

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 over 100 years, the remaining 10 to 15 million buffalo on the Great Plains were killed in a punctuated slaughter in a little more than 10 years. I employ theory, data from international trade statistics, and first person accounts to argue that the slaughter 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.

1 Introduction

200 YEARS AGO, Meriwether 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 west of the Mississippi. Westward expansion with its stories of frontier hardship have shaped much of American national identity by showing how self-reliance, risk-taking and hard work could tame a wild frontier. 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 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This paper examines the slaughter using theory, empirics, and first person accounts from diaries and other historical documents.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 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.² While removing buffalo east of the Mississippi took settlers well over a 100 years, the remaining 10 to 15 million were killed in a

¹The term buffalo is a misnomer but I will use it throughout since this is common usage. The description of the kill as a *slaughter* is also conventional. It is perhaps wise to inform the reader at the outset that this paper is concerned exclusively with positive questions. I leave it to the reader to determine for themselves whether the slaughter was unfortunate or inevitable.

²The species *Bison bison* comes with two distinct varieties: the common Plains bison and the less common Woods bison found exclusively in Canada. I focus on the extinction of the plains bison or buffalo in the U.S., leaving an examination of the Canadian case for future work.

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.

The argument I develop proceeds in three steps. First I build a novel model of buffalo hunting. It assumes potential buffalo hunters differ in their hunting skill, and allows for easy entry and exit.³ For the most part, I take world prices as given and assume throughout that there are no controls over hunting. 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 delivers two key results. First, it shows how 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, the buffalo herds decline rapidly, and the "harvest" of buffalo hides booms.⁴ 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; and the tanning innovation plus hunter heterogeneity 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.

Second, the theory show how rigid prices are necessary for the story. If prices adjust considerably to changes in supply - as they typically would if buffalo products had only a domestic market - then the number of hunters can rise over time even as the buffalo are wiped out. The "punctuated slaughter" is smoothed out over time, and hide prices rise as the buffalo approach extinction. All of these predictions are inconsistent with the historical record: hide prices fell slightly over the period; there was massive entry and then exit, and

³The model is most closely related to Brander and Taylor (1997), but bears some resemblance to resource models with entry such as Wilen (1976) or Brander and Taylor (1998).

⁴The 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)

the slaughter was in fact just that.

In sum the theory provides a *prima facie* case for the importance of international markets in the slaughter, and directs us to look at international trade statistics for empirical evidence. Accordingly, the second step is to examine evidence on U.S. exports of buffalo hides.

A natural consequence of the rapid elimination of the buffalo is that records of the number killed are non-existent, and only very partial shipping records exist. U.S. trade statistics from the 19th century contain categories of exports that contain buffalo products, but no individual entry is labelled buffalo meat, buffalo robes or buffalo hides. The key series I employ is "hide and skins exports" and this surely contains both cattle and buffalo hides. 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 series is then cross-checked for consistency against several pieces of independent evidence. The cross checks examine the magnitude of the implied exports, their timing, and their geographic variation. I also find direct supporting evidence of buffalo hide exports in newspaper accounts, personal diaries, and business directories in importing countries. Finally, I examine import data from Canada, the UK, and France and develop an alternative quasi-experimental approach to estimating buffalo hide exports.

While the model's analytic results prove that my three conditions are sufficient to generate the slaughter they do not prove necessity. The final step then is to argue for necessity by showing the newly constructed export data support the export-driven slaughter hypothesis. The magnitudes of the export flows are considerable. Approximately 6 million buffalo hides are exported over the 1871-1883 period and this represents a buffalo kill of almost 9 million. The timing of greatest export flows fits the historical record extremely well. The implication is clear: absent the innovation that made full time buffalo hunting possible, the buffalo population west of the Mississippi would have trended slowly downward for decades as it had east of the Mississippi. History however was not so kind to the buffalo.

There is a huge literature studying the buffalo and other related aspects of westward

expansion in the 19th century. This literature includes literally hundreds of contributions from history, political science and sociology but only a handful 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 makes no mention of international trade. Other classic contributions such as "The Plains of the Great West" by Richard Irving Dodge (1877), and Joel Allen's 1876 contribution "The American Bisons: Living and Extinct" offer us first person accounts (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 earlier centuries.⁵ 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 earlier contributions in several ways. 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 100 years.

⁵An early and excellent discussion of the slaughter, the hide trade, and the attempts to legislate hunting is contained in Hanner (1981).

This focus on the *slaughter* is important, because it suggests international markets may have soaked up the excess supply while 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. The earlier contributions from economic history explored rather different positive and normative questions, and in each case there was little debate as to the ultimate cause of resource depletion. In contrast, I argue that the usual suspects held responsible for the slaughter on the plains - the Railroads, the U.S. Army, Environmental change or altered native hunting practices - are in fact innocent.

An examination of the slaughter also provides important case study evidence on the speed with which property rights institutions can adapt in the face of new circumstances. In this case the changed circumstance was an innovation, and the adjustment, as measured by new regulation, was slow. In contrast, market responses were immediate and powerful. This relative speed of adjustment is key to many policy debates, and given the dearth of empirical evidence directly on point, case study evidence can be of great value.⁶

Looking back to our past provides us with guidance for the future. For in the not too distant past, Europe was the high income developed region, while America was a young still developing country. 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. Written in this way it is apparent that the story of the buffalo has as much relevance today as it did 130 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 globalization pressures these nations face today, and the policy choices they have to make, are not too different from those facing the U.S. in the late 19th century.

⁶Lueck (2002) argues that the slaughter was due to a change in property rights regime from common property to open access during the hide hunt. He argues that the costs of enforcement exceeded the benefits of protection leading to the change in regime to open access. In contrast, I take the property rights regime as open access throughout, identify international trade as the driving force for the slaughter, and use this insight to provide estimates of the magnitude of the slaughter to show it was critical to the extermination.

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 the hunting model to examine how the time path of buffalo kills responds to an unexpected tanning innovation. In section 4 I construct the buffalo-hide-export data, and provide a series of cross-checks. Section 5 concludes.

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 other regions of North America. The newcomers were unanimous in their appraisal of buffalo as "innumerable" 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 early estimates of the buffalo population vary from over 100 million to less than 20.⁷ The most reliable estimates come to a figure somewhere between 25 and 30 million

⁷The naturalist Thomas Seton (1909) estimated the population circa 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.

buffalo. These estimates are constructed 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 98th meridian. By 1820 or 1830, buffalo were largely gone east of the Mississippi. 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 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 Northern and Southern 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 from the tracks creating a 50 mile wide corridor centered on

the Union Pacific line.⁸ 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, Hanner notes⁹

..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.

The force of habitat destruction was minimal on the Great Plains. In 1860, they held only 164 thousand people. Farms were less than 1% of the land area.

The Civil War brought a temporary reprieve for the buffalo. Major battles occurred in regions with few or no buffalo, and this provided a break from the slow but steady destruction that had marched westward. Despite this reprieve, settlement and habitat destruction had taken a toll: estimates of the buffalo population in 1865 range from 10 to 15 million.

2.2 The Innovation

The temporary reprieve ended quickly when in 1870 or 1871 tanners in England and 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,

⁸To 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 entrepreneurial young boy of 18 when he offered to supply the Union Pacific workers with buffalo meat. William Cody got the contract with Union Pacific, but even his own (perhaps inflated) accounts indicate he killed only 4 to 5 thousand buffalo per year. Hornaday claims that killing by whites, natives and half-breeds totalled less than 500,000 before 1870 and was sustainable (Hornaday, (1889) p.466.) .

⁹See Hanner (1981, p.243).

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 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 "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)."¹⁰

¹⁰It appears this article is unknown to other researchers: see "Buffalo Hides: Some eight or ten months ago", The Times, August 17, 1872, pg. 4, Issue 27458, col. F. It is not known who the enterprising New Yorkers were, although one possibility is William C. Lobenstein (a pelt dealer with an office in Levingworth Kansas) who "is well known as the first dealer to introduce buffalo hides to the market" Fort Griffin Echo,

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."¹¹ 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 "Hoodoo" 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."¹²

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

April 19th, 1879. Lobenstein later lived on the Upper East side of Manhattan.

