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Debunking the myth that a legal trade will solve the rhino horn crisis: A system dynamics model for market demand

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ABSTRACT

There is considerable debate in the literature over whether or not to legalise the trade in rhino horns. Here a system dynamics model is developed that considers five components: rhino abundance, rhino demand, a price model, an income model and a supply model. The study indicates the importance of shifting from a conventional (sectoral) conservation model to a more non-conventional (sustainable) approach that models the interactions between the different components. While the results under the no trade scenario are similar for both the equilibrium and disequilibrium model, under the trade scenario results were sometimes quite disparate. This study finds that sometimes second best solutions from an economic perspective may be optimal if conservation interests are to be achieved.

1. Introduction

There is much debate in the conservation literature over whether or not to legalise the trade in rhino horns. Biggs et al. (2013) write that a legal trade can only work if, among other things, "the demand does not escalate to dangerous levels as the stigma associated with the illegality of the product is removed." A number of authors (e.g. Collins, Fraser, & Snowball, 2013; Prins & Okita-Ouma, 2013) emphasise uncertainties over responses of market demand to a legal trade. If demand is positively sloping, by an Anthropogenic Allee Effect (AAE), then species extinction could actually be exacerbated by demand reduction strategies (Hall, Milner-Gulland, & Chourchamp, 2008). The AAE effect implies that the perceived rarity of a wildlife product could actually increase demand and therefore extinction risk (Courchamp et al., 2006). On the other hand, Biggs et al. (2013) argue demand is downward sloping (but inelastic). They argue, therefore, that demand reduction strategies would actually reduce the supply of rhino horns to the market. Those that advocate for the liberalisation of the rhino horn trade argue that allowing the sale of rhino horns will generate additional income for rhino farmers that will aid in the conservation of the species (e.g. Hanks, 2015). Alternatives that have been proposed to solve the 'rhino horn trade dilemma' include dehorning (Milner-Gulland, 1999) and consumer behaviour modification (Litchfield, 2013). As these issues are debated, poaching continues to increase, with the possibility that South African rhinos could be extinct in the next 20 years if current trends continue (Di Minin et al., 2015).

It is therefore important to develop a model to estimate the response of consumers to changes in demand, prices and income. Rhino horn price and income elasticities were estimated by Millner-Gulland (1993) using multivariate linear regression. Her model showed that the price coefficient was insignificant while the income elasticity was 1.06, indicating that rhino horns were luxury goods. However, market demand have increase dramatically in the past 20 years. We therefore need to ascertain whether or not these conditions still hold. Furthermore, estimation of market dynamics requires an understanding of how different market components (preferences, income and price) interact with each other. We therefore need to develop a model to consider the market dynamics associated with the rhino horn trade in order to estimate several crucial elasticities (price, income and consumption). However, instead of using the standard regression techniques to estimate elasticities, we develop a systems model that replicates the known behaviour of the system. Once the elasticities are known, we use the model to answer "what if" type questions on the behaviour of the system. In particular, we want to know the effect of legalising the trade in rhino horn on all key participants (rhino populations, rhino horn consumers and game reserve "suppliers"). In addition to the trade/no trade policy that forms the central thesis of this article, the model is also capable of modelling a number of other mitigation

