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Learning by Doing, Knowledge Spillovers, and Technological and Organizational Change in High-Altitude Mountaineering

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Abstract

We present an analysis of microlevel data from mountaineering on the 14 peaks over 8,000 m in height during the period 1895-1998. Prior to 1950, no expedition was successful in making an ascent and almost half of expeditions experienced a death, frostbite, or altitude sickness. By the 1990s, however, over half of the expeditions would successfully make an ascent and only about one in seven would experience an adverse outcome. Our objective is to distinguish between the effects of learning by doing and knowledge spillovers versus the effects of changes in technology or economic organization in explaining these results. As we can identify each climber by name and nationality, as well as each expedition team's methods and outcomes, we are able to disentangle the effects of learning at the individual, national, and international levels from effects due to improvements in climbing technology or changes in organizational methods and objectives. We find evidence that both individual learning by doing and learning through knowledge spillovers have contributed to the observed increase in ascent rates and to the decrease in death, frostbite, and altitude sickness rates.

Keywords

learning by doing, knowledge spillovers, technological change, mountaineering

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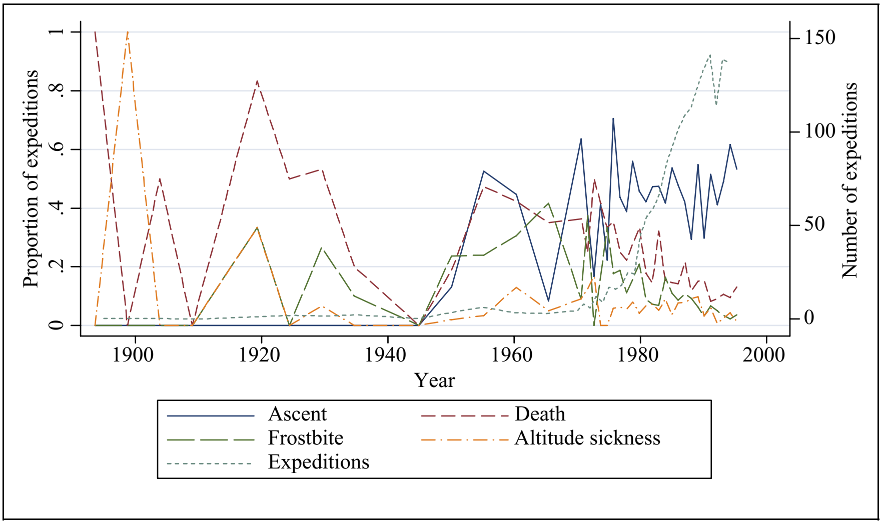

Figure 1. Number of expeditions and proportion of expeditions experiencing each of four outcomes on the 8,000-m peaks, 1895-1994.
Note: The number of expeditions includes all expeditions to peaks over 8,000 m by year. The outcome data are proportion of expeditions experiencing an ascent and suffering death, frostbite, or altitude sickness. Data prior to 1970 are 5-year averages.

Introduction

In 1895, the British climber Albert Mummery led the first expedition to make a serious attempt to climb one of the fourteen mountains in the world that are more than 8,000 m in height.[1] Unfortunately, his expedition to climb Nanga Parbat in present-day Pakistan failed to reach the summit, and Mummery and two companions died in the attempt. Over the next five decades, 30 expeditions to the 8,000-m peaks resulted in no successful ascents and more than 50 deaths. Yet by the 1990s, over 100 expeditions *per year* would set out to climb these mountains, and over half of the expeditions would place at least one team member on the summit, while only one in seven would suffer a death or a case of frostbite or altitude sickness.[2] Indeed, through the use of guide services, climbing Mt. Everest would become possible even for persons of modest climbing ability.

Evidence of these changes in the high-altitude mountaineering "industry" can be seen in Figure 1, which displays the number of expeditions per year to the fourteen 8,000-m peaks from 1895 to 1994 and the proportion of expeditions that made an ascent or suffered death, frostbite, or altitude sickness.[3] Although the early data fluctuate due to the small number of expeditions, the overall trends are clear; there have been major improvements in expedition outcomes since the initial attempts at the turn of the 20th century.

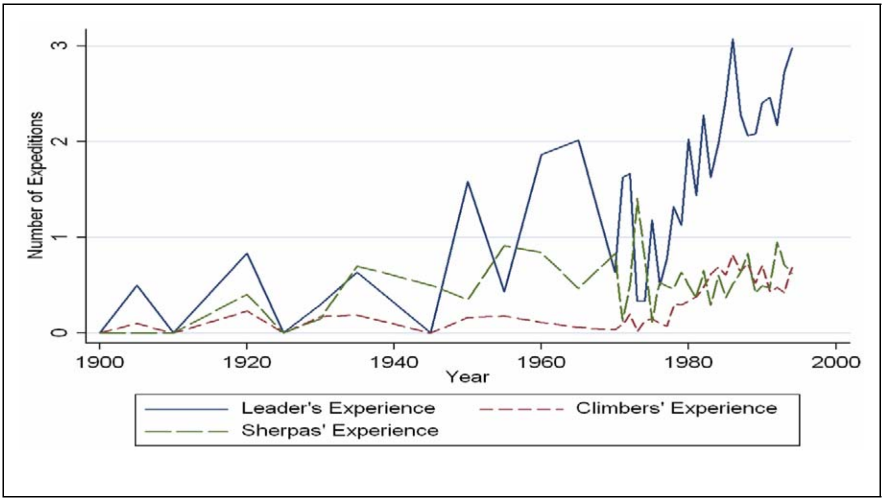

Figure 2. Average prior experience of climbers on expeditions to the 8,000-m peaks, 1895-1994.
Note: Data are annual average number of prior 8,000-m peaks expeditions. Data prior to 1970 are 5-year averages.

Why have these improvements occurred? One hypothesis is that the technology that climbers rely upon has improved, from the tweed jackets and leather boots of the early days of exploration to the high-tech fibers, down suits, and plastic boots used by today's mountaineers. For example, when the body of George Mallory, who died in the 1924 British expedition to the Tibet side of Mt. Everest, was discovered in 1999, the seven layers of clothing on his body were assessed to provide less insulation from the cold than the modern down suits serving as the outer layer in the clothing system used by Mallory's discoverers—a system that included several fleece jackets as well as expedition-weight long underwear underneath and a high-tech fabric shell jacket on top (Anker and Roberts 2001, p. 166).[4]

A second hypothesis is that there has been learning by doing.[5] The cost of expeditions dropped dramatically after 1970, when individuals were allowed to obtain a climbing permit without using diplomatic services. As seen in Figure 1, this resulted in the rapid increase in the number of expeditions after 1970. Figure 2 shows that this was accompanied by an increase in the average experience levels of expedition leaders and climbers. Thus, it is possible that climbers became better at climbing because they had more experience.[6]

A third hypothesis is that climbers have learned from the mistakes and successes of their predecessors; that is, there have been knowledge spillovers across expeditions, whether those spillovers came from all previous climbers or only those on past expeditions from the same country.[7] Figure 3 plots the natural logarithm of the number of prior expeditions in total, the average of the number of prior expeditions to

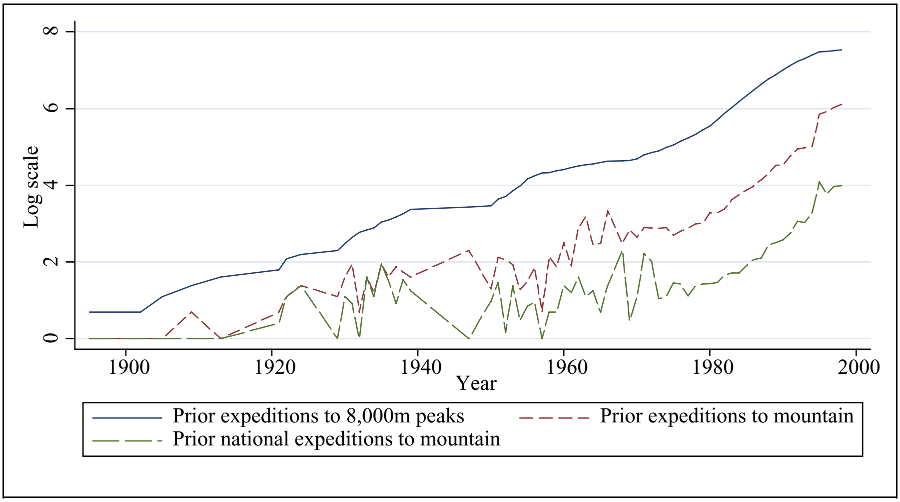

Figure 3. Cumulative prior expeditions to mountain, 1895-1994.
Note: Data are the annual across-expedition average of the number of prior expeditions. Plot of log of one plus the cumulative number of prior expeditions, prior expeditions to mountain, and prior national expeditions to mountain, 1895-1994.

each mountain, and the average of the prior number of expeditions to each mountain by climbers from the same country as the current expedition. The sharpest rate of growth in each of these occurs at about the same time as the growth in ascent rates and the declines in death, frostbite, and altitude sickness rates.

A final hypothesis is that climbers have adopted organizational structures or developed goals and methods that allowed them to be more successful. Figure 4 shows that there were periods dominated by large national expeditions (e.g., from the 1960s to the mid-1970s) as well as periods in which bottled oxygen use declined (the 1930s and again, briefly, in the early 1980s). Similarly, Figure 5 shows that the number of expeditions climbing new routes and unclimbed routes declined as the number of unclimbed potential routes was exhausted. There was also a strong trend toward climbing the "normal" route, typically the easiest route up the mountain.

This article attempts to sort out the relative contributions of each of these elements to the observed changes in the rates of ascent, deaths, frostbite, and altitude sickness. Our data set covers all the known expeditions to the 8,000-m peaks over the span of 100 years and includes variables that can be used to test each of these hypotheses. The outcomes are easily measured: ascents are positive outcomes, and deaths, frostbite, and altitude sickness are each negative outcomes. For each expedition, we observe not only these outcomes but also the past climbing histories on the 8,000-m peaks of the individual mountaineers and the past history of mountaineering to that mountain. In addition, we observe the technologies that were available, the

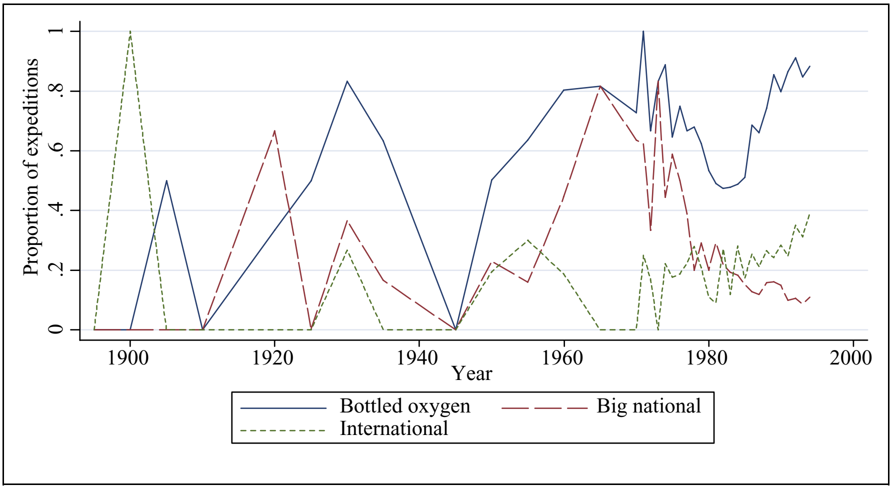

Figure 4. Proportion of expeditions using bottled oxygen and proportion of large national and international expeditions, 1895-1998.
Note: Data are annual proportion of expeditions using bottled oxygen and proportion that are large national or international. Data prior to 1970 are 5-year averages.

methods that were used by the expedition (e.g., the number of climbers and the number of Sherpas hired to assist the expedition, the expedition style, whether the expedition uses bottled oxygen, etc.), and the objectives it undertook (e.g., which mountain and route).[8] Therefore, we are able to measure the effect of each of these potential explanations for the observed variation in expedition outcomes.

Our main results are the following. First, we find evidence of learning by doing: an increase in the experience of the climbers and Sherpas assisting the climbers has contributed to the increase in ascent rates among expeditions. We also find evidence that knowledge spillovers may have played a factor in the increase in ascent rates as well as in the decrease in frostbite and altitude sickness rates.[9]

Two caveats are attached to our conclusion about knowledge spillovers. The first is that in contrast to Jaffe, Trajtenberg, and Henderson (1993) and Thompson (2006), we find no evidence that knowledge spillovers are geographically concentrated. Rather, we find that high-altitude mountaineers appear to readily share information across borders. Communication of results may well occur internationally because climbers have clear-cut incentives both to provide information about their exploits and to do so in detail. Unlike other claims to property, a mountaineer's claim of an ascent cannot be usurped by competition, because the claim is to a climb that has already occurred.[10] Indeed, the more accurate a description a climber provides of the obstacles and features of a route, the better to maintain his claim, as it can be more easily verified by later expeditions.[11] In addition, communication of results is easily facilitated. As there are specific times of the year during which climbs are best

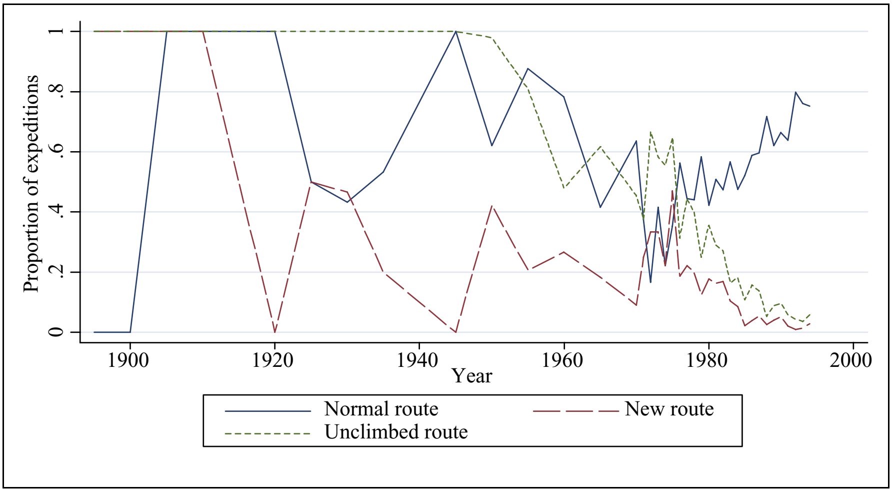

Figure 5. Climbing objectives of expeditions climbing the 8,000-m peaks, 1895-1994.
Notes: Data are annual proportion of expeditions by type of route climbed. Data prior to 1970 are 5-year averages.

undertaken (e.g., spring in the Himalayas and late summer in the Karakoram), climbers tend to converge upon these mountains at the same time and through Kathmandu, Nepal, or Islamabad, Pakistan, where permits are issued.[12] Furthermore, the methods, techniques, and results of the exploits of climbers from many nationalities are widely reported in the journals of each of the major national mountaineering clubs. The low costs of obtaining and transmitting information, plus the fact that high-altitude mountaineering is a dangerous and complex activity that requires a great deal of planning, together suggest that knowledge spillovers will be of the broadest sort.

The second caveat to our knowledge-spillover result is that we find very little evidence that learning spillovers, or indeed the acquisition of human capital, have contributed much to the reduction in death rates. We do find that it is possible to learn from others how to prevent frostbite (e.g., by proper hydration and the use of bottled oxygen, which ensure that blood flows to the body's extremities, and the use of plastic double boots) and altitude sickness (e.g., by moving up a mountain slowly enough to acclimatize), but it is apparently not as easy to learn how to avoid misfortunes such as growing too weary on descent (which can be avoided only by choosing not to ascend), falling, or being hit by an avalanche, falling ice, or falling rocks.[13]

In addition, there are a number of organizational factors that may have contributed to the change in the rates of success and failure on the 8,000-m peaks. We find evidence that expeditions that are larger, both in terms of numbers of climbers and in terms of numbers of Sherpas hired to support the expedition, are more likely to have success in placing a climber on the summit. This is even more true of large national expeditions, which we define as expeditions with teams of 10 or more climbers from the same nation. These expeditions are often well financed and supported by their home government; such expeditions achieved all but one of the 14 first ascents. Furthermore, expeditions that choose to use the normal route are more likely to be successful in making an ascent. We also find that expeditions that include female climbers in their team are more likely to make an ascent.

The final result that is of particular interest concerns the use of bottled oxygen. We find that expeditions that use bottled oxygen, which enables climbers to stay at the 8,000-m "death zone" longer than they would otherwise be capable of doing, are significantly more likely to experience a death on the expedition. Furthermore, expeditions using bottled oxygen are significantly less likely to make an ascent. Thus, it appears that bottled oxygen may have very large costs associated with its use. We postulate that the lower success rates and higher death rates may be related to two factors. First, there may be a "lulling effect" in that climbers believe that bottled oxygen, like seat belts in a car, makes them invincible (e.g., Peltzman 1975, Viscusi 1984). Second, bottled oxygen adds a lot of weight to an expedition. That extra weight translates into more trips carrying loads up the mountain, which may account for both the lower ascent rates and the higher death rates.[14]

A Brief History of Himalayan Mountaineering

The early attempts on the high peaks, such as that of the British on Mt. Everest in the 1920s and the Germans on Nanga Parbat in the 1930s, were typically large campaigns that used a method that came to be known as "expedition style." These often involved a dozen or more climbers and as many high-altitude Sherpas following a strict regimen of establishing camps in a pyramid structure, so that each camp could supply the next. These types of expeditions were mounted by the British to Mt. Everest (1913, 1921, 1922, 1924, and 1953), by the Germans to Nanga Parbat (1934, 1937, 1938, 1939, 1950, and 1953), and by the Americans on K2 (1938, 1939, and 1953). After the spectacular failures of both the British and the Germans on the early expeditions, in the 1930s, British teams with fewer than 10 men in total, led by H. William Tilman and Eric Shipton, rejected the use of bottled oxygen and climbed as did mountaineers in the Alps, advancing quickly with few, if any, fixed camps and bivouacking as necessary, in "alpine style."[15] This style, however, did not catch on for a number of years, primarily because it was the large expeditions that saw the first successes.

After more than 50 years of failure, in 1950, a French expedition-style team led by Maurice Herzog finally accomplished the first successful ascent of an 8,000-m peak when they reached the top of Annapurna. Herzog and his summit partner Louis Lachenal, however, both suffered severe frostbite and survived only because their teammates and Sherpas successfully evacuated them. In 1951, an expedition led by Shipton discovered the South Col route on the Nepal side of Everest, after years of attempts from the Tibetan side. This route would be used for the first ascent of Everest (and has since become the normal route). The British were nearly beaten to the summit by a Swiss expedition in 1952, but the following spring, they finally succeeded on Everest with Edmund Hillary and Sherpa Tenzing Norgay, who had climbed to within 300 m of the summit with the Swiss. A few days later, the Germans finally placed a man on the summit of Nanga Parbat when Hermann Buhl, taking stimulant pills but climbing solo without bottled oxygen, reached the summit just before dark; he then spent the night standing on a ledge and returned to camp the next day with frostbite injuries.[16] Ascents of K2 in 1954 (by an Italian team, that succeeded after three American failures), Cho Oyu (Austrian, 1954), Kangchenjunga (British, 1955), Makalu (French, 1955), Lhotse (Swiss, 1956, with the second ascent of Everest), Manaslu (Japanese, 1956), Gasherbrum II (Austrian, 1956), Broad Peak (Austrian, 1957), and Hidden Peak (American, 1958) were then quickly completed. Dhaulagiri, which had been attempted seven times, including by an Argentinean army team that used dynamite to blast out a spot on which to camp, was finally climbed in 1960 by an international expedition. Shisha Pangma, which the Chinese closed to Western climbers after invading Tibet in 1950, was the last 8,000-m peak to be climbed, when a large Chinese expedition placed 11 climbers on the summit in 1964. With the exception of Broad Peak, each of the 8,000-m peaks fell to large expeditions placing fixed camps, using Sherpas, and for the most part using bottled oxygen.[17]

The second major phase in Himalayan mountaineering arguably began in 1956, with a Swiss dual-objective Everest-Lhotse expedition. To a great extent, this phase consisted of large national expeditions using bottled oxygen, as can be seen in Figure 4.[18] Expeditions, however, typically upped the ante by trying for not just any ascent but one on a difficult route or carried out in a difficult manner. Thus, the 1963 American Everest expedition attempted simultaneously to climb Mt. Everest by two different routes, the "normal" South Col route and the difficult unclimbed West Ridge route. On the latter route, Tom Hornbein and Willi Unsoeld made the first ascent and, by descending the South Col route, they also achieved the first traverse of the mountain. This phase reached its maturity by 1970, when British climbers attempted the south face of Annapurna and a German-Italian team attempted the Rupal Face of Nanga Parbat. These were frontal assaults on 4,000-m rock and ice walls involving much technical climbing. When Don Whillans and Dougal Haston reached the summit of Annapurna and Tyrolean-Italians Reinhold and Gunther Messner attained the summit of Nanga Parbat, mountaineers around the world realized that climbs at a difficult technical standard were possible on the 8,000-m peaks. At the same time, there was a relaxing of rules under which expeditions could obtain a permit to climb in Pakistan and Nepal, and the result was an upsurge of climbing. The total number of routes climbed jumped to almost 60, with all of the 8,000-m peaks except Shisha Pangma—closed to Western climbers until 1980—seeing attempts on new routes.[19] There was also a sharp increase in the number of international expeditions, as top climbers from around the world united to take on difficult projects. Figure 5 shows how the objectives of mountaineers changed over time; in the early 1970s, over 60% of the expeditions were on routes that had not yet been climbed, and less than half of the expeditions climbed the normal route. By the 1990s, however, over 80% of the expeditions would climb the normal route.

The third phase in mountaineering on the 8,000-m peaks saw the revival of the alpine style, which had been discredited by the successes of expedition-style climbs and was largely forgotten until a series of climbs in the late 1970s involving Reinhold Messner. Messner and Austrian Peter Habeler made a successful alpine-style climb (i.e., without bottled oxygen, Sherpa support, or fixed ropes) of Hidden Peak in 1975 and then climbed Everest without bottled oxygen in the spring of 1978 (though as part of an expedition in which other members did use bottled oxygen).[20] Messner then completed the first solo climb of Nanga Parbat, on a new route without bottled oxygen or other support, and in 1980, he made the first successful solo ascent of Everest.[21] While the Annapurna and Nanga Parbat expeditions of 1970 had shown that technically difficult climbs were possible at high altitude, Messner's climbs showed that small, unsupported, and relatively inexpensive expeditions could be successful. The alpine style also carried prestige in that it was an attempt "by fair means," as according to Messner, the use of bottled oxygen turned Everest into a 6,400-m peak (Messner 1999, p. 73).[22]

The fourth and most controversial phase in Himalayan mountaineering saw the advent of guided climbs, characterized by two highly publicized cases. The first of these was the successful completion in 1985 of the ascents of the highest peaks on each continent—the "Seven Summits"—by Texas real-estate developer and neophyte climber Dick Bass.[23] The second was the 1996 disaster on Everest in which guides and clients on two expeditions on the South Col route were caught in a sudden storm. New Zealand guide Rob Hall and American guide Scott Fischer, leaders of their respective expeditions, plus several clients and assistant guides—a total of eight climbers—died, and client Beck Weathers, who was twice left for dead, suffered horrific frostbite damage to his face, hands, and feet.[24] The incident was described in Jon Krakauer's *Into Thin Air* (1997), the first of numerous books on the disaster and an indictment of the concept of guided expeditions. Guided expeditions were a small part of the overall picture—less than 10% of expeditions—until the mid-1990s.

Hypotheses

The data in Figure 1 suggest that there have been systematic changes in the incidences of outcomes—ascents, deaths, frostbite, and altitude sickness—experienced by expeditions to the fourteen 8,000-m peaks. We use expedition-level data to examine this by estimating regressions of expedition outcomes on a set of covariates that might explain the changes in success rates. For each outcome, we observe either that the outcome occurred ($y_{ij} = 1$) or that it did not occur ($y_{ij} = 0$) for expedition i and outcome j. The latent success rate is given by y_{ij}*, which is related to the k observable covariates, x_{ik}, according to

$$y_{ij}* = \Sigma_{k=1}^{m} x_{ik} \beta_{jk} + \varepsilon_{ij}. \tag{1}$$

We set $y_{ij} = 1$ if $y_{ij}* > 0$ and $y_{ij} = 0$ otherwise. Hence,

$$\begin{aligned} \Pr(y_{ij} = 1 | x_{ik}) &= \Pr(y_{ij}* > 0 | x_{ik}) = \Pr(\varepsilon_{ij} > -\Sigma_{k=1}^{m} x_{ik} \beta_{jk}) \\ &= 1 - \Phi(-\Sigma_{k=1}^{m} x_{ik} \beta_{jk}) = \Phi(\Sigma_{k=1}^{m} x_{ik} \beta_{jk}), \end{aligned}$$

where $\Phi(.)$ is the standard normal distribution and the β_{ik} are parameters to be estimated. Estimation is by probit.

For each outcome, we estimate Equation 1 using five different specifications, where the specifications differ by what is included in the list of explanatory variables, x_{ik}. The parameters β_{jk} measure the change in the $\Pr(y_{ij}* > 0 | x_{ik})$ as x_{ik} changes; these are the marginal effects reported below. The specifications vary in two main dimensions. Models 1–3 vary in the specification of technological change in three ways. Model 1 simply includes a year trend variable; model 2 includes year-dummy variables; and model 3 uses a year-time trend plus dummy variables to mark important technological innovations. Models 4 and 5 restrict the sample to the post-1970 period. Model 4 is the post-1970 analog to Model 1; Model 5 further restricts the sample to 1978-1994 data to measure effects on outcomes of idiosyncratic weather conditions faced by each expedition.

The first hypotheses have to do with learning by doing. In Figure 2, we displayed the human capital of climbers in each year, as measured by the average prior 8,000-m peaks experience of leaders, climbers, and Sherpas.[25] The first major upswing in experience occurred with the 1920s British expeditions. There are two more spikes in the leader's average experience levels in the 1960s, which are mainly due to small samples. However, from the 1970s forward, there is an unmistakable increase in the experience levels of leaders and climbers. This suggests that human capital may play a role in explaining the changes in the outcome rates. Specifically, we test the hypotheses that an increase in the experience of the leader, the climbers, or the Sherpas increases the probability of an ascent and decreases the probability of a bad outcome.

The second hypotheses have to do with learning spillovers and their source. The number of cumulative prior expeditions over time acts as a proxy for external knowledge spillovers. Unfortunately, the number of cumulative prior expeditions is highly correlated with the year-trend variable that we use to measure general technological improvement ($r = .76$), so it is difficult to separate out the two effects.[26] The cumulative prior expeditions to the *mountain* being climbed by the expedition in each observation is, however, highly correlated with the cumulative prior expeditions to all 8,000-m peaks ($r = .74$) but has a lower correlation with the year–time trend ($r = .51$). We use this variable and the cumulative prior expeditions to the mountain by nations represented in the expedition as measures of knowledge spillovers in the regressions reported below. We test the hypotheses that learning spillovers increase the probability of ascent and decrease the probability of a bad outcome. Figure 3 plots the logarithm of the annual averages of these two variables, which even in the annual averages show much more variation than does the cumulative-prior-expeditions variable.

The third hypothesis we test is that technological improvements have increased the probability of an ascent and decreased the probability of a bad outcome. In Models 1 and 3–5, this is tested by regressing the outcomes on the year of the climb. Alternatively, in Model 2, we use year-dummy variables to see whether the mean value of these is increasing over time for ascents and decreasing over time for bad outcomes. In Model 3, in addition to a year–time trend variable, we also include indicator variables that mark important innovations in technology. These include 1945, from which point nylon ropes were available, 1968, from which point technical ice axes became available, and 1974, from which point plastic boots became available.

In addition, there are a number of expedition characteristics that may affect outcomes. These include the size of the expedition, in terms of the number of climbers and Sherpas on the expedition. We hypothesize that large expeditions, by having more resources to throw at the mountain, are more likely to succeed in making an ascent. However, large expeditions experience greater logistical problems that increase their exposure to risk. Thus, we also hypothesize that large expeditions will have higher incidences of the bad outcomes. Related to this is the hypothesis that large national expeditions (i.e., those comprised of climbers from only one country), which often have support from national governments, will be more likely, all else constant, to make an ascent. One question, however, is whether the greater support given to those expeditions overcomes the exposure to risk. If so, we expect these expeditions to lower the incidence of bad outcomes. Another related hypothesis has to do with expeditions whose membership is international. Those expeditions may suffer from language and cultural differences, which would translate into lower success rates and higher incidences of bad outcomes.

In addition, the methods chosen by the expedition—such as mountain, route, the use of bottled oxygen, time of year, and whether guides are used—should influence the incidence of outcomes. If expeditions choose the methods so as to optimize some weighted combination of their probability of ascent and the probability of a bad outcome, then we expect these choices to either result in higher ascent rates or lower incidences of bad outcomes. However, expeditions may face tradeoffs, in which case, the probability of both an ascent and a bad outcome move in the same direction. Finally, we also control for differences across the nationalities of the climbers, and, in Model 5, for weather conditions faced by the expeditions.

The Data

The data we analyze cover all 1,766 known expeditions to the fourteen 8,000-m peaks and their subsidiary peaks over 8,000 m during the period 1895-1994, plus

143 expeditions to Mt. Everest over the period 1995-1998, for a total of 1,909 expeditions.[27] The data were collected using the *Himalayan Index*, expedition reports from the *American Alpine Journal* and the *Alpine Journal*, and additional supplemental sources.[28] The main source of information was the *American Alpine Journal*, which contains expedition reports that range from very detailed multiple-page articles written by members of the expedition to a single sentence written by journalists such as Elizabeth Hawley and Michael Cheney. These reports can include the team size, names of climbers including those who successfully reached the summit, the highest elevation that was attained if the expedition was unsuccessful, the number or names of Sherpas, and incidences of frostbite, altitude sickness, or death.[29] Ascents were cross-checked with an appendix in Sale and Cleare (2000). Information on ascents and deaths is quite good, but other information is often less accurate. The data end in 1994 for all peaks except Everest because of an editorial policy change at the *American Alpine Journal* that excluded reports of expeditions on "normal" routes, which comprise the bulk of expeditions.[30] The Mt. Everest data from 1995 to 1998 are from an appendix in Unsworth (2000).[31]

Table 1 defines the variables used in the analysis and provides additional summary statistics for the expeditions to the 8,000-m peaks in five periods of exploration, in total through 1994, and on all Everest climbs from 1995 through 1998.[32] Because of the inherent advantages national expeditions have for fundraising, we use as a proxy for public funding a dummy variable, "large national," which is set to one for teams of 10 or more individuals that are all from the same country (see Figure 4 above).[33] This variable misses some expeditions that were national in character such as the British 1953 Everest expedition, which included New Zealanders Edmund Hillary and Ed Lowe, but it allows us to test whether organizations with better access to funding are more likely to be successful. We include a variable for expedition size, which has ranged from one up to several hundred.[34] A large expedition has lots of resources available if trouble occurs, but it is also exposed to risk for a longer time because it must move much more equipment to high camps. We also include an indicator variable to address the question of whether guided expeditions create more risk due to less-experienced clients paying for the service of being guided to the top of a mountain. The trends apparent in the data in Figures 1 through 5 also appear in the averages by period in Table 1.

Table 2 displays the data broken out by mountain. About 90% of expeditions on Broad Peak and Gasherbrum II use the normal route. The "easy" 8,000-m peaks of Cho Oyu, Gasherbrum II, and Shisha Pangma have ascent rates of over 60%, while Makalu, K2, and Annapurna have ascent rates of about 30%. On average, K2 sees the most experienced climbers and leaders, while Mt. Everest and Kangchenjunga have the most experienced Sherpas. Expeditions to Mt. Everest are on average about 40% larger than expeditions on other mountains.

Table 3 shows that there are also differences when the data are examined by country. The Polish are least likely to use bottled oxygen; the Koreans use it almost all the time. While the United States has mounted the most expeditions, its ascent rate is

Table 1. Expedition Summary Statistics by Period, 1895-1998

		All 8,000-m Peaks						Everest
Variable	Description	1895-1994	1895-1945	1946-1969	1970-1979	1980-1989	1990-1994	1995-1998
Expeditions	Total number of expeditions to any 8,000-m peak	1766	30	78	146	848	664	143
New routes	Total number of new routes attempted	148	12	24	34	61	17	0
First ascent route	Total number of routes first ascended	130	0	17	32	62	18	1
Cumulative prior expeditions to mountain	Cumulative prior expeditions by any nation to mountain	100.4	3.03	7.81	16.87	54.49	127.8	400.9
Prior national expeditions to mountain	Cumulative prior expeditions by nations on expedition to mountain	13.6	1.83	1.74	3.14	6.88	18.45	50.7
Leader's experience	Team average prior expeditions to any 8,000-m peak by leaders	2.19	0.45	1.16	0.95	2.18	2.56	2.80
Climbers' experience	Team average prior expeditions to any 8,000-m peak by climbers	0.51	0.16	0.16	0.16	0.61	0.54	0.36
Sherpas' experience	Team average prior expeditions to any 8,000-m peak by Sherpas	0.64	0.31	0.65	0.57	0.53	0.63	1.39
Bottled oxygen	Dummy variable = 1, if all members use bottled oxygen, 0 otherwise	0.72	0.53	0.68	0.72	0.63	0.86	0.82
Normal route	Dummy variable = 1, if expedition attempts "normal route," 0 otherwise	0.62	0.57	0.68	0.45	0.57	0.72	0.94
Guided expedition	Dummy variable = 1, if expedition is guided, 0 otherwise	0.03	0	0	0	0.03	0.04	0.14
Climbers	Number of climbers (including leaders but excluding Sherpas)	10	10	12	16	9	9	12
Sherpas	Number of high-altitude porters	9	20	18	11	5	11	20

(continued)

Table 1. (continued)

		All 8,000-m Peaks						Everest
Variable	Description	1895-1994	1895-1945	1946-1969	1970-1979	1980-1989	1990-1994	1995-1998
Female	Percentage of female climbers on expedition	5	2	2	4	5	5	4
Large national expedition	Dummy variable = 1, if same nationality and number of climbers >10, 0 otherwise	0.17	0.23	0.33	0.45	0.17	0.11	0.03
International expedition	Dummy variable = 1, if not all climbers of the same nationality, 0 otherwise	0.25	0.13	0.19	0.18	0.21	0.32	0.26
Autumn	Dummy variable = 1, if month is September–November, 0 otherwise	0.35	0.10	0.20	0.27	0.34	0.41	0.25
Winter	Dummy variable = 1, if month is December–February, 0 otherwise	0.05	0	0.01	0.01	0.08	0.03	0
Ascent	Dummy variable = 1, if any member of expedition makes ascent, 0 otherwise	0.45	0	0.29	0.47	0.43	0.51	0.54
Death	Dummy variable = 1, if any member of expedition suffers death, 0 otherwise	0.16	0.42	0.29	0.32	0.17	0.10	0.14
Frostbite	Dummy variable = 1, if any member of expedition suffers frostbite, 0 otherwise	0.08	0.13	0.23	0.18	0.09	0.04	0.01
Altitude sickness	Dummy variable = 1, if any member suffers altitude sickness, 0 otherwise	0.05	0.10	0.08	0.06	0.07	0.03	0.01

Note: Data are the averages for the period, except for the number of expeditions, routes, and first ascents, which are totals. Table reports the proportion of expeditions for which the dummy variable equals one. Statistics include the full sample of 1,909 expeditions. Season dummies do not add to 100% because of missing season data.

Table 2. Expedition Summary Statistics by Mountain, 1895-1994

Mountain	Annapurna	Broad Peak	Cho Oyu	Dhaulagiri	Everest	Gasherbrum II	Hidden Peak	K2	Kangchenjunga	Lhotse	Makalu	Manaslu	Nanga Parbat	Shisha Pangma
Height (m)	8,091	8,047	8,201	8,167	8,848	8,035	8,068	8,611	8,586	8,516	8,463	8,163	8,126	8,027
Location	Nepal	Pakistan/Tibet	Nepal/Tibet	Nepal	Nepal/Tibet	Pakistan/Tibet	Pakistan/Tibet	Pakistan/Tibet	Nepal/India	Nepal/Tibet	Nepal/Tibet	Nepal	Pakistan	Tibet
First ascent	1950	1957	1954	1960	1953	1956	1958	1954	1955	1956	1955	1956	1953	1964
Expeditions	105	115	185	128	348	108	63	102	86	76	112	97	142	99
Routes	18	7	8	13	16	6	10	12	15	8	8	7	9	11
Percentage of expeditions experiencing these outcomes														
Ascent	33.3	45.2	63.8	42.2	42.8	65.7	47.6	34.3	57.0	40.8	29.5	36.1	38.0	65.7
Death	25.7	9.6	6.5	18.8	20.2	11.1	11.1	25.5	23.3	14.5	8.9	19.6	15.5	9.1
Frostbite	7.6	6.1	4.3	7.0	6.7	5.6	6.3	11.8	14.0	10.5	10.7	10.3	9.9	6.1
Altitude sickness	3.8	0.9	3.2	6.3	5.3	11.1	1.6	8.8	7.0	1.3	6.3	1.0	9.2	3.0
Percentage of expeditions choosing														
Normal route	22.9	87.8	77.8	68.8	64.9	90.7	20.6	49.0	40.7	67.1	44.6	67.0	50.0	81.8
Bottled oxygen	69.5	76.5	73.0	74.2	76.4	72.2	69.8	61.8	65.1	67.1	63.4	73.2	75.4	77.8
Guided	1.0	3.5	2.7	0	4.9	5.6	4.8	1.0	0	0	0	2.1	1.4	8.1
Percentage of expeditions														
International	15.2	27.0	31.9	24.2	27.1	18.5	15.8	35.3	22.1	17.1	25.9	21.6	18.3	31.3
Large National	17.1	5.2	6.5	18.0	24.2	9.2	11.1	19.6	25.6	21.1	14.2	20.6	13.4	11.1
Autumn	53.3	3.5	49.7	54.7	37.1	0.9	3.2	2.0	31.4	46.1	52.7	51.5	6.3	58.6
Winter	15.2	0	5.4	7.8	5.3	0	0	1.0	7.0	6.6	7.1	6.2	3.5	0.0

(continued)

Table 2. (continued)

Mountain	Anna-purna	Broad Peak	Cho Oyu	Dhaul-agiri	Everest	Gasher-brum II	Hidden Peak	K2	Kangch-enjunga	Lhotse	Makalu	Mana-slu	Nanga Parbat	Shisha Pangma
Mean climbing team size														
Climbers	8.37	7.82	8.32	8.18	14.25	8.03	7.60	9.28	11.58	7.95	7.21	8.43	8.05	9.96
Sherpas	5.80	5.12	10.40	9.03	14.44	6.70	6.47	4.28	11.06	5.42	6.43	8.65	3.68	10.63
Female (%)	4.0	5.2	5.1	4.5	4.5	8.8	4.6	5.8	4.7	2.7	4.5	3.0	5.3	5.2
Mean experience (prior expeditions)														
Climbers	0.89	1.32	0.96	0.88	0.66	0.72	1.05	2.20	1.27	1.73	1.30	0.62	0.96	1.33
Sherpas	2.96	0.44	1.37	2.97	4.07	0.22	0.09	0.40	5.36	2.67	1.36	1.77	0.18	1.18
Leader	1.84	2.07	1.99	1.65	1.96	1.40	2.41	3.50	1.94	3.05	2.19	2.09	2.13	2.92

Note: Statistics are based on the sample of 1,766 expeditions recorded prior to 1995. Everest data for 1995-1998 are contained in Table 1.

Table 3. Expedition Summary Statistics by Country, 1895-1998.

Nation	Expeditions: Total	Expeditions: International (%)	Percentage Experiencing Outcome: Ascent	Percentage Experiencing Outcome: Death	Percentage Experiencing Outcome: Frostbite	Percentage Experiencing Outcome: Altitude Sickness	Percentage Choosing: Normal Route	Percentage Choosing: Bottled Oxygen	Average Number: Climbers	Average Number: Sherpas	Average Prior Experience: Leader	Average Prior Experience: Team	Average Prior Experience: Sherpas
Australia/New Zealand	92	68.5	48.9	15.2	12	5.4	76.1	72.8	8.72	8.31	3.08	0.7	0.89
Austria	146	67.1	54.8	16.4	13.7	3.4	72.6	71.9	10.05	7.40	2.73	0.76	0.52
Canada	57	59.6	43.9	17.5	10.5	19.3	66.7	71.9	9.95	5.80	2.26	0.69	0.85
China/Tibet	29	37.9	69.0	34.5	3.4	10.3	96.6	79.3	44.33	46.76	0.59	0.31	0.44
Czechoslovakia	56	67.9	58.9	23.2	5.4	8.9	37.5	60.7	12.09	5.63	2.89	0.96	0.47
France	212	35.4	43.9	14.2	6.1	3.8	62.7	62.3	7.74	7.02	2.92	0.52	0.49
Germany	194	64.9	50.0	18.0	10.3	3.6	66.5	73.7	10.14	9.01	3.38	0.63	0.45
Great Britain	182	57.7	39.0	18.1	9.3	6.6	61.0	64.8	9.88	10.35	3.35	0.79	0.65
India	24	33.3	54.2	50.0	20.8	8.3	66.7	91.7	19.90	31.87	1.75	0.33	1.26
Italy	190	51.6	51.6	11.6	5.8	4.7	60.5	68.9	8.95	8.63	4.10	0.89	0.40
Japan	239	9.2	49.0	18.8	4.2	2.9	58.2	78.2	12.21	12.11	1.45	0.27	1.06
Korea	91	2.2	44.0	22.0	3.3	0	68.1	95.6	11.72	14.72	0.51	0.13	1.30
Latin America	77	59.7	55.8	20.8	13.0	5.2	77.9	81.8	10.32	10.41	3.10	0.59	0.74
Netherlands	54	44.4	53.7	13.0	3.7	7.4	79.6	83.3	8.17	8.29	2.27	0.63	1.16
Pakistan/Nepal	28	60.7	57.1	25.0	14.3	3.6	82.1	75.0	14.80	6.70	2.52	0.74	1.23
Poland	132	68.9	59.1	22.0	13.6	6.1	46.2	57.6	9.71	5.18	5.50	1.81	0.55
Scandinavia	43	62.8	60.5	16.3	9.3	9.3	81.4	83.7	11.03	15.90	2.29	0.66	0.99
Soviet Union	51	49.0	77.4	24.5	5.7	7.5	58.5	79.2	14.26	10.78	2.44	0.55	0.97
Spain	218	18.3	43.6	12.4	6.0	5.0	75.7	84.9	7.51	8.53	1.24	0.46	0.63
Switzerland	176	58.5	51.1	17.6	6.8	7.4	70.5	72.2	9.59	7.78	4.09	0.84	0.37
United States	274	55.5	40.9	14.6	9.1	9.1	62.4	68.6	9.85	8.35	2.51	0.71	0.86
Yugoslavia	59	32.2	49.2	13.6	11.9	5.1	40.7	66.1	10.35	5.22	1.95	0.92	0.07

(continued)

Table 3. (continued)

	Expeditions		Percentage Experiencing Outcome				Percentage Choosing		Average Number		Average Prior Experience		
Nation	Total	International (%)	Ascent	Death	Frostbite	Altitude Sickness	Normal Route	Bottled Oxygen	Climbers	Sherpas	Leader	Team	Sherpas
Other Eastern Europe	22	40.9	58.3	25.0	16.7	4.2	75.0	91.7	9.97	10.48	1.77	0.4	0.29
Other Countries	55	47.3	65.5	5.5	1.8	1.8	83.6	81.8	10.81	31.90	3.65	0.43	1.20
International	475	100	56.8	17.7	9.1	6.3	68.6	71.4	10.96	10.01	3.89	1.04	0.77

Note: There are a total of 1,909 expeditions. In the "Expeditions" columns, the "Total" contains the number of expeditions that include at least one member from that country group, and the "(%) International" contains the percentage of expeditions in which a member from that country has teammates from one or more other countries. The "Pakistan/Nepal" row excludes expeditions where nationals from those countries serve as high-altitude porters or guides for other expeditions. The "International" row contains data for expeditions involving two or more nations.

barely half that of the former Soviet Union. Chinese and Indian expeditions on average are three to four times larger than those of other countries. The Japanese and Koreans are least likely to climb in international expeditions. The Indians and the Chinese have the highest death rates. The Polish have the most experienced leaders and climbers. The most experienced Sherpas are on expeditions led by India, Pakistan, and Nepal, which are the same countries (along with Tibet) that supply most high-altitude porters.

Empirical Results

We now turn to an analysis of the data to estimate the marginal effects of different factors. We drop 167 expeditions for which there is no information about the size of the climbing team. In 596 of the 1,742 remaining expeditions, we do not know whether any Sherpas are employed, and in these cases, we set the number of Sherpas to zero.[35]

We estimate the probability of the four expedition outcomes using a probit model. Table 4 contains the marginal effects and, because the maximum likelihood estimation assumes asymptotic normality, their z values. Panel (a) presents the results for the ascents outcome, Panel (b) for the deaths outcome, Panel (c) for the frostbite outcome, and Panel (d) for the altitude sickness outcome. Each of the four outcome equations is estimated with five specifications. We present a variety of specifications for each model to check the robustness of the results. Model 1 includes the expedition characteristics from Table 1 plus a year–time trend, representing a general improvement in technology over time, and country and mountain effects.[36] Model 2 replaces the year–time trend with year fixed effects. Model 3 is the same as Model 1 except that dummy variables are included for three important technological advances: the introduction of nylon ropes in 1945, the development of the first technical ice climbing axe in 1968, and the advent of plastic boots in 1979. Model 4 contains the same variables as Model 1, but the sample is restricted to the period 1970-1998. Model 5 augments Model 1 with wind and temperature data that are expedition specific.[37] This effectively restricts the sample to 1978-1994, the period during which the weather data were available.

Expeditions appear to learn from the cumulative industry-wide experience of others. Every additional 100 expeditions that preceded an expedition up a given mountain—a proxy for the knowledge gained from those experiences (Argote 1993)—increases its ascent probability by .1 to .2, decreases its frostbite probability by .03 to .06, and decreases its altitude sickness probability by .02 to .06.[38] The average ascent, frostbite, and altitude sickness probabilities are about .45, .08, and .05, respectively; so these changes in the probabilities represent between 25% and 50% changes in the base results. These results are all subject to qualification, as none of the results are statistically significant at the 10% level in the year effects specification (Model 2). Furthermore, given the linearity between outcomes and prior

Table 4. Marginal Effects of Expedition Characteristics on Outcomes

	(a) Ascents					(b) Deaths				
	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
Cumulative prior expeditions on mountain (×100)	0.093***	0.100	0.113***	0.204***	0.169**	−0.006	−0.023	0.010	0.025	−0.095*
	(2.82)	(1.61)	(3.19)	(4.81)	(2.05)	(−0.3)	(−0.61)	(0.44)	(0.99)	(−1.92)
Cumulative prior national expedition on mountain (×100)	0.056	0.066	0.054	0.025	0.228	0.018	0.017	0.016	−0.006	−0.027
	(0.5)	(0.52)	(0.47)	(0.22)	(1.17)	(0.27)	(0.26)	(0.25)	(−0.1)	(−0.23)
Leader's experience	0.005	0.008*	0.005	0.006	0.005	−0.001	−0.001	0.000	0.000	0.000
	(1.11)	(1.8)	(1.23)	(1.42)	(0.93)	(−0.2)	(−0.3)	(−0.04)	(−0.16)	(−0.03)
Climbers' experience	0.066***	0.073***	0.068***	0.070***	0.077***	−0.001	0.000	0.001	0.001	0.004
	(4.72)	(5.1)	(4.81)	(4.97)	(4.15)	(−0.07)	(−0.01)	(0.06)	(0.07)	(0.36)
Sherpas' experience	0.048***	0.047***	0.048***	0.046***	0.026***	0.006	0.006	0.006	0.006	0.008*
	(6.03)	(5.79)	(6.06)	(5.76)	(3.03)	(1.46)	(1.37)	(1.47)	(1.48)	(1.69)
Bottled oxygen (0/1)	−0.187***	−0.153***	−0.183***	−0.175***	−0.209***	0.033	0.040*	0.037*	0.039*	0.047**
	(−5.88)	(−4.59)	(−5.7)	(−5.34)	(−5.31)	(1.61)	(1.95)	(1.8)	(1.92)	(2.09)
Normal route (0/1)	0.205***	0.211***	0.212***	0.206***	0.216***	−0.020	−0.016	−0.015	−0.016	−0.014
	(6.7)	(6.57)	(6.89)	(6.46)	(5.67)	(−0.96)	(−0.73)	(−0.7)	(−0.75)	(−0.6)
Guided expedition (0/1)	0.140*	0.135	0.138*	0.128	0.154	−0.014	−0.033	−0.016	−0.021	−0.005
	(1.75)	(1.63)	(1.72)	(1.61)	(1.48)	(−0.27)	(−0.7)	(−0.32)	(−0.46)	(−0.08)
Number of climbers	0.008***	0.008**	0.007**	0.008**	0.012***	0.001	0.001	0.001	0.001	0.001
	(2.6)	(2.56)	(2.48)	(2.58)	(2.67)	(1.12)	(1.08)	(0.98)	(0.85)	(0.67)
Number of Sherpas	0.006***	0.005**	0.006***	0.004	0.033***	0.002*	0.002*	0.002**	0.002	−0.002
	(2.89)	(2.3)	(2.98)	(1.54)	(4.23)	(1.96)	(1.76)	(2.08)	(1.25)	(−0.64)
Percentage female climbers	0.241**	0.211**	0.236**	0.272***	0.104	0.060	0.068	0.056	0.041	0.066
	(2.42)	(2.07)	(2.36)	(2.66)	(0.86)	(0.94)	(1.06)	(0.88)	(0.65)	(0.94)
Large national expedition (0/1)	0.123***	0.110**	0.119**	0.096*	0.025	0.055*	0.044	0.050	0.056*	0.017
	(2.59)	(2.28)	(2.48)	(1.91)	(0.38)	(1.79)	(1.45)	(1.64)	(1.8)	(0.5)

(continued)

Table 4. (continued)

	(a) Ascents					(b) Deaths				
	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
International expedition (0/1)	−0.071	−0.071	−0.068	−0.055	−0.151**	−0.002	−0.002	0.000	0.027	0.005
	(−1.4)	(−1.34)	(−1.33)	(−1.06)	(−2.28)	(−0.05)	(−0.06)	(−0.01)	(0.76)	(0.12)
Autumn (0/1)	−0.099***	−0.079**	−0.094***	−0.075**	−0.071*	0.039	0.047*	0.043*	0.034	0.018
	(−2.91)	(−2.21)	(−2.76)	(−2.12)	(−1.68)	(1.61)	(1.86)	(1.72)	(1.39)	(0.65)
Winter (0/1)	−0.309***	−0.300***	−0.306***	−0.297***	−0.033	0.034	0.040	0.038	0.024	−0.032
	(−5.98)	(−5.08)	(−5.84)	(−5.22)	(−0.32)	(0.73)	(0.83)	(0.8)	(0.54)	(−0.66)
Year (×100)	0.572***		0.002	−1.345***	−1.316	−0.383***		−0.007***	−0.915***	−0.325
	(2.91)		(0.49)	(−2.99)	(−1.57)	(−3.9)		(−2.69)	(−3.27)	(−0.64)
Nylon rope (=1, 1945+)								0.058		
								(0.78)		
Technical axes (=1, 1968+)			0.218**					0.103***		
			(2.11)					(2.88)		
Plastic boots (=1, 1979+)			−0.043					−0.001		
			(−0.6)					(−0.03)		
Wind (m/s)					−0.030**					−0.008
					(−2.52)					(−1.05)
Temperature (Celsius)					0.022***					−0.003
					(4.64)					(−1.07)
Country effects, χ^2 (23)	43.9***	42.7***	43.0**	43.4***	51.5***	32.6*	37.6**	34.2*	35.8**	40.6**
Mountain effects, χ^2 (13)	105.2***	97.8***	108.3***	116.6***	99.0***	33.0***	28.1***	30.3***	31.9***	31.3***
Year effects, $\chi^?$ (N)	No	135.0***	No	No	No	No	55.9**	No	No	No
Number of observations	1,742	1,707	1,742	1,640	1,228	1,742	1742	1742	1640	1228
Likelihood ratio test (LRT)	458.5***	499.1	462.5***	412.7***	386.3***	169.6***	211.0	173.6***	156.2***	128.5***
LRT degrees of freedom	52	83	54	52	54	52	89	55	52	54
Pseudo R^2	.190	.211	.191	.182	.223	.105	.131	.108	.107	.121

Table 4. (continued)

	(c) Frostbite					(d) Altitude sickness				
	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
Cumulative prior expeditions on mountain (×100)	−0.030**	−0.034	−0.064***	−0.056**	−0.055	−0.030**	−0.001	−0.024*	−0.035**	−0.058*
	(−2.49)	(−1.27)	(−3.1)	(−2.49)	(−1.45)	(−2.49)	(−0.06)	(−1.81)	(−2.14)	(−1.66)
Cumulative prior national expedition on mountain (×100)	0.002	0.063	0.074	0.063	0.035	0.002	0.004	0.002	0.014	0.078
	(0.05)	(1.25)	(1.41)	(1.25)	(0.4)	(0.05)	(0.12)	(0.05)	(0.37)	(1.21)
Leader's experience	0.000	−0.001	0.000	−0.001	−0.002	0.000	0.000	0.000	−0.001	−0.001
	(−0.07)	(−0.33)	(−0.26)	(−0.51)	(−0.75)	(−0.07)	(−0.16)	(0.07)	(−0.36)	(−0.46)
Climbers' experience	0.005	−0.006	−0.005	−0.004	−0.003	0.005	0.004	0.006	0.006	0.010*
	(1.29)	(−0.94)	(−0.74)	(−0.65)	(−0.37)	(1.29)	(1.1)	(1.32)	(1.38)	(1.82)
Sherpas' experience	−0.002	0.001	0.001	0.001	0.002	−0.002	−0.002	−0.002	−0.002	−0.002
	(−0.76)	(0.4)	(0.35)	(0.24)	(0.57)	(−0.76)	(−0.78)	(−0.74)	(−0.62)	(−0.43)
Bottled oxygen (0/1)	−0.011	−0.036**	−0.038**	−0.028*	−0.024	−0.011	−0.010	−0.008	−0.008	−0.022
	(−0.95)	(−2.39)	(−2.46)	(−1.87)	(−1.35)	(−0.95)	(−1.01)	(−0.75)	(−0.72)	(−1.39)
Normal route (0/1)	−0.002	−0.005	−0.004	−0.001	−0.006	−0.002	−0.001	0.000	0.000	−0.001
	(−0.23)	(−0.39)	(−0.31)	(−0.05)	(−0.37)	(−0.23)	(−0.07)	(0.02)	(0.04)	(−0.07)
Guided expedition (0/1)	0.038	−0.007	−0.002	−0.003	−0.038	0.038	0.021	0.036	0.036	0.038
	(0.89)	(−0.22)	(−0.06)	(−0.1)	(−1.46)	(0.89)	(0.63)	(0.87)	(0.87)	(0.69)
Number of climbers	0.000	0.000	0.000	−0.001	−0.001	0.000	0.000	0.000	0.000	0.000
	(−0.18)	(−0.04)	(−0.27)	(−0.69)	(−0.66)	(−0.18)	(−0.31)	(−0.37)	(−0.08)	(0.38)
Number of Sherpas	0.000	0.000	0.000	0.000	−0.001	0.000	0.000	0.000	0.000	0.000
	(0.99)	(0.27)	(0.35)	(−0.01)	(−0.33)	(0.99)	(1.3)	(1.17)	(−0.02)	(−0.05)
Percentage female climbers	−0.014	−0.022	−0.014	−0.007	0.019	−0.014	−0.012	−0.015	−0.010	−0.010
	(−0.4)	(−0.52)	(−0.33)	(−0.17)	(0.39)	(−0.4)	(−0.41)	(−0.45)	(−0.3)	(−0.24)

(continued)

Table 4. (continued)

	(c) Frostbite					(d) Altitude sickness				
	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
Large national expediton (0/1)	0.022	0.038*	0.044*	0.030	0.041	0.022	0.022	0.021	0.010	0.015
	(1.27)	(1.76)	(1.9)	(1.34)	(1.22)	(1.27)	(1.36)	(1.24)	(0.64)	(0.61)
International expedition (0/1)	0.003	0.021	0.017	0.020	0.013	0.003	0.005	0.004 (0.	0.001	0.005
	(0.21)	(0.95)	(0.76)	(0.91)	(0.46)	(0.21)	(0.34)	22)	(0.05)	(0.23)
Autumn (0/1)	−0.009	0.032**	0.031*	0.030*	0.036*	−0.009	−0.010	−0.009	−0.008	0.001
	(−0.82)	(1.99)	(1.86)	(1.82)	(1.77)	(−0.82)	(−1.13)	(−0.85)	(−0.68)	(0.05)
Winter (0/1)	−0.003	0.047	0.043	0.029	−0.041*	−0.003	−0.006	−0.003	−0.001	0.087
	(−0.14)	(1.18)	(1.1)	(0.82)	(−1.9)	(−0.14)	(−0.38)	(−0.16)	(−0.05)	(1.05)
Year (×100)	0.022		0.000	−0.204	−0.192	0.022		−0.001	−0.032	0.056
	(0.44)		(−0.09)	(−1.1)	(−0.54)	(0.44)		(−1)	(−0.2)	(0.17)
Nylon rope (=1, 1945+)			0.038					0.018		
			(1.34)					(0.55)		
Technical axes (=1, 1968+)			−0.019					0.031**		
			(−0.38)					(2.54)		
Plastic boots (=1, 1979+)			−0.025					0.012		
			(−0.75)					(0.65)		
Wind (m/s)					0.002					0.003
					(0.36)					(0.75)
Temperature (Celsius)					−0.004***					0.003*
					(−2.75)					(1.68)
Country effects, χ^2 (23)	32.1*	36.5**	37.9**	30.2	20.0	32.1*	32.6*	33.2*	34.3**	35.9**
Mountain effects, χ^2 (13)	32.3***	8.7	11.1	11.6	14.8	32.3***	26.1**	29.9***	31.4***	19.6*
Year effects, χ^2 (N)	No	32.6*	No	No	No	No	67.0***	No	No	No
Number of observations	1666	1693	1742	1640	1228	1666	1594	1666	1564	1106
Likelihood ratio test (LRT)	94.8***	145.2	125.9***	102.3***	68.0*	94.8***	118.9	97.4***	91.9***	84.9***
LRT degrees of freedom	51	84	55	52	54	51	81	54	51	51
Pseudo R^2	.128	.144	.124	.114	.101	.128	.163	.132	.136	.153