¹¹Spoilage was a problem. Green hides collected by farmers and hunters soon rotted. Once commercial tanning was available, hides could be preserved before tanning by placing them in a lime solution. This removed hair and facilitated shipping as a wet hide.

¹²Interview with George W. Brown reported in Gilbert et al. (2003), p. 55.

leather. The first was for sole 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 hide.

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.¹³

The eventual diffusion of the innovation to tanners in the U.S. and other European countries is difficult to establish, although often claimed in the literature (recall for example Gard's account). The best evidence of diffusion of the innovation to U.S. tanners comes from NY Chamber of Commerce Annual reports that list prices 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. This suggests the innovation may have diffused to U.S. tanners by the late 1870s.¹⁴

Evidence for diffusion to other countries is also difficult to establish, but here again business directories help. For example, the Foreign Appendix to Slater's 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.

¹³See 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.

¹⁴I say "may have" since the U.S. was importing large volumes of leather products at this time and the bison sole leather could have been imported rather than produced domestically.

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 million buffalo over the 1872-1874 period.¹⁵ Once the herd in Kansas disappeared the hunters turned south towards present day Oklahoma, western Texas and eastern New Mexico. 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 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. The Northern Herd was already diminished by the robe trade that, as early as 1850, sent 200,000 to 300,000 robes yearly down the Missouri.¹⁶ 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.¹⁷

¹⁵See Dodge (1877).

¹⁶See Robinson (1995, p. 31).

¹⁷See Hammer (1981, p.246).

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 hunters, he finally succeeded in collecting specimens for his innovative diorama of buffalo on the Montana plains. At this time, Hornaday estimated the wild buffalo population in Great Plains states at less than 100.¹⁸

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 in the Conservation movement experienced the slaughter first hand - Teddy Roosevelt, John James Audobon, John Muir and William Hornaday.¹⁹ 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

¹⁸In 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.

¹⁹The 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 buffalo bull immortalized on the buffalo nickel was modeled after a large bull in the live buffalo collection created by Hornaday at the Bronx Zoo. There are numerous Hornaday awards given by Conservation groups all across America.

these efforts, over 300,000 buffalo are alive today in reserves and commercial ranches across North America.

3 The Model

I develop a simple dynamic model where agents hunt for buffalo or work in the outside good sector. Buffalo hunters were typically young single men with relatively low opportunity costs and limited skills. Many were civil war veterans or new immigrants 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.²⁰ 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 that lined rivers and closed off all avenues of escape. Since the entry and exit margin is so important to capture, I will determine the number of active hunters endogenously while representing the pool of potential hunters by a continuum of agents with mass N .

3.1 Individual Decisions

I assume potential hunters differ in their hunting skill but are equally productive working in any one of the number of low-skilled occupations represented by the outside good sector. Differences in hunting skill are important in determining a margin for entry and exit, but they also reflect the very real fact that some hunters are simply better than others.

If an agent hunts, they earn the value of harvest ph over the next increment of time dt ,

²⁰Teddy Roosevelt described them as "absolutely shiftless and improvident; they had no settled habits; they were inured to peril and hardship, but entirely unaccustomed to steady work; and so they afforded just the materials which to make the bolder and more desperate kinds of criminals", Roosevelt (1889, p.13). More detailed, and less harsh, personal accounts are compiled in Gilbert et al. (2003).

where h is the quantity of buffalo killed and p the price of buffalo products obtained from a kill. If the hunter remains in the outside good sector they earn the value of their marginal product given by their wage w . 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.

Let $S(t)$ denote the size of the buffalo herd in physical units at time t . Then assuming a hunter's productivity is proportional to the size of the herd, a hunter with skill α earns $ph = p\alpha S(t)$ per unit time. To allow for skill differences across hunters let $\alpha \in [0, \bar{\alpha}]$ with $F(\alpha)$ being the distribution function of hunting skill.²¹ With these assumptions in place the *marginal hunter*, if one exists, is defined by his/her productivity, α^* , such that:

$$p\alpha^*S = w \tag{1}$$

where the dependence of S on time has been suppressed. Assuming free entry and exit, we obtain a simple division of agents at any point in time. Any agent with skill $\alpha \geq \alpha^*$ hunts; the remainder work in the outside good sector.²²

3.2 Resource constraints

Two aggregate constraints close the model. If the mass of potential hunters is N , and the total *number* of active hunters is $N[1 - F(\alpha^*)]$, then $NF(\alpha^*)$ must work in the outside good sector. Since $\alpha^* > 0$ (recall 1), the outside good is always produced. Assuming constant returns in the outside goods sector, and choosing units such that output equals labor input, $w = 1$ at all times.

The second constraint links the buffalo kill to the evolution of herd size. Define $K(\alpha^*, S)$,

²¹Some productivity figures are available in the literature; for example, W.S. Glenn reports that a remarkable hunter can kill 75-100 per day; an average hunter 50; a common hunter 25, and others hardly enough to run a camp. See Strickland (1949).

²²There were fixed and sunk set up costs in hunting which I am ignoring here for simplicity. An earlier version of the model allowed potential hunters to make a truly dynamic investment decision. The more complicated model yielded predictions very close to those given by this simpler set up. Occam's razor, and seminar participants, pushed me to adopt the simpler specification.

as the number of buffalo killed per unit time when the herd is of size S , and agents with productivity no less than α^* are engaged in buffalo hunting; that is:

$$K(\alpha^*, S) = SN \int_{\alpha^*}^{\bar{\alpha}} \alpha f(\alpha) d\alpha \quad (2)$$

where the density of buffalo hunters with productivity α is $F'(\alpha) = f(\alpha)$, their mass is $Nf(\alpha)$, and their productivity in hunting is αS . I refer to 2 as the kill function. Since the marginal hunter is determined at every moment in time by the prevailing price and herd size, we obtain with a slight abuse of notation, $K(\alpha^*(p, S), S) \equiv K(p, S)$.

To determine how the kill responds to herd size, differentiate 2 to obtain:

$$\frac{dK(p, S)}{dS} = N \int_{\alpha^*}^{\bar{\alpha}} \alpha f(\alpha) d\alpha - NS\alpha^* f(\alpha^*) \frac{d\alpha^*}{dS} > 0 \quad (3)$$

where $\frac{d\alpha^*}{dS} < 0$, from 1. When the herd grows in size the productivity of inframarginal hunters rises, and new lower skilled hunters enter. The combination of increased entry and greater productivity means buffalo kills rise with herd size. When the herd becomes small, agents exit and average productivity drops. As a result, there will exist a herd so small that only the most skilled find it worthwhile to hunt. Since the highest productivity hunters have productivity, $\bar{\alpha}$, the *smallest huntable herd*, S_s must satisfy:

$$p\bar{\alpha}S_s = w \quad (4)$$

Rational agents will never hunt a herd if $S < S_s$. Taking this into account, the kill

function becomes:

$$\begin{aligned}
 K(p, S) &= 0 && \text{if } S < S_s \\
 K(p, S) &= NS \int_{\alpha^*}^{\bar{\alpha}} \alpha f(\alpha) d\alpha && \text{if } S_s \geq S
 \end{aligned}
 \tag{5}$$

To determine the dynamics of herd size I assume herd size grows in accordance with a standard compensatory growth function drawn from resource economics. Biological growth, $G(S)$, is assumed to be a positive (strictly) concave function of herd size. Natural growth is zero when the buffalo are gone $G(0) = 0$, and zero when the buffalo reach the carrying capacity of the Great Plains, $G(C) = 0$.

The evolution of herd size can now be written as:

$$\dot{S} = G(S) - K(p, S)
 \tag{6}$$

Solving 6 (subject to an initial condition) generates a time profile for the buffalo herd, the kill, hunter numbers, and output of the outside good.