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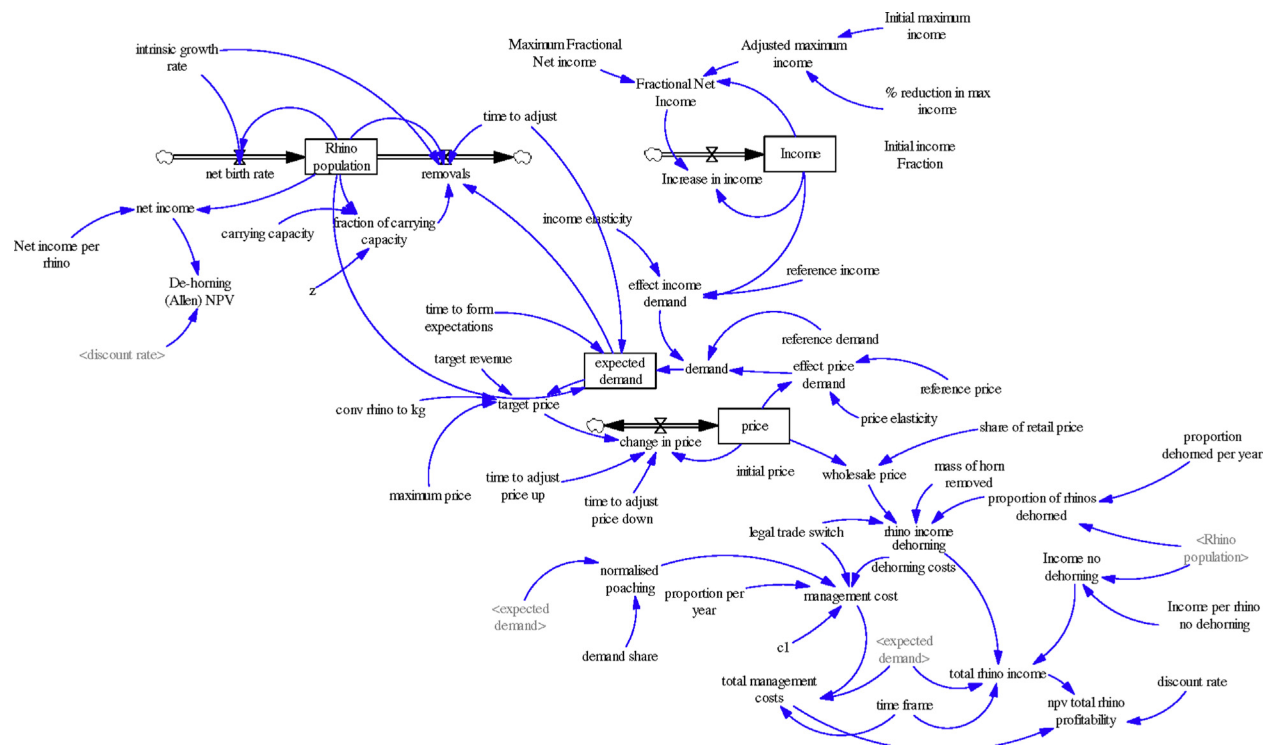

Fig. 1. Stock flow diagram of the market model.
The figure indicates the interactions between the different components of the model, namely a population model, market demand (price and income), and the profitability of rhinos for game farmers.

type policies, including consumer behaviour modification, as well as the effectiveness of a de-horning strategy.

A number of studies have utilised system dynamics models for wildlife populations. Chen, Chang, and Chen (2014) develop a model that simulates the effect of air pollution on habitat, which in turn affects the migratory behaviour of birds. Beall and Zeoli (2008) model the dynamics of Greater sage grouse populations in Western North America. Land management decisions are the main driver of population declines. Semeniuk, Haider, Cooper, & Rothley (2010) examine the effect of tourism on stingray populations. An interesting feature of the model is the use of a logistic growth formulation to model a density dependent tourism growth function. As far as mammals are concerned, Faust, Jackson, Ford, Earnhardt, and Thompson (2004) develop a stochastic, two sex, four stage model for grizzly bears in zoos, as well as the Yellowstone National Park. On the African continent, Weller et al. (2014) model African penguin populations subject to a number of pressures, including oil spills and competition for food from the fishing industry. An age structured model characterises the penguin population dynamics. This selection of studies indicates that system dynamics modelling is relatively common for modelling wildlife populations. However, applications to the rhino horn trade, apart from this study, are non-existent.

There are very few studies that have adopted an empirical approach to assess whether or not a legal trade in rhino horn is viable (but see Di Minin et al., 2015 as a notable exception). The rhino horn trade is a complex system with many participants, from the dynamics of rhino populations themselves, to producers (game farms) and the final consumer. A modelling approach that is capable of modelling complex systems is therefore required, hence the choice of system dynamics modelling. This study is the first known study to develop an integrated model that considers the interactions between the major participants of the rhino horn trade (populations, producers, consumers) in an interactive manner. The systems model distinguishes between two elements. Firstly, an equilibrium model is developed which follows largely a neoclassical framework. And secondly, a disequilibrium model is then developed to consider the dynamics of the trade. It is extremely rare for a systems model to contain both equilibrium (neoclassical) and disequilibrium (heterodox) elements (Crookes and De Wit, 2014). The model therefore makes a contribution to the systