Human–Wildlife Interactions 12(1):58–74, Spring 2018

Synthesis

A review of economic studies related to the Bureau of Land Management's Wild Horse and Burro Program

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Abstract: This paper reviews literature addressing the benefits and costs of the Bureau of Land Management's Wild Horse and Burro (WHB) Program. Within the framework of a comprehensive benefit cost analysis of the WHB Program, I find that program cost estimates are readily available from numerous sources. A more limited set of estimates of the opportunity cost of WHB on the range is available, as is a single estimate of the benefits provided by animal adoption. In contrast, there are no economic estimates of ecological damages caused by WHB in excess of the Appropriate Management Level, nor does a search of the literature reveal any estimate of the use and nonuse benefits of having WHB on the range. Dynamic bioeconomic models—which would be ideal for analysis of intertemporal program benefits and costs—have been restricted, for the most part, to only the analysis of costs. Further, I demonstrate how published opportunity cost estimates have sometimes been misinterpreted. This study sorts out confusion regarding reported opportunity costs and, using the missing elements of the comprehensive benefit cost analysis as a guide, identifies a path for future research.

Key words: benefit cost analysis, economics, Wild Horse and Burro Program

Beginning with the 1971 Wild Free-Roaming Horses and Burros Act, the Bureau of Land Management (BLM) became responsible for managing horses and burros on the public range in the United States. The legislation mandated that the BLM control wild horse (*Equus ferus caballus*) and burro (*E. asinus*; WHB) populations to achieve a thriving ecological balance with other plant and animal species (Figure 1). Under its WHB Program, the BLM establishes an Appropriate Management Level (AML) for a given range unit and tries to keep the population at or beneath the AML. Its primary population control methods are removing animals from the range to long-term holding facilities, adopting out removed animals to households, and applying contraceptives to mares. Other methods of population control, such as euthanasia and slaughter for food, are prohibited by law.

Three trends have dominated in recent years: removal activities have been scaled back, animal adoptions are now less than half what they were in 2002, and contraceptive methods are not applied to enough animals to effectively control the aggregate size of the WHB herd (BLM 2017*b*). Consequently, the population of animals in long-term holding facilities has grown rapidly, as has the on-range population. The number of animals cared for by the BLM has grown from about 5,000 in FY99 to >45,000 in FY17 (Department of the Interior [DOI] 2016); the number of free-roaming animals on the range has grown from just >42,000 in 1996 to almost 73,000 in 2017 (BLM 2017*a*). Given that the WHB population doubles every 5 years or so (NRC 2013), failure to effectively control WHB populations could result in severe ecological consequences for public rangelands and vastly increased program costs (Figure 2).

The National Research Council (NRC) and BLM have studied the WHB issue intensively yet, curiously, little concentrated attention has been given to the full array of economic aspects of WHB management (NRC 2013). The WHB economics literature remains scattered across official government reports, the refereed literature, and the gray literature. Without claiming to be exhaustive, this study attempts to gather the bulk of that literature into a single place. Such an approach allows not only for cross-study comparisons but also identifies

Figure 1. The Wild and Free-Roaming Horse and Burro Act mandated that the Departments of the Interior and Agriculture manage wild horse (*Equus ferus caballus*) and burro (*E. asinus*) populations to achieve a thriving ecological balance with other plant and animal species. Horses of the Maverick-Medicine Horse Management Area wait for their turn for a drink of the scarce water resource on degraded rangeland (*photo courtesy of the Bureau of Land Management*).

Figure 2. Dolly Varden Springs in Antelope Valley, Nevada, USA. The Appropriate Management Level of this area is 464 horses (*Equus ferus caballus*), and currently there are 3,160 horses. There is no livestock grazing in this area, which used to be a riparian habitat. The spring is privately owned and legally the landowner could fence out horses (*photo courtesy of B. Masters*).

the key aspects of a benefit cost analysis that have yet to be studied. I begin by reviewing the elements of a comprehensive benefit cost analysis. The review then turns to the cost side, examining per-animal average costs of major BLM programmatic functions and the opportunity costs of WHB on the range. On the benefits side, econometric models of adoption and sale of horses and burros are reviewed, as well as the unintended consequences of the horse slaughter ban on the fees paid to adopt or purchase wild horses. I then look at dynamic bioeconomic models that capture the intertemporal dimensions of WHB and livestock on the public range. The paper concludes with a summary and recommendations for future research.

Benefit cost analysis

Benefit cost analysis (BCA) is a comprehensive approach to evaluating all economic aspects of a given public policy into a single metric: the net benefits of a policy program. Within the context of wild horses and burros, the methodology can help determine (1) whether the benefits of managing WHB populations exceed the costs of managing those populations and (2) the optimal scale (population) at which WHB should be managed. Hyde (1978) laid out the problem concisely by noting that benefits of management include the recreational value of viewing WHB, the nonuse benefits of WHB (such as those who value the vicarious experience of knowing horses are on the range), and the benefits garnered by those participating in the WHB adoption and sale program. Costs include explicit program costs, opportunity costs of displacement of other wildlife species and domestic livestock from the public range, and ecological damage to the range of excess WHB populations. The major programmatic functions of the BLM (i.e., gathering animals, applying fertility controls, removing animals from the range for adoption, sale, or placement in long-term holding) are supposed to achieve an AML, which is the primary choice variable. Mathematically, one can lay out the arguments of Hyde's (1978) BCA proposal as a net benefits function,

$$NB(AML) = [UV(AML) + NUV(AML) + ASV(AML)] - [PC(AML) + OC(AML) + EC(AML)]$$

where net benefits (NB) are the difference between total benefits and total costs. Total benefits consist of use values (UV), nonuse values (NUV), and adoption/sales values (ASV). Total costs are program costs (PC), opportunity costs (OC), and ecological costs (EC). All benefits and costs flow from the choice of an AML. The BCA would identify the optimal program scale by choosing an AML such that net benefits are at a maximum; the optimal AML is determined where the benefit of having an additional animal on the range is exactly equal to the additional cost incurred.