3.3 Steady State Solution

A typical interior steady state is shown in Figure 1. The growth function $G(S)$ starts at $S = 0$, rises and then returns to zero growth when the herd reaches its carrying capacity at C . A typical kill function is also shown. The kill is zero for small herd sizes, but at $S_s(p)$ hunting begins and then grows in intensity. The kill function is not necessarily convex (as shown), but even when it is not, under mild conditions, there is a unique interior solution.

Proposition 1. Assume: $C > S_s$, then there exists

- i) a unique interior steady state herd size $S^* \in [S_s, C]$;
- ii) a unique marginal hunter $\alpha^*(p, S^*) \in (0, \bar{\alpha})$; and,
- iii) starting from any $S > 0$, convergence to S^* is monotonic.

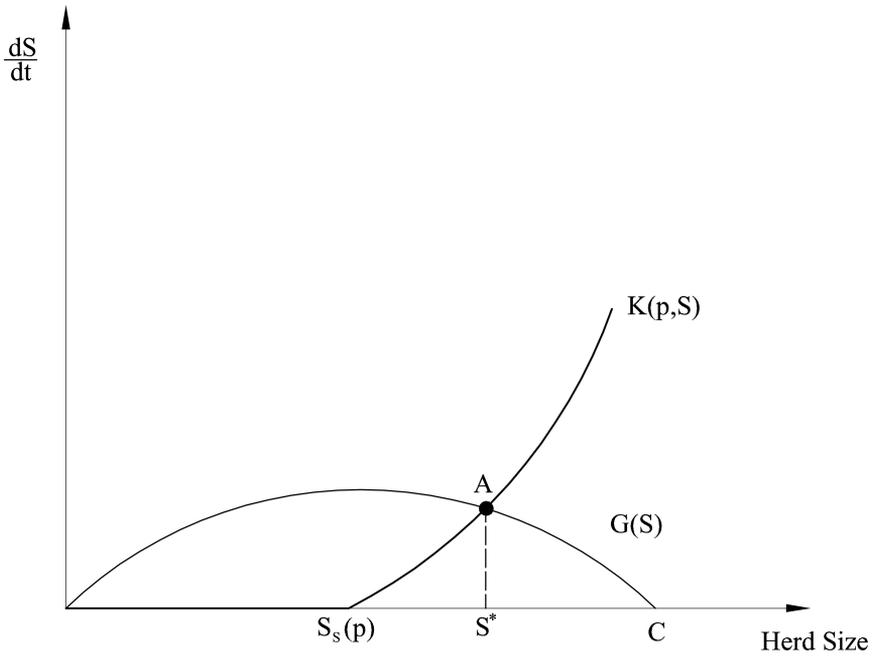


Figure 1

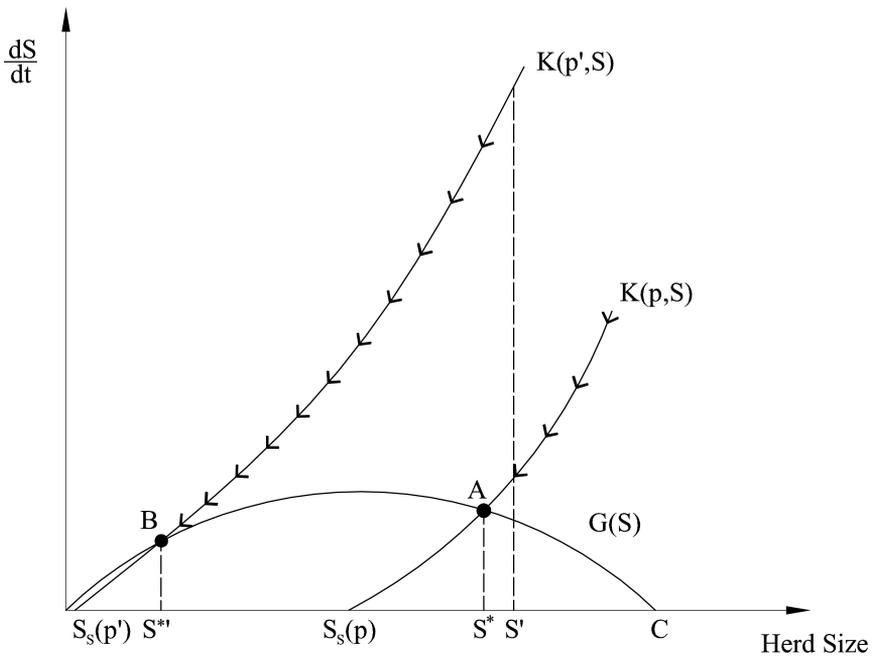


Figure 2

Proof: See Appendix.

Uniqueness and existence are guaranteed by very weak conditions. If the carrying capacity is greater than the smallest huntable herd then $C > S_s$ and $p\bar{\alpha}C > w$: buffalo hunting provide rents to the most productive hunters when the herd is close to carrying capacity. An interior steady state exists. The steady state also determines the number of hunters $N[1 - F(\alpha^*)]$, their aggregate kill $K(p, S^*)$, and output of the outside good $NF(\alpha^*)$. It is clear from Figure 1 that the interior steady state is globally stable. Starting from any positive stock level $S > 0$, convergence to the steady state is monotonic.

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.

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 of the year when robes were virtually worthless. 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' .²³

The historical account is also fairly clear that before the tanning innovation, buffalo numbers were falling although slowly. Hunting pressure and eventually habitat destruction would have led buffalo numbers to fall as they had east of the Mississippi, but the strength

²³Modeling 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.

of these two forces was weak in the 1860s. To capture this feature of the pre-1870 period, I assume the economy was operating somewhere along its transition path to an initial steady state when the price shock hit.

3.4.1 Destroying the Southern Herd

In Figure 2 I plot the growth function and two kill functions $K(p, S)$ and $K(p', S)$. Prior to 1870 the value of a buffalo kill was given by p , and hence the kill function $K(p, S)$ intersects the horizontal axis at $S_s(p)$; the corresponding steady state is given by A . I assume the economy was moving along $K(p, S)$ towards the steady state at A from the right. Buffalo numbers were falling, but slowly.

The tanning innovation changed all that. When the price shock hit, the kill function shifts to $K(p', S)$, dramatically raising the kill. There is a flood of new entry as the hunting skill needed to justify entry drops discretely from $\alpha^*(p, S')$, to $\alpha^*(p', S')$. The boom in new entrants raises the rate of buffalo kill abruptly and the slaughter begins. Relatively high cost hunters enter today knowing that this will be a short-lived game, and as the boom unwinds more and more hunters retire from buffalo hunting. Only those with very low hunting costs remain as the economy moves towards its new steady state at B .

It is apparent from the figure that both the buffalo herd and the number of buffalo hunters adjusts when prices rise. Surprisingly, the steady state buffalo kill may rise or fall in response. The kill rises if the buffalo herd exceeded $C/2$ prior to the price shock and the price shock itself was marginal. In all other cases it falls. Since Hornaday estimated that less than 100 buffalo were left in the wild by the late 1880s while C is perhaps 25 million, the $S^* < C/2$ case is most relevant to our discussion. In this case, the aggregate kill, in steady state, also falls with the price shock.

3.4.2 Destroying the Northern Herd

The history of the Northern Herd is slightly more complicated. By the mid 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.²⁴ 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 early 1880s that the remaining Sioux were either killed or settled peacefully on reservations. The legendary Crazy Horse surrendered in 1877, while the chief who defeated Custer - Sitting Bull - surrendered in 1881. During most of this period, 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 shift rightward in the distribution $F(\alpha)$. The new railroad would represent a small price shock, since transportation along the Missouri by steam ship was already an available and well used transportation option. These two shocks work in much the same way as the initial tanning innovation. Therefore, while it is unclear what determined the exact timing of the Northern Herd's slaughter, the model's assumptions combine to deliver excessive hunting, overshooting in hunter numbers, 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 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,

²⁴At this time, the Sioux, Northern Cheyenne and Northern Arapho were not yet part of the reservation system. They were led by the most important non-treaty chief: Sitting Bull.

