simple as possible. We assume that the world is flat, the moon is a sphere, and there is no wind. We may also assume that the distribution of the population across the world is uniform. In order to simplify the problem, we may also assume that the population is constant. However, this is not necessarily the case. The population of the Earth is constantly changing due to natural processes such as births and deaths. To simplify the problem, we may assume that the population is constant. However, this is not necessarily the case. The population of the Earth is constantly changing due to natural processes such as births and deaths. To simplify the problem, we may assume that the population is constant. However, this is not necessarily the case. The population of the Earth is constantly changing due to natural processes such as births and deaths. To simplify the problem, we may assume that the population is constant. However, this is not necessarily the case. 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In the absence of a food supply, the population is stable at the carrying capacity, which is the maximum number of individuals that can be supported indefinitely by the environment. This is often referred to as the equilibrium population size. The population growth rate is zero when the population size is equal to the carrying capacity.

\[ \frac{dN}{dt} = 0 \]

When the population size is less than the carrying capacity, the population grows exponentially.

\[ \frac{dN}{dt} = rN \]

When the population size is greater than the carrying capacity, the population decreases exponentially.

\[ \frac{dN}{dt} = -rN \]

The carrying capacity is determined by the environment and is often referred to as the maximum sustainable yield. It is the point at which the population size is maximized and the population growth rate is zero.

\[ N = \frac{K}{r} \ln \left( \frac{K}{N_0} \right) \]

where K is the carrying capacity and N0 is the initial population size.
PROPOSITION 1: If the initial population is not large enough to ensure that the population cannot be maintained, the population becomes extinct. The existence of the population is determined by the equation

\[ D(c_i - c(x)) \frac{dx}{dt} = \frac{d\ln(t)}{dt} \]

where \( c \) is the price at which it becomes profitable to protect the resource as private property.

**PROOF:** If \( P_c < P_a \), then the price charged for the best mating opportunities is less than the price of the resource. If the population is not large enough, the population will not be able to maintain itself and will die out.

The price \( P_c \) is determined by the equation

\[ P_c = C_w \left( \frac{1}{(1 - F_s)^{1/2}} \right) \cdot \left( \frac{1}{(1 - F_l)^{1/2}} \right) \cdot \left( \frac{1}{(1 - F_p)^{1/2}} \right) \]

where \( F_s, F_l, \) and \( F_p \) are the proportions of the population found in the optimal mating areas, the optimal location, and the optimal protection areas, respectively.

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\[ D(c_i - c(x)) \frac{dx}{dt} = \frac{d\ln(t)}{dt} \]

where \( c \) is the price at which it becomes profitable to protect the resource as private property.

The equation can be solved numerically to find the critical thresholds for the population to remain stable.

**REFERENCES:**


**FIGURE 3:** The change in the population density over time for different values of the harvesting parameter, \( h \).

The population density is given by the equation

\[ N(t) = N_0 e^{rt} \]

where \( N_0 \) is the initial population density, \( r \) is the growth rate, and \( t \) is time.

**FIGURE 4:** The change in the population density over time for different values of the harvesting parameter, \( h \).

The population density is given by the equation

\[ N(t) = N_0 e^{rt} \]

where \( N_0 \) is the initial population density, \( r \) is the growth rate, and \( t \) is time.

**FIGURE 5:** The change in the population density over time for different values of the harvesting parameter, \( h \).

The population density is given by the equation

\[ N(t) = N_0 e^{rt} \]

where \( N_0 \) is the initial population density, \( r \) is the growth rate, and \( t \) is time.
We now examine under which circumstances the equilibrium graph can move from the position

C: Transition from the Position Without Intervention

"\( x > x^* \)" and "\( x < x^* \)" will be considered above. When the position of the equilibrium graph is changed, the condition of the population without intervention is still satisfied. Therefore, the population without intervention remains at \( x^* \). The population is determined by the equilibrium graph, and the position of the equilibrium graph remains unchanged if it is in the position without intervention. Therefore, the population without intervention and the equilibrium graph are determined by the equilibrium graph. The equilibrium graph is determined by the population without intervention. The equilibrium graph is determined by the population without intervention. Therefore, the population without intervention is in the position without intervention. Therefore, the population without intervention is in the position without intervention.
PROPOSITION 2: Suppose that at time 0, we can explain the equilibrium. The consumer's demand for goods is given by the following utility function:

\[ U(c, x) = c^{\alpha} x^{1-\alpha} \]

where \( c \) is the consumption of goods and \( x \) is the consumption of the non-traded good. The entrepreneur's supply function is:

\[ S(x) = x \]

The market clears when the sum of the entrepreneur's supply and the consumer's demand equals the total quantity available.