Note: Absolute value of z statistics in parentheses. ***Significant at 1% level. **Significant at 5% level. *Significant at 10% level. Korea is omitted from the models of altitude sickness. Individual mountain and country effects coefficients are not reported. "(0/1)" indicates marginal effect for discrete change. Degrees of freedom for year dummies: $N = 31$ (ascent), 38 (death), 24 (frostbite), 29 (altitude sickness). "No" means the effect was not included in this specification.

experience in our specification, these inferences are restricted to a narrow range of additional expeditions, because it is unlikely that an additional 500 to 1,000 expeditions to Mt. Everest would result in 100% success rates.

There appear to be no learning-by-doing effects regarding the deaths outcome. This suggests that although knowledge concerning such matters as the easiest route up a mountain and how to avoid frostbite and altitude sickness are passed between expeditions, knowledge of how to avoid avalanches and falling rocks or ice and when it is best to turn around rather than to continue an attempt are things that are not easily learned from others.

Furthermore, while we find evidence of knowledge spillovers from previous expeditions on a mountain, we find that the cumulative experience of the nations represented on an expedition does not appear to be a distinct channel of learning for any of the outcomes. The fact that all climbers converge upon the mountains through the same cities (Katmandu and Islamabad, where most climbers pick up their permits) in the season that is best for climbing suggests that climbers will find it easy to communicate with climbers from many other countries. In addition, we show evidence below that expedition reports appear in a wide variety of alpine journals. Thus, climbers may view the experience of their compatriots as only one among many sources of information.

We also find that human capital of individuals matters, albeit in a very specific way. What we see is that the average climbers' and Sherpas' experience level has a positive effect upon ascents, but we find no robust effects on the other outcomes.[39] This suggests that personal experience matters in learning actually how to climb these mountains. We find that one additional prior expedition for each expedition member increases the probability of an ascent by between .066 and .077 for climbers and by between .026 and .48 for Sherpa support members. Thus, both personal experience and what one can gather from others affect outcomes. Knowledge about how to avoid frostbite and altitude sickness appears to be due only to knowledge spillovers, not from learning by doing.

We also find that greater leader experience does not improve outcomes. This is in contrast to the results found by Karpoff (2001) with respect to arctic expeditions, but our results are not surprising in that climbing organizations tend to be quite informal; teams are formed for a specific objective and are disbanded after the objective is completed or abandoned.[40] It is also the case that some of the most experienced leaders were not themselves the main climbers: Karl Maria Herrligkoffer of Germany, for example, led 20 expeditions but never climbed above base camp. Indeed, on one Mt. Everest expedition, Herrligkoffer was flown into base camp by helicopter, where he promptly showed signs of altitude sickness and had to be flown out again. A less extreme example is Chris Bonington, who climbed in a dozen expeditions, five of which he led, but typically acted as support to the principal climbers, making an attempt on the summit himself only after other members of the expedition had succeeded.

There are a number of other interesting results. Expeditions that use bottled oxygen are between .15 and .21 less likely to make an ascent and, in four of the five specifications, between .037 and .047 more likely to suffer a death.[41] This suggests that the costs of carrying bottled oxygen may be quite high, due to a complacent reliance on technology (a "lulling effect," see Peltzman 1975, Viscusi 1984), due to an increased exposure to risk because of the greater logistical demands of carrying and deploying oxygen to high camps, or due to the danger a climber faces if he is not properly acclimatized and his bottled oxygen inadvertently runs out at altitude. However, we do observe in three of the five specifications that expeditions that used bottled oxygen were .028 to .036 less likely to suffer from frostbite. Because frostbite occurred in about 8% of expeditions, these expeditions experienced frostbite rates of one third to one half that of the typical expedition.

Climbing the normal route on a mountain increases the probability of an ascent by .2, or approximately a 50% increase in the average probability. Guided expeditions are about .15 more likely to make an ascent and are no more likely to suffer an adverse outcome than a nonguided expedition. We attribute this to the fact that the average guided expedition has more experienced leaders (4.62 vs. 2.06 previous 8,000-m peaks expeditions; $\chi^2 = 41.7$, $p < .01$), more experienced climbers (0.59 vs. 0.51; $\chi^2 = 5.78$, $p = .02$), and more experienced Sherpas (1.76 vs. 0.60; $\chi^2 = 11.5$, $p < .01$). These results are likely to be surprising to critics of guided climbing. Krakauer (1997), for example, noted that his fellow client Charlotte Fox had climbed an 8,000-m peak before (Gasherbrum II) but largely dismissed this as being irrelevant. Fox, like Krakauer, reached the summit and survived her Mt. Everest climb.

We also find evidence of expedition size effects. Each additional climber or Sherpa on a team raises the probability of an ascent, but additional Sherpas slightly increase the probability of a death as well. Teams with female members are about .25 more likely to make an ascent, but whether this is due to the high quality or beneficial effects of female team members, to females participating in higher quality expeditions, or perhaps to climbing being an extreme expression of sex competition, we cannot tell. Large national expeditions have about a .12 higher probability of an ascent than other expeditions but also suffer higher rates of death and frostbite (although this is found in only two of the five specifications), so such expeditions appear to be only moderately more successful in Himalayan climbing than in arctic exploration as studied by Karpoff (2001). As a point of comparison, Karpoff noted that one reason publicly funded arctic expeditions were more likely to fail was that their leadership structure was often disassociated from the expeditions themselves. We find that mountaineering expeditions in which the leader was not a climber do experience a lower ascent rate on average (35% vs. 46%; $\chi^2 = 4.48$, $p = .03$), but this effect disappears when this variable is included in the multivariate regressions. Just 99 of the 1,909 expeditions (5.2%) had nonclimbing leaders, and almost a quarter of these were led by Karl Herrligkoffer. As mentioned above, Herrligkoffer was decidedly not a climber, but the expeditions he organized to Nanga Parbat in 1962 and in 1970 each succeeded on a new route to the summit.

International expeditions are less likely to make an ascent, although this result is statistically significant at the 10% level in Model 5 only. In terms of adverse outcomes, international expeditions are no different from expeditions that form within a single country. Expeditions in the autumn are less likely to be successful and more likely to suffer frostbite; winter expeditions are much less likely to be successful but are no more likely to suffer any adverse outcome.

We attempted to measure technical change in several ways. The effects we find from technological change are, however, somewhat ambiguous. When a time trend variable is included, we find that the time trend is negative and significant in the deaths equation in three of four specifications. Furthermore, a plot of the marginal effects of the year-dummy variables when they are included in the deaths, frostbite, and altitude equations reveals that the average marginal effect is declining over time in each ($p < .01$), based on an ordinary least squares estimate of the effect of a time trend on the estimated dummy variable parameters.[42] In the ascents equation, however, the results are more mixed. The year–time trend marginal effect is statistically significant in only two of the cases, and in Model 1, it has a positive sign, but in Model 4, which uses data from 1970 forward, it is negative. A plot of the year-dummy marginal effects for ascents reveals that these are declining in the latter part of the sample, although on average they are increasing over time ($p < .01$). When we measure technical change using the combination of a time trend and dummy variables, which switch from zero to one in value after important innovations such as nylon ropes, technical ice axes, and plastic boots occurred, we find that the time trend in the ascents equation is statistically insignificant and that the advent of technical axes increased the ascent rate by .218. We also find, however, that the introduction of technical axes corresponded to an increase in the death rate of .103 and an increase in the rate of altitude sickness of .031. With technical axes, climbers were able to attempt more difficult climbs, which may account for the increase in death rates. The introduction of technical axes, however, was contemporaneous with the opening of the mountains to private expeditions after 1970. Thus, the dummy variable for the introduction of technical axes may be confounded with the easing of access. This is also consistent with the increase in death rates. The introduction of plastic boots and nylon ropes had no effects upon the outcomes. We cannot, however, estimate the effect of nylon ropes on ascents, as no ascents of 8,000-m peaks occurred prior to the introduction of nylon ropes.

When we include measures of wind speed and temperature in the regressions, we find that each has the expected effect on ascents: expeditions that faced less wind were more likely to make an ascent, as were expeditions that experienced higher temperatures. Similarly, we find that as the temperature rises, expeditions are less likely to experience frostbite, although the effect is relatively quite small (a reduction of .004 on the average frostbite rate of .08). We find, however, that expeditions that experienced higher temperatures were more likely to experience altitude sickness. We ascribe this result to the fact that all expeditions typically face only brief windows of good weather and thus may be tempted to push too hard while they have the chance.

Finally, as shown in Table 3, late entry to the climbing industry may allow some countries to start with a stronger set of skills (Argote, Beckman, & Epple, 1990); for the countries that began climbing in the pre–Second World War era (Britain, United States, France, Germany, Italy, Switzerland, and Japan), the overall ascent rate is never higher than 51.6%, and only Italy, Switzerland, and Germany have success rates in excess of 50%. In contrast, among countries whose first expedition occurred between 1950 and 1970, only two have ascent rates less than 50% (Canada and Australia/New Zealand), and more than half make an ascent over 55% of the time. Although these results might reflect different climbing objectives, they remain apparent in the multivariate analysis, which controls for mountain and route effects. Furthermore, in parallel with Thompson's (2001) observation that in the Liberty Ships program some shipyards appear to have traded quality for quantity of output, it may be that some countries have traded lives for an ascent. In particular, the former Soviet Union and Czechoslovakia, as well as the Latin American countries, may be guilty of this.[43]

We have also attempted to control for potential endogeneity of bottled oxygen use. These results are not reported here, but they differ only slightly from the probit estimation results. This is not surprising, because the large dip in bottled oxygen use in the early 1980s (see Figure 4) did not correspond to observable changes in the outcomes in Figure 1.

Discussion and Conclusions

This article has measured the economic impact of a number of causes for the increase in ascent rates and decrease in death, frostbite, and altitude sickness rates of expeditions to the 8,000-m peaks. Both human capital accumulation and technological change have been shown to be very important in the development of this industry. We also find compelling evidence of broad knowledge spillovers across expeditions over time and at the international level, in that an increase in the number of prior expeditions to a mountain, regardless of the national origin of the leaders and climbers, decreases frostbite and altitude sickness rates. Thus, in an interesting contrast to previous literature that uses patent citations to trace knowledge flows, we find no evidence of the geographic localization of spillovers.