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 imply that large exports of buffalo hides must have occurred over this period, and this is yet to be proven.

An alternative hypothesis is that tanneries in the eastern U.S. provided the demand for hides, and in many accounts a strong U.S. domestic demand for leather is implicated in the slaughter. Evidence for this connection is however weak. Apart from the price quotes for bison sole leather in the N.Y. market for 1878 and 1879 (which I discovered), and some mention of eastern tanneries in Hornaday, I have been unable to find any direct evidence in the form of shipments, tanned hide output, etc.²⁶ Census figures from this period argue against the large scale use of buffalo in tanning, since the total measured input of raw hides into U.S. tanning and currying, falls short of the number of cow hides imported plus the (estimated) domestic slaughter. This leaves no room at all for the millions of buffalo hides to be used in the U.S. tanning industry. These census figures are only for two years, 1870 and 1880, and we have only estimates for the domestic cow slaughter. Therefore, the data is not definitive on this issue, and it is useful to ask if the market had been purely domestic what would have happened to the buffalo? Is a fixed price and robust export market necessary to explain the slaughter on the plains or is it merely sufficient?

To examine these questions I develop an autarky counterfactual by introducing domestic market clearing. Since the elasticity of demand ought to be critical in determining the price response, I adopt a constant elasticity of demand formulation where tastes over the two goods: hides and manufactures (the outside good) are homothetic. I again solve for the model's steady state and examine the response of hide hunters to a shock that raises the value of a buffalo kill (by making their hides useful leather products).

²⁵See 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).

²⁶There is an often repeated story of 57 hides sent by Wright Moar to his brother in N.Y. city who then sold them to Pennsylvania tanners thus starting the U.S. domestic market.

3.5.1 Market Clearing

The relative supply of hides to manufactures *at any point in time* is given by the buffalo kill divided by output from the outside good sector.²⁷

$$\left(\frac{H}{M}\right)^S = \frac{K(p, S)}{F(\alpha^*(p, S))N} = RS(p, S) \quad (7)$$

The relative supply of hides to manufactures is increasing in p . Relative demand is independent of income and can be written as:

$$\left(\frac{H}{M}\right)^D = \varphi(p) = \beta[p]^{-\sigma} \quad (8)$$

where $\beta > 0$ is a demand shifter. Equating supply and demand solves for the equilibrium price p^e as a function of herd size and other parameters.

$$\beta[p^e]^{-\sigma} = RS(p^e, S) \quad (9)$$

Differentiate 9 with respect to the herd size to find, after some rearrangement,

$$\frac{dp^e}{dS} \frac{S}{p^e} = - \left[\frac{1 + \varepsilon_{rs,p}}{\sigma + \varepsilon_{rs,p}} \right] < 0 \quad (10)$$

where $\varepsilon_{rs,p} > 0$ is the elasticity of the relative supply curve with respect to p .²⁸ With this result in hand it is now possible to prove an important intermediate result:

Lemma 1. Buffalo hunter numbers rise, stay constant, or fall with an increase in the buffalo herd, S , as σ is greater than, equal to, or less than one in magnitude.

Proof: See Appendix.

Not surprisingly, Lemma 1 has an important bearing on the model's predictions. Using

²⁷ $RS(p, S) = 0$ for $p \leq w/\bar{\alpha}S$, and is positive otherwise; i.e. there exists a minimum price needed to generate hunting at any stock.

²⁸See the proof to Lemma 1 for a derivation.

lemma 1 we know that when σ is equal to one, α^* is independent of herd size. This implies that in autarky the kill function would appear as a straight line through the origin if drawn in Figure 1. When σ is greater than one, $\frac{d\alpha^*}{dS} < 0$, and the kill function is positively sloped as it was before. In both of these cases we can employ the techniques used in the proof of Proposition 1 to show that any autarky steady state is unique. But when σ is less than one we cannot rule out a negatively sloped kill function and multiple steady state equilibria. Despite these complications, we can proceed. To do so we need another intermediate result.

Lemma 2. A positive demand shock $d\beta > 0$ shifts the kill function upwards and raises the domestic price for any given herd size, S .

Proof: See Appendix.

Using Lemma 1 and 2, I can now prove

Proposition 2. Starting from any stable steady state, an unexpected and permanent demand shock, $d\beta > 0$:

- i) lowers the steady state buffalo herd, S ;
- ii) raises buffalo hunter numbers on impact;
- iii) leads to falling (constant, rising) hunter numbers along the transition path if σ is greater than (equal to, or less than) one in magnitude.

Proof: See Appendix.

Proposition 2 tells us that the autarky counterfactual can deliver a boom and bust pattern in hide hunting when demand is sufficiently elastic. When the innovation arrives the demand for buffalo products shifts up along a given supply curve. The surge of new entrants raises the kill on impact. Over time the herd shrinks, the supply curve shifts back, prices rise, and hunter numbers adjust to the combination of changing prices and a shrinking herd size. When σ is greater than one the transition period exhibits excessive entry and then exit along the path to the new steady state. When demand is unitary elastic, the initial surge of entry is followed by zero exit; when demand is inelastic the initial surge of entrants is reinforced

over time. In all cases, hide prices rise as the slaughter continues.

The autarky counterfactual is important in demonstrating that 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 domestic demand for buffalo hides. While several authors have argued that the U.S. had a large domestic demand for industrial leather at the time and this demand was pivotal in the slaughter, these accounts become less persuasive in the face of evidence that the innovation was foreign made, that hide prices did not rise over the period, and that buffalo hide exports represent a significant portion of the slaughter.

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 mid-1870s, Colonel Richard Irving Dodge 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 (ATS) responded

and provided figures for hides shipped in 1872, 1873 and 1874.²⁹ *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 estimates of kills by natives and settlers.

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 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 very high and Dodge estimates that in 1871 every hide shipped represents five dead buffalo. In 1872 this falls to three, and by 1873 one shipped hide represents two dead buffalo; finally in 1874 there was very little waste with one shipped hide representing one and a quarter dead buffalo. By these methods, Dodge arrives at the estimate of a little over 3 million buffalo killed from 1872-1874 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 more tenuous. The northern shipping point 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 the peak years of 1881 and 1882 at 270,000.³⁰ Hornaday estimated that the kill off in the north must have been less than 1.5 million.

It is obvious from this account that very little is known with certainty about the magni-

²⁹The 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 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 Hanner (1981).

³⁰Robinson (1995, p.140) however presents larger estimates. 250,000 from a dealer H.F. Douglas, another 180,000 from Custer county, and an additional 200,000 hauled on the Northern Pacific. I have been unable to find corroborating primary source evidence for these figures.

tude and pace of the slaughter. Unfortunately, this is as true today as it was in 1889 when Hornaday wrote,³¹

Had there been a deliberate plan for the suppression of all statistics relating to the slaughter of buffalo in the United States, and what it yielded, the result could not have been more complete barrenness than exists today in regard to this subject. There is only one railway company which kept its books in such a manner as to show the kind and quantity of its business at the time. Excepting this, nothing is known definitely

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 of say 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, 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. Accordingly, trade statistics often tell a story where production statistics alone cannot. The same appears to be true here, although with some caveats.

³¹Hornaday (1889, p. 435)

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. hide exports from 1865 to 1886.³² 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 complete price series by taking individual estimates provided in the data and filling in the gaps using a price index for leather and leather products provided by Warren and Pearson (1933). The constructed price series is then checked against other individual price quotes found in the literature. For example, an additional source for price data is the series of Annual Reports of the New York Chamber of Commerce which report prices for important items in the New York market.³³ One item consistently reported over this period is sole leather (hemlock tanned). This price series can be used in place of the Warren and Pearson index as a check on our initial construction.