Proof: If the entrepreneur supplies more than the consumer demands, then the surplus goes to the entrepreneur. Conversely, if the consumer demands more than the entrepreneur supplies, then the shortage is absorbed by the consumer. The equilibrium is reached when the market clears, i.e., when the supply equals the demand.

The equilibrium price and quantity are determined by the intersection of the demand and supply curves.

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The equilibrium price and quantity are determined by the intersection of the demand and supply curves.
instantaneous cull, which will make the species extinct if \( X_s < U(c_m) \) and (ii) if \( T \) is great enough, then the survival equilibrium may be eliminated even if \( X_s > U(c_m) \).

**PROOF:**

See the Appendix.

**B. Policies to Eliminate the Extinction Equilibrium**

Just as an expected shift to an antipoaching policy which reduces the long-run harvest may lead to an immediate cull, an expected shift towards an antipoaching policy which increases the long-run harvest may lead to a temporary cessation of poaching as the economy switches to a storage without poaching subpath. In particular, governments may be able to coordinate on survival equilibria by committing to follow certain policies. It is beyond the scope of this paper to fully specify optimal antipoaching expenditure and stockpile purchases and sales as functions of \( x \), or more generally, the history of \( x \). However, it is possible to show that for low enough interest rates, the optimal long-run policy involves committing to implement draconian antipoaching policies if the population falls below a threshold, or if this commitment would not be credible, building up stockpiles and threatening to sell them if the population falls below that threshold.

As is clear from Figure 1, if one takes the available habitat as given, the minimum antipoaching expenditure such that there is a steady state with positive population is \( E_{MIN} \) such that \( D(c(x, E_{MIN})) \) is tangent to \( B(x) \). Let \( x_{MIN} \) denote the steady-state population associated with antipoaching expenditures of \( E_{MIN} \). Consider the case in which \( x_{MIN} > U(c_m) \).

The steady-state cost of eliminating the extinction equilibrium is minimized by spending \( E_{MIN} \) on antipoaching efforts and committing that if \( c \) falls below some threshold, the government will temporarily implement tough antipoaching measures that raise \( c \) above \( p_m \) until the population recovers to \( x_{MIN} \). This threshold can be any level of population less than \( x_{MIN} \). (In this model, the population is not subject to stochastic shocks, and hence the exact threshold is irrelevant, since in equilibrium, the population never falls below \( x_{MIN} \).) To see that this policy minimizes the steady-state cost of eliminating the extinction equilibrium note first that there is no extinction equilibrium under this policy, since the cost of poaching is above \( p_m \) when \( x \) is below the threshold. The population cannot be eliminated instantaneously in a cull before the government has an opportunity to raise the cost of poaching above \( p_m \) since \( x_{MIN} > U(c_m) \). Note also that no policy with lower expenditure is consistent with survival, since the population cannot survive indefinitely with antipoaching expenditures of less than \( E_{MIN} \).

In general, optimal long-run policy may not minimize steady-state costs because moving to this policy would entail transition costs. To take an extreme example, if the initial population is small enough, assuring species survival will be so costly that the government will allow extinction. However, as the discount rate approaches zero, the optimal long-run policy will approach the policy which minimizes steady-state costs (assuming that these costs are less than the flow value the government attaches to eliminating extinction equilibria).

The model suggests that if a government or international organization could credibly commit to spend a large amount on elephant protection if the herd fell below a certain critical size, it would never actually have to spend the money. This provides a potential rationale for endangered species laws that extend little protection to a species until it is endangered, and then provide extensive protection with little regard to cost.

Note that the policy which minimizes the steady-state cost of eliminating the extinction equilibrium may leave the population close to extinction. Some additional margin of safety would likely be optimal in a more realistic model in which the population was subject to stochastic shocks.

