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Buffalo Hunt

International Trade and the Virtual Extinction of the North American Bison

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Abstract

In the 16th century, North America contained 25-30 million buffalo; by the late 19th century less than 100 remained. While removing the buffalo east of the Mississippi took settlers two centuries, the remaining 10 to 15 million buffalo on the Great Plains were killed in a punctuated slaughter in a little over 10 years. I employ theory, data from international trade statistics, and first person accounts to argue that the frenzied slaughter on the Great Plains was initiated by a foreign-made innovation and fueled by a foreign demand for industrial leather. Ironically, the ultimate cause of this sad chapter in American environmental history was of European, and not American, origin.

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1 Introduction

200 YEARS AGO, Merriwhether Lewis and William Clark completed their epic voyage of Western discovery. Their vivid account of the West's natural beauty and its limitless wealth spurred on thousands of Americans to carve out a new life and new nation east of the Mississippi. Westward expansion with its stories of frontier hardship have shaped much of American national identity by stressing the values of self-reliance, risk-taking, and wealth creation by taming the natural world. While the 19th century is surely one of the most inspirational periods in American history, it also bears witness to a less flattering record with regard to the environment: most significantly, the shameful slaughter of the plains bison, or buffalo.[1]

This paper examines the slaughter using theory, empirics, and first person accounts from diaries and other historical documents. It argues that the story of the buffalo slaughter is surprisingly not, at bottom, an American one. Instead I argue that the slaughter on the plains was initiated by a tanning innovation created in Europe and maintained by a robust European demand for buffalo hides. These market forces overwhelmed the ability of a young and still expanding nation, just out of a bloody civil war, to carefully steward its natural resources.

Specifically, I argue that three conditions are jointly necessary and sufficient to explain the time pattern of buffalo destruction witnessed in the nineteenth century. These are: (1) a price for buffalo products that was largely invariant to changes in supply; (2) open access conditions with no regulation of the buffalo kill; and (3), a newly invented tanning process that made buffalo hides into valuable commercial leather.

In the 16th century, North America contained 25-30 million buffalo; by the late 1880s less than 100 remained wild in the Great Plains states. While removing buffalo east of the Mississippi took settlers over 200 years, the remaining 10 to 15 million were killed in a punctuated slaughter in a little over 10 years. Standard explanations hold some combination of U.S. army policy, the railroads, and changes in native hunting practices responsible. My claim is that (1), (2) and (3) are both necessary and sufficient to generate

[1]The term buffalo is a misnomer but I will use it throughout since this is common usage. The species Bison bison comes with two distinct varieties: the common Plains bison (Bison, bison, bison) and the less common Woods bison (Bison, bison, athabascae) found exclusively in Canada. I focus on the extinction of the plains bison in the U.S., leaving an examination of the Canadian case for future work.

the frenzied slaughter witnessed on the Great Plains from 1870 to 1886.

The argument I develop proceeds in three steps. First I build a novel model of buffalo search and hunting to capture the essentials of the buffalo hunt. Buffalo hunters search for buffalo, lose the herds with some probability, and obtain hunting opportunities with varying costs. Uncertainty and cost heterogeneity are an important part of the historical record, but more importantly their introduction here provides for a margin of entry and exit by hunters. Since the slaughter on the Great Plains was a frenzied punctuated kill followed by a bust, these entry and exit margins are especially important to model.

For the most part, I take world prices as given and assume throughout that there is no control over hunting the buffalo. The model is made general equilibrium by the addition of a numeraire good sector which serves as the outside option for potential buffalo hunters. The general equilibrium structure is helpful to our discussion of export flows, and necessary for our construction of an autarky counterfactual.

The theory shows that the combination of an innovation in tanning, fixed world prices for hides, and open access to the herds proved fatal to the buffalo. The innovation in tanning creates frenzied entry into hunting. All agents understand its consequences for the future, and alter their hunting behavior accordingly. A discrete jump in the number of hunters occurs, the buffalo herds decline rapidly, and the harvest of buffalo hides for export booms. The slaughter continues unabated until only a small number of buffalo remain and hunters exit the industry.[2]

Fixed prices ensure the new supply of buffalo hides cannot dampen the incentive to hunt; open access ensures that regulations limiting the kill are not forthcoming from government; and rational expectations generates an overshoot in hunter numbers that delivers a punctuated slaughter. Rigid prices, no controls on hunting, and a slaughter compressed in time are important and verifiable features of the historical record.

Since this theory implicates trade and specifically exports in the slaughter, the second step is to examine evidence on U.S. exports of buffalo hides. A natural consequence of the rapid and violent slaughter of the buffalo is that records of the number killed are non-existent, and only very partial shipping

[2]The pace of the slaughter was such that many contemporary writers thought extinction was all but inevitable. Allen writing in 1876 said "The fate of none of our larger animals is more interesting than is that of the bison, since total extermination is eventually surer to none than to this former "monarch of the prairies." p. 71 Allen (1876)

records exist.

U.S. trade statistics from the 19th century contain categories of exports that contain buffalo products, but no individual entry is labelled as either buffalo meat, buffalo robes or buffalo hides. The key series I employ is "hide exports" and this surely contains both cattle and buffalo hide exports. To solve this problem, I employ economic theory and independent work on the U.S. cattle cycle to construct a time series of buffalo hide exports from the overall export figures. This constructed time series is then cross-checked for consistency against several other pieces of independent evidence. The cross checks examine the magnitude of the implied exports, their timing, and their geographic variation. In addition, I find direct supporting evidence of buffalo hide exports in newspaper accounts, personal diaries, and business directories in importing countries. These numerous independent checks lend support to the constructed series.

The final step in the argument is to examine the main alternative hypotheses in light of our new data. While the model's analytic results prove that my three conditions are sufficient to generate the slaughter they do not prove necessity. To argue for necessity, I show that the new constructed export data strongly support the export-driven slaughter hypothesis. The magnitudes of the export flows are considerable. Approximately 6 million buffalo hides are exported over the 1870-1883 period and this represents a buffalo kill of almost 9 million. The timing of greatest export flows fits the historical record extremely well. I then discuss the three major alternative hypotheses and argue that they do far less well in matching the data.

There is a huge literature studying the buffalo and other related aspects of westward expansion in the 19th century. This literature includes contributions from history, political science and sociology but only a handful of contributions from economics. Perhaps the best known contribution is the 1889 monograph by William Temple Hornaday who was then the chief taxidermist of the Smithsonian Institute. Hornaday's monograph "The Extermination of the American Bison" is the classic account of the elimination of the buffalo both east and west of the Mississippi. Hornaday collects figures on the number killed from various sources, and provides the first definitive account of the slaughter. Hornaday's account however make no mention of international trade. Other classic contributions such as "The Plains of the Great West" by Richard Irving Dodge, and Joel Allen's 1876 contribution "The American Bisons: Living and Extinct" offer us first person accounts of the slaughter (in the case of Dodge), and a scholarly examination of the process from a naturalist at Harvard, but neither seek to identify the underlying cause.

More recent work by economists include Dean Lueck (2002) and Bruce Benson (2006) who focus on property rights issues, and a series of papers by economic historians linking market forces to overuse and depletion of renewable resources in early centuries. Prominent among these are the series of papers by Carlos and Lewis (1993, 1999) who examine the depletion of beaver in the 18th century; Patterson and Wilen (1977) who study the northern pacific fur seal hunt; and most recently Allen and Keay (2004) who study the extinction of the Arctic Bowhead whale.

The work presented here differs from these contributions in three significant ways. First, and most importantly the focus here is on the "slaughter." There is no real mystery as to why the buffalo were eliminated from their previous ranges - an expanding population, conversion to agriculture, and industrialization all spelt the end for the buffalo sometime during the late 19th or early 20th century. What is surprising is the rate of killing and its variation over time: one half of the pre-contact buffalo population was killed in just ten years time post 1870; the elimination of the other half took over 200 years.

This focus on the *slaughter* is important, and absent from the other contributions. It is important, because a rapid slaughter greatly constrains the ability of governments and agents to respond and strengthen property rights institutions. Many developing countries in the world today are heavily reliant on resource exports, and few, if any, have stringent regulations governing resource use. The slaughter on the plains gives us compelling case study evidence showing how demand from high income countries can destroy resources in just a few years.

The existence of the slaughter also leads one to ask why markets didn't adjust to the huge increase in the supply of buffalo products and thereby slow the carnage. Because the corollary of a quick and large slaughter should be a glut of buffalo products and depressed prices, my focus on the slaughter suggests international markets may have soaked up the excess supply keeping prices constant. Investigation of this possibility led to the major contribution of this work: the identification of international trade as a key driver in the process.

While the earlier contributions in economic history explored various positive and normative questions concerning resource depletion, there was little mystery as to the ultimate source of the depletion. The Bowhead whale was eliminated by Dutch and English whalers over almost three centuries; while the beaver and seal were depleted by the fur trade.[3] In contrast I argue that the usual suspects - the railroads, the U.S. Army, environmental change or changed native hunting practices - are in fact innocent.

Finally, modeling the buffalo kill off as a punctuated event - compressed in time - with excessive entry and then exit requires the introduction of new methods and tools to the renewable resource and international trade literature. While the earlier contributions of economic historians use theory to flesh out and strengthen their hypotheses, they do not provide independent theoretical contributions. The theory presented here is however novel and adds to a growing body of theoretical work examining the impact of international markets on the environment.[4]

The rest of the paper proceeds as follows. In section 2, I set out important background material on the history and biology of the buffalo which is generally not known. In section 3, I construct a search and hunting model to examine how the time path of buffalo kills responds to an unexpected tanning innovation that makes buffalo products more valuable. In section 4 I construct the buffalo-hide-export data, and provide a series of cross-checks against independent sources in the historical record. Section 6 considers alternative hypotheses while section 6 concludes. Two appendices follow.

2 History and Biology

Buffalo are the largest terrestrial mammals in North America, and have been since the Pleistocene extinctions over 10,000 years ago. Earliest recorded European observations came from Spanish explorers in the early 1500s who remarked on the vast herds of native cattle in present day Mexico. Similar observations were subsequently made by French and English explorers in

[3] These other contributions examine different aspects of depletion: Carlos and Lewis link variation in depletion rates across trading posts to differences in competition; Patterson and Wilen examine how international rivalry and transboundary issues affect depletion; and Allen and Keay ask whether depletion could have been avoided by enlightened public policy.

[4] The two most related papers would be Brander and Taylor (1997) which introduces a simple two sector model similar to the one employed here, and Copeland and Taylor (2004) which provides conditions under which "open access" arises as an endogenous outcome. Neither contain the search or hunter heterogeneity elements that are key to the model I develop here.

other regions of North America. The newcomers were unanimous in their appraisal of buffalo as "innumberable" or "countless" and the country was famously described as "one black robe" of buffalo.

The American explorers, Lewis and Clark, met buffalo at many points along their voyage of discovery. On their return voyage in 1806 at the mouth of the Yellowstone river where it meets the Missouri, they recorded: "The buffalo now appear in vast numbers. A herd happened to be on their way across the river [the Missouri]. Such was the multitude of these animals that although the river, including an island over which they passed, was a mile in length, the herd stretched as thick as they could swim completely from one side to the other, and the party was obliged to stop for an hour."

Since extrapolating from any first person account can lead to serious error, it is not surprising that estimates of the buffalo population prior to European contact vary from over 100 million to less than 20 million.[5] The most reliable population estimates come to a figure somewhere between 25 and 30 million buffalo. They do so by multiplying the carrying capacity on agricultural land with estimates of the original buffalo range of almost 3 million square miles. Buffalo were in all of the lower 48 (save the New England states), the four westernmost Canadian provinces and its two territories, and the northernmost part of present day Mexico.

2.1 Habitat Destruction and Subsistence Hunting

The buffalo east of the Mississippi were removed by a combination of habitat destruction and subsistence hunting. The gradual removal of buffalo proceeded westward when settlers crossed the Allegheny mountains into Kentucky in the early 1800s. It continued unabated for the next fifty years as settlers moved towards the "Great Plains" at approximately the 90th meridian. By 1820 or 1830, buffalo were largely gone east of the Mississippi (over 200 years from first contact). During much of this early period natives hunted the buffalo not only for their own subsistence needs but also to trade buffalo robes at forts and towns. A buffalo robe is the thick and dark coat of a buffalo that is killed in mid winter. Robes could be used as throws for carriages, or cut to make buffalo coats and other fur items. They were a popular item in the 19th century and they made their way to eastern markets

[5] The naturalist Thomas Seton estimated the population at 1600 at 75 million, but with little factual basis. The historian Dan Flores (1991) employed a more transparent method to arrive at a figure of 27 million.

by transport along the Missouri river to St. Louis or overland via the Santa Fe trail. In the 1840s settlers pushed through the Great Plains into Oregon and California. The movement of the 49ers to California and the Nevada gold rush years brought a steady stream of traffic through the Platte river valley. Subsistence hunting along the trail plus the movement of cattle and supplies, divided the existing buffalo herd into what became known as the Southern and Northern herds.

The division of herds became permanent with the building of the Union Pacific railroad through the Platte River valley in the 1860s. The railroad created a local demand for buffalo meat, and brought sport hunters, inquisitive easterners and foreign dignitaries eager to go out West on a buffalo hunt. While subsistence hunting for the railroad crews surely had some effect on buffalo numbers, as did the railroad's popular day trips to kill buffalo, the harried buffalo herds withdrew creating a 50 mile wide corridor centered on the Union Pacific line.[6] The railroads also provided transportation for buffalo products to eastern and foreign markets, but in the 1860s railway cars were not refrigerated, and hence buffalo meat was only marketed as salted, cured or smoked.

Despite the railroads, the market for buffalo robes, the increase in subsistence hunting, and the conversion of the high prairie to agriculture, Utley notes that "contemporaries detected no major reduction in the abundance of the species. Most observers thought the killing was not greater than the natural increase of the species and expected the extermination of the buffalo from the High Plains would occur gradually over a span of decades in a manner similar to what had happened east of the 99th meridian."[7]The force of habitat destruction was minimal on the Great Plains. In 1860, they held only 164 thousand people on an area of 416 million acres. Farms were less than 1% of the land area.

The Civil war brought a temporary reprieve for the buffalo . Major battles

[6]To see why subsistence and sport hunting could make only a small dent in the herd a little calculation is helpful. If the carrying capacity of the Great Plains was 15 million buffalo, and if we take their intrinsic growth rate at .2, then (using the logistic growth equation for the buffalo) a maximum sustainable yield population of 7.5 million allows for a yearly sustainable kill of 750,000 buffalo. To put this in perspective, the most famous buffalo hunter ever known - Buffalo Bill Cody - was an entrepreunial young boy of 18 when he offerred to supply the Union Pacific workers with buffalo meat. William Cody got the contract with Union Pacific, but from his own accounts he killed only 4 to 5 thousand buffalo per year.

[7]See Utley (2003), p. 243.

occurred in regions with few or no buffalo , and these years provided a break from the slow but steady destruction that had marched westward. Despite this reprieve, the impact of habitat destruction and settlement had taken its toll on the buffalo. By 1865, the buffalo population was only 10 to 15 million.

2.2 The Innovation

The temporary reprieve ended quickly when in 1870 or 1871 tanners in England and perhaps Germany developed a method for tanning buffalo hides into useful leather. While natives had always been able to tan the thick haired buffalo hides taken in winter months into buffalo robes, their process was laborious and required ingredients from buffalo themselves (the brain, liver, and fat or tallow). A cheap simple commercial process was as yet unknown. Various historical accounts attribute the breakthrough to tanners in Germany and still others to English tanners. Many accounts suggest the "innovation" was soon imitated by U.S. tanners, but exactly when and where is unclear.

There are several elements of the innovation that are important to discuss: its timing, the initial location of the innovation in one or more foreign countries, the fact that it represented a shock to the buffalo hunting industry, the use to which buffalo hides were put once tanned, and the eventual diffusion of the innovation to other countries.

The hardest evidence for timing and location is given by a London Times article reporting from New York city in August of 1872. It reports that a few enterprising New Yorkers thought that buffalo hides might be tanned for leather, and when the hides arrived they were "sent to several of the more prominent tanners who experimented upon them in various ways, but they met with no success. Either from want of knowledge or a lack of proper materials, they were unable to render the hides soft or pliable, and therefore they were of no use to them."

The report continues though to note "several bales of these hides were sent to England, where they were readily taken up and orders were immediately sent to this country for 10,000 additional hides. These orders were fulfilled, and since then the trade has continued." Further still, the methods are spelt out in full "The hides are collected in the West by the agents of Eastern houses; they are simply dried, and then forwarded to either New York or Baltimore for export...The low price that these goods have reached on the

English market, and the prospect of a still further decline, may in time put an end to this trade, but *at present the hides are hunted for vigorously, and, if it continues, it will take but a few years to wipe the herds out of existence* (my emphasis)." [8]

A secondary account comes from Gard (1960, p.90) "In 1870, J. N. DuBois, a Kansas City dealer in hides, furs and wool shipped several bales of buffalo hides to Germany, where tanners had developed a process for making them into good leather. Other orders followed, and soon some American tanners either learned of this process or developed a similar one of their own. In the spring of 1871, DuBois sent hundreds of circulars out to the buffalo ranges, offering to buy at attractive price all hides taken at any time of the year. DuBois also encouraged the hunters by telling them how to peg the hides, flesh side up, for drying. In addition, he sold them a poison, imported from South America, to kill the bugs that infested and damaged many of the hides."

Putting these together it appears the innovation was made in England and Germany at roughly the same time in 1871. Importantly, U.S. tanners were unable to tan buffalo hides at this time.

The fact that the innovation was an unexpected shock is of little doubt, and supported by many accounts. The account of buffalo hunter George "Hodoo" Brown is especially on point as it provides evidence on both the timing and unexpectedness of the innovation. When returning from a meat hunting trip in May of 1871 to Fort Wallace, Brown had the following conversation with fellow hunters at the fort:

"We told them the weather was getting so warm it was almost impossible to get meat to market before it spoiled. They said to me, 'Why don't you skin them and just take the hides, and let the meat lay?' I says, 'What the devil would I do with the hides?' One man said, 'Ship them to Leavenworth to W.C. Lobenstine. He'll buy your hides and send a check'. So Burdett and I on our next trip went to skinning."[9]

Other accounts attest to the unexpectedness of the innovation and introduction of buffalo hides as a valuable commodity. It is less clear however how buffalo tanned leather was used, and why it had such a strong foreign demand. The literature mentions two uses of the leather. The first was for sole

[8] "Buffalo Hides: Some eight or ten months ago", The Times, August 17, 1872, pg. 4, Issue 27458, col. F.

[9] Interview with George W. Brown reported in Gilbert et al. (2003), page 55.

leather, with a burgeoning European demand coming from refitting armies in the post 1870 period. Specifically, several sources mention the British Army and its demand for buffalo leather as it was tougher and thicker than cow hides.

Buffalo hunter John R. Cook's account attests to this view. Cook recounts his conversation with a buying agent of W.C. Lobenstine (the hide dealer mentioned above) when the two of them brought in Cook's hides for transport. "In a few moments we were saddled up and off. I found him to be a good conversationalist, well informed and in possession of knowledge upon the latest current events. He said all of Loganstein [sic] & Company's hides went to Europe, that all the English Army accouterments of leather were being replaced with buffalo leather, on account of its being more pliant and having more elasticity than cowhide."[10]

In addition to sole leather, the tough buffalo hides found use as industrial belting for machinery in England and elsewhere on the continent. Many secondary sources make this connection, but primary source evidence is also available from English business directories. For example, Slater's Royal National Commercial Directories at the time list numerous tanners, hide merchants, and leather belt manufacturers in their directory of trades. These businesses list as products buffalo hides, buffalo skips, buffalo hide shavings, buffalo pickers, and strapping for cotton gins.[11]

The eventual diffusion of the innovation to tanners in the U.S. and other European countries is more difficult to establish, although often claimed in the literature. The best evidence of diffusion of the innovation to U.S. tanners comes from NY Chamber of Commerce Annual reports that list price quotes for hemlock tanned sole leather made from a variety of hides (Buenos Ayres, California, etc.). These price quotes do not include bison in the early 1870s, but price quotes for bison tanned leather soles first appear in the 1877/1878 report, continue for 1878/1879, and then disappear the following year. Clearly, the innovation did diffuse to U.S. tanners by the late 1870s.

[10] Excerpted from Cook John R. The Border and the Buffalo, Crane and company, Topeka, 1907. Reprint by State House Press, Austin, 1989.

[11] See for example in Slaters Business Directory, 1879 for Manchester and Salford, advertising by John Tullis & Son Tanners and Curriers and Leather Belt Manufacturers, p.80; the list of hide dealers and merchants, p.103; the advertising by Heyworth & Law Tanners and Curriers and manufacturers of Machine Belting, p.126; the advertising of Hepburn & Sons, Tanners and Curriers & Leather Factors, p.85.

Evidence for diffusion to other countries is more difficult to establish, but here again business directories help. For example, the Foreign Appendix to Slaters Business Directory of London in 1884 lists the Poullain Brothers of Paris as Tanners specializing in straps and leather for steam works and buffalo leather rubbers for spinning mills. Given the diffusion to U.S. tanners in the 1870s and the close proximity of most European countries, diffusion from England and Germany to other countries seems highly likely.

2.3 The Flint Hide Market

Regardless of the innovation's source, its effect on the Great Plains was electrifying. The market for buffalo hides boomed; buffalo hunters already in the field - like George "Hodoo" Brown - started to skin buffalo for their flint (hairless) hides, and hundreds if not thousands of others soon joined in the hunt. Previous to the innovation, hides taken from the Southern herd or hides taken in all but three winter months were virtually worthless as fur items. The only saleable commodity from a buffalo killed in these regions or times was its meat, but this market was severely limited by transportation costs. With the advent of a flint-hide market, killing a buffalo anywhere and at anytime became a profitable venture. By 1872 a full scale hide-boom was in progress.

Although no accurate figures are available, Colonel Richard Irving Dodge (of Dodge city fame) estimated the buffalo kill in Kansas at close to 3.5 million buffalo over the 1872-1874 period.[12] Once the herd in Kansas disappeared the hunters turned south towards Texas and present day Oklahoma. Reports of large herds south of the Arkansas river, lured hunters into land granted to the Comanches in the Medicine Lodge Treaty of 1867. Hunting south of the Arkansas was a dangerous game and a major battle between hide hunters and Comanches occurred at Adobe walls in June of 1874. A short buffalo war ensued, but the U.S. Army eliminated the Indian threat by 1875. In doing so the Army opened up the whole of present day Oklahoma, western Texas and eastern New Mexico to the hide hunters.

The business of hide hunting did not last long - less than 7 years in Kansas and areas to the south. And when the Southern herd was eliminated in 1879, many hide hunters looked north to the only significant herd left in existence. The key bottleneck in the north was the still hostile Sioux. After the defeat

[12] See Dodge (1871).

of the Sioux in the late 1870s, the Northern Pacific Railroad extended its tracks west from Bismarck into the heart of the Montana plains reaching Glendive in 1880 and Miles City in 1881. With easy transportation and the elimination of the Indian threat, hide hunters flooded the northern range. Hide hunting in the north reached a peak in 1881 or 1882 and by 1883 the commercial hide hunt was faltering. In 1884 the last of the flint hides were shipped east.[13]

2.4 The Road to Conservation

In 1886, William Templeton Hornaday urged his superiors at the Smithsonian to fund an expedition to kill and mount a grouping of buffalo for posterity. Although it took Hornaday two expeditions, four months of effort, and the help of professional hunting guides, he finally succeeded in collecting specimens for his innovative diorama of buffalo on the Montana plains.[14] At this time, Hornaday estimated the wild buffalo population in Great Plains states at less than 100.[15]

The slaughter of the North American buffalo surely represents one of the saddest chapters in American environmental history. To many Americans at the time, the slaughter seemed wasteful and wrong as many newspaper editorials and letters to Congressmen attest, but still little was done to stop the slaughter. While several Great Plains states enacted legislation to limit and control the hunt, these laws were ineffective and unenforceable. The only serious piece of federal legislation was passed by both houses in 1874 only to be killed by a pocket veto by President Grant.

The destruction of the buffalo and the wanton slaughter of other big game across the west did however pay some dividend. The slaughter of the buffalo in particular was pivotal in the rise of the Conservation movement in the late 19th and early 20th century. Almost all of the important players

[13] See Hanner (1981, p. 246).

[14] An updated version of Hornaday's diorama can be seen today by visiting the American Museum of Natural History in New York or via their website at www.amnh.org (search for bison and pronghorn diorama).

[15] In response to the rising scarcity several ranchers thought it worthwhile to capture and breed bison. Famed Texas Rancher Charles Goodnight obtained several buffalo from the panhandle that were remnants of the great Southern herd. These animals became of one five foundation herds in the U.S. from which almost all bison are descended. Other bison herds were collected and some of these became the foundation stock for the Yellowstone herd set up in the early 1890s.

in the Conservation movement experienced the slaughter first hand - Teddy Roosevelt, John James Audobon, John Muir and William Hornaday.[16] The creation of the national park system in general, and the Yellowstone herd in particular, are a direct consequence of the revulsion many felt to the slaughter on the Great Plains. Because of these efforts, over 300,000 buffalo are alive today in reserves and commercial ranches across North America.

2.5 Buffalo Biology

Buffalo are enormous animals, and surely the most splendid element of the original aboriginal fauna present when Europeans made first contact. Mature males are 10-12 feet in length, 6.5 feet in height, and weigh up to 2500 lbs. Female buffalo are proportionately smaller but still very large. They are also surprisingly agile given their size and weight: buffalo can broad jump over 15 feet, jump 6 foot high fences and run at a top speed of 40 m.p.h. for several miles. Buffalo have very poor eyesight, good hearing and a very acute sense of smell. Their natural predators are few: grizzly bears are an occasional predator, while wolves are a threat to the herd's sick, old and the very young.

Buffalo are perhaps more fecund than cattle with rates of net fertility in the range of .15-.25. Breeding can occur at anytime of the year but peak season is from early June to the fall. In a well nourished herd, 85 to 90% of the mature cows will bear a calf in the spring. Not surprisingly given their original abundance, buffalo make very efficient use of prairie grasses. While they have four stomachs like cattle and other bovines, their slower metabolism withdraws more energy from the same grass.[17]

These features of buffalo biology determined much of their history. Given their size, dexterity and speed, killing a buffalo from horseback using stone tools is not a simple task. Even though natives used buffalo jumps, surrounds, and pens to kill buffalo en masse, subsistence hunting could only have a small impact on a population with such a robust growth rate. Before

[16] The badge worn by National Park Service employees features a buffalo bull modeled after the bull killed and mounted by Hornaday in his buffalo diorama. Hornady became the first director of the Bronx Zoo, and was the first head of the American Bison Society. The model buffalo bull imortalized on the buffalo nickel came from the buffalo collection created by Hornaday at the Bronx Zoo. There are numerous Hornaday awards given by Conservation groups all across America.

[17] See Lott (2002).

European contact, buffalo numbers were kept in check by natural and not man made limits. Given their 3 million square miles of range, huge buffalo herds result.

Two other features of buffalo biology play an important role in their history. Buffalo divide into sex segregated herds for much of the year. Bull herds and cow-calf herds are the predominate forms, although for some time of the year yearlings also separate. Only during the spring and summer (May through August depending on location) do these herds meet and congregate on the open plains. During the rest of the year the herds divide up into much smaller groups of 60 to 100 that seek out small river valleys and other sheltered locations where vegetation is more plentiful and winter storms less severe. As a consequence, the only time to efficiently kill large numbers of buffalo is in the summer months when they are concentrated on the open plains.[18]

While hunting in winter meant facing difficult winter conditions, finding only small groups of buffalo , and obtaining less meat from the leaner buffalo , it is during winter that the buffalo's thick coat reaches its pinnacle. Starting in early fall, buffalo regrow their winter coat which they then subsequently shed in the spring. Winter coats are dark and thick and make handsome buffalo robes when tanned; summer coats are thin, scruffy and not suitable for the robe market. Buffalo hides suitable for "buffalo robes" were taken only during three months of the winter, and some buffalo on the southernmost ranges never sported a robe worth taking.

These last two features of buffalo biology played a critical role in limiting the market for buffalo products. When buffalo were easy to kill, their robes were virtually worthless; when they were difficult to kill, their robes were valuable. Nature inadvertently endowed the buffalo with a defense against over exploitation.

European contact and the conversion of lands east of the Mississippi to agriculture, changed the buffalo's limiting factor from nature to man. Hunting increased and was spurred on by both a domestic and world demand for buffalo robes, but this demand could not exceed a supply constrained by the natural rhythms of buffalo biology and the supply bottleneck created by a laborious native tanning process. Even after the civil war, the Great Plains

[18] The herds could be immense with many reported herds containing 50 to 100 thousand animals. Colonel Irving Dodge in 1871 came across a herd along the Arkansas river near Fort Larned that was subsequently estimated (by Horndady see (1889, p.390) to contain 4 million buffalo. Dodge's original account is contained in Dodge (1877, p.120).

were virtually deserted, and this left the buffalo much of the most productive mid-grass prairie in Kansas, Oklahoma and northern Texas. Absent an innovation that made full time buffalo hunting possible, the buffalo population would have trended slowly downward for decades as it had east of the Mississippi. History however was not so kind to the buffalo.

3 The Model

We develop a simple dynamic model where agents search and hunt for buffalo. An agent chooses to hunt buffalo today or wait for a potentially better opportunity tomorrow. Buffalo hunters were typically young single men with relatively low opportunity costs and limited skills. Many were civil war veterans who had moved west seeking their fortune. Their alternative occupations as laborers in frontier towns, cow punchers, soldiers, or railroad crew workers rarely paid very well.[19] To someone with limited skills, except perhaps with a rifle, buffalo hunting was a potential road to riches.

Not surprisingly, entry and exit from buffalo hunting was common. Indeed the explosion of activity at the start of hide hunting in the early 1870s was nothing less than spectacular. Historic accounts describe an industry of hunters that grew from a small cottage industry that supplied nearby towns and railroad crews with meat to an army of thousands of crews that lined rivers and closed off all avenues of escape for the buffalo. Since the entry and exit margin is so important to capture, we will determine the number of active hunters endogenously while representing the total fixed pool of potential hunters with a continuum of agents with mass N.

3.1 Individual Decisions

Potential buffalo hunters were distributed throughout the Great Plains, but concentrated in small towns and forts near known buffalo ranges. By 1870, it was common knowledge that the Southern herd was concentrated in Kansas, southern Nebraska, northern Texas, (present day) Oklahoma, and eastern New Mexico; the Northern herd was concentrated in Montana, northern Wyoming and the eastern parts of the Dakotas. Naturally potential buffalo hunters congregated in just these areas. The arrival time of a herd near a town or fort was however uncertain. Since arrival uncertainty is a feature

[19] Several first person accounts of buffalo hunting are compiled in Gilbert et al. (2003).

of any real hunt, we assume buffalo herds arrive near potential hunters at the rate θdt. The probabilistic nature of herd "arrival" reflects the fact that buffalo are neither stationary nor migratory, but are nomadic with little set pattern of movement across the Great Plains. While buffalo were relatively easy to kill, they were not always easy to find.

I assume that once a buffalo herd arrives nearby, potential hunters draw their hunting cost from a known and common distribution $G(c)$ with support $[0, \infty)$. The introduction of heterogenous hunting costs differentiates agents and is important in determining a margin for entry and exit. It also reflects the very real fact that some hunting opportunities are simply better than others. The cost of hunting any given herd is determined by a myriad of factors: variation in wind patterns (you must work your way downwind of the herd); topography (a hill or bluff is best to shoot from, an open plain the worst); the organization of the herd (a herd is actually composed of numerous small bunches of 50 to 100 buffalo); and distance to a railhead or river for transport of the hides. All of these factors create heterogenous hunting costs.

When faced with the opportunity to hunt, a potential hunter has two choices: ignore the herd and remain in the outside good sector; or, incur the hunting cost and hunt. If an agent hunts, they earn the value of harvest ph over the next increment of time dt, where h is the quantity of buffalo killed and p the price of buffalo products obtained from a kill. All prices and costs are measured in terms of the outside good which we take as the numeraire; therefore p is the relative price of buffalo products.

Hunting is a risky venture: with probability λdt the hunter loses the herd at the end of dt; with probability $1 - \lambda dt$, the hunter continues to hunt next period. Hunters became separated from the herd with the appearance of hostile natives, violent storms, or stampedes.

Let $V^H(t)$ represent the expected present discounted value of future earnings for an agent who is currently hunting buffalo. Let $V^W(t)$ represent the expected present discounted value of future earnings for an agent who is currently employed in the outside good sector and waiting for a new hunting opportunity. If agents are risk neutral and their productivity in killing is proportional to the stock of buffalo, S, then over a small increment of time we can write $V^H(t)$ as

$$V^H(t) = p\alpha S dt + [1 - \delta dt][\lambda dt V^W(t + dt) + [1 - \lambda dt]V^H(t + dt)] \qquad (1)$$

where δ is the agent's rate of time preference, α is a productivity parameter, and $e^{adt} \approx 1 - adt$ for dt small. The hunter earns the value of the kill over the increment dt, and earns the expected discounted continuation value for $t + dt$. With probability $1 - \lambda dt$, the hunter remains hunting and obtains $V^H(t + dt)$. With probability λdt the hunter loses the herd, returns to their previous occupation, and obtains the continuation value $V^W(t + dt)$.

Expanding and collecting terms we find the value of hunting has to satisfy:[20]

$$\delta V^H = p\alpha S + \dot{V}^H + \lambda[V^W - V^H] \tag{2}$$

The return on "the position of hunting" equals the flow benefits of killing buffalo plus the capital gain accruing over the period dt minus the instantaneous probability of a discrete capital loss created when the herd is lost at the end of dt.

By similar methods, we can write $V^W(t)$ as:

$$\begin{aligned} V^W(t) &= wdt + [1 - \delta dt][\theta dt \int_0^{c*} [V^H(t + dt) - c]dG(c) \qquad (3) \\ &\quad + \left[\theta dt[1 - G(c^*)]V^W(t + dt) + [1 - \theta dt]V^W(t + dt)\right]] \end{aligned}$$

An agent earns w while in the outside goods sector over the increment dt plus a discounted continuation value that is comprised of three terms. Recall that with probability θdt a herd arrives nearby, and the agent takes a draw from the distribution of hunting costs $G(c)$. If the draw is sufficiently low ($c \leq c*$) the agent chooses to hunt, pays the cost c, and obtains the continuation value $V^H(t + dt)$. Since the exact draw is uncertain at t, the first continuation value represents the expected continuation value of an agent who chooses to hunt. Alternatively, if the draw is too high ($c > c*$) the herd is ignored: hunting costs are not incurred, and the agent obtains the continuation value $V^W(t + dt)$. This possibility occurs with probability $[1-G(c^*)]$ and is captured by the second continuation value in the expression. The final term tells us that with probability $1 - \theta dt$ the agent remains in the outside good sector waiting for a hunting opportunity. In this third case, the agent obtains the continuation value $V^W(t + dt)$.

[20] To derive this and the other equations that follow take a Taylor series approximation around t for any variable $X(t + dt) = X(t) + \dot{X}dt$, simplify, and take the limit as dt goes to zero.

Expanding and collecting terms we find the return on the position of waiting is:

$$\delta V^W = w + \overset{\bullet}{V}^W + \theta \int_0^{c*} [V^H(t) - c - V^W] dG(c) \tag{4}$$

The return is composed of the flow return to work in the outside good sector plus the capital gains accruing on this position, plus the expected discrete capital gain created by a transition to hunting at the end of dt.

The two conditions 4 and 2 are linked by c^* which we refer to as the *maximal* hunting cost. Rationality on the part of agents requires c^* solve

$$V^H(t) - c^*(t) = V^W(t) \tag{5}$$

The hunter who obtains the draw c^*, and is just willing to make the transition to hunting is therefore the *marginal* hunter. Since the marginal hunter plays such an important role in determining entry and exit into buffalo hunting, it proves useful to focus on c^* directly. To do so, differentiate 5 with respect to time to obtain:

$$\overset{\bullet}{c}^* = \overset{\bullet}{V}^H - \overset{\bullet}{V}^W \tag{6}$$

The maximal hunting cost any hunter is willing to incur rises when the expected value of hunting rises relative to waiting. When c^* rises, entry occurs; when c^* falls exit occurs.