In Table 1 below I present the series for hide prices developed using the Warren and Pearson price index and the alternative price series constructed using the price data drawn from Annual NY Chamber of Commerce reports. I have also included an estimate of the price a hunter may have received assuming transportation and distribution account for 40% of the delivered hide price. Since hides were worthless until 1871, the price-to-hunters series, starts at zero and then takes a jump upwards when the innovation hit. All of the constructed price series exhibit a slight downward trend over time. For example, the WP export price for hides was \$3.93 in 1871 the first year of the slaughter and \$3.27 in 1885 the last year. As shown, the NY hide price series differs very little from the main WP series,

³²See United States, Department of Treasury, Bureau of Statistics, Foreign Commerce and Navigation of the United States. Available online through Archive of Americana, U.S. Congressional Serial Set, 1817-1980, published by Readex, a division of Newsbank, inc. at <http://infoweb.newsbank.com/>.

³³See State of New York Chamber of Commerce Annual Report, Press of the Chamber of Commerce, 1865-1890.

and all conclusions of the paper are unaffected by my choice of price index.

Table 1 - Hide Prices (\$/Hide)

Year	W.P.	N.Y.	H.P.	Year	W.P.	N.Y.	H.P.
1866	4.56	4.74	0	1876	3.25	4.04	2.32
1867	4.12	4.82	0	1877	3.40	3.42	2.43
1868	3.93	4.43	0	1878	2.96	3.03	2.12
1869	4.18	4.66	0	1879	3.12	4.51	2.23
1870	3.99	4.51	0	1880	3.53	3.58	2.52
1871	3.93	4.35	2.81	1881	3.40	3.42	2.43
1872	4.06	4.35	2.90	1882	3.37	3.26	2.41
1873	4.12	4.35	2.94	1883	3.34	3.34	2.38
1874	3.99	4.20	2.85	1884	3.46	3.26	2.47
1875	3.84	3.89	2.74	1885	3.28	3.58	2.34

Notes: W.P. is hide prices found using the Warren and Pearson price index. N.Y. is hide prices found using data drawn from the Annual NY Chamber of Commerce reports. H.P. is the price-to-hunters series.

It is tempting of course to attribute the decline in hide prices to the additional supply created by the buffalo slaughter in the U.S. While in theory the slaughter could have an effect on world prices, as an empirical matter this is unlikely. The worldwide hide market was huge with yearly exports exceeding 100 million US dollars by 1880.³⁴ The US share of this market is always small during the relevant period ranging from a high of 3% in 1860 to .5% in both 1880 and 1890.

Finally, while the two or three dollar jump in the value of a buffalo hide in 1871 seems relatively small to have such large effects, it should be remembered that a seasoned hunter could kill several thousand buffalo a season. Alternatively he could earn perhaps 50\$/month

³⁴For information on the magnitude of the world hide market see John R. Hanson, *Trade in Transition: Exports from the Third World, 1840-1900*, data sets are available online at <http://eh.net/databases/developing>.

as a cattle hand. Even at these relatively low hide prices, the rents to hide hunting were potentially very large.

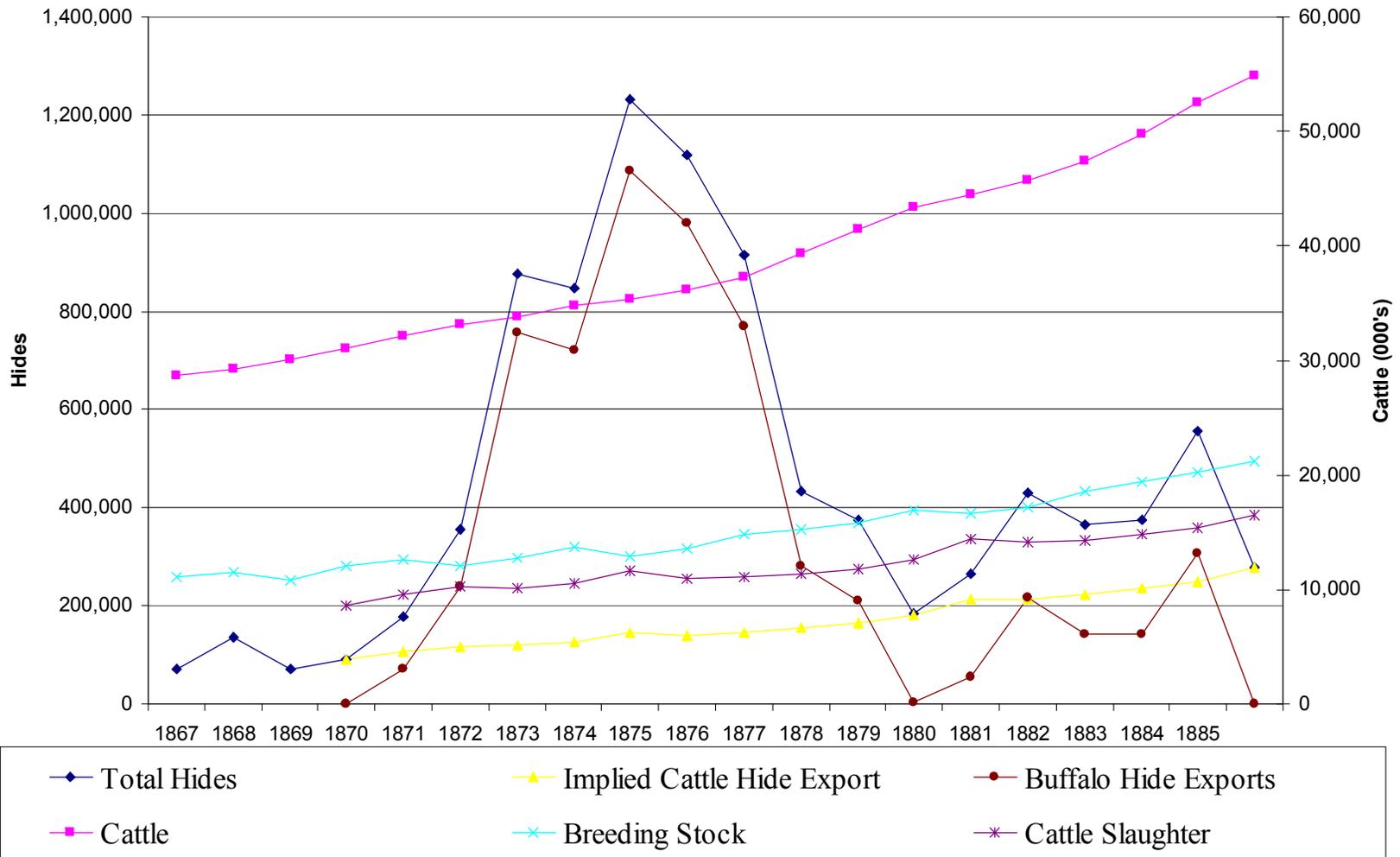
By using the WP hide price series I obtain a volume of hide export series shown in Figure 3 as the top most line with the large bulge centered on 1875. The line labelled Total Hides starts from a low of less than 100,000 in 1867, peaks at a little over 1.2 million in 1875, then declines until it reaches 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 cattle hides from the volume of hide export series I construct a measure of cattle slaughtered in the U.S. using a well known economic model of the cattle cycle. 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 3 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.³⁵ 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 3 and given their magnitudes both are graphed against the right hand side axis.

³⁵See appendix B of my NBER working paper No. 12969, March 2007 for further details.

Figure 3
The Construction of Buffalo Hide Exports



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 U.S. exports of hides could only be those of cattle. Under this assumption, I find only 1% of the hides from slaughtered cattle are being exported in 1870. 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 assume that in 1886, the export of hides must again represent only cattle. By 1886, I find 1.7% of the hides from slaughtered cattle are exported. Using these two points as anchors, I construct a linear interpolation for the years in between. Doing so gives the light colored line representing an estimate of that part of the existing U.S. cattle slaughter that represents exported hides. Subtracting the cattle hides exported from the overall export numbers gives an estimate of the number of buffalo hides exported from 1870 to 1886.

4.2 Variation over time and regions

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, note that by construction the series reaches zero in 1870 and 1886 (the two "identification points"), but also exhibits a severe dip 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 pause as the hunt moved from south to north.

Further confirmation comes from other aspects of the series. Using the series I calculate

the implied number of buffalo hides exported during the entire 1871-1886 period. It sums to almost 6 million exported hides. Of the 6 million hides exported, 5 million hides come from what I am 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 3 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 downplayed the extent of the Southern Herd destruction that occurred post 1874. 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 the peak of 750 thousand the year before. New evidence on hide shipments I uncovered in the Annual reports of the New York Chamber of Commerce is inconsistent with this view. For example, the Chamber of Commerce report for 1875/76 states that 200 thousand *bison hides* were shipped by rail to the port of New York alone in that year.³⁶ This newly discovered data from the Chamber of Commerce report strongly suggests the Southern Herd was not destroyed by 1874 - a fact further corroborated by contemporary news stories and numerous personal accounts of buffalo hunters which make it clear that the Southern Herd was not destroyed until 1879.³⁷

When considering the 1872-1874 period alone, my constructed series and Dodge's (constructed) numbers are much closer. For example, Dodge's estimate of hide shipments over

³⁶The 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", p. 115. 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.

³⁷For e.g., the Fort Worth Democrat, Nov. 8, 1876, has a front page story titled "Freighters Wanted. The Largest Buffalo Hunt Ever Known". The story reports countless thousands of buffalo cover the prairies while the hunt is the largest ever known. Regarding the end of the hunt see the Frontier Times article "The Last Buffalo Hunt Held in the Lone Star State", reprinted by the Dallas Morning News Aug. 9, 1925. The article dates the last hunt to Nov. 1879.

the 1872-1874 period is approximately 1.4 million hides; the implied shipment of hides for exports from Figure 3 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.

4.3 Across country and across hide variation

U.S. export data show the value of hide exports to Germany being negligible in the 1860s, and then skyrocketing to over \$100,000 in 1871-72, rising further to over \$500,000 in 1874, and then declining to \$50,000 in 1880. It is striking that the sudden 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. The sudden explosion in exports to England, together with the historical accounts of Lobenstein's activities provides further corroboration.

It may however, be inappropriate to attribute all of the "explosion in exports to England", or the "sudden rise in exports to Germany" to the impact of the innovation. Exports of hides to Europe may have risen for many reasons. The 1870s was a very tumultuous time in Europe with German unification in 1870, the Franco-Prussian war in 1871, and colonial expansion later in the decade. Perhaps the explosion in U.S. hide exports to Europe reflects a temporary European event and not the availability of buffalo hides from the U.S.

4.3.1 Ruling out a European Demand Shock

If a European specific demand shock is driving U.S. hide exports upwards for reasons unrelated to the availability of buffalo, this shock should show up in European imports from other countries as well. To examine this possibility, I collected, where possible, hide import data from European countries that were major European destinations for U.S. hide exports. The

major destinations for U.S. hide exports were France, Germany, and the UK. At present, I have collected this data from all countries except Germany.³⁸ Using this data, I examine how the share of hide imports coming from the U.S. varies over time. The rationale for using imports shares is simple: a uniform demand shock in Europe should raise its imports of hides from all sources leaving the U.S. share unchanged; a U.S. specific shock - such as the availability of buffalo hides - should however raise the share of imports coming from the U.S. dramatically and temporarily.

This new data also allows for a further sharpening of the hypothesis. The UK and French data allow me to divide their hide imports into tanned and raw hide categories; this is very fortunate since the available U.S. export data makes no such distinction.³⁹ Since it is my contention that the buffalo hide exports to Europe were motivated by the inability of the U.S. domestic industry to tan buffalo hides, increased buffalo hide exports coming from the U.S. must come in the raw hide category.

In Table 2 below I present the results from a difference-in-means test on the U.S. share of raw hide imports into the U.K and France.

Table 2 - Difference in Means Test

$H_o : m_o - m_1 = 0$			
$H_a : m_o - m_1 < 0$			
	Difference	t	$P < t$
France	-5.02 ^a	-3.69	0.001
UK	-3.39 ^a	-2.71	0.001

³⁸For the France data see France, Direction général des douanes, Tableau général du commerce de la France avec ses colonies et les puissance étrangères, Renaud, Paris, published annually for the years 1825-1895. For the UK data see Great Britain, Annual Statement of the Trade and Navigation of the United Kingdom with Foreign Countries and British Possessions, for the years 1853-1870 and Annual Statement of the Trade of the United Kingdom with Foreign Countries and British Possessions, London, H.M.S.O. for the years 1871-1924. The German data is not up to the task as hides are grouped in with fur items, and there is an incomplete record of imports across countries. I would like to thank Andy Strangeman and Investra ltd. for their help in acquiring this data.

³⁹The new data is useful in two other ways. The French data divides out skins from hides and assures us that goat and deer skins were only 1-2% of total US hides and skins exports. The French and U.K data also give hide imports in quantities.

Notes: m_1 is the mean of the Southern Treatment Group and m_o is the mean of the Other group. t is Student's t-statistic, and P indicates probability values. The superscript ^a, indicates significance at the 0.01 level. The dependent variable is the share of raw hide imports from the U.S. in total raw hide imports from all countries.

In light of Figure 3, I divide the sample period into the period of Southern Herd destruction, 1871-1879, and refer to this as the Southern Treatment Group while the remaining period is captured in Other. I test the null of equality in mean import shares across these two periods against the alternative that the import share of raw hides was higher during the period the Southern Herd was destroyed. The results are consistent with my earlier claims. The equality of means is rejected at very high levels of significance arguing against a broad based demand shock.

4.3.2 Ruling out a U.S. Supply Shock

While the difference-in-means test argues against a European demand shock, perhaps the bulge in exports shown in Figure 3 represents a U.S. supply shock unrelated to the buffalo slaughter. For example, a U.S. specific event such as the completion of railroads, the creation of an open range cattle industry, or the concentration of production in large slaughterhouses could have raised U.S. hide exports.⁴⁰

To investigate I exploit one more feature of the data and one more piece of information regarding the innovation. The only non-European country receiving significant hide exports from the U.S. is Canada.⁴¹ Since there is no evidence that the tanning industry in Canada was involved in the commercial tanning of buffalo hides, whereas the innovation was known in various European countries, I treat the innovation as a quasi-experiment with Canada as the control with no ability to tan buffalo hides, and the UK and France as treatment countries with the ability to tan.⁴² Canada is not a perfect control: Canada was far less

⁴⁰ Any explanation along these lines does however have to explain why these U.S. specific events led to a *temporary*, and not permanent, rise in hide exports.

⁴¹ For the Canadian data see Canada, General Statement of Exports, Sessional Papers 1860-1890.

⁴² Canadian trade statistics do contain categories of exports tied to the buffalo (buffalo hair was one such

developed than France or the UK in the 1870s, and its distance from the U.S. market is much smaller.

The UK and France are reliable treatment groups, if the assignment to treatment is exogenous. The London Times article, discussed previously, establishes that the timing of the innovation was exogenous to any characteristic of France or the UK, since these countries were not the intended market for the hides. The subsequent shipment of hides to the UK was likely determined by the sheer economic might of the UK at the time, the existence of other trading relations between the two nations, knowledge that the UK tanning industry was advanced, or even a common language. Similar shipments to Germany or France would be determined by similar factors. It is difficult to see why any of these factors - which determined assignment to treatment - should play a role in determining the over-time variation in the share of raw hide imports coming into these countries from the U.S. As a consequence, the assignment to treatment may well provide the exogenous variation we need to identify buffalo hides in the data.

The innovation was a necessary but not a sufficient condition for exports. The herds had to exist for exports to occur. I date the availability of the innovation at 1871, and as before assume the Southern Herd was available until 1879. The Northern Herd was available to hide hunters in the early 1880s, when the threat from the Sioux was eliminated, and was destroyed by 1886. The most general specification would allow for two treatment effects (North and South), country specific time trends and country dummies as follows:

$$s_{it} = \alpha_i + \beta_i t + \gamma T_{it}^S + \delta T_{it}^N + \epsilon_{it} \quad (11)$$

where s_{it} is the U.S. share of raw hide imports in total raw hide imports into country

item), but despite this practice of specifically labeling buffalo products there is no category for exported buffalo hides from Canada. This is perhaps not surprising because the Canadian buffalo episode is quite different from the American. In Canada, trade in buffalo robes was very important to depletion as was the associated hunting by natives and Metis. As well, buffalo were driven to extinction in Canada prior to the arrival of connecting Canadian railways. All of this suggests no hide exports came from Canada, and hence the import of cow hides into Canada was determined by the same forces driving demand for hides in Europe: a demand for leather for machinery, saddlery, and footwear.