Some governments with open-access resources may not be able to credibly commit to spend heavily on antipoaching enforcement if the population falls below a threshold, since this policy will be time inconsistent if the cost of imposing tough antipoaching enforcement is sufficiently high. In the case of goods used to produce storable, nondurable goods, we argue below that the cheapest way for such governments to eliminate the extinction equilibrium may involve maintaining a stockpile and threatening to sell it if the population falls below a threshold or becomes extinct. Promises to sell stockpiles, unlike promises to increase antipoaching expenditure, are likely to be time consistent, since there is no reason not to sell stockpiles if a species is becoming extinct anyway. (It is important to note that while stockpiles can help protect animals which are killed for goods which are storable but not durable, such as rhino horn, stockpiles will not help protect species which are used to produce durable goods, i.e., goods which are not destroyed when they are consumed.\

14 The government has no reason to store durable goods, since private agents will store any durable goods sold on the market. As noted in the introduction, however, few goods are completely durable.

15 This discussion assumes that the poachers can conduct an instantaneous cull before the government can react. However, a similar phenomenon would occur even if the government could raise \( E \) as soon as the population hit a threshold. If poachers believed that the government would eventually give up protecting the animal, they would keep forcing the population back to the threshold, and this could cause the government to spend so much on antipoaching enforcement that the government would in fact prefer to let the species go extinct.

13 Note that \( x_{MIN} \) would be an unstable steady state if the government maintained constant expenditure of \( E_{MIN} \) instead of letting expenditure depend on \( x \).

Policy is calculated taking the \( c(x) \) function as exogenous, \( E(x) \) is calculated based on \( c(x, E(x)) \) where \( E(x) \) is the government’s optimal antipoaching expenditure, given a population \( x \).

Suppose that \( x_{MIN} \) is greater than \( x_{MIN} \). To provide a switch to the extinction equilibrium will exist in steady state if \( x_s = x_{MIN} \) and the government does not hold stockpiles. In order to prevent extinction equilibrium, the government could either maintain a live population of \( x_{MIN} \) or maintain a steady-state live population of \( x_{MIN} \) and a stockpile of \( x_{MIN} - x_{MIN} \), which it promises to sell if the population falls below a threshold. To see why holding \( x_{MIN} - x_{MIN} \) either as live population or stockpile will eliminate the extinction equilibrium, note that a cull could only move the system along a 45-degree line extending ‘northwest’ from the initial point in population-stores space. It is impossible to reach an extinction path along this line, then there will be no extinction equilibrium.

To compare the cost of holding \( x_{MIN} - x_{MIN} \) as live population and stockpile, denote the steady-state cost of antipoaching enforcement and other conservation activity needed to maintain the population at \( x_{MIN} \) as \( E(x_{MIN}) \). Note that if \( x_{MIN} \) is beyond the carrying capacity, \( E \), even the complete elimination of poaching will be insufficient to maintain the population at \( x_{MIN} \). Food will have to be brought in for the animals, and as overcrowding increases, disease may become a more severe problem. We assume that, at least for large enough \( x \), the expenditure needed to maintain a population of \( x \), denoted \( E(x) \), increases at least linearly in \( x \), i.e., \( E(x) \geq 0 \).

Suppose that there are initial \( x_{MIN} \) animals.

The discounted cost of supporting the animal population at \( x_{MIN} \) indefinitely is \( E(x_{MIN}) \). De note the cost of culling a population of \( x_{MIN} \) to a population of \( x_{MIN} \) as \( c(x_{MIN}, x_{MIN}) \). We assume that \( c(x) \) increases less than linearly with \( x_{MIN} \), since it is presumably easier to cull animals when there are more of them. The discounted cost of sustaining a population of \( x_{MIN} \) and a stockpile of \( x_{MIN} - x_{MIN} \) is thus \( E(x_{MIN}) + E(x_{MIN}) \). The cost advantage of stockpiling is thus \( (E(x_{MIN}) - E(x_{MIN})) \). This is positive if \( c(x_{MIN}, x_{MIN}) < E(x_{MIN}) \). For small enough \( r \), this will be the case. To see this, note that \( x_{MIN} \) (and hence \( E(x_{MIN}) \)) do not depend on \( r \), since \( x_{MIN} \)
depends only on the \(D(p)\) and \(B(z)\) functions, each of which depends on current and not future variables. As \(r\) approaches zero, \(x_{NC}\) (and hence \(E(x_{NC})\)) grow without bound, since \(s\) is bounded below by 0, and \(x_{NC} - s\) will grow without bound as \(r\) falls, because as \(r\) approaches zero poachers will become willing to hold stockpiles for arbitrarily long periods prior to selling at \(p_m\). Under the assumptions that for large enough \(x\), \(E(x) \geq 0\), and \(x_{NC} - s < 0\), L'Hopital's rule implies that in the limit as \(r\) approaches zero, \(r^{x_{NC}/x_{MIN}}\) will grow less quickly than \(E(x_{NC}) - E_{MIN}\) and, hence, stockpiling will be cheaper than maintaining the animal population at \(x_{NC}\) indefinitely.