Using 2 and 4 and substituting from 5 and 6 we obtain, with some rearrangement, one differential equation describing the evolution of the maximal hunting cost over time:

$$\overset{\bullet}{c}^* = (\delta + \lambda)c^* + \theta[\int_0^{c^*} [c^* - c] dG(c)] - [p\alpha S - w] \tag{7}$$

3.2 Resource constraints

We now add several aggregate constraints to close the model. The first is simply an adding up constraint. Those hunting plus those waiting must equal N which we normalize to one. Then denote by b the number (proportion of

N) of agents actively hunting buffalo. Since the b agents actively hunting lose the herd at rate λdt while new hunters enter at rate $\theta G(c*)dt$ from the waiting population of $[1-b]$, the evolution of hunters over time is given by

$$\overset{\bullet}{b} = -\lambda b + \theta[G(c^*)][1-b] \tag{8}$$

Since historical accounts describe potential hunters leaving their alternative employment the moment a herd arrives, I reduce the dimensions of the problem by assuming hunters move instantaneously across sectors of the economy.[21] This assumption implies 8 is replaced by its steady state analog

$$b = \frac{\theta G(c*)}{\lambda + \theta G(c*)} \tag{9}$$

The number of agents hunting at any instant in time is increasing in the maximal hunting cost c^*, increasing in the probability of herd arrival, θ, and decreasing in the probability of losing the herd λ. If c^* was zero, then the maximum cost any agent would incur to hunt is zero. No one would hunt and 9 tells us $b = 0$. As $c^* \to \infty$, $G(c^*) \to 1$ and everyone is willing to hunt, but since herds arrive and disappear with some probability, the number of agents, b, hunting at any instant only reaches a maximum of $\theta/[\theta + \lambda]$ which is strictly less than one.

We can now describe the dynamics of the buffalo stock by combining our solution for hunter numbers in 9 with an assumption on natural regeneration. For simplicity we adopt a logistic growth curve and hence the evolution of the buffalo stock is governed by[22]

$$\overset{\bullet}{S} = rS[1 - S/K] - \alpha S b \tag{10}$$

where r is the intrinsic growth rate, and K the carrying capacity. With no hunting at all, the buffalo population would return to its carrying capacity level of K. With active hunting the herd will be smaller, and could in principle be driven to zero depending on parameter values.

[21] This is an assumption of "fast" adjustment of labor across sectors relative to "slow" adjustment of the resource stock. This assumption can be made precise by introducing two time scales into the model. For an application of this technique in ecology see Rinaldi et al. (2000), and for the background theory of fast and slow dynamics see Naidu (2002).

[22] For much of the analysis we could replace the logistic with a standard concave compensatory growth function.

If we substitute for the number of hunters using 9 we obtain a relatively simple two equation dynamic system relating the buffalo stock, S, and the maximal hunting cost, c^*:

$$\dot{S} = rS[1 - S/K] - \alpha S[\frac{\theta G(c^*)}{\lambda + \theta G(c^*)}]$$

$$\dot{c}^* = (\delta + \lambda)c^* + \theta[\int_0^{c^*} [c^* - c]dG(c)] - [p\alpha S - w] \tag{11}$$

Solving these equations subject to an initial condition on the buffalo stock and a terminal condition imposed by rational expectations produces our results.

3.3 Steady State Solution

To start we examine the steady state of the system. The equations in 11 have no closed form solution, but their implicit solutions are instructive. Setting the buffalo growth to zero yields the $\dot{S} = 0$ isocline which we will refer to as the resource constraint:

$$\frac{r[1 - S/K]}{\alpha} = \frac{\theta G(c^*)}{\lambda + \theta G(c^*)} \tag{12}$$

The steady state stock of buffalo falls with c^*. It does so because the number of hunters rises with c^*; hence we find a simple negative relationship between the buffalo stock and the maximal hunting cost.

By setting the change in the maximal hunting cost to zero we obtain the $\dot{c}^* = 0$ isocline which we will refer to as the free entry condition

$$[p\alpha S - w] - \theta[\int_0^{c^*} [c^* - c]dG(c)]] = (\delta + \lambda)c^* \tag{13}$$

When $c^* = 0$, the marginal hunter pays nothing to enter and is indifferent between entering or remaining in the outside good sector if they provide the same returns. The two sectors will provide the same returns when rents from buffalo hunting are zero: i.e. when a unit of labor time spent hunting reaps a value of marginal product equal to that of a unit of labor time spent in the outside good sector. Indifference implies $p\alpha S = w$, which is what 13 gives when $c^* = 0$.

When entry is costly, $c^* > 0$ and this investment must yield a return. Since the return must come from buffalo hunting, S must rise to make $p\alpha S > w$, and 13 yields a positive relationship between the stock of buffalo and the maximal hunting cost.

By rearranging 13 slightly, our interpretation of 13 as a free entry condition becomes clearer. Rewriting we obtain:

$$\delta c^* = p\alpha S - \lambda c^* - [w + \theta[\int_0^{c*} [c^* - c]dG(c)]] \tag{14}$$

By definition the marginal hunter makes an investment of c^* to hunt. In steady state, the return on this investment must equal the difference between the returns from hunting minus those from waiting. The return to hunting is equal to the value of buffalo hides $p\alpha S$ minus the prospect of a catastrophic capital loss of c^* that occurs with probability λ. The return to waiting is equal to the wage of w plus the expected capital gain if the agent makes a transition to hunting: note, $c^* - c = V^H - c - V^W$.

It is now straightforward to show that under mild conditions, the free entry and resource constraint have a unique interior solution .

Proposition 1. Assume: i) $p\alpha K > w$, ii) the support of $G(c)$ includes zero, and iii) $\theta/[\theta+\lambda] > r/\alpha$, then there exists a unique interior steady state.

Proof: See Appendix A.

The uniqueness and existence are guaranteed by very weak conditions. An interior steady state can only exist if buffalo hunting is profitable at some stock level. When $p\alpha K > w$ buffalo hunting provides rents when the stock is sufficiently close to K. To capture these rents hunters incur hunting costs, and we need to ensure these costs are not so large as to bar entry. By assuming the support of $G(c)$ contains zero, we ensure that at least some agents (those with low cost draws) will hunt.

To ensure not all agents are willing to hunt, $G(c^*) < 1$, we limit the fecundity of the buffalo so that extinction is possible when all agents wish to hunt. This is guaranteed by the last condition. It requires the technology for hunting α, be sufficiently productive relative to buffalo's intrinsic rate of reproduction r so that hunting could in principle drive the buffalo extinct. In the case of the buffalo this condition was met.

We will discuss the stability of the interior steady state at a later point; at present it is useful to examine some comparative steady state impacts of parameter changes.

Proposition 2. A price shock that raises p lowers the steady state stock S, raises the maximal hunting cost c^*, and increases the number of hunters b. The aggregate harvest of buffalo in physical units may rise or fall.
Proof: See Appendix A.

An increase in the price for buffalo raises the rents earned in the industry. Hunting becomes more attractive and entry occurs. Entry of new hunters drives down the stock; therefore both the buffalo stock and the number of buffalo hunters adjusts when prices rise. Surprisingly, the steady state buffalo kill may rise or fall. The kill rises if the buffalo stock exceeded $K/2$ prior to the price shock, but falls otherwise. Since Hornaday estimates less than 100 buffalo were left in the wild by the late 1880s while K is perhaps 15 million, the $S < K/2$ case is most relevant to our discussion. In this case, the aggregate kill, in steady state, falls with a price shock.

An improvement in the technology parameter α has a similar impact on the buffalo stock, but we find an ambiguous effect on the maximal hunting cost c^*.[23] The maximal hunting cost should rise as the return to hunting is higher with better technology and this creates entry. But with a better technology, fewer hunters are needed to exhaust the buffalo stock and this creates rationalization and exit with fewer hunters. Whether c^* rises or falls depends delicately on the properties of $G(c)$ as this determines the strength of the entry response.

Entry and exit rates also have predictable impacts on the buffalo stock. An increase in the probability of losing the herd, λ, lowers hunter numbers and raises the buffalo stock in steady state. Therefore, we should expect that a rise in λ created, say by a native uprising, should lower hunting and raise the stock.

An increase in the arrival rate θ, has less obvious effects. An increase in the arrival rate raises the return to waiting for better hunting, and this tends to lower hunter numbers and raise the buffalo stock. But an increased arrival rate also raises the probability of being able to hunt at any instant in time, and this impact dominates so that the buffalo stock falls when the arrival rate rises.

[23] See Appendix B for the calculations.

Finally, if we raise the arrival and exit rates proportionately, the buffalo stock rises while hunter numbers fall. The reason is that each new buffalo hunt requires a new fixed hunting cost as the shooter must set up one more time. Exit even with re-entry is costly. Raising both rates proportionately lowers the return to hunting.

3.4 Slaughter on the Great Plains

For the most part I focus on the destruction of the Southern herd as this was the immediate result of the tanning innovation and signalled the introduction of the hide market. I will discuss the destruction of the Northern herd, but the timing of its destruction was determined largely by the elimination of the threat posed by the Sioux in the late 1870s.

The introduction of buffalo hide tanning was a positive price shock for buffalo products. Before the tanning innovation, a buffalo hunter would kill for some combination of the animal's meat (including the tongue) and robe. A buffalo kill was a joint product yielding a fixed ratio of several outputs each with its own price. Once the tanning of buffalo hides was possible, the composition of these outputs changed to include hides. Historic accounts are clear that the introduction of the hide market vastly increased the return to buffalo hunting so that most meat was left to rot on the plains, and killing took place in regions where robes were of poor quality (much of the southern U.S.) and at times when robes were virtually worthless (all but 3 winter months). All of this implies that we should model the impact of the tanning innovation as raising the effective price for a buffalo kill from p to p'.[24]

The historical account is also fairly clear that before the tanning innovation, buffalo numbers were falling although slowly. Hunting pressure alone may have led buffalo numbers to fall as they had east of the Mississippi, but the pace of these reductions was slow. To capture this feature of the period prior to 1870, I assume the economy was operating somewhere along its transition path to an initial steady state when the price shock from p to p' occurs.

In Figure 1 we plot one resource constraint and two free entry conditions and indicate their intersections at points A and C. The resource constraint was described previously. It has a horizontal intercept at K, and a vertical

[24] Modeling the tanning innovation as an increase in harvesting productivity α would not be correct. Tanning did not increase the technical efficiency of buffalo hunting, it just raised the economic returns to it.

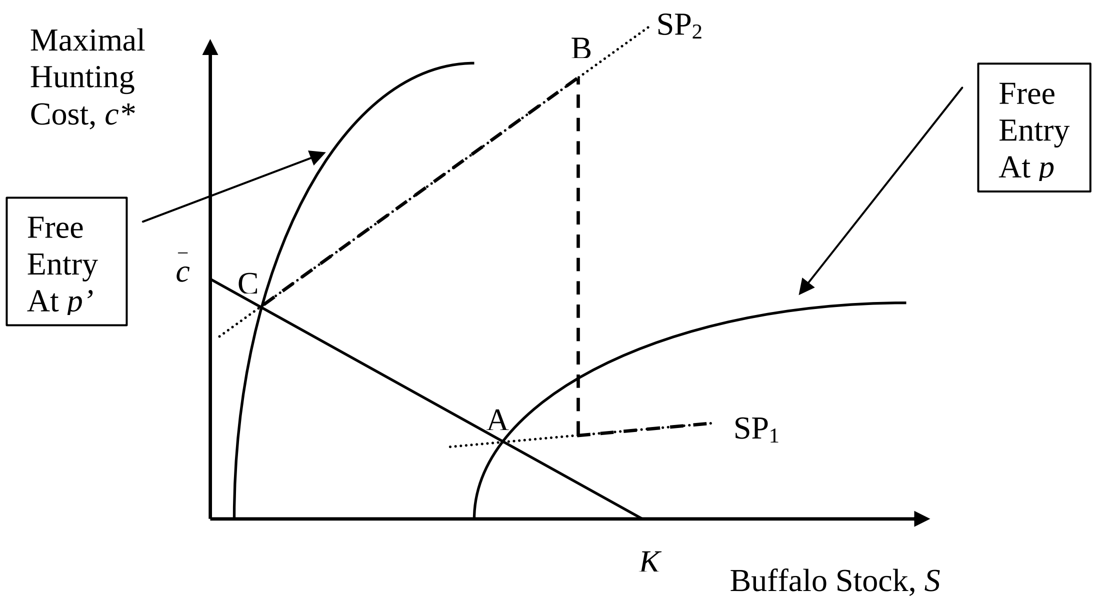


Figure 1
The Slaughter

intercept at the maximal cost draw $\bar{c}$ which would induce enough entry to drive the stock to zero. The resource constraint must intersect the vertical axis when the conditions of Proposition 1 hold. The isocline need not be linear.

The two free entry conditions are upward sloping and concave. Concavity is easily proven by differentiating 14. The upper free entry condition corresponds to free entry with a price of p' while the lower one corresponds to free entry with a price of p. The two arrowed lines labeled SP_1 and SP_2 are saddle paths leading into the steady states at A and C. By drawing in the arrows of motion, or by linearizing the system, it is straightforward to show

Proposition 3. The steady state is saddle-path stable. The stable arm is positively sloped but less steep than the free entry condition.

Proof: See Appendix.

3.4.1 Destroying the Southern Herd

Prior to 1870 the value of a buffalo kill was given by p, and hence the free entry condition intersects the horizontal axis at $w/\alpha p$; the steady state corresponding to this price is given by A. I assume the economy was moving along the saddle path SP_1 towards A. Buffalo numbers were falling, but slowly. There were relatively few buffalo hunters since c^* is low near A and rents are low as well given the location of the zero rent point. Without the tanning innovation, the economy would have moved closer to A over time with falling buffalo numbers, lower rents and fewer hunters. An important feature of the model is that with small rents in buffalo hunting prior to the innovation, only a small number of agents are active in hunting even though rents are positive.

The innovation of tanning in 1870 changed all that. When the price shock hit the new steady state became C. On impact, the acceptable maximal hunting cost jumped dramatically to point B, directly above the pre-existing stock along the new saddle path SP_2. Buffalo herds that were yesterday ignored because of their distance or relatively small size are now hunted vigorously. Even though in steady state the buffalo kill will be smaller than it was prior to the price shock (assuming $S < K/2$ to start with), the number of buffalo killed initially skyrockets. The kills only start to decline over time as the initial discrete jump upwards in hide hunter numbers is slowly unwound as we move from B towards the new steady state at C from above.

The transition path exhibits overshooting in the number of hide hunters for a simple reason: a rational expectation that rents cannot last. Potential hunters realize the buffalo's fate is sealed - the new steady state involves far fewer buffalo. This dismal expectation implies that entry today is more valuable than entry tomorrow when herds are sure to be smaller. The rational hunter with a relatively bad cost draw today enters regardless, but in the coming weeks when he loses the herd, he may not enter again because the buffalo will then be less abundant and the rents far less. As the herd continues to diminish, more and more hunters retire from buffalo hunting. Only those with very low hunting costs or very good luck remain in the industry. The new steady state features more hunters chasing fewer but more valuable buffalo, with the marginal hunter again receiving no rents at all.

3.4.2 Destroying the Northern herd

The history of the Northern herd is slightly more complicated. By the late 1870s, the innovation and the advent of the flint hide market were all in place, but the boom in northern hunting did not occur until 1881. The reason for the delay seems to be the hostile Sioux nation. The Sioux nation was the last significant Indian threat in the U.S., and after the defeat of Custer in 1876 the U.S. Army began an unrelenting campaign to eliminate this threat. It was only in the late 1870s that the remaining Sioux were either killed or settled peacefully on reservations. Until that time, hide hunting in the north was very dangerous. At virtually the same time, the Northern Pacific railroad made its way into Montana. This surely lowered transport costs and raised the price buffalo hunters could obtain for a kill.

In terms of our model, the change in hunter safety could be taken as an exogenous fall in λ. The new railroad could be taken as a small price shock. These two changes work in much the same way and generate the same dynamics as the price shock we examined above. Therefore, while it is unclear what determined the exact timing of the Northern herd's slaughter, the model's assumptions of rational expectations and a fixed price for buffalo products combine to deliver excessive hunting, overshooting, and a punctuated buffalo slaughter. These are important features of the Northern slaughter.

3.5 The Autarky Counterfactual

The model does a reasonable job in replicating the broad features of what we know about the hide hunt. The tanning innovation was unexpected, and its impact created a great deal of entry that was subsequently followed by exit. Early hunters earned large rents as they often left to buy ranches, saloons, or set up stores in frontier towns.[25] Late entrants and the stragglers seemed to do less well. Although the model is successful in replicating the historical record, it does rely on a fixed price for buffalo products. As such it implies that large exports of buffalo hides must have occurred over this period, and this is yet to be proven. In addition, it begs the question as to what would have occurred had their been domestic price adjustment: is a fixed price and robust export market necessary to explain the slaughter on the plains or is it merely sufficient?

To examine this question we now consider an autarky counterfactual by introducing domestic market clearing. It seems reasonable to expect that if domestic markets had to clear, the relative price of hides would have fallen in response to the slaughter. The price fall could have lowered the incentive to hunt while stabilizing the buffalo population. Since the elasticity of demand ought to be critical in determining the price response to the surge in supply, I adopt a constant elasticity of demand formulation where tastes over the two goods: hides and manufactures (the outside good) are homothetic. We again solve for the model's steady state and examine the response of hide hunters and the harvest to a shock that raises the value of buffalo hides (by making them useful leather products).

I solve for the market clearing price by equating relative supply and demand. The relative supply of hides to manufactures at any point in time is given by the harvest of hides divided by manufacturing output. To find hide output apply 9 to the harvesting function for hides; to find the output of manufactures recall employment in this sector must be $1 - b$. With constant returns to effort in the outside good sector, we can choose units so that one unit of effort produces one unit of manufactures. This implies relative supply at any point in time is given by:

$$\left(\frac{H}{M}\right)^S = \frac{\alpha S \theta G(c^*)}{\lambda} \tag{15}$$

[25] See Gard (1955), the personal accounts reported in Gilbert et al. (2003), and the highly entertaining first person account of Frank Mayer "the last living buffalo hunter" in Mayer and Roth (1958).

The relative supply of hides to manufactures is rising in the maximal hunting cost, rising in the buffalo stock and falling in the probability of losing the herd. Because of homotheticity, relative demand is independent of income and can be written as

$$\left(\frac{H}{M}\right)^{D} = \varphi(p) = \beta[p]^{-\sigma} \tag{16}$$

where p represents the relative price of hides to manufactures, and $\beta > 0$ is a demand shifter. Equating supply and demand solves for the domestic relative price

$$p = \beta^{1/\sigma}\left[\frac{\alpha S\theta G(c*)}{\lambda}\right]^{-1/\sigma} \tag{17}$$

We can now substitute 17 in 11 to eliminate p, and obtain the following two equation system.

$$\begin{aligned} \overset{\bullet}{S} &= rS[1 - S/K] - \alpha S[\frac{\theta G(c^{*})}{\lambda + \theta G(c^{*})}] \qquad (18) \\ \overset{\bullet}{c^{*}} &= (\delta + \lambda)c^{*} + \theta[\int_{0}^{c^{*}} [c^{*} - c]dG(c)] \\ &\quad -[[\alpha S]^{1-1/\sigma}[\beta\lambda/\theta G(c^{*})]^{1/\sigma} - w] \end{aligned}$$

The resource constraint is unaffected, and hence delivers a negatively sloped relationship between the maximal hunting cost and the stock of buffalo in steady state. The free entry condition is however potentially very different. In steady state, the slope of the free entry condition is positive, as before, when $\sigma > 1$; it is horizontal when $\sigma = 1$, and it is negatively sloped when $\sigma < 1$.

By drawing in the arrows of motion, it is relatively easy to see that if the slope of the resource constraint is less than that of the free entry condition, then the system in autarky is saddle path stable. Since the slope of the resource constraint is always negative, the system must be saddle path stable whenever $\sigma > \bar{\sigma}$ where $1 > \bar{\sigma} \geq 0$. When the elasticity of demand falls below $\bar{\sigma}$ the dynamics of the system change dramatically to become either a stable focus or a stable spiral.

In all cases, a positive demand shock $d\beta > 0$ shifts the free entry condition upwards and if the system is saddle path stable, the steady state stock falls.

Therefore, even in autarky a demand shock created by the advent of tanning will diminish the buffalo herd. An important difference though is in the transition to the new steady state. Again by graphical or analytic methods it is relatively easy to show:

Proposition 4. The number of hide hunters declines, is constant, or rises along the transition path towards the new steady state as σ is greater than, equal to, or less than one in magnitude.

Proof: See Appendix.

Proposition 4 tells us that the autarky counterfactual can deliver a boom and bust pattern in hide hunting when demand is sufficiently elastic. Only when σ is greater than one is the new steady state approached from above with excessive initial entry and then exit along the transition path. This is of course what the historical record reveals, and the result should come as no surprise since the fixed price case is equivalent to an autarkic demand with infinite elasticity.

The intuition for Proposition 4 is best understood by considering the $\sigma = 1$ case. When the demand shock occurs the value of hunting rises and this creates a surge of entry. Over time, the buffalo stock is driven down but the reduction in the quantity of the buffalo killed is fully offset by a change in relative prices that leaves total revenues constant. Consequently the marginal hunter is indifferent between entering today and entering tomorrow; after the initial jump in entry, the number of hunters is constant along the transition path. When demand is elastic, total revenue earned falls along the path as prices rise. This leads to exit along the transition path, and we converge from above. When demand is less elastic, both revenues and hunter numbers rise along the path. Only the $\sigma > 1$, case is consistent with the historical account of a hide hunter boom followed by exit as buffalo became scarce.

Therefore, the pattern of boom and bust experienced on the Great Plains is consistent with the slaughter being fueled by the tanning innovation together with an elastic demand for buffalo hides. Several authors have noted that the U.S. had a large domestic demand for industrial leather at the time as evidenced by the large imports of cow hides from various South American countries. From these accounts it would appear that U.S. domestic demand for leather fueled the slaughter on the Great Plains, with trade playing, if anything, a role in lessening the slaughter by meeting some of domestic demand via imports.

4 Empirical evidence

A natural consequence of the rapid and violent slaughter of the buffalo is that records of the number of buffalo killed are non-existent. Existing academic work instead relies on a variety of sources to quantify the extent and timing of the kill. One common estimate of the slaughter's magnitude starts with estimates of an initial stock of buffalo using carrying capacity estimates of the Great Plains and then finishes with the observation that by the late 1880s the number in the wild was estimated at less than 100. The difference say, between a mid century estimated population of 15 million, and the final figure of 100 represents the slaughter. While this procedure is valuable in setting rough parameters for a more detailed accounting, it says little about the pace of the slaughter, its geographic location, or its ultimate cause.

An alternative approach is to employ data that is available on shipments of hides by the railroads operating in buffalo country and then amend these to take account for wastage prior to delivery. In the late 1870s, Colonel Richard Irving Dodge (of Dodge City fame) contacted the three major railroads serving the main buffalo hunting areas. Dodge contacted the Atchison, Topeka and Santa Fe, the Kansas Pacific and the Union Pacific railroads asking for data on the shipments of buffalo products. Of these three, only the Atchison, Topeka and Santa Fe responded and provided figures for hides shipped in 1872, 1873 and 1874.[26] *It is important to note that these three numbers (one for each year) for hides shipped are the only data available on the number of buffalo killed in the southern herd.* Additional numbers are often presented in secondary sources, but these additional data come from either extrapolations, estimated wastage adjustments, or implied additional kills by natives.

Dodge makes two adjustments to the shipping numbers. First, to correct for the non-response of the other two major railroads, Dodge multiplied ATS numbers by three since he viewed the other two as equally likely to have shipped as many hides. Second, to account for the loss of killed or injured animals on the ground or the ruining of hides in skinning or transport, Dodge

[26] The lack of enthusiasm in reporting shipments is not surprising. Most of the states in the Great Plains were considering or had put in place restrictions on buffalo hunting; in addition, sentiment out East was moving against the slaughter. The railroads however desperately needed cartage business and would not have wanted the bad publicity - and perhaps federal legislation - such revelations could have brought. A good account of the history of restrictions on buffalo hunting can be found in Gard (1960).

inflates individual year shipment data by a factor representing the ratio of buffalo killed to buffalo hides shipped. In the first years of the slaughter, waste was initially very high and Dodge estimates that in 1872 every hide shipped represents three dead buffalo. In 1873, waste was less partly due to the experience of skinners but still Dodge estimates that in 1873 one shipped hide represents 2 dead buffalo; finally in 1874 there was very little waste with one shipped hide representing 1.25 dead buffalo. By these methods, Dodge arrives at the estimate of a little over 3 million buffalo killed in these three years on the southern plains. Hornaday (1889) adds to Dodge's estimate a figure representing hunting by natives and settlers to arrive at an estimate of 3.7 million.

Estimates of the slaughter in the North are even more tenuous. The Northern shipping points was Fort Benton, located in northern Montana on the Missouri until the Northern Pacific Railroad hit Miles city. Koucky reports the number of hides shipped in 1881 and 1882 - the peak years - was only 270,000. Hornaday estimates that the kill off in the North could not have exceeded 1.5 million.

It is obvious from this account that very little is known with certainty about the magnitude and pace of the slaughter. Many observers lamented the sorry state of the plains at this time - the lines of putrid carcasses, the bone fields, and the large stack of hides at railroad stations. From these it is clear that a punctuated slaughter did occur, but its extent and exact timing are far less certain. Individual eye witness accounts add colorful description to more factual accounts, but are not of much use in distinguishing between a slaughter say of 3 million and one of 10 million.

To examine the potential role of international trade in the buffalo's demise it is of course natural to look at trade statistics, which until now, apparently have been ignored by researchers in this area. The benefit of trade statistics is that they often provide estimates of key physical and value flows when production data are known to be either incomplete or entirely absent. Governments have a strong incentive to record and meter the value and volume of materials entering and leaving their country since import and export taxes were a major source of revenue at the time.[27] Accordingly, trade statistics often tell a story where production statistics alone cannot. The same appears

[27] For example, the U.S. had a 10% import duty on hides until August of 1872. When the duty was removed, hide prices in the N.Y. hide market fell by the amount of the duty - just as they should if the U.S. was truly a small player in the global hide market as I have assumed.

to be true here, although with some caveats. U.S. trade statistics from the 19th century contain categories of exports that contain buffalo products, but no individual entry is labelled as either buffalo meat, buffalo robes or buffalo hides. Despite these limitations, by employing economic theory, estimates from empirical work on the cattle cycle, and judicious use of the first person accounts drawn from the historical record we can reconstruct what I believe to be a fairly reliable time series of buffalo hide exports from the U.S. This record then allows us to evaluate our hypothesis.

4.1 Buffalo Hide Exports

I employ a multi-step procedure for identifying buffalo products in the international trade statistics. The procedure starts with the value of U.S. hides exports from 1855 to 1886. To ensure that these are not re-exports from Canada, Mexico or other countries, I employ an exports from domestic production series. I start by converting hide values into hide numbers by deflating value figures for exports, using estimates for hide prices. Hide prices are provided inconsistently in the series. I generate a price series by taking individual estimates provided in the data and linking them using a price index for leather and leather products provided by Warren and Pearson. The constructed price series is then checked against other individual price quotes found in the literature.[28] The constructed price series shows a slight downward trend in hide prices. Export prices for hides were $3.93 in 1871 the first year of the slaughter and $3.27 in 1885 the last year.

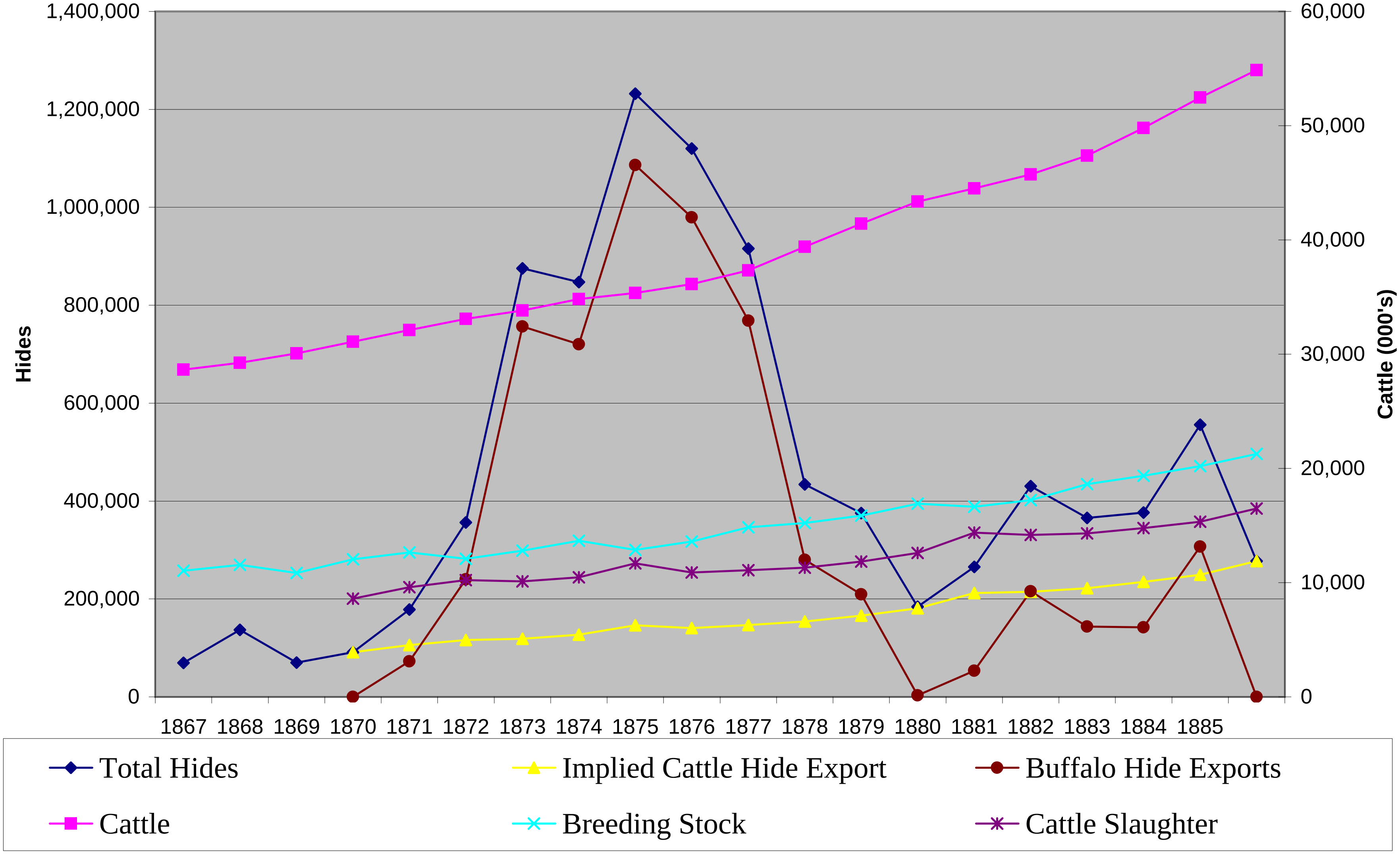
The resulting volume of hide exports is shown in Figure 2 as the top most line with the large bulge centered on 1875. As shown, the line labelled Total Hides starts from a low of less than 100,000 in 1867, peaks at a little over 1.2 million in 1875, then declines until they reach 200,000 in 1880. In the early 1880s exports cycle back upwards only to fall again in 1886. I will argue that the large bulge of exports in the mid 1870s represents the destruction of the Southern herd, while the smaller bulge in the early 1880s corresponds to the destruction of the Northern herd.

To eliminate from these data the component that represents cattle hides,

[28] For example, the constructed series has 1864 and 1865 hide prices at 5.11 and 4.74; the true prices were 5.44 and 4.97. Similarly the constructed price series has prices in 1880 to 1884 from 3.5 to 3.3 per hide, whereas Hornaday (1889) lists prices ranging from 3.34 to 2.85 over this period. It is unclear though whether Hornaday's prices are export prices or prices recieved by hunters.

Figure 2

The Construction of Buffalo Hide Exports



I construct a measure of cattle slaughtered in the U.S. using statistics on the number of cattle within the U.S., and then employ a well known economic model of the cattle cycle to generate estimates of the cattle slaughter. The U.S. Agricultural Department publishes data from 1867 onwards on the number of cattle in the U.S. I have graphed this data in Figure 2 as Cattle. Since the number of cattle in the U.S. in 1867 is approximately 25 million and is over 55 million in the late 1880s, the slowly rising line shown in the figure is graphed against the alternate right hand side axis which is measured in thousands of animals.

To move from cattle numbers to an estimate of the number of cattle hides exported several steps are required. First, I employ estimates drawn from Rosen, Scheinkman and Murphy, RSM, (1994) to generate an implied breeding stock from the overall cattle numbers. This step is necessary because not all cows are fertile, and not all cattle are cows. Using the implied breeding stock I then employ RSM's empirical estimates to generate an implied yearly slaughter. RSM develop a dynamic forward looking model of cattle supply to study the cattle cycle in the U.S. and estimate their model on data starting in 1867. By employing their estimates I have calculated both the underlying breeding stock and the slaughter coming from the stock. The implied breeding stock and slaughter numbers are shown in Figure 2 and given their magnitudes both are graphed against the right hand side axis.

The final step in the identification of buffalo hides in exports uses additional data from historical sources and makes one further assumption. Historical sources all agree that prior to 1870, there was no market in buffalo hides. Up to this point in time, buffalo was hunted for its robe, its meat or killed for amusement. Without knowledge of how to tan a buffalo hide, the hide market was non-existent. This implies that in 1870, the U.S. exports of hides could only be those of cattle. Similarly, historical accounts indicate that hunting on the northern plains stopped sometime during the 1883-84 season; shipment of hides down the Missouri by steamboat or via the Northern Pacific by rail may have ended sometime later, and exports later still because of potential inventory effects. Accordingly, I have assumed that in 1886, the export of hides must again represent only cattle hides. Using these two points as anchors, I then use a linear interpolation for the years in between. Doing so generates the light colored line representing an estimate of that part of the existing U.S. cattle slaughter that is exported. Subtracting the implied cattle hides from the overall hide export numbers yields our estimate for the number of buffalo hides exported from 1870 to 1886.

4.2 Using time, geographic and country variation

The method of data construction is fairly lengthy and detailed. Were it not for the absolute paucity of other data on the number of buffalo killed or exported, and the existence of other confirming evidence that I shall now present, there would be little to suggest its acceptance. The series as constructed however has several desirable characteristics that argue in its favor.

First, we note that by construction the series reaches zero in 1870 and 1886 (our two "identification points"), but also exhibits a severe dip in hide exports in 1880. 1879 was the last year of the Southern hunt; and 1881 the first significant year of the Northern hide hunt. It is therefore striking that our constructed series exhibits a significant pause as the hunt moved from south to north.

Further confirmation comes from other aspects of the series. Using the series we can calculate the implied number of buffalo hides exported during the entire 1870-1886 period. It sums to almost 6 million exported hides. Of the 6 million hides exported, 5 million hides come from what we are calling the 1870s destruction of the Southern herd, and only 1 million from the destruction of the Northern herd. This is consistent with the accounts of Hornaday and many others indicating the Southern herd was much larger than the Northern. For example, Hornaday estimates a northern kill of only 1.5 million whereas figure 1 generates a total close to 1 million. Therefore the series generates a distribution across geographic region that roughly matches the historical account.

The total of 5 million killed in the South is however higher than that given in the estimates of Hornaday and Dodge, but both of these authors severely down played the extent of the Southern herd destruction that occurred in the Texas panhandle post 1874. As shown by the series in Figure 2, while exports peaked in 1875 there was still substantial hide exports well into the late 1870s. My own reading of the historical accounts of buffalo hunters (not available to either Hornaday or Dodge) indicates that hide hunting of significant magnitude did occur post 1874.[29] For example, Dodge reports that in the last year of the Southern slaughter 1874 the number of hides shipped by rail was only 126 thousand falling from over 750 thousand the year before. The Chamber of Commerce of New York however reports that

[29] Dodge's Plains of the Great West was published in 1877; Hornaday account was published in 1889 but it relies heavily on Dodge's account. The compilation of personal accounts of buffalo hunters by Gilbert et al. first appeared in 2003.

200 thousand buffalo hides were received in the port of New York alone in 1875.[30] Personal accounts of buffalo hunters working in the panhandle of Texas and present day Oklahoma also make it clear that the Southern herd was not destroyed until 1879.

When we consider only the 1872-1874 period, our constructed series and Dodge's (constructed) numbers are much closer. For example, Dodge's estimate of hide shipments over the 1872-1874 period is approximately 1.4 million hides; the implied shipment of hides for exports from figure 2 is somewhat higher at 1.7 million. Therefore, the magnitude of the Southern herd destruction and its pace in the early years of the slaughter roughly match those available in the literature.

Further evidence comes from an investigation of the hide dealers themselves. Historical accounts of the hide trade reveal that two individuals were critical in its progression. One was a Kansas city pelt trader called J.N. Dubois. The standard historical account given by Gard (1960, p. 90) appeared earlier in the paper.

Another trader often mentioned in early accounts was W.C. Lobenstein. Lobenstein was a well known trader in leather products who sometime in late 1870 or early 1871 started to fill orders for hides to ship to England. The accounts mention that English tanners had discovered the secret to tanning buffalo hides. Therefore, to the best of our knowledge the discovery of buffalo tanning was made in Germany and England, and U.S. hide merchants with contacts in these countries were the first to enter the hide market and subsequently to remain major players. Given these historical accounts it is revealing to note that the geographic distribution of U.S. hide exports offers two other pieces of confirming evidence. U.S. export data show the value of hide exports to Germany being negligible in the early 1860s, and then skyrocketing to a little over 100,000 dollars in 1871-72, rising to over 500,000 in 1874, and then declining to 50,000 in 1880.[31] It is striking that the sudden

[30] The Chamber of Commerce of New York 18th Annual Report for 1875/1876 contains the throw away line "Included in the receipts by railroad are about 200,000 bison hides", p115. Since rail was only one of many transportation routes, and New York only one of several large export ports, it is reasonable to assume the total number of bison hides reaching the international market was much higher.

[31] Prior to unification of northern Germany in 1870, these exports are to cities in the Hanseatic league; specifically Hamburg and Bremen. These towns disappear in the data in 1870 and are replaced by Germany as an entry. City specific export data (from the port of NY) is available in the NY Chamber of Commerce Annual Reports, and these data confirm that the Hanseatic cities are the leading destinations post 1870. Therefore, a

rise in exports of hides to Germany occurs just when other historical accounts place J.N. DuBois at center stage in the buffalo hide trade.

The English data is equally striking. In the post civil war period, 1866-1870, U.S. hide exports to England averaged \$50,000/year. Starting in 1872 however these exports took off rising to over \$2 million in 1873 and averaging over \$1.3 million dollars per year for the next six years. Again the sudden explosion in exports to England, together with the historical accounts of Lobenstein providing a major trade route is again independent confirmation of the constructed series.

4.3 Neccesity and Sufficiency

Putting all of this evidence together generates a circumstantial, but hopefully compelling case. Independent historical evidence was shown to be consistent with the series magnitude, timing, and geographic variation in terms of both the location of the slaughter and the destination of exports.

The introduction to this paper claimed that (1) a price for buffalo products that was largely invariant to changes in supply; (2) open access conditions with no regulation of the buffalo kill; and (3), a newly invented tanning process that made buffalo hides into valuable commercial leather were jointly necessary and sufficient for the slaughter on the Great Plains. The results thus far demonstrate that the combination of a tanning innovation, open access to buffalo hunting, and fixed world prices delivers a punctuated slaughter that matches that witnessed on the Great Plains. Therefore we have proven sufficiency. The proof of necessity is less satisfactory.

To prove the necessity of a market price that is "largely invariant" to changes in supply we can invoke Proposition 4 where we found domestic demand needed to be elastic in order to generate a hide boom with excessive initial entry followed by exit. By defining largely invariant conveniently, necessity is proven.

The proof of necessity of the tanning innovation is proven by the absence of the slaughter during the five years prior to 1872 when the Union Pacific had reached the heart of buffalo country at Cheyenne Wyoming, but no slaughter occurred. The two other major railroads - the Kansas Pacific and the Atchison, Topeka and Santa Fe also reached Kansas in 1870, but still the Kansas hide boom did not occur.

change in definition to Germany is not responsible for the blip in exports.

Finally to prove that open access is necessary for the slaughter we note that even if we adopt an intrinsic growth rate of 15% per year (at the low end of the estimates for bison), extinction of the buffalo is unlikely to be optimal; if some semblance of harvesting control had been put in place the slaughter would not have occurred. The need for regulation was in fact so acute, that private parties eventually established property rights on their own by capturing live buffalo. Several entrepreneurial ranchers in the 1870s and 1880s established private herds that, until federal legislation arrived in the mid 1890s, probably saved the buffalo from extinction.

4.4 Caveats

I suspect that the buffalo export series underestimates the true slaughter. There are two reasons why there is likely some "missing kill". First, there was undoubtedly some domestic market for buffalo hides. Historic accounts tell of a buffalo hunter John Wright sending hides to his brother in N.Y. who then sold them to Pennsylvania tanners. Wright was originally commissioned to provide hides to Lobenstein for the English tanners, and hence Wright knew the potential value of buffalo hides as leather once tanned. By all accounts, the tanners in Pennsylvania were successful and further orders followed.

Wright's brother soon joined him to hunt buffalo out west. How large the shipments to N.Y. were, or whether they ended up in exports or not I cannot tell but this account does open up the possibility of a sizeable domestic market for hides. The U.S. was at the time importing large quantities of cow hides from South America, and the leather and tanning industry in NY and Pennsylvania could have made good use of buffalo leather.[32] It seems foolish therefore to think that the entire buffalo kill is captured by the hide data.

A second source of error comes from the exclusion of buffalo robes. Robes would be included in fur exports, and not in hide exports. Hide hunters took buffalo in all seasons of the year once the boom started, and this implies that at least a fraction of the skinned hides would have been of sufficient quality to be classified and sold as robes. In the North the quality of the robes was

[32] Recall that in 1878 and 1879 the NY Chamber of Commerce Annual report contains a price series on hemlock-tanned-bison sole leather. Industry yearly reviews, contained in the annual reports, tell of a strong European demand for sole leather at exactly this time. This suggests that bison hides tanned in the U.S. could very well have found their way to Europe as sole leather.

much better and the advent of hide hunting may have pressured natives and other hunters to accelerate their own robe hunt.

A cursory examination of US fur exports suggests this may have indeed been the case. There is a similar spike in fur exports in the 1870s and 1880s that closely matches the slaughter. This data is potentially very useful, but there are also confounding factors. The U.S. purchased Alaska in 1867 and it is not clear what portion of the fur boom is due to this addition; as well the Northern Pacific Seal hunt Treaty was yet to be signed and therefore the boom in fur exports could be a boom in seal pelts rather than buffalo robes. Resolving these issues is left to future work.[33]

5 Alternative Hypotheses

Amazon.com lists over 4000 book entries when buffalo is entered as a search term; a library of congress search generates the maximum of hits; and any visit to your local bookseller will reveal several new books on buffalo history, biology, etc. printed in just the last few years. Given the importance of the buffalo to Native and Western history, and its role as a national symbol it should come as no surprise that there are numerous explanations for the buffalo's demise. The slaughter has been linked to disease, native over hunting, U.S. army policy, hide hunting, and environmental change. Research contains numerous book length treatments, hundreds of scholarly articles and many theses and dissertations. It is not possible here to develop in any detail a careful examination of all of the hypotheses; instead I will discuss how key alternatives are largely inconsistent with the data and arguments presented here.

[33] It is possible to infer how large the "missing kill" must be under some assumptions. I will provide an analytic expression in the next draft. For now take an initial 1870 Southern herd stock of 9 million, an intrinsic rate of growth of .18, and the kill represented by our export series, then we can then solve for the "missing kill" that is needed to drive the Southern stock to zero by 1880. This exercise is full of caveats, but it further constrains us by providing a dynamic adding up constraint. The result is that, under these assumptions, the export series over 1870-1879 is "missing" 1/3 of the needed kill, and the total cumulative kill needed over this period is 11.5 million bison. Are the "missing kill" the bison used by U.S. tanners to make sole leather; are they the bison with hides rich enough to be classified as robes?

5.1 The Army

Many accounts of the buffalo slaughter contend that the elimination of the buffalo was a secret goal of government policy. The evidence provided for this hypothesis is the many failed and stalled bills introduced in Congress, and various quotes from government officials noting the salutary effect an extinction would have on domiciling the natives. For example, a bill restricting the harvest of female cows to only Indian hunters on all federal lands passed both the House and the Senate in June of 1874, but was killed by a pocket veto by President Grant. This result is not that surprising since Grant's Secretary of the Interior Columbus Delano was in favor of the destruction of the buffalo. He refused to stop hide hunters from entering Sioux lands, and in his report for 1873 wrote "I would not seriously regret the total disappearance of the buffalo from our western prairies, in its effect upon the Indians. I would regard it rather as a means of hastening their sense of dependence upon the products of the soil and their own labors " Gard (1960, p. 207).

Other accounts coming from speeches made by General Sherman, Sheridan or Custer are all similar in that these men thought the destruction of the herds would have a beneficial effect in reducing Indian resistance.[34] While this aspect of the story is surely true, and while federal legislation may have helped stem the tide of the slaughter, the regulatory problem was formidable.[35] The Great Plains is an incredibly large area that was only sparsely populated in 1870. Over much of the relevant time period, the federal government already had its hands full managing Indian wars, economic crises, and the progress of reconstruction after a bloody civil war. While the absence of federal regulation made the slaughter simple to conduct and legal, it was the economic incentive created by the tanning innovation that fueled the frenzy.

[34] For example, General Sherman's quote "I think it would be wise", he said of the Sioux insistence on hunting on the Republican River, "to invite all the sportsmen of England and America there this fall for a Grand Buffalo hunt, and make one grand sweep of them all", p.166, Utley (2003).

[35] The regulatory problem was well known. In 1866, a Harper's Magazine writer commenting on the introduction of a bill to restrict buffalo hunting noted that "The difficulty will be to secure its enforcement, as the extermination of these animals, which is now impending, is brought about by parties who, at a distance from any control, are a law unto themselves, and who are not likely to be influenced by any enactments that do not involve the means of execution." Harper's Magazine, April 15th, 1866, Scientific Intelligence section.

5.2 The Railroads

Another often mentioned hypothesis is that the railroads killed the buffalo. They promoted buffalo hunting excursions to eastern hunters and allowed shooting from rail cars when buffalo were present. More importantly, the railroads were a major transportation link in the buffalo hide trade.

Since the natural growth rate of buffalo is reasonable high (somewhere between .15 and .25), localized sport hunting along the track could never deplete the herds significantly. It is also difficult to ascribe the slaughter to an improvement in transportation. As discussed previously the railroad arrived close to the Southern herd years before the hide boom occurred questioning its relevance there. In the North, there is no gap in time between the completion of the Northern Pacific into Montana and the slaughter of the Northern herd. In this case, the arrival of the railroad would seem critical, but this is not entirely clear. Prior to and after the railroad arrived, goods came and went by river boat on the Missouri. While the railroad may have lowered transportation costs, this region had other transportation options. It seems likely in fact that the northern slaughter was delayed by the hostile Sioux Indians, and not any lack of transportation. It was not until the early 1880s that the northern buffalo range was made safe for buffalo hunters - and made safe for the Northern Pacific to complete its construction into Montana. Therefore, while the railroad facilitated the northern slaughter, it is difficult to argue it was in any sense causal.

5.3 Environmental Change & Native Overhunting

A final explanation for the slaughter is environmental change and drought coupled with native over hunting. The Great Plains experienced a very wet period up to the early 1850s and had a series of serious droughts in the subsequent 30 years. Some authors contend that these environmental changes weakened the buffalo and reduced their numbers considerably prior to 1870. If we add to these stresses native over hunting created by the robe market and the breakdown of historic norms, we obtain a large reduction in buffalo numbers prior to the hide hunters.

The evidence presented earlier is largely at odds with this explanation. The buffalo slaughter was large and not small, and it was primarily propagated by white hide hunters. While it is virtually impossible to prove the herds were not larger in 1850 than at the start of hide hunting in the 1870s, it is clear that the slaughter during the 1870s and 1880s was spectacular in its magnitude. Environmental change may have contributed to an overall lessening of buffalo numbers, but had it not occurred I suspect hide hunting would have just lasted longer. Long term change in the West's environment did not kill the buffalo - it was the simple profit motive created by technological change and maintained by robust export markets.

6 Conclusions

The purpose of this paper was to investigate the slaughter of the plains buffalo in the 19th century using a combination of theory, empirics and first hand accounts of buffalo hunters. I have presented an explanation for the slaughter that is not conventional. While hide hunting, the U.S. Army, native over hunting and the railroads are typically held responsible for the slaughter, the role of international trade has featured minimally if at all. Instead, I have argued that free trade in buffalo hides was critical to the explosion of activity on the plains in the 1870s. The plains buffalo was not eliminated by the usual suspects, it was instead the victim of global markets and technological progress.

It is somewhat ironic, that what must be the saddest chapter in U.S. environmental history was not written by Americans; it was instead, the work of Europeans. Europe in the 19th century was the high income developed region, while America was a young developing country recently rocked by a bloody civil war caused by racial strife. In the 1870s, America was a large resource exporter with little or no environmental regulation while Europe was a high income consumer of U.S. resource products apparently indifferent to the impact their consumption had on America's natural resources. Written in this way it is apparent that the story of the buffalo has as much relevance today as it did 200 years ago. Many developing countries in the world today are heavily reliant on resource exports, are struggling with active or recently past civil wars fueled by racial strife, and few, if any, have stringent regulations governing resource use. The slaughter on the plains tells us that waiting for development to foster better environmental protection can be a risky proposition: in just a few short years, international markets and demand from high income countries can destroy resources that otherwise would have taken centuries to deplete.

7 Appendix A: Data (Incomplete)

7.1 Hide Prices

There are three sources of hide prices. First, we can employ the limited number of hide prices given in Foreign Commerce and Navigation figures for hides and skins exports. This is our primary source. To construct the price index for hides I employ price per hide data from 1864, 1865 and 1866. Price per hide is found by dividing that year's export revenue by the number of hides exported. I then take a simple average of these three years, and employ the leather and leather goods price index of Warren and Pearson to generate an estimated price per hide for 1865 to 1886.

The second source are price quotes given in historical documents listing the price paid to hunters for hides or robes. This data is infrequent, and varies with the region and the type of hide sold (bull, cow, calf, hairless, etc.); nevertheless it is instructive to look for any common trend in hide prices.

The third source are actual transaction prices for cow hides sold in the New York hide market. These data are available from the New York Chamber of Commerce Annual Reports for 1865 through to 1886. These data are fairly complete, and I am in the process of compiling them to obtain an alternative price series.

7.2 Hide Exports

I assume the number of cattle hides produced is equal to the annual slaughter of U.S. cattle. To calculate the slaughter over the 1870-1886 period, I proceed in two steps. In step one, I calculate the breeding stock of cattle. I follow Rosen, Murphy and Scheinkman (1994) by relating the total head count $y(t)$ of all cattle to current and past values of the breeding stock $x(t)$. The total stock of cattle is equal to this year's breeding stock $x(t)$, plus last years calves, $gx(t-1)$ plus yearlings that have yet to be slaughtered $gx(t-2)$. That is:

$$y(t) = x(t) + gx(t-1) + gx(t-2) \tag{19}$$

where g is the natural growth rate set equal to .85. The U.S. data for $y(t)$ starts in 1867. Since 1867 is close to the period of time we are most interested in, I follow RMS by initializing the series employing the historical growth rate of the cattle population and making a steady state assumption. In particular, set

$$\begin{aligned} x(1867) &= y(1867)/[1 + (g/1.045) + (g/1.045)^2] \qquad (20) \\ x(1868) &= 1.045x(1867) \qquad (21) \end{aligned}$$

where the first equation follows from the steady state version of 19. g is given by the average annual growth rate of the U.S. cattle population over the 1875-1990 period which is approximately 4.5 %. The second equation also reflects a steady state assumption. By using the initial breeding stock figures for 1867 and 1868, it is now straightforward to manipulate 19 to solve for $x(1869)$ and all subsequent years using data on the series $y(t)$ alone.

To calculate the implied slaughter of cows I employ the empirical estimates RMS obtain when they run the following regression over the 1900-1990 period.

$$x(t) + c(t) = b_0 + b_1 x(t-1) + b_2 x(t-2) + b_3 x(t-3) + u_t \qquad (22)$$

where $x(t)$ is the breeding stock RMS generate when they assume $g = .85$ and $c(t)$ is the actual slaughter figure (only available from 1900 onwards). The addition of these two figures is then regressed on the lagged breeding stock plus a constant. I employ RMS's estimates of b_i from their Table 1, and by rearranging obtain an implied slaughter:

$$c(t) = -1,524 + 1.01x(t-1) + .09x(t-2) + .92x(t-3) - x(t) \qquad (23)$$

With the implied slaughter figures in hand I employ my three identifying assumptions. One, I assume hide exports in 1870 can only be from cattle; therefore, $h(1870) = f(1870)c(1870)$ where $f(t)$ is the fraction of total cattle hides exported in year t. Two, I assume the same is true for 1886, hence $h(1886) = f(1886)c(1886)$. And three, for any year between these two points I employ a linear interpolation for f; that is

$$\begin{aligned} f(t') &= f(t'-1) + [[f(1886) - f(1870)]/16] \qquad (24) \\ h(t') &= f(t')c(t') \qquad (25) \end{aligned}$$

The exported slaughter $h(t)$ is approximately 1% of the total slaughter in 1870 $c(t)$, but rises to 1.7% in 1886. Therefore, these estimates imply the vast majority of hides coming from the U.S. cattle slaughter are used in the U.S. This seems reasonable since the U.S. was a large importer of hides over this period.

The estimate for buffalo hides exported is calculated as:

$$bh(t) = th(t) - h(t) \tag{26}$$

where $th(t)$ is the total export number for hides calculated from U.S. trade statistics, $bh(t)$ is the estimated buffalo hides exported as shown in Figure 2, and $h(t)$ is the estimated cattle hide exports calculated using the procedure above.

8 Appendix B: Proofs (Incomplete)

Proof of Proposition 1. We have

$$\overset{\bullet}{S} = rS[1 - S/K] - \alpha S[\frac{\theta G(c^*)}{\lambda + \theta G(c^*)}] \tag{27}$$

$$\overset{\bullet}{c}^* = (\delta + \lambda)c^* + \theta[\int_0^{c^*} [c^* - c]dG(c)] - [p\alpha S - w] \tag{28}$$

Set $\overset{\bullet}{c}^* = \overset{\bullet}{S} = 0$. Note from 28 that $c^* = 0$ implies $S^0 = w/p\alpha$ and $S^0 < K$, by the assumption i) $p\alpha K > w$. By differentiating establish $\frac{dc}{dS} > 0$ along the free entry condition. Therefore, the free entry condition starts at the interior "open access stock" and is positively sloped in $\{c^*, S\}$ space. Note from 27 that $c^* = 0$ implies $S = K$ when $G(0) = 0$ which is true by our assumption ii) on G. By differentiating establish $\frac{dc}{dS} < 0$ along the resource constraint. Therefore, the resource constraint starts at $S = K$ and is negatively sloped in $\{c^*, S\}$ space. At $S = S^0 > 0$ on the resource constraint, there is a $\infty > c^* > 0$. This follows from assumption iii) $\theta/[\theta + \lambda] > r/\alpha$ because it ensures that some interior c^* will drive the stock to zero. Since 27 and 28 are continuous there must exist an interior intersection $(S^*, c^*) >> 0$. This intersection is unique since the isoclines are monotonic.$\shortparallel$

Proof of Proposition 2. Write 27 and 28 in steady state as

$$\begin{aligned} F(S, c^*, \alpha) &= 0 \\ G(S, c^*, \alpha, p) &= 0 \end{aligned}$$

Establish that: $F_s < 0, F_c < 0$, $F_\alpha < 0$, and $G_s < 0, G_c > 0, G_\alpha < 0$,and $G_p < 0$. Totally differentiating and solving shows:

$$\begin{aligned} \frac{dS}{dp} &= \frac{G_p F_c}{\Delta} < 0 \\ \frac{dc}{dp} &= \frac{-G_p F_s}{\Delta} > 0 \end{aligned}$$

where Δ is the determinant $F_sG_c - G_sF_c < 0$. From the definition of b in 9, we know $db/dp > 0$. Finally note that in steady state we must have $H = rS(1-S/K)$ where H is the aggregate harvest. Therefore, dH/dp takes the same sign as dS/dp when $S < K/2$, and the opposite sign otherwise. ||

Other comparative statics. (Incomplete)

A change in the harvesting technology results in:

$$\begin{aligned} \frac{dS}{d\alpha} &= \frac{G_\alpha F_c - F_\alpha G_c}{\Delta} < 0 \\ \frac{dc}{d\alpha} &= \frac{F_\alpha G_s - F_s G_\alpha}{\Delta} \gtrless 0 \end{aligned}$$

.

Proof of Proposition 3. Take a Taylor series approximation of 27 and 28 around (S^*, c^*) and rewrite as:

$$\begin{bmatrix} \dot{S} \\ \dot{c} \end{bmatrix} = \begin{bmatrix} F_s & F_c \\ G_s & G_c \end{bmatrix} \begin{bmatrix} dS \\ dc \end{bmatrix}$$

where all partial derivatives are evaluated at (S^*, c^*). It is easy to establish that the determinant of this matrix $\Delta = F_sG_c - G_sF_c < 0$. The characteristic equation is defined by

$$(F_s - \lambda)(G_c - \lambda) - G_sF_c = 0$$

or

$$\lambda^2 - (F_s + G_c)\lambda + \Delta = 0$$

The roots become:

$$\begin{aligned} \lambda_1 &= [(F_s + G_c) + \sqrt{(F_s + G_c)^2 - 4\Delta}]/2 \\ \lambda_2 &= [(F_s + G_c) - \sqrt{(F_s + G_c)^2 - 4\Delta}]/2 \end{aligned}$$

Since $\Delta < 0$, $\lambda_1 > 0$ and $\lambda_2 < 0$ implying the systems is saddle path stable. For any given value of S, the system must jump to the stable arm by adjustment of c^*. Recall c^* is the difference between two "asset values" $V^H(t)$ and $V^W(t)$. The saddle path has to satisfy

$$
\begin{aligned}
S(t) &= \alpha v_1 e^{\lambda_2 t} + \overline{S} \\
c^*(t) &= \alpha v_2 e^{\lambda_2 t} + \overline{c}^*
\end{aligned}
$$

where $\overline{S}$, $\overline{c}^*$ denote steady state values, and $[v_{1,}v_2]'$ is the eigenvector associated with λ_2. Solving for this vector yields $G_s v_1 + (G_c - \lambda_2)v_2 = 0$. Setting $v_2 = 1$ as a normalization we find $v_1 = (\lambda_2 - G_c)/G_s$ where $\lambda_2 < 0$, $G_c > 0$, and $G_s < 0$. Solving yields the equation of the saddle path as:

$$
\frac{[c^*(t) - \overline{c}^*]}{[S(t) - \overline{S}]} = \frac{G_s}{\lambda_2 - G_c} > 0
$$

The slope of the free entry isocline is $\frac{dc}{dS} = -\frac{G_s}{G_c} > 0$ and hence the saddlepath is positively sloped but less steep than the free entry isocline. This implies that along the transition path to a new steady state with a lower stock we have $c^*(t) \geq \overline{c}^*$, and hence $b(t) \geq \overline{b}$ since $b(t) = \theta G(c^*)/[\lambda + \theta G(c^*)]$. The number of harvesters jumps with the jump in c^* and overshoots its new steady state value. Since the total harvest is given by $H = \alpha S b$ anywhere along the transition path, and $S(t)$ falls monotonically along the saddle path, it is also clear that the aggregate harvest first overshoots its new long run level and then falls throughout the transition.$\shortparallel$

Proof of Proposition 4. (to be added)

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