We have argued that the reason for this difference lies in the incentives faced by climbers to provide accurate information so that future climbers may provide credibility to their accomplishments. Although climbers come from many countries and speak many different languages, which might suggest localized sharing of knowledge, they make their reputations by telling the world about what they have done. Unlike obtaining a patent, which reveals to others how to mimic one's work, publishing a description of a first or difficult ascent in greater detail merely allows the claim to be verified, and mimicry cannot diminish the claim. Thus, climbers who push the limits of what is possible have excellent reasons to publish this information in the international climbing literature.[44] The hazardous nature of high-altitude mountaineering provides a strong incentive for information gathering from all possible sources, assuring that reports of the exploits of expeditions from many

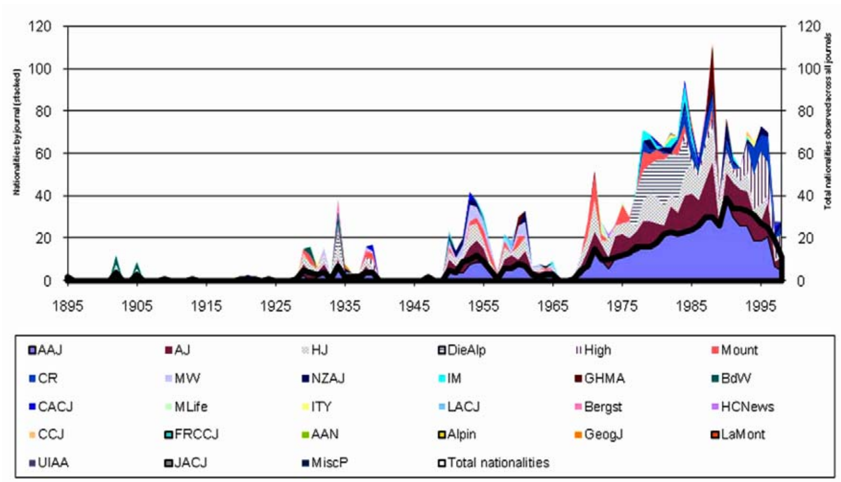

Figure 6. Nationalities in expeditions to the 8,000-m peaks as covered by mountaineering journal articles, 1895-1998.

Notes: The number of nationalities appearing in each journal is stacked; total nationalities appearing are given by a thick black line. Journals are the *American Alpine Journal* (*AAJ*), *Alpine Journal* (*AJ*), *Himalayan Journal* (*HJ*), *Die Alpen* (*DieAlp*), *High Mountain Sports* (*High*), *Mountain* (*Mount*), *Climber & Hill-Walker/Rambler* (*CR*), *Mountain World* (MW), *New Zealand Alpine Journal* (*NZAJ*), *Indian Mountaineer* (*IM*), *Groupe de Haute Montagne Annuaire* (*GHMA*), *Berge der Welt* (*BdW*), *Canadian Alpine Club Journal* (*CACJ*), *Mountain Life* (*MLife*), *Iwa To Yuki* (*ITY*), *Ladies Alpine Club Journal* (*LACJ*), *Bergsteiger* (*Bergst*), *Himalayan Club Newsletter* (*HCNews*), *Climbers Club Journal* (*CCJ*), *Fell & Rock Climbing Club Journal* (*FRCCJ*), *American Alpine News* (*AAN*), *Alpin* (*Alpin*), *Geographical Journal* (*GeogJ*), *La Montagne* (*LaMont*), *World Mountaineering + Climbing* (*UIAA*), *Japanese ACJ* (Sangaku; *JACJ*), and miscellaneous periodicals (*MiscP*). Data are from the *Himalayan Index*.

countries will appear in English-, French-, German-, Spanish-, and even Japanese-language journals and that this literature will be widely available around the world.

Figure 6 and Table 5 provide support for the latter claim. Figure 6 displays the number of expedition nationalities that appear in mountaineering journal articles published about expeditions to the 8,000-m peaks that occurred between 1895 and 1998. These data are taken from the *Himalayan Index*, which provides the disclaimer that although its coverage of articles from the *Alpine Journal, American Alpine Journal*, and *Himalayan Journal* is comprehensive, the data include very few articles from non-English-language journals. Despite this bias toward English-language journals, it is seen in Figure 6 that many different nationalities are represented in the reports. Furthermore, reports appear in a large number of journals; the average expedition to the 8,000-m peaks during these years is typically covered in more than

Table 5 Earliest Recorded Holdings of Four Mountaineering Journals in Libraries, Various Countries

Country	*Alpine Journal*	*American Alpine Journal*	*Die Alpen*	*Himalayan Journal*
Australia	1972			1929
Austria	1863		1927	
China		1957		1930
Czech Republic				1931
Denmark	1949			
Finland			1956	
France	1864	1929		
Italy	1903	1929		
Japan	1863	1929	1925	1929
Netherlands		1932		
New Zealand	1949	1939		
South Africa	1863			

Note: Data were obtained by searches of national library catalogues using IFLANET (International Federation of Library Associations and Institutions, http://www.ifla.org) and other library catalogues using Libdex (http://www.libdex.com/).

one journal and sometimes in as many as six. A nonscientific and nonexhaustive search of the online catalogs of a number of libraries around the world provided the information given in Table 5 on the earliest date of their holdings of the *Alpine Journal, American Alpine Journal, Die Alpen*, and the *Himalayan Journal*. Assuming that these holdings were obtained at the time they were published and were accessible to interested parties in those countries, they give an indication of the early international interest in mountaineering. The data suggest that published material that covers expeditions from many nations has been readily available worldwide, increasing the likelihood that information gathering will include international sources.

We also find that part of the increase in success rates can be attributed to a change in the objectives and methods of climbers. Although high-altitude mountaineering has always been a hazardous affair, in the early days, it was made more so because climbers often had no knowledge of what they would encounter on a given mountain or route. Today's climbers embark on their journey with a good deal of knowledge of what to expect, in part due to the wide reporting of previous exploits. In addition, fewer climbers are tackling difficult routes or using methods such as alpine climbing that increase the chance of failure. Guided expeditions, in particular, allow climbers with little experience to use the knowledge of others. The fact that these are typically large teams that use bottled oxygen, climb on the normal route, and use plenty of Sherpa support suggests that these expeditions have indeed learned these lessons.

Notes

1. The fourteen 8,000-m peaks of the Himalaya and Karakoram mountains of India, Nepal, Pakistan, and Tibet are (in descending order of elevation) Mt. Everest, K2,

Kangchenjunga, Lhotse, Makalu, Cho Oyu, Dhalagiri, Manaslu, Nanga Parbat, Annapurna, Hidden Peak (Gasherbrum I), Gasherbrum II, Broad Peak, and Shisha Pangma.

2. Altitude sickness includes acute mountain sickness (AMS), high-altitude pulmonary edema (HAPE), and high-altitude cerebral edema (HACE; Houston 1998).
3. We also examine data from 143 expeditions to Mt. Everest over 1995-1998. Table 1 shows that the data are most similar to the data in the 1990s from other mountains.
4. Some technologies changed incrementally through the years. Anker and Roberts (2001, p. 166) note that their expedition's oxygen equipment weighed 14 pounds, compared to 30 for Mallory, and each modern bottle provided two to three times as much oxygen. This sort of technological improvement is typically measured through the inclusion of a time trend variable. Other innovations occur at specific observable times. For example, after the Second World War, nylon ropes, which stretch to absorb some of the shock in a fall, replaced hemp ropes, for which the motto was "the leader must not fall." Other new technologies for which the time of introduction is known include technical ice axes (1968), which allowed climbers to climb steep and even vertical or overhanging ice; spring-loaded cams (1978), which allowed climbers to set removable protection in rock; and plastic boots (1979), which remained dry and provided better insulation than leather boots (see Parsons and Rose 2003). The effects of these events can be modeled with dummy variables that turn on once the technology becomes available. The adoption of most technological improvements was relatively uncontroversial—only the French continued climbing up mountains walking backward (using the *pied a plat* or "flat-footed" technique) or cutting steps on 10-point crampons for a decade after the advent of the 12-point crampons (the 10-point crampons did not have points sticking out toward the front of the foot that enabled one to climb facing the mountain).
5. While learning by doing has been studied extensively since the 1930s, there has recently been new interest in what had been a fairly settled literature. In large part, this resurgence of interest has focused on two issues: the extent to which learning by doing has been mismeasured in the presence of other sources of productivity gains such as capital investments (Thompson 2001) and the extent to which such learning, and in general any knowledge applicable to improving productivity, spills over across organizations and geographically (Zimmerman 1982, Jaffe et al., 1993, Irwin and Klenow 1994, Joskow and Rose 1985, Thornton and Thompson 2001, Thompson 2006).
6. A policy change by the governments of Nepal and Pakistan allowed individuals to apply for permission to climb mountains, beginning in the 1970s. Prior to that, expeditions typically obtained permission when the national government of the home country would obtain permission from the government of the country in which the expedition was to occur. Tibet, which had served as the pre–World War II era approach to Mt. Everest, was closed to foreign climbers by the Chinese after their invasion of Tibet in 1950. The Chinese did not allow foreign climbers to climb in Tibet until 1980. In the late 1970s, however, there were reports of climbers illegally venturing into Tibet to climb Cho Oyu, which is located on the Nepal–Tibet border.
7. In other contexts, improvements in performance have been shown to occur through learning by doing by individuals (see Argote 1993 for a survey), through internal spillovers of

knowledge among individuals within a firm or across units of an organization (for example, Epple, Argote, & Murphy, 1996, Darr, Argote, & Epple, 1995, Zimmerman 1982, Joskow and Rose 1985, Irwin and Klenow 1994, Benjamin and Tifrea 2007), and through external spillovers of knowledge from one firm to another within an industry.

8. The Sherpas are Nepalese of Tibetan descent living in the Khumbu valley near Mt. Everest. They are often hired by mountaineering expeditions to be high-altitude porters, carrying loads and sometimes taking a more active role in the climb. Other cultural groups that have a history of serving as high-altitude porters include the Balti and Hunzi, regional groups in Pakistan. In what follows, we refer to people working in these roles as "Sherpas," but the cultural heritage of the people doing these tasks may be quite diverse.
9. In the knowledge-spillovers literature, new data sets have allowed researchers to trace out learning by following patent citations (e.g., Jaffe et al., 1993, Thompson 2006) and productivity in manufacturing, although none of these studies can distinguish between individual learning and external spillovers. Furthermore, while patent citations can establish the pattern of knowledge flows, models based on patent citations have not established the effect such learning has had on productivity. The data set used in the current study allows for the exploration of such a connection. Moreover, microlevel studies, which may have the best hope of disentangling the effects of learning by doing, knowledge spillovers, and productivity-enhancing investments, are rare. Reagans, Argote, and Brooks (2005) is the first study we know of that estimates effects of individual learning separately from organizational experience.
10. In this respect, our results are similar to those of Allen (2007), who found that miners in the remote environment of the Klondike gold rushes of 1896-1899 widely shared information about their finds, unlike miners in earlier gold rushes. Allen argues that a necessary condition for revealing information is secure property rights—that a claim cannot be stolen or encroached upon. In the case he examines, this was facilitated by the presence of a strong police force.
11. There are a few disputed ascents of the 8,000-m peaks. Perhaps, the most famous of these is the claimed first solo ascent of the south face of Lhotse by Tomo Cesen in 1990. Cesen has since retracted that he made the summit, claiming to have made only the summit ridge. Even this is disputed.
12. Argote and Epple (1990) suggest that transfer of knowledge across firms can occur by, for example, the movement of personnel, communication, or participation in meetings and conferences. In high-altitude mountaineering, climbers' published records of their exploits are filled with descriptions of interactions with other climbing expeditions that were in the area. As well as the usual descriptions of what climbers observe concerning the gear and methods that other expeditions use, some include accounts of fistfights as climbers compete for scarce campsites.
13. There are examples where deaths have led to information about hazards. For example, on the 1963 American expedition to Mt. Everest, climber Jake Breitenbach's death in the Khumbu icefall due to a falling serac (a house-sized block of ice) taught all future expeditions to travel through the icefall early in the day and as quickly as possible.

14. The use of bottled oxygen also requires some technical expertise. Sandy Irvine, who would die with George Mallory on their 1924 attempt on Mt. Everest, was selected for the summit team not because of his climbing abilities but because of his abilities in working with the bottled-oxygen apparatus.
15. The deaths of George Mallory and Sandy Irvine in 1924 effectively ended the British attempts at climbing Everest using large-scale expedition tactics until their return in 1953. The Germans lost 10 men in the 1934 expedition to Nanga Parbat and another 16 men in 1937. They were undeterred by these losses, however, mounting expeditions again in 1938 and 1939. The 1939 expedition became embroiled in the Second World War when the British held the team members as prisoners. Heinrich Harrier, one of four German climbers to escape from the British prison camp, later wrote of his experiences living in Tibet in the book *Seven Years in Tibet* (Harrier 1954/1997). The 1953 American expedition to K2 almost ended in disaster when, while climber Art Gilkey, who suffered from blood clots in the leg, was being lowered, one climber fell, causing the rest of the team of climbers to begin to fall. They were saved when the seventh climber on the team, Pete Schoening, was able to use his ice axe to belay the other climbers. Only Gilkey, who disappeared in the fall (perhaps from cutting the rope himself), died. Schoening, together with Andy Kauffman, would make the first ascent of Hidden Peak in 1958.
16. Buhl died climbing Chogolisa (7,654 m) shortly after taking part in the first ascent of Broad Peak (his second first ascent of an 8,000-m peak) in June 1957.
17. The Broad Peak expedition had only four members, although they still placed fixed camps.
18. Bottled oxygen is coded as one whenever *all* members of the expedition use bottled oxygen on the ascent attempt. Bottled oxygen use was not reported for over 1,200 of the expeditions in our sample. As a climb that does not use bottled oxygen is highly regarded by climbers, we assume that even if bottled oxygen use was not reported, then the expedition used bottled oxygen. An exception to this was if the reported expedition style was solo (because carrying bottled oxygen is too much of an increase in gear for an expedition unsupported by Sherpas), alpine (which by definition eschews fixed ropes and bottled oxygen), or reconnaissance (as such expeditions rarely get to an altitude requiring bottled oxygen). In those cases, we assume that the expedition did not use oxygen when it is not reported.
19. The normal route is the first-ascent route, except on Mt. Everest, where we also include Mallory's North Col route (first ascended by the Chinese in 1960), which has been attempted by 170 expeditions (35%), and on Nanga Parbat, where we also include the Diamir Face route (first climbed by the Germans in 1962), which has been attempted by 71 expeditions (50%).
20. A fixed rope is one that is left anchored on difficult sections so that the climber is protected in that section.
21. His was not the first attempt at a solo climb of Mt. Everest. Maurice Wilson made an attempt in 1934, Earl Denman made an illegal attempt in 1947, and Klaus Becker-Larsen made an attempt in 1951. None of these climbers had much climbing experience. In fact, it was Becker-Larsen's first time using an ice axe.

22. Houston (1998, p. 199) found that the oxygen carried in the blood by acclimatized climbers at 8,000 m averages about 32% of what it is at sea level, and at the summit of Everest (8,848 m), it is 25% of what it is at sea level. He states that "breathing bottled oxygen increases the percentage, and thus the partial pressure, of inhaled oxygen, in effect 'taking the climber down' a few thousand feet" (p. 220). Houston estimates that a climber using bottled oxygen on the summit of Everest is breathing the equivalent of oxygen at 6,700 m above sea level. Well-prepared climbers may choose not to use bottled oxygen because it goes against their ethic of climbing a mountain. See Loewenstein (1999) for a discussion on motivations of mountaineers such as "self-signaling," "mastery," and "meaning."
23. Bass chose Australia's Mt. Kosciusko (2,228 m) as his summit for Australasia. Carstensz Pyramid in Indonesia is 4,884 m. Canadian Pat Morrow was the first to climb the Seven Summits with Carstensz Pyramid included.
24. Hall had led successful guided expeditions on Everest each year from 1992 to 1995 (Krakauer 1997, pp. 34-35).Although Fischer had acted as a guide on only one previous expedition and was not the lead guide then, Hall said he felt pressure from Fischer, because "he's based in America [and] eighty to ninety percent of the potential market for guided expeditions is in the United States" (quoted in Krakauer 1997, pp 61-67).
25. The experience level of the climbers or Sherpas who go unnamed in an expedition report is assumed to be the same as the average experience of those that are named. When there are no named climbers or Sherpas, all are assumed to have no experience. We have no way of testing this assumption, because we have no method for modeling who is and is not named.
26. When both prior cumulative expeditions and prior national expeditions were included with the year–time trend, each was insignificant in the ascent and deaths equations estimated below. When the year–time trend was omitted, prior cumulative expeditions had the same sign and significance of the omitted year variable, and when both year and prior cumulative expeditions were excluded, prior national expeditions had the same sign and significance level as year. This problem was resolved by using "prior expeditions by mountain" and "prior national expeditions by mountain" instead.
27. Inclusion of the subsidiary peaks is not controversial for mountains such as Kangchenjunga, with four subsidiary peaks over 8,400 m, or Lhotse, with Lhotse Shar, which are viewed as distinct summits. Shisha Pangma's central summit and Broad Peak's foresummit are bumps on the ridge an hour away from the main summit. When climbers claim an ascent of a subsidiary peak, or if they by error claim an ascent of the main summit, we code this as an ascent, albeit of a subsidiary peak. Thus, of the 307 ascents claimed on Shisha Pangma, only 149 are of the main summit. The south summit of Everest is an exception, as no one has claimed reaching the south summit as an ascent. The other subsidiary summits over 8,000 m include the east and middle summits of Annapurna, the south summit of Nanga Parbat, the west summit of Kangchenjunga (also known as Yalung Kang), the south and central summits of Kangchenjunga, and the central summit of Broad Peak.
28. About halfway through the collection of the data, we became aware of a data set called the *Himalayan Database*, which was collected from climbers in Katmandu by Elizabeth

Hawley and compiled by Richard Salisbury. As our requests for use of that data were never fulfilled, we continued to build our own data set. The *Himalayan Index* is an electronic database maintained by the Alpine Club (UK) and made available to us by Mike Westmacott. Unfortunately, the index is designed as a source for climbers, so it contains only the first few expeditions on a route. Nevertheless, the *Himalayan Index* was very useful in that it contained basic information for many expeditions, including the names of the climbers on those expeditions.

29. There are, however, several disputed ascents, including Lydia Bradey's 1988 ascent of Mt. Everest (which probably did occur) and Cesen's ascent of Lhotse in 1990 (which probably did not).
30. Future reports are limited (Anonymous, 1996) to the recording of only the "*significant climbing activity* of the year" [italics theirs], meaning a climb that breaks "new or unusual ground." Because the majority of climbs on all mountains follow previous ascent routes, we include only Everest—for which we had complete information—after 1994. Everest is also of interest because it is Everest, the highest and best known of the 8,000-m peaks.
31. We felt that it was important to include these data if we were to discuss guided expeditions, particularly because the 1996 Everest disaster occurred during this period.
32. The periods roughly correspond to the prewar exploration phase, the 1950-1969 first ascents phase, the 1970s difficult routes phase, the 1980s "by fair means" phase, and the 1990s guided expedition phase.
33. In including a variable that represents public funding, we follow Karpoff's (2001) analysis of 92 arctic expeditions from 1818 to 1909. We were unable to identify the source of funding for most expeditions, but many early expeditions were publicly funded. For example, the Nazi party funded the Austrian-German Nanga Parbat and Kangchenjunga expeditions of the 1930s. Even large "national" expeditions were funded in large part by private donations. The National Geographic Society covered U.S.$114,000 of the U.S.$400,000 cost of the 1963 American Everest expedition, for which the National Aeronautics and Space Administration provided contributions of equipment (Unsworth 2000, pp. 365-366). NASA, however, refused to help the 1970 International Everest expedition (p. 404) although it had the same expedition leader, Norman Dyhrenfurth.
34. The 1960 Chinese Expedition to Everest had 214 members, and expeditions by the Italians, Indians, and British have consisted of more than 50 team members. At the other end of the spectrum, there have been more than 60 solo climbs.
35. Excluding these observations has little qualitative effect on the results. With fewer observations, some variables are of lower significance. The percentage guided and percentage female are each insignificant in the ascent equations; prior climbs on the mountains is insignificant in the deaths equation (though previous national experience on the mountain is weakly negative); and the big national expeditions indicator variable and the year–time trend are each insignificant in the frostbite equations.
36. Country- and mountain-specific results were not included in the tables but are available from the authors on request.
37. The data are from the European Centre for Medium-Range Weather Forecasts and include daily temperature and wind-speed data for 2.5° grids (approximately 175 miles

by 175 miles). Thus, we have separate weather forecasts for Kangchenjunga, for the Everest group (Everest, Lhotse, Makalu, Cho Oyu, and Shisha Pangma), for western Nepal (Annapurna, Dhaulagiri, and Manaslu), for the K2 group (K2, Broad Peak, Gasherbrum II, and Hidden Peak), and for Nanga Parbat. The weather data are measured on the day the expedition makes the summit or the day it chose to abandon the climb. Huey, Eguskitza, and Dillon (2001) identified temperature and wind speed as factors affecting success on Himalayan climbing expeditions.

38. The average number of prior expeditions was about 200 for Mt. Everest and was below 100 for the other mountains.
39. An increase in Sherpas' experience has a positive effect on the probability an expedition experiences a death in each specification. Only in Model 5, however, where we account for weather effects, do we find that this effect is statistically different from zero at the 10% confidence level. Similarly, climbers' experience has a positive effect on the probability of altitude sickness in each of the models but again is only statistically different from zero at the 10% confidence level in Model 5. Both of these results could be valid, as expeditions trying very difficult climbs—which we cannot measure very well—tend to hire experienced Sherpas. In addition, once a climber experiences altitude sickness, she or her is more likely to experience it again.
40. Many of the arctic expeditions used ships, which would necessitate a much more hierarchical organization.
41. Huey and Eguskitza (2000) and Eguskitza and Huey (2000; see also Huey and Eguskitza, 2001, and Huey, Eguskitza, and Dillon, 2001) examine the relationship between deaths on descent from the summit and the use of bottled oxygen on K2 and Mt. Everest, using data on climbers who successfully made an ascent between 1978 and 1999. Although Huey and Eguskitza (2000) found that the use of bottled oxygen increases the chance that a climber reaching the summit will survive the descent, they note that "a full assessment of supplemental oxygen use awaits incorporation of data on death rates during ascent, risk to porters ferrying oxygen canisters, actual causes of death, and weather conditions" (p. 181). The current study includes data from all 8,000-m peaks and attempts to capture the costs as well as the benefits that bottled oxygen yields by examining all expeditions, not just those that successfully reached the summit. We have not tried to distinguish between deaths due to objective hazards (that is, bad luck) and those due to subjective hazards (poor decisions).
42. The omitted dummy variable is the year 1998, the omitted country is the United States, and the omitted mountain Annapurna. Thus, the decline is relative to those being held constant.
43. China and India, however, appear to be expending lives and getting no improvement in ascent rates in return. The 1966 Chinese Everest expedition, which resulted in 24 dead climbers, "were told that what they had to do to keep warm was to remember the teachings of Mao Tse Tung ... which they must still be doing, as they were never seen again" (Guha, 1968, p. 211).
44. The publishing of "firsts" is ubiquitous in climbing. For example, guide books to local rock-climbing areas typically list the names of the first ascensionists and the year of first ascent for each of the climbing routes, which may number in the 100s.

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