Hyde (1978) recommended that the AML be determined for individual herd management areas because benefits and costs were likely to vary geographically. That said, the BLM's selection of an AML cannot have been the result of a carefully considered BCA because economists have yet to estimate values for all of the benefit and cost categories needed to implement the Hyde model. Instead, economists (and others) have focused mostly on costs and benefits that are easiest to measure, namely, program costs, opportunity costs, and the adoption market.

Costs: program costs

Adjusted to constant 2017 dollars, the BLM's annual WHB program budget has grown at a compound annual rate of >7.5%, from $21.5 million in FY98 to almost $80 million in FY16 (DOI 2016). Much of the increase in program costs is due to the growth in the number of animals held by BLM in short-term corrals and, for those animals not adopted, pastured over the long-term. Off-range holding costs have grown to comprise nearly two-thirds of the BLM's WHB budget in recent years. Growth in the total budget of the BLM has not kept pace with its obligation to support an ever larger number of off-range animals, so its budget for gathers and removal has fallen. This tradeoff has led directly to the increase in the on-range population (Garrott and Oli 2013, DOI 2016, Garrott 2018).

Average cost information for major programmatic functions are shown in Table 1. All costs have been converted to constant 2017 dollars (some studies have used costs from different years and failed to adjust for the changing value of a dollar). Total costs consist of fixed costs—costs that do not vary with the number of animals treated, such as administrative expenses—and variable costs such as holding costs and fertility control, which do vary by the number treated. The average cost is simply total cost divided by the number of animals treated. In general, years in which a large number of animals are included under a given programmatic function should have lower average costs because fixed costs can be spread over more animals.

Gather costs

In its FY16 report, the BLM provided only the number of animals removed from the range and the number of mares treated with contraceptives, and it did not provide a count of the total number gathered (BLM 2017*a*). Reports for FY11 through FY15 show that the number of animals gathered exceeded the sum of those removed or contraceptively treated by an average of 10.4%. I estimate the number of animals gathered in FY16 by increasing the sum of removals and contraceptively-treated mares by this percentage.

Average cost estimates for gather of animals from the range appear in the top portion of Table 1. Costs for FY12 through FY16 were calculated by dividing program costs by the number of animals gathered. Total program costs for FY11 were reported by Hooks (n.d.) and then supplemented with BLM (2017*a*) gather data to calculate the average cost of gathering. Finally, Bartholow (2007) reported average gather costs for 10 western states but noted that fixed costs and gather size greatly affected the average cost for each state. The cost figure appearing in Table 1 is the Olympic mean (the average after dropping the highest and lowest cost) for the 10 western states.

Gather costs range from a low of $418 per animal to a high of almost $1,100 per animal. The pattern of average costs does not follow economic predictions (e.g., average costs for 4,500 animals in FY15 are lower than average costs for >10,000 animals in FY12), suggesting some flexibility in the BLM's budget, either from year to year or among programmatic functions within a given year. Perhaps the best estimate of gather costs can be obtained by summing the budget between FY11 through FY16 ($28.1 million) and dividing by the total number of animals gathered (about 35,900) to obtain a per-animal average gather cost of $782.71.

Off-range holding costs

The BLM uses corrals in the short-term to treat gathered animals with veterinary and farrier services and to provide halter and/or saddle training in preparation for the adoption market (Figure 3). Caring for WHB in corrals also requires feeding animals with purchased hay. Animals that are not adopted are transferred to privately contracted pastures for the remainder of the animal's life. Thus, short-term holding costs exceed those of long-term holding facilities (DOI 2016).

Table 1. Unit costs for major functions of the Bureau of Land Management (BLM) Wild Horse and Burro Program (constant $2017)[a].

Fiscal year	Budget ($M)	Animals (#)	Cost per animal	Source/notes
Average cost, gathers				
2016	$3.11	3,869	$803.82	BLM (2017*a*)
2015	$1.89	4,515	$417.71	BLM (2017*a*)
2014	$1.25	1,860	$670.90	BLM (2017*a*)
2013	$5.09	4,702	$1,082.71	BLM (2017*a*)
2012	$8.40	10,465	$802.77	BLM (2017*a*)
2011	$8.38	10,504	$797.35	Hooks n.d., BLM (2017*a*)
2004			$483.27	Bartholow (2007)
				Olympic mean of 10 western states
Average cost, off-range holding				
2016	$50.22	45,044	$3.05/day	BLM (2017*a*); STH and LTH[b]
2015	$50.81	47,393	$2.94/day	BLM (2017*a*); STH and LTH
2014	$44.96	48,194	$2.56/day	BLM (2017*a*); STH and LTH
2013	$48.96	49,472	$2.71/day	BLM (2017*a*); STH and LTH
2012	$46.26	46,891	$2.70/day	BLM (2017*a*); STH and LTH
2011	$50.30	42,835	$3.22/day	Garrott and Oli (2013); STH and LTH
2011	$29.94	11,682	$7.02/day	Hooks n.d., BLM (2017*a*); STH
2008			$5.80/day	GAO (2008); STH
2004			$4.53/day	Batholow (2007); STH
2001			$4.05/day	GAO (2008); STH
2011	$17.41	30,012	$1.59/day	Hooks n.d., BLM (2017*a*); LTH
2008			$1.45/day	GAO (2008); LTH
2001			$1.62/day	GAO (2008); LTH
Average cost, adoption and sales				
2016	$7.49	3,116	$2,404.69	BLM (2017*a*)
2015	$6.49	2,898	$2,240.45	BLM (2017*a*)
2014	$4.78	2,222	$2,152.81	BLM (2017*a*)
2013	$7.95	2,376	$3,347.88	BLM (2017*a*)
2012	$7.65	2,985	$2,561.83	BLM (2017*a*)
2011	$7.97	2,844	$2,802.76	Hooks n.d., BLM Public Land Statistics
2004			$486.14	Bartholow (2007)
				Olympic mean of 10 western states

[a] All dollar figures adjusted by GDP price deflator to constant $2017.
[b] STH (short-term holding); LTH (long-term holding).

The middle portion of Table 1 presents average holding costs for removed animals. The BLM program data (BLM 2017*a*) can be used to calculate average holding costs without distinguishing between short-term holding (STH) and long-term holding (LTH). Data for FY12 through FY16 showed rising average costs, from $2.70 per day increasing to $3.05 per day. Garrott and Oli (2013) reported an annual per-animal holding cost for FY11, which was converted to a per-day figure and adjusted to constant 2017 dollars. This average cost ($3.22 per day) was slightly higher than, but still comparable to, the FY12–FY16 figures. Using BLM data on the total expenditures for holding facilities in FY11 through FY16 ($291.5 million) and dividing by the total number of animals in those facilities over the same time period (280,000) yields an estimate of about $2.85 per day.

Short-term and long-term costs are shown for selected years as reported in the literature. The STH average costs range between $4.05 and $7.02 per day; although there were only 4 observations, the pattern shows that STH costs appear to be rising over time. Three estimates of LTH costs range from $1.45 per day to $1.62 per day. The difference between mean STH and mean LTH costs in Table 1 is $3.80, which is quite comparable to the difference ($3.62, constant $2017) reported by DOI (2016).

Adoption and sales costs

The final portion of Table 1 reports on average per-animal costs of the BLM's adoption/sales program. The BLM (2017*a*) data were used to calculate average adoption and sales costs for FY12 through FY16; Hooks (n.d.) reported the total BLM adoption budget for FY11, which was then supplemented with adoption and sales data from BLM Public Land Statistics. Average per-animal adoption costs over the 6 fiscal years ranged from $2,153 (FY14) to $3,348 (FY13). Following a similar procedure to that used for gather and holding costs, the mean adoption/sale average cost over 6 years is $2,575.39. It is unclear how these costs compare to that provided by Bartholow (2007), which was lower by a factor of five. The Bartholow (2007) figure is the Olympic mean of the average costs for 10 western states, which may mask the effect of differing numbers of animals adopted across states, as well as differing proportions of fixed and variable costs.

Costs: opportunity costs of WHB on the public range

The principal opportunity cost associated with growing on-range populations of free-roaming horses and burros is displacement of other wildlife species and livestock that compete for the same forage resources. The literature reports opportunity costs in different ways: marginal costs versus average costs, costs reported for a single year versus costs discounted over a much longer timeframe, and costs that are restricted only to losses to ranchers versus those that include non-market losses. Here, I sort through the literature and make recommendations as to which costs should be used when.

Market plus non-market opportunity costs

Based on a FY98 population of on-range animals (47,400), Pimentel et al. (2005) estimated annual foregone forage losses of $7.1 million (constant $2017), or an average of $149.32 per wild horse or burro per year. The authors provided no information about how their initial figure was determined, but the context of the study makes it reasonable to assume that the value estimate is for displacement of both cattle (*Bos taurus*) and other wildlife such as elk (*Cervus canadensis*), bighorn sheep (*Ovis canadensis*), deer, etc. It is unclear if the value included other ecological damages associated with excess WHB populations.

Bastian et al. (1999) developed a linear programming model to estimate the forgone cost of wild horses on a 36,000-ha range allotment in Wyoming, USA administered by the BLM. The objective function of the programming model maximized the number of animals on the range subject to different stocking levels of horses. Other species using the range were elk, mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), and cattle. Seasonal forage constraints were developed according to the forage preferences for each species; total forage consumption across all species was not permitted to exceed 50% of range productivity. Opportunity costs were measured as the foregone value of hunting (elk, mule deer, and

Figure 3. The Bureau of Land Management uses short-term facilities to treat gathered animals with veterinary and farrier services, and to provide halter and/or saddle training in preparation for the adoption market (*photo courtesy of E. Thacker*).

pronghorn) and reduced ranch profits (cattle); the opportunity cost for wildlife species was set equal to the average consumer surplus per hunting trip per animal displaced.

The objective function gave all species an equal weight. As rangeland forage was consumed by an increasing number of wild horses, the model's seasonal forage constraints determined which of the other species (wildlife and/or cattle) were to be removed from the range. Relative to the baseline (0 horses), adding 128 horses to the allotment required a reduction of 449 cattle, 90 mule deer, and 1 antelope. No elk were removed. Similar analyses were conducted for 184, 196, and 241 horses. The present value of total foregone costs for the first 128 horses was $25,000 (constant $2017), for an average opportunity cost of $195 per horse. For this first group of horses this is also equal to the marginal cost. A marginal increase of 56 horses (to 184) results in a further reduction of 156 mule deer and 187 cattle, with concomitant average and marginal costs of $278 and $467 per horse, respectively.

As even more horses are added to the allotment, forage constraints begin to bite seriously: a marginal increase of 12 horses (to 196 total horses) reduces stocking of another 343 antelope, 286 mule deer, and 11 head of cattle. This displacement of wildlife and cattle resulted in average opportunity costs of $534 and marginal opportunity costs of $4,453 (or, as reported in the original publication, $1,992 in constant $1982). When 241 horses were stocked, average and marginal costs increased to $1,524 and $5,839, respectively. It is difficult to compare the Bastian et al. (1999) and Pimentel et al. (2005) studies because the latter study provided no information about how the value was derived.