$i = \{Canada, France, UK\}$ in year t from 1866 to 1887; α_i is a country specific constant, and $\beta_i t$ is a country specific time trend. T_{it}^S is the treatment effect which takes on the value 1 during 1872-1879 and is zero otherwise; T_{it}^N takes on the value 1 from 1881 to 1886 and is zero otherwise.

Table 3 presents results from estimating, via OLS, various specifications of 11. As we move left to right in the table more restricted versions of 11 are estimated. It is apparent that we cannot distinguish between the constants for the UK and France, and hence from column III forward they are grouped together under Europe. The constant terms for Europe and Canada are however very different. Over 90% of raw hides imported into Canada come from the U.S; whereas, outside of the treatment period, the U.S. market share in Europe is only .5%. This difference is not surprising given the proximity of the U.S. to Canada. There is also little evidence of time trends in the data. A common to Europe trend is imposed in column II, while a common to all countries trend is introduced in column IV. The regressions' high level of fit comes from features of the data. Most of the variation in the data is cross-country; therefore, country specific constants alone capture much of the variation. Despite this both treatment effects are positive but only the Southern treatment is statistically significant.

The relative and absolute magnitudes of the treatment effects also bear scrutiny. The Southern treatment effect is estimated to be four to five times larger than the Northern which is consistent with the historical accounts of the relative size of the Northern and Southern slaughters by Hornaday and others. The absolute magnitude of the Southern treatment effect is estimated at close to 5% points. Therefore the Southern treatment effect represents a very large ten fold increase in the share of raw hides coming from the U.S.

One final means of evaluating these results is to employ them to construct a measure of implied buffalo hide shipments from the U.S. to the UK and France. I calculate counterfactual imports into the UK and France under the assumption that the innovation did not arrive in these countries.

Table 3 - A Quasi Experiment

<i>Dependent variable is s_{it}</i>	I	II	III	IV	V
<i>$i = \{Canada, France, UK\}$</i>					
France Intercept	-.33 (.89)	.24 (.67)			
UK Intercept	1.24 (.85)	.67 (.84)			
Europe Intercept			.46 (.41)	.47 (.67)	.60 (.78)
Canada Intercept	91.12 ^a (2.99)	91.12 ^a (2.96)	91.12 ^a (2.94)	91.08 ^a (2.09)	90.73 ^a (1.86)
France Time	.09 (.07)				
UK Time	-.01 (.07)				
Europe Time		.04 (.05)	.03 (.05)		
Canada Time	.03 (.18)	.03 (.17)	.03 (.17)		
Time				.04 (.09)	.07 (.06)
North Treatment	1.07 (.71)	1.07 (.67)	1.07 (.67)	1.10 (1.05)	
South Treatment	4.80 ^a (1.10)	4.80 ^a (1.08)	4.80 ^a (1.09)	4.81 ^a (1.09)	4.38 ^a (1.07)
<i>R²adjusted</i>	.99	.99	.99	.99	.99
<i>RMSE</i>	4.67	4.63	4.60	4.56	4.53
<i>No.obs.</i>	66	66	66	66	66

I employ the estimates from column V and set the treatment effects to zero to obtain a predicted import share for each country together with their 95% confidence intervals. Multiplying these predicted import shares by actual imports generates a counterfactual import quantity. Subtracting counterfactual from actual imports gives an estimate of the buffalo hides imported by the UK and France. Figure 4 presents the mean estimate for the U.K together with an upper and lower estimate generated when I employ the lower and upper 95% confidence interval for the predicted import share in the calculations. Figure 5 does the same calculation for France.⁴³

The figures are striking. The implied buffalo hide imports into the U.K. and France are predicted to be either very small or negative until the early 1870s. This is as it should be since buffalo hide imports must be zero prior to the innovation. Post innovation, imports rise dramatically until 1875 only to fall again near to zero in the late 1870s. The figure shows what may be a small Northern Herd impact in the early 1880s that falls off in 1886. It is interesting to note that the UK series jumps upwards before that of France - consistent with the UK being the original innovator and France the follower. Simply adding the imported hides in 1875 shows the UK and France importing over 1 million buffalo hides, which is consistent with the aggregate figure presented previously in Figure 1. Summing the hide imports over the entire period (including the negative elements) yields imports to Europe of more than 3.5 million buffalo. If we gross these up by Dodge's wastage estimates, the implied kill would be larger still.⁴⁴

⁴³Two additional assumptions are made here, and one caveat is in order. First, since U.K. and French imports are in terms of weight, I have to translate hundredweights and kilograms of hides into buffalo hide numbers. I assume a hide weighs 28 lbs (then there are 4 in an English hundredweight), which is a conservative estimate given my reading of the history. Second, I have assumed the overall quantity of hide imports into the UK and France would have remained the same absent the innovation. I think this is reasonable. Recall that the US was only a small provider to these countries, their aggregate demand for hides was set by a derived demand for leather which should be independent of the innovation, and the hide market worldwide was huge and hence hide prices would not be affected by the absence or presence of US buffalo hides. Finally, the reader should note that the upper and lower estimates presented in the figures are not confidence intervals for the implied buffalo hide exports.

⁴⁴The implied imports of hides differ slightly from those I presented in figure 4 of NBER 12969. There I use the deflated U.S. export series to create the counterfactual; here I use the country specific import data. The figures tell the same story.

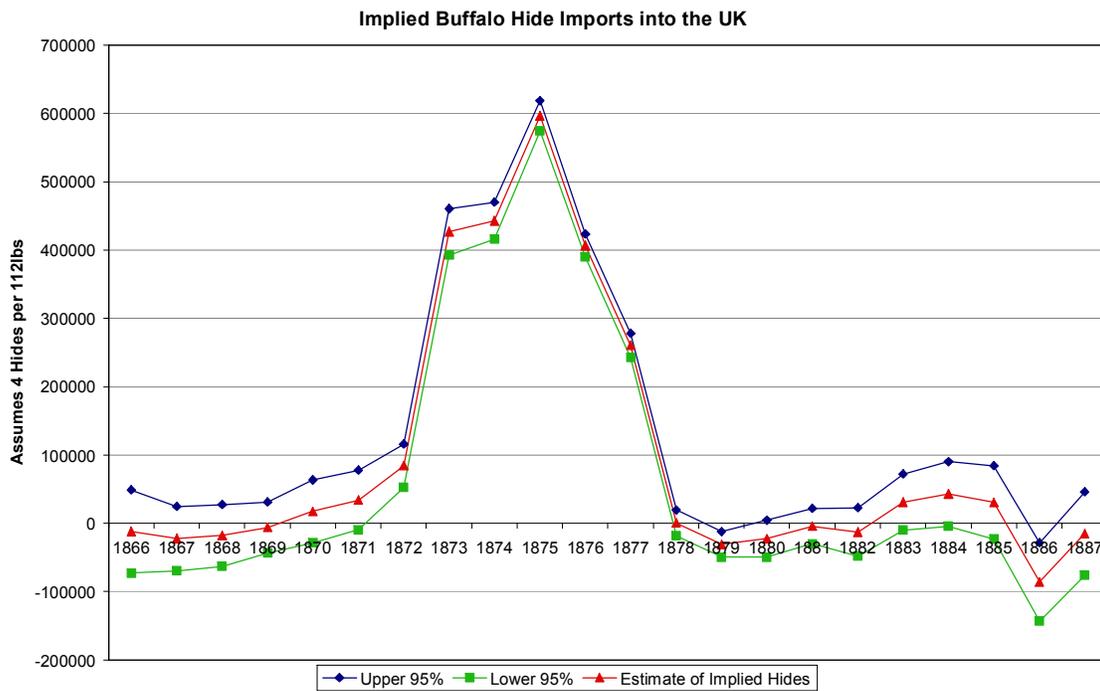


Figure 4

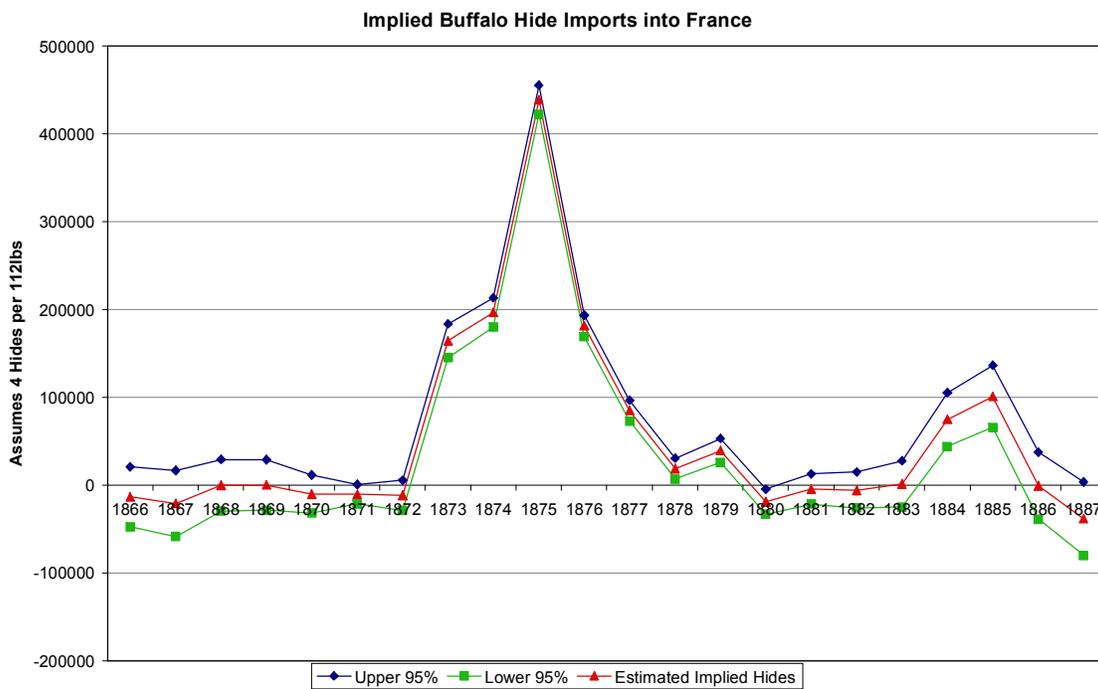


Figure 5

Overall, the examination of the across country and across hide variation in the data supports my earlier conclusions. The increase in raw hide imports from the U.S., during the time of the Southern Herd destruction, is a European/U.S. specific event. Despite the fact that the data used is different, the method of identifying buffalo hides is different, and the variable under study is different (import shares of raw hides vs. export levels of all hides) the results are remarkably similar to those presented earlier. There is strong evidence that the tanning innovation led to an unusual and temporary level of raw hide imports into the UK and France, but not Canada. It appears that this surge did not occur because of a broad based demand shock in Europe, nor because of a supply shock to cattle production in the U.S.. While alternative explanations for this data remain, the set of credible alternatives has been narrowed considerably.

5 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. By employing insights from theory, I have pieced together statistical evidence from numerous countries, diary and newspaper accounts, and logic to present a largely circumstantial, but hopefully compelling case that the plains buffalo was not eliminated by the usual suspects - it was instead the victim of global markets and technological progress.

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 theoretical results demonstrate that the combination of a tanning innovation, open access to buffalo herds, and fixed world prices delivers a punctuated slaughter matching that witnessed on the Great Plains. I take this as proof of sufficiency.

I have also demonstrated that the slaughter can only be generated when demand is very elastic. This establishes the necessity of a market price that is "largely invariant" to changes in supply. The tanning innovation was proven to be necessary by the absence of the slaughter during the five years prior to 1872 when the Union Pacific had reached the heart of buffalo country. And the necessity of open access for the slaughter is proven by numerous private parties who found buffalo to be such a valuable resource that they established property rights on their own by capturing and then breeding 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.

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 130 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 decades to deplete.

6 Appendix

Proposition 1. Suppose not. Let both $S_1 \neq S_2$ solve $K(p, S) = G(S)$. Let $0 < S_1 < S_2$, then $G(S_1)/S_1 > G(S_2)/S_2$ by the strict concavity of G . Since $K(p, S_1) = G(S_1)$ and $K(p, S_2) = G(S_2)$, $K(p, S_1)/S_1 > K(p, S_2)/S_2$, or $N \int_{\alpha_1^*}^{\bar{\alpha}} \alpha f(\alpha) d\alpha > N \int_{\alpha_2^*}^{\bar{\alpha}} \alpha f(\alpha) d\alpha$. Note $\alpha_1 = w/pS_1 > \alpha_2 = w/pS_2$ hence $N \int_{\alpha_1^*}^{\bar{\alpha}} \alpha f(\alpha) d\alpha > N \int_{\alpha_1^*}^{\bar{\alpha}} v f(\alpha) d\alpha + N \int_{\alpha_2^*}^{\alpha_1^*} \alpha f(\alpha) d\alpha$ implies $0 > N \int_{\alpha_2^*}^{\alpha_1^*} \alpha f(\alpha) d\alpha$ which is a contradiction. The uniqueness of α^* follows directly.

Lemma 1. If α^* rises (stays constant, falls) hunter numbers fall (stay constant, rise). To prove the result, note that the elasticity of α^* with respect to S and p are equal at -1 . To determine how S affects p , note $RS(p, S) = SN \int_{\alpha^*}^{\bar{\alpha}} \alpha f(\alpha) d\alpha / [F(\alpha^*(p, S))N]$, and hence by inspection RS falls with α^* . This implies $RS(p, S)$ is increasing in both S and p and establishes that their partial elasticities must be positive $\varepsilon_{rs,p} > 0, \varepsilon_{rs,s} > 0$. Differentiating RS shows $\varepsilon_{rs,s} = 1 + \varepsilon_{rs,p} > 0$. Now differentiate the market clearing condition 9 to find 10. Finally, differentiating 1 and using 10 yields $[d\alpha^*/dS][S/\alpha^*] = [\frac{1+\varepsilon_{rs,p}}{\sigma+\varepsilon_{rs,p}} - 1]$. Therefore when σ is greater (equal to, less) than one, α^* falls (stays constant, rises) with herd size, and buffalo hunter numbers rise (stay constant, fall) with herd size.

Lemma 2. Differentiating 9 with respect to β holding S constant yields $[dp^e/d\beta][\beta/p^e] = [\frac{1}{\sigma+\varepsilon_{rs,p}}] > 0$.

Proposition 2. Steady state is defined by $G(S^*) = K(\alpha^*, S^*)$, where $\alpha^* = m(p^e, S^*)$ is given by 1, and $p^e = g(\beta, S^*)$ is given by 9. Substitute for equilibrium prices and the marginal hunter in the steady state condition. Differentiate with respect to β to find: $dS/d\beta = [K_\alpha m_p g_\beta] / [G' - \frac{dK}{dS}]$ where subscripts denote partial derivatives. We have already established $K_\alpha < 0$ and $m_p < 0$. Lemma 2 established $g_\beta > 0$. Therefore the numerator of $dS/d\beta$ is positive. Local stability requires $\dot{S} < 0$ for S above S^* , and $\dot{S} > 0$ for S below S^* . Using 6, this requires $\dot{dS/d\beta} = [G' - \frac{dK}{dS}] < 0$, where $\frac{dK}{dS}$ is a total derivative taking into account price adjustment in autarky. Requiring local stability signs $dS/d\beta < 0$.

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