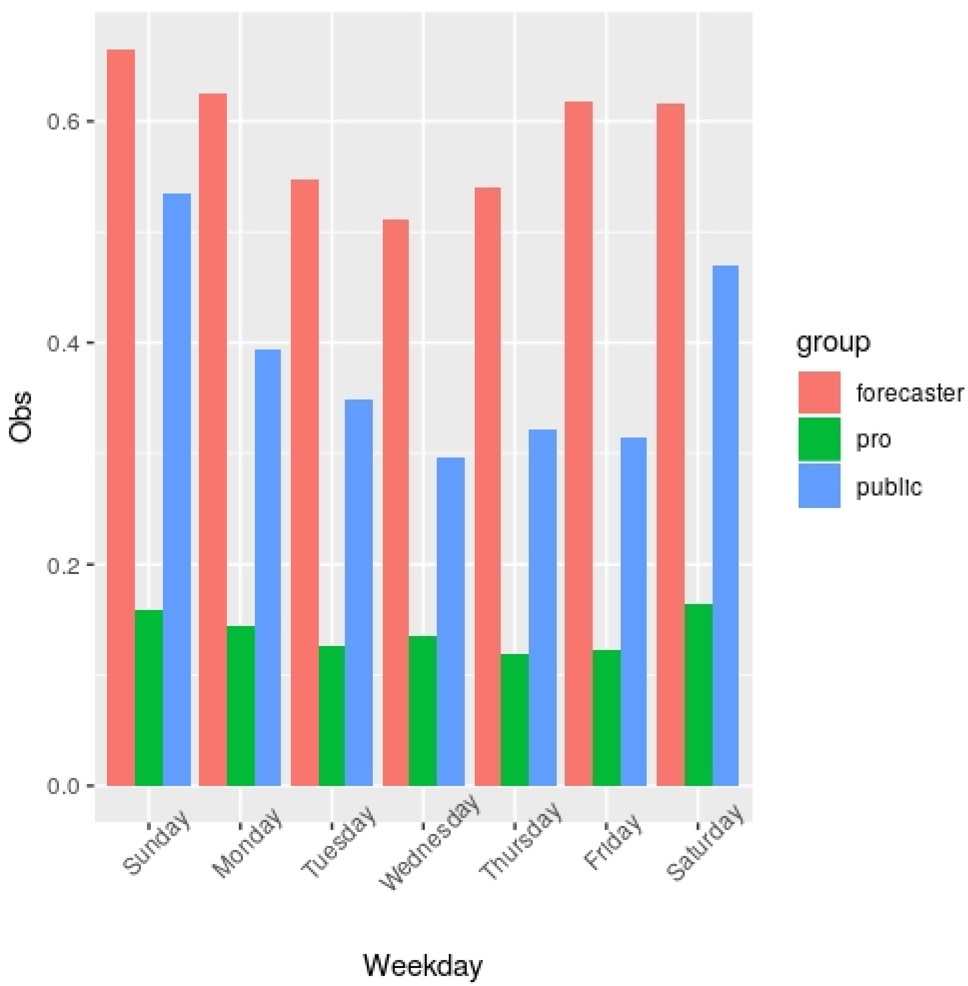


Table A2: *Instrument Estimation using 1 day lead of reports*

	Dependent variable:			
	Public		Forecaster	
	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)
$Fore_{t-1}$	0.034^{**}	0.216^{**}	0.236^{***}	0.216^{***}
	(0.013)	(0.086)	(0.048)	(0.050)
$Fore_{t-2}$			0.099^{***}	0.085^{***}
			(0.013)	(0.021)
$Fore_{t-3}$			0.060^{***}	0.056^{***}
			(0.021)	(0.018)
Pub_{t-1}	0.155^{***}	0.140^{***}	0.039^{*}	0.446^{***}
	(0.015)	(0.020)	(0.021)	(0.159)
Pub_{t-2}	0.102^{***}	0.092^{***}		
	(0.016)	(0.020)		
Pub_{t-3}	0.088^{***}	0.086^{***}		
	(0.015)	(0.013)		
Pro_{t-1}	0.038	0.034	0.004	−0.017
	(0.031)	(0.028)	(0.029)	(0.028)
Pro_{t-2}	0.005	0.004	0.030	0.015
	(0.012)	(0.010)	(0.029)	(0.019)
Pro_{t-3}	0.003	−0.003	0.010	0.007
	(0.022)	(0.022)	(0.014)	(0.012)
First Stage Day lead reports		0.18^{***}		0.147^{***}
		(0.029)		(0.023)
First Stage F Stat		39.719		42.343
Zone FEs	Y	Y	Y	Y
Daily FEs	Y	Y	Y	Y
Observations	18,700	18,690	18,700	18,690
R^2	0.345	0.308	0.376	0.308
Adjusted R^2	0.270	0.229	0.305	0.229
Residual Std. Error	0.696 (df = 16788)	0.716 (df = 16779)	0.877 (df = 16788)	0.924 (df = 16779)

Note: *p<0.1; **p<0.05; ***p<0.01
SEs clustered on Zone and Season