Market opportunity costs only

Another measure of opportunity cost comes from Resource Concepts ([RCI] 2017). The WHB population on the Ely (Nevada, USA) BLM district was far in excess of its AML: some 9,382 horses were on the range in 2017, yet the district-wide AML was only 1,695 animals. At 1.3 animal unit months (AUM) per horse, this means that nearly 120,000 AUMs were being consumed in excess of the AML in FY17. The study reported a BLM grazing permit value of $127 per AUM (based on recent grazing permit transactions) and a production value of $84 per AUM, which RCI (2017) equated to foregone ranch income. Both figures were used to estimate the opportunity cost to ranchers of wild horses on the range, but the authors failed to recognize that these values were inconsistent with one another.

One can discern the inconsistency by thinking of the $84 annual income per AUM as an annuity, *A*, to permit holders (i.e., the income that flows year after year to permit holders), in perpetuity. (Permits have a 10-year life but are almost always renewed such that the perpetuity assumption is a reasonable approximation; reducing the timeframe to 40 or 50 years has little effect on the analysis.) If a grazing permit yields $168 in nominal income in just 2 years (and $252 in 3 years, etc.), why should a permit have a present value, *PV*, of only $127? Applying a standard annuity formula ($PV = A/i$, where i is the discount rate) suggests that, if the 2 figures ($127 and $84) are correct, then ranchers discount future income at >66%. This is far too high, so something must be awry.

The problem can be uncovered by going back to the source document on which the RCI study relies, which models a representative ranch located in Elko county of northeastern Nevada (Alevy et al. 2007). The representative ranch produced 700 head of cattle and held permits to 4,148 AUMs on federal rangeland, of which 89% were used, on average, in any given year. When there were no restrictions on access to federal land, forage sourced from federal rangelands accounted for 44% of all AUMs fed. Other forage sources included leased pasture, deeded rangelands, produced hay, and purchased hay. Adjusted to constant $2017 and assuming no access restrictions, this ranch would have gross revenues of $350,000, which, after dividing by 4,148 AUMs, yielded the RCI (2017) estimate of $84/AUM. This actually measures gross revenue per AUM, not income. Further, it is not clear why one should attribute 100% of ranch revenue to federal AUMs, particularly when federal AUMs comprise only 44% total forage requirement for the herd. Such an approach implicitly assumes that ranchers have no forage options other than federal range.

The Alevy et al. (2007) report showed how the representative rancher would adjust to reductions in federal AUMs by reducing herd size and using more expensive feed sources, including purchased hay. The authors simulated federal AUM reductions of 10%, 25%, 50%, 75%, and 100%. An initial 10% reduction from baseline federal AUMs (a loss of 415 AUMs) caused ranch income (revenues minus costs) to fall by just >$2,220, for an average opportunity cost (profit loss per AUM lost) of $5.36 per AUM. Put another way, the last 415 federal AUMs each added an average of $5.36 ranch profit. This figure ($5.36) now squares with the reported present value of a BLM permit ($127/AUM) because it implies a much more reasonable discount rate of 4.2%. A further loss of 622 AUMs yielded a marginal profit loss of $10.46/AUM and an average profit loss of $8.42 per AUM on the cumulative loss of 1,037 AUMs (25% reduction). The 50% AUM loss scenario implied a marginal loss of another 1,037 AUMs and a cumulative loss of 2,074 AUMs; the loss in marginal profit rose to $12.18 per AUM whereas the average loss in profit was $10.30 per AUM.

Alevy et al. (2007) estimated average and marginal opportunity costs for ranchers in response to access restrictions on federal rangeland, which can be applied to restrictions on grazing access regardless of the motivating issue (e.g., livestock displacement by WHB, sage-grouse [*Centrocercus urophasianus*], wildfire damage, etc.). Returning to the RCI (2017) study, the confusion between gross revenues and income means that one should take care in evaluating not only their reported opportunity costs, but also their economic impact analysis. Input-output models will generate different results depending on how changes in the final demand vector are constructed. It does matter if the $10.1 million in lost production value (120,000 lost AUMs multiplied by $84 per AUM) were treated as foregone ranch income versus separating it into ranch income (profit) and production expenditures across different input sectors, each of which will differ in its income, employment, value-added, and fiscal multipliers.

Making sense of opportunity cost estimates

A WHB program will maximize net benefits when the additional (marginal) benefit of increasing the AML by 1 animal is equal to the additional (marginal) cost imposed by that animal. The marginal opportunity costs (reported by Bastian et al. 1999 and calculated from Alevy et al. 2007) are not as useful as they might be because economists have yet to estimate the marginal benefit of a wild horse or burro on the range. Further, one should not (as some have done) multiply a marginal opportunity cost by the number of displaced AUMs (or animals, depending on the unit of measure) because this is very likely to provide an erroneous estimate of total opportunity costs. Total opportunity costs may be calculated as an integral of the marginal opportunity cost function, but this review of the literature did not reveal such a function.

In contrast, the connection between average opportunity cost and total opportunity cost is straightforward: simply multiply average cost of a lost AUM by the number of displaced AUMs. For example, RCI (2017) reports a loss of 120,000 AUMs in the Ely BLM District Office, which is a district-wide reduction in federal AUMs of just >35%. Using the Alevy et al. (2007) model, average ranch income losses are \$8.42/AUM for the 25% reduction scenario and \$10.30/AUM for the 50% reduction scenario. Multiplying these average opportunity costs by 120,000 AUMs means that annual aggregate profit losses to ranchers in the Ely BLM District Office are likely to be in the range of \$1.01 million to \$1.24 million. This assumes that AUM reductions were shared proportionately by all ranchers in the Ely district; if range restrictions were disproportionately applied to a smaller group of ranchers then total opportunity costs would be much higher. Further, these opportunity estimates do not include costs of other displaced wildlife; as such, this is a lower bound on the opportunity cost.

Wild horses and burros can be long-lived animals, living up to 30 years (de Seve and Boyles Griffin 2013). Sustaining WHB on the range over lengthy periods of time generates interest in the cumulative opportunity costs of WHB, which should be discounted over time back to a present value. This is where the permit value of \$127/AUM (as reported by RCI 2017) is handy. The permit value is the present value of profit flowing from perpetual use of the federal range that, as was demonstrated above, is consistent with the initial average profit losses per AUM emanating from the Alevy et al. 2007 model. At 2017 WHB levels in excess of the AML for the Ely BLM district, RCI (2017) found cumulative discounted opportunity costs estimated to be \$15.23 million (\$127/AUM × 120,000 AUMs). Again, a permit value does not incorporate opportunity costs associated with displacement of other species by WHB; thus, this valuation approach provides only a lower bound on opportunity costs.

Benefits: economic analysis of BLM adoption and sales auctions

Economists have devoted some research effort to the BLM adoption and sales markets, examining the probability that a given wild horse with specific characteristics will be adopted or sold, as well as modeling the fee received for horses with given characteristics.

Probability of adoption or sale

Three studies have gauged the effect of horse characteristics (and other factors) on the probability that a given animal would be adopted or sold (Table 2). Harris et al. (2005) and Adekunle (2015) used a stated preference valuation method (the choice experiment) based on survey data, whereas Elizondo et al. (2016) used revealed preference data on actual adoptions and sales as gathered by the BLM.

Harris et al. (2005) had 2 different samples, resulting in 2 different models. The first sample was composed of participants at a 2005 BLM Wild Horse Expo held in Reno, Nevada; attendees were asked to drop completed surveys into a box located at the exhibition hall exit point. Some 60 respondents completed the survey, which included 6 questions concerning hypothetical adoption of a wild horse. A parallel survey was administered online, with the sampling frame consisting of Expo website viewers and listserv members of WHB groups. The internet survey had 94 completed surveys; each respondent answered 6 questions regarding hypothetical adoption of a horse. Both samples were composed primarily of experienced horse buyers, with 73% of the on-site sample and 83% of the internet sample having purchased at least 1 wild horse at a past BLM auction.

The conjoint choice experiment was similar across the 2 samples. Respondents were asked to compare 2 horses that differed in characteristics and were given the choice of adopting Horse A, adopting Horse B, or adopting neither horse. The characteristics included size (ranging from 10–15 hands), color, bonding (gentle, inquisitive, or expressive), sex, activity level (quiet, active, or wild), and purchase fee. Table 2 reports the sign of the coefficients for each statistically significant characteristic; a positive sign means horses with that characteristic were more likely to be adopted, whereas a negative sign implies horses with that characteristic were less likely to be adopted. Characteristics included in the model but not statistically significant are marked with N/S; characteristics that are blank were not included in the reported model.

The Harris et al. (2015) on-site sample preferred larger horses, but not too large, as the negative sign on the quadratic term implies (Table 2, column 2). Horses that were young and quiet were more likely to be adopted than horses that did not share these characteristics. Relative to black horses, sorrel, bay, and gray horses were less likely to be adopted. The internet sample had preferences similar to the on-site sample. Larger horses were preferred to smaller, as were horses characterized as quiet (Table 2, column 3). Expressive horses were not as likely to be adopted as those that were less exuberant. Relative to black horses, gray horses were less likely to be adopted.

Adekunle (2015) employed a survey approach quite similar to that of Harris et al. (2005) in that her conjoint choice experiment was an onsite survey of participants at a BLM wild horse auction in 2014, this time in Frankfort, Kentucky, USA. Some 65% of the 56 respondents had attended ≥2 BLM auctions in the past, and almost 63% had purchased a wild horse. Respondents were asked to answer 4 adoption choice questions using a construction similar to that of Harris et al. (2005; Horse A, Horse B, or neither). Characteristics included age, color, sex (mare or gelding), size, temperament (calm or nervous), and training (untouched, halter-broke, or started under saddle).

Survey participants preferred larger horses to smaller ones and were more likely to adopt horses with some training (halter or saddle; Table 2 (column 4). Calm horses were also more likely to be adopted. Relative to black horses, palominos were more likely to be adopted. Neither age nor sex were statistically related to the probability of adoption.

The Harris et al. (2005) and Adekunle (2015) studies relied upon stated preference information regarding hypothetical adoption of horses in a constructed market; in contrast, Elizondo et al. (2016) used actual adoption data included in the BLM Information System. The vastly increased sample size (114,882 horses available for adoption from 1997 until 2010) allowed the authors to examine the influence of many more characteristics than the studies reviewed above. Almost 60,300 horses in the sample were adopted (52.5%), with another 3,800 sold (3.3%). Halter or saddle training had been provided to 4.2% of the sample (7.6% of all animals adopted or sold).

As with the previous studies, younger horses were more likely to be adopted (Table 2, column 5). Stallions were preferred to mares which, in turn, were preferred to geldings. Every horse in the sample that had been trained in some way was adopted, implying positive coefficients in the model. Relative to bay or brown horses, horses of any color except gray or sorrel were more likely to be adopted. Finally, distinguishing characteristics such as face whorls, a blaze, or white feet significantly increase the probability of adoption.

Fees received from adoption or sale

Adekunle et al. (2014) and Elizondo et al. (2016) used actual BLM auction sales data to relate horse characteristics to the fee received. Adekunle et al. (2014) restricted their sample (n = 93) to only horses who were adopted or sold; the Elizondo et al. (2016) fee model was the second stage of a Heckit model that adjusted parameters to reflect selection of >64,000 horses from the original sample of almost 115,000 horses. The sample selection portion of the Elizondo et al. (2016) model was discussed in the previous section (Table 2, column 5).