Note that if it is optimal to hold stockpiles if the initial population is \(x_{NC}\), then the cheapest policy that eliminates the risk of extinction must involve holding stockpiles in the long run, no matter what the initial level of population. To see this, note that the cheapest long-run policy that eliminates the risk of extinction without stockpiles is to maintain a population of \(x_{NC}\) but that once population had reached \(x_{NC}\), it would be cheaper to cull to create a stockpile of \(x_{NC} - s_{MIN}\) and to maintain a population of \(x_{NC}\), than to maintain the population at \(x_{NC}\). Hence the cheapest long-run policy that eliminates the risk of extinction must involve holding stockpiles.

While holding sufficient stockpiles will eliminate the extinction equilibrium, the process of building the stockpiles changes the survival equilibrium state, as well as the perfect foresight model of Sections 1-IV.16 merely holding stockpiles does not affect the survival steady state, since it changes neither demand nor supply.

Whereas under the perfect foresight model the survival steady state is the same with and without stores, under the stochastic model of Section V, government stockpiles affect the survival steady state as well as the extinction transition path. In the absence of government stockpiles, private agents will hold sufficient stores in the pre-sunspot steady state that the expected profits in case of a switch to the extinction equilibria just offset the storage costs if no sunspot appears. Government accumulation of stores will crowd out private stores, until private agents no longer hold any stores. Once the government accumulates sufficient stores, the extinction equilibrium will disappear.

Ted Bergstrom (1990) has suggested that confiscated contraband should be sold onto the market. Many conservationists oppose selling confiscated animal products on the market, fearing that it would legitimize the sales of illegal trade products. Using confiscated contraband to build stores helps avoid this problem. Stores could potentially be held until scientists develop ways of marking or identifying "legitimately" sold animal products so that they can be distinguished from illegitimate products. We have assumed that the only cost of holding stores is the interest cost, but if governments confiscate contraband, they will increase the cost of holding stores, and this will reduce the scope for extinction equilibria.

Our model does not allow for stochastic shocks to population, nor does it differentiate animals by health, age, or sex, but in more realistic models there may be ways of building stores that do not reduce the live population one for one. Stores could be built up by harvesting sick animals, or harvesting animals during periods when population is temporarily above its steady state, due for example to a run of good weather. In future work, we plan to explicitly model the potential of stockpiles to smooth stochastic shocks to population, for example due to weather and disease.

It is worth noting that stockpiles could be built up not only by the government of the country where the species lives, but also by conservation organizations or foreign governments. A further analysis of this case would have to consider strategic interaction between the conservation organization and the government.

We have assumed that the government knows the parameters of the model, but of course this is unlikely to be the case in practice. It is worth noting that inferences about parameters based on the Gordon-Schafer model may lead to a false optimism if the good is storable. Under the Gordon-Schafer model of nonstorable open-access resources, stability of the population could be interpreted as indicating that parameters are such that the species will survive.

In contrast, under the model outlined here, species with constant population may be vulnerable to a switch to an extinction equilibrium. One should not become complacent even if the population is increasing, since along Storage Without Poaching Subpaths, the population may temporarily increase above its steady-state level, even if the ultimate steady state is extinction.

Although we have focused on how governments could coordinate on the survival equilibria, and assumed that poachers are homothetic and take prices as given, it is worth noting that a "George Soros" of poaching who held large stores and had access to sufficient capital could try to coordinate on the extinction equilibrium simply by offering to buy enough of the good at a high enough price. (In practice such an offer could provoke a government reaction.)

Stepping further outside the model, we speculate that if the population of live animals were very small, poachers and storers might not take prices as given, and would instead take into account that killing animals could raise prices. This may help explain why rhinos in Zimbabwe which had been de-horned by game wardens to protect them from poachers were nonetheless killed by poachers. The New York Times (1994), quotes a wildlife official as explaining the poachers' behavior by saying: "If Zimbabwe is to lose its entire rhino population, such news would increase the values of stockpiles internationally.11" It is plausible that traders holding even modest stores would order poachers to kill de-horned rhinos, since rhino populations are small, and once poachers have found a rhino and realized that its horn has been removed, killing the rhino costs only a bullet.

APPENDIX

PROOF OF PROPOSITION 2:

After period \(T\) there will be no steady state with positive population and hence the system must follow an extinction equilibrium path. The date-\(T\) extinction path will have a higher starting price and lower starting population for any initial \(Q\) than the date-0 extinction path, because poaching will be greater for any population level, and hence the species will become extinct faster, so the price will reach \(p_m\) more quickly. [Both the date-\(T\) and date-0 extinction trajectories will pass through \((0, U(c_{MN}))\), but otherwise the date-\(T\) extinction trajectory will lie above the date-0 extinction trajectory in \(x-x\) space.] Since no jumps in price can be anticipated, if \(T\) is small enough, poachers will cull immediately.

PROOF OF PROPOSITION 3:

(i) Consider first the extreme case in which \(T\) is infinitesimal. Following a cull of \(\Phi < X_t\) at time 0, stores will be \(\Phi\) and the price will be \(c(X_t - \Phi, E)\). Along a rational expectations equilibrium path in which some animals survive, stores at time \(T\) must be \(U(c(X_t - \Phi, E))\), so that the stores will be exactly consumed during the time it takes the price to rise to \(p_m\). Thus the equilibrium \(\Phi = U(c(X_t - \Phi, E))\). If \(X_t < U(c_{MN})\), there is no \(\Phi\) satisfying this equation. To see this, note that \(c(x)\) is decreasing in \(x\) and \(U(c)\) is increasing in \(c\). Therefore, for \(X_t > U(c_{MN})\), \(c(X_t - \Phi) \leq c_{MN}\), and \(U(c(X_t - \Phi)) \geq U(c_{MN}) > X_t \geq \Phi\). Since \(\Phi\) cannot be less than \(X_t\) there will be a unique equilibrium in which the entire population is culled at time 0 and the price rises above \(c_{MN}\).

(ii) Now consider the case in which \(T\) is greater than the time until population and stores equal zero on any path with a cull. In this case, no equilibrium cull is consistent with survival. If there is no immediate cull, then the price must be continuous. If the price is continuous, then if maximum stores along the path satisfying the differential equation for extinction trajectories, (9), and passing through the point \((X_t, 0)\) are less than \(U(c_{MN})\), there can be no survival equilibrium. To see this, note that for the animal to survive, the price at time \(T\) must be less than \(c_{MN}\). If the price at time \(T\) is less than \(c_{MN}\), then on a rational expectations path, stores at time \(T\) must be greater than \(U(c_{MN})\).

PROPOSITION A1: The path of population, \(x\), stores, \(s\), and price, \(p\), is continuous on an equilibrium path.
Proof:

\[
\begin{align*}
0 > & \quad (aX + (\bar{a}X)x)\Delta = - \\
& \quad \int (x + \Delta x) f(x) \, dx = 1 \\
& + \int (\Delta x) f(x) \, dx \\
& = \Delta x \int f(x) \, dx \\
& = \Delta x \\
& = 0 \\
& \Rightarrow \quad (x + \Delta x) f(x) \leq x f(x)
\end{align*}
\]

The function \( f(x) \) is non-decreasing in \( x \).

Reference:

Kremer and Moretti, Economic Review.

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Theorem A: Consider the system of differential equations for the no-inflation scenario:

\[
\begin{align*}
(\bar{a}X + (\bar{a}X)x)^{\Delta} = 1 \\
& \quad \int (x + \Delta x) f(x) \, dx = 1 \\
& + \int (\Delta x) f(x) \, dx \\
& = \Delta x \int f(x) \, dx \\
& = \Delta x \\
& = 0 \\
& \Rightarrow \quad (x + \Delta x) f(x) \leq x f(x)
\end{align*}
\]

The function \( f(x) \) is non-decreasing in \( x \).