Adekunle et al. (2014) did not report an average adoption or sales fee, but they did provide several econometric models that related the fee received to characteristics of the horses sold (Table 3, column 2). Stallions and mares received a price premium relative to geldings, as did horses that had been halter-trained. Saddle-training did not add to the adoption fee relative to no training at all. Relative to black horses, horses with any coloring at all were conveyed at a higher price. The authors did not find a statistical relationship between a blaze or stockings and the fee received.

Adjusted to constant $2017, Elizondo et al.

Table 2. Models for probability and sale of wild horses (*Equus ferus caballus*) and burros (*E. asinus*).

	Harris et al. (2005)	Harris et al. (2005)	Adekunle (2015)	Elizondo et al. (2016)
Type of data	Stated preference	Stated preference	Stated preference	Revealed preference
Sample size	60 × 6 questions	94 × 6 questions	56 × 4 questions	114,882
Model selected for comparison	Table A2 Model 3	Table A3 Model 3	Table 6.19 Model MNL-0	Table 6 Model 4
	Sign of statistically significant variables[a]			
Size				
Size (hands)	+	+	+	
Size squared	–			
Age				
Age 2–6 years old	+		N/S	
Age 7–10 years old	N/S			
Age at capture				–
Sex (baseline)			(Gelding)	(Mare)
Stallion				+
Gelding				–
Mare			N/S	
Training[b]				
Halter-trained			+	+
Saddle-trained			+	+
Temperament				
Calm/quiet	+	+	+	
Gentle	N/S			
Expressive		–		
Color (baseline)	(Black)	(Black)	(Black)	(Bay or brown)
Sorrel	–			
Bay	–	N/S	N/S	
Palomino	N/S		+	+
Gray	–	–		
White or gray				+
Sorrel or chestnut			N/S	+
Dun, buckskin, or grulla			N/S	+
Roan				+
Black				+
Pinto			N/S	+
Appaloosa				+
Distinguishing characteristics				
Face whorls				+
Blaze				+
Any white feet				+

[a] N/S = not statistically significant. A "blank" means this variable was not included in the model specification.
[b] All trained horses in the Elizondo et al. (2016) sample were adopted or sold. The positive sign is implied and was not included in their model.

Table 3. Models for wild horse (*Equus ferus caballus*) and (*E. asinus*) adoptions and sales.

	Adekunle et al. (2014)	Elizondo et al. (2016)[b]
Estimation method	OLS	Heckit
Sample	Onsite survey of BLM sale participants	BLM adoption/sales database
Sample size	93	63,983
Model selected for comparison	Table 3	Table 7 Model 4
	Sign of statistically significant variables[a]	
Size (hands)	N/S	
Age		
Age	N/S	N/S
Age squared		N/S
Sex (baseline)	(Gelding)	(Mare)
Stallion	+	N/S
Gelding		+
Mare	+	
Training		
Halter-trained	+	
Saddle-trained	N/S	
Any training		+
Color (baseline)	(Black)	(Bay or brown)
Any color	+	
Palomino		+
White or gray		+
Sorrel or chestnut		+
Dun, buckskin, or grulla		+
Roan		+
Black		+
Pinto	+	+
Palamino		+
Appaloosa		+
Cremello		+
Distinguishing characteristics		
Blaze or stockings	N/S	
Face whorls		+
Blaze		+
Anywhite feet		N/S
Visible defect		–

[a] N/S = not statistically significant. A "blank" means this variable was not included in the model specification.
[b] The Elizondo et al. (2016) model is a Heckit model linked to probit adoptions/sales specification appearing in Table 2.

(2016) reported an average fee of $191.86 for adopted horses and $19.60 for sold horses. One can interpret these figures as marginal benefits for use in a comprehensive BCA. The adoption fee received was unrelated to age (age effects were captured in the selection model). Stallions generated fees that were not significantly different from those received by mares, but geldings received a premium of about $11. Training added about $141 to the adoption fee. Relative to bay or brown, any other color added to the adoption fee, ranging from the $12 premium for sorrel or chestnut horses, up to the $112 premium garnered by dun, buckskin, or grulla horses. Other colors received premia in amounts between these 2 extremes. Distinguishing characteristics were also of value relative to horses without such markings: a blaze was worth almost $11 whereas face whorls were worth an additional $109. Conversely, any visible defects reduced the adoption fee by just under $26.

Effect of horse slaughter ban on auction fees

In 2007, all slaughter of horses in the United States stopped as its last 3 slaughter plants ceased operations. The plant closures eliminated any salvage value for horses and left horse owners responsible for the increased costs associated with the care and welfare of horses nearing the end of their lives. A number of studies have examined the effect of the slaughter ban on the demand for horses (North et al. 2005, GAO 2011, Taylor and Sieverkropp 2013, Vestal et al. 2015), finding that the price for low-quality horses has declined by amounts that exceed 10%. Wild horses certainly fit into the low-quality category. Elizondo et al. (2016) also included a variable capturing the effects of the slaughter ban. The adoption/fee model (Tables 2 and 3) suggested that the price received at BLM auctions for wild horses has been almost $18 lower since the slaughter ban went into effect.

Auction structure and fees received

Economists have also studied the effect of auction structure on the fees received and the number and value of bids received. For example, in 2004 the BLM changed its auction process to include a number of additional means of adopting a horse, including auctions conducted on the internet. The Elizondo et al. (2016) sales model showed that per-animal adoption fees have fallen by roughly $100 since then. It is not clear if this is the result of (1) the change in auction structure, (2) reduced adoption demand for horses in recent years, or (3) some combination of the two. That said, Alevy et al. (2010) reported that bids received in internet auctions were, on average, less than bids received at onsite auctions. While both internet and onsite bids varied according to horse characteristics (primarily sex and color) in a manner similar to the pattern (Tables 2 and 3), internet bids were, as a rule, lower than onsite bids.

Li (2010) examined the effect of "jump bidding" and "sniping" in WHB internet auctions. Jump bidding is the act of increasing one's bid for an animal in excess of the minimum required increment ($5) and is designed to signal aggressive behavior, force others to prematurely terminate their bidding activity, and keep the price low. Sniping is the act of waiting until the last few minutes of an auction before placing a bid; the goal is to hide one's willingness to pay from others in an attempt to keep the winning bid as low as possible. Using BLM internet auction data for adoptions occurring between 2006 and 2008, Li (2010) reported that >2,300 bids were received for 505 animals. Of the total number of bids, 623 were jump bids in excess of the $5 minimum increment. Li (2010) found that each jump bid increased auction revenue by 0.22%, so that jump bidding failed in its goal to lower the final adoption fee. Late bids (sniping), defined as those that arrive in the last 30 minutes of an auction, comprised one-third of all bids; 19% were submitted in the last 5 minutes. Li (2010) found that late bidding had no effect on auction revenue and sniping was not an effective auction strategy.

Intertemporal bioeconomic models

A few studies have examined the longer-term dynamics of wild horse range management using bioeconomic models. Such models are well suited to conducting intertemporal BCA because they can easily include both benefits and costs within a dynamic optimization framework. However, none of the models appearing in the literature achieve the ideal of Hyde's (1978) BCA model.

Huffaker et al. (1990) illustrated the tradeoffs between wild horses and domestic livestock within an optimal control framework. Their theoretical model balanced wild horse and livestock stocking densities to achieve an ecological balance with range vegetation. Wild horse populations were managed by periodic removals from the range, whereas livestock populations were controlled by changing the grazing fee charged by the BLM. The objective function was set up to achieve range conditions of a quality needed to sustain multiple use demands. Higher rates of horse removal allowed the range to support more livestock, and a lower grazing fee could be charged while still maintaining desired range quality. Similarly, lower rates of horse removal, holding range quality constant, required higher grazing fees to encourage ranchers to stock fewer animals. The model solution yielded the jointly optimal rate of animal removal and stocking fee needed to achieve multiple-use goals for public rangeland.

Most intertemporal models of WHB control found in the literature have been constructed to minimize the cost of achieving AML goals rather than maximizing net benefits. Bartholow (2007) used BLM's WHB planning tool, WinEquus, to simulate herd dynamics with management tools that included different time intervals between WHB removals, changing population sex ratios, and recurring application of fertility control. The study was conducted for 4 herd management areas over a 20-year time horizon using 100 stochastic simulations. Simulations differed in initial population size and structures, along with subsequent animal survival. Contraceptive treatment was, in general, found to be cost effective for all but 1 (naturally) slow-growing population. Using baseline 2004 costs, the most cost-effective management approach combined application of contraceptives every 3 years, changing the age structure of animals targeted for adoption, and increasing the proportion of females removed from the range. An annual nationwide savings of $7.8 million in variable program costs could result if the most cost-effective strategy were to be adopted.

Arneson et al. (2002) used a bioeconomic model to track program costs as they varied the length of time between gathers, fertility control intervals, and sex ratios. Per-horse gather costs were assumed to decline with the size of the population in a given herd management area. Fertility controls were assumed to reduce annual population growth from 20% to 8.1%. The authors found that the most cost-effective strategy was to gather horses every 4 years and administer 2-year contraceptives to mares. Results were found to be insensitive to relatively wide variation in the parameters chosen for program costs.

de Seve and Boyles Griffin (2013) compared the effect on horse populations under 3 management approaches: no management, removal only, and removal and contraception. The authors simulated a hypothetical herd of almost 900 horses over a 12-year period; removals occurred during years 3, 7, and 11. Over the planning horizon, the number of horses removed to long-term holding pastures was reduced by 55% and managers came closer to satisfying the AML. Relative to a removals-only policy, the present value of total costs for a removal and contraception policy was reduced by $3.7 million (35%) over 12 years at a single-herd management area. Again, there was no attempt to measure benefits as defined by Hyde (1978).

A recent study by Fonner and Bohara (2017) used an optimal control model to determine how to achieve herd levels with animal removals only, fertility control only, and a combined removal/contraceptive program. This model departs from others in that the objective function includes a measure of benefits. The benefits function, though, did not match that envisioned by Hyde (1978). Instead, the authors' benefit function was constructed to include use and nonuse net benefits of the marginal costs as estimated by Bastian et al. (1999). To understand their approach, go back to Hyde's (1978) equation and set total benefits equal to total costs, and then subtract opportunity costs from both sides of the equation. The benefits function is now, UV(AML) + NUV(AML) + ASV(AML) – OC(AML). Use, nonuse, and adoption benefits were not estimated by Fonner and Bohara (2017); instead, marginal benefits, net of marginal opportunity costs, were set equal to zero at the selected AML. That is, the maintained assumption is that the BLM had chosen the AML needed to maximize benefits. Despite the implausibility of the assumption, it cleverly allows the authors to parameterize a complex, dynamic model in the absence of information about benefits. The study's inclusion of opportunity costs results in a more broad-based analysis than the other bioeconomic studies reviewed in this section.

Cost information, gathered from a variety of sources, was used to develop state-level models for Oregon and Nevada. Three policy options were examined for each state over a 50-year planning horizon. The model demonstrated that a fertility control-only policy was not effective at controlling on-range populations and thus generated the lowest net benefits and left the largest number of free-roaming animals. In fact, the fertility control-only program was found to raise costs over status quo program expenses in both states. In both states, a removal-only management policy achieved on-range free-roaming populations similar to that of a hybrid removal-and-fertility policy. However, the number of animals in LTH was greater under a removal-only policy, resulting in higher costs relative to a hybrid program. The model for Nevada found LTH populations under the hybrid program just slightly lower than a removal-only policy, but Oregon's higher rate of adoption resulted in an LTH population under the hybrid approach that was about half that of the removal-only option. Both the removal-only and the hybrid program in Nevada generated substantial cost savings relative to the status quo (about $1.3 billion over 50 years). Optimal herd management in Oregon under either a removal-only or hybrid program generated cost savings of about $300 million over 50 years.

Summary

Forty years have passed since Hyde (1978) first outlined 6 primary categories of benefits and costs needed to conduct a full economic analysis of WHB management on public lands. This survey of the literature has found far more emphasis on program costs—the costs of gathering, holding, and adopting out horses and burros—than on any of the other 5 elements of benefit and cost. Program costs are explicit expenditures readily found in public documents and relatively easy to quantify, so this is not a surprise. What is surprising is the relative paucity of other cost and benefit information.

Only 1 study (Bastian et al. 1999) explicitly measures the opportunity cost of displacement of wildlife species (elk, mule deer, and pronghorn) that share the range with WHB. These authors base opportunity costs on foregone hunting values and do not include any foregone nonuse values associated with the displaced species. Thus, even this study underestimates the opportunity costs of displaced wildlife. Further, the opportunity cost estimate is unique to the portion of Wyoming studied; as Hyde (1978) anticipated long ago, the type of species and the number of animals displaced by WHB may vary geographically, so one should be wary of simply transferring the Bastian et al. (1999) estimate without considering its applicability to the region under study.

A much easier opportunity cost to gauge is the value of displaced commercial livestock. Bastian et al. (1999) included commercial opportunity costs, as did RCI (2017) and Alevy et al. (2007). As demonstrated with the Alevy et al. (2007) model, the opportunity costs may be estimated from any study that examines changes in federal AUMs. Again, the opportunity cost per AUM may vary geographically—relatively low where comparably priced substitutes to federal rangeland are available and higher where they are not. If one is fortunate to have a representative ranch model developed for a region of interest, then the analysis of AUM losses due to WHB may be transferred from studies conducted for other purposes, such as habitat restoration or wildfire damages. A closely related approach may use livestock production budgets that are produced by extension personnel in many states. A livestock budget provides a snapshot of output, inputs, prices, and profit for a representative farm. While less dynamic than representative farm programming models, one could work with livestock extension agents and the production budget to estimate losses in profit (opportunity costs) associated with more limited access to federal rangeland.

I could find no studies quantifying, in dollar terms, the ecological damages caused by excess WHB populations. Estimating ecological losses

Figure 4. Excessive utilization wild horses in the Antelope Complex in Nevada, USA. Estimating ecological losses associated with changing feral horse (*Equus ferus caballus*) populations will undoubtedly be challenging (*photo courtesy of the Bureau of Land Management*).

associated with changing WHB populations is undoubtedly a challenging prospect (Figure 4). At a minimum, such a study would require the involvement of a multidisciplinary team to document the physical damages to the rangeland at different WHB population levels, translate those damages into descriptions that are meaningful to people, and then conduct a cost survey using up-to-date non-market valuation methods (Boyle 2017, Brown 2017).

Turning to the benefits side, only 1 of the 3 benefit categories (adoption and sales value) has seen any work by economists. Though the number of adoption studies is relatively small, the results are remarkably consistent across studies and identify the characteristics of horses most likely to be adopted. In particular, every horse with some training in the BLM database was adopted and received a $141 premium (Elizondo et al. 2016). Given the cost of long-term holding (about $570 per year), the payoff to training horses prior to auction is substantial. Further, the database maintained by the BLM allows one to estimate an adoption value. Assuming the scale of adoption activity remains at historical levels, the average fee received for an adopted animal could be used as a reasonable approximation of the marginal benefit of adoption.

In contrast to the adoption/sales literature, economists have conducted no studies to estimate the use value of viewing WHB or the nonuse value of having WHB on public rangeland. A relatively small "wild horse and tourism" literature exists but does not estimate use values in a way that can be employed in a benefit cost analysis (see, for example, the review by Notzke 2016). Rosenberger (2018) regularly updates a database of recreational use values, which is currently composed of 421 studies conducted between 1958 and 2015. The database includes a large number of value estimates for wildlife viewing (at an average of just >$59 per person per day), but the majority of these studies are not for a specific species—only wildlife viewing as a general activity. To the degree that wildlife-viewing studies focus on a type of animal, they generally focus on birds, or a particular species of bird. Very few wildlife-viewing studies concern mammals, and the majority of those are for elk. Absent a use value study for WHB viewing, one must engage in a benefit transfer (Rosenberger and Loomis 2017). If, for example, a researcher happened to have an estimate of the number of people viewing WHB on a given herd management area, a simple way to gauge the WHB benefit would be to multiply the number of visitor days by the $59 per person per day values. This estimate of use benefits would surely be fraught with error, but at least one would be making a step toward a more complete benefit cost analysis.

Relative to adoption values or use values, estimating nonuse values for any species under any circumstances is both difficult and controversial. Nonuse values are estimated by stated preference models, which are difficult to master, expensive to administer, and often attacked (Hausman 2012, Bishop and Boyle 2017, Boyle 2017). Still, the fervor with which people advocate on behalf of WHB—even when they have no intention of adopting a horse or making a visit to view them—would suggest strongly held nonuse values for free-roaming WHB (Hayden 2016, Shaer 2017). A study would need to establish not just an estimate of nonuse value, but also the size of the population holding such values.

Acknowledgments

This research was funded solely by the Utah Agricultural Experiment Station and the Utah Extension Service. The author is not affiliated with any Koch Foundation-funded entity at Utah State University. I thank R. Fonner, T. Harris, T. DeVault, HWI Associate Editor, and 2 anonymous reviewers for comments on an earlier manuscript draft. All errors remain those of the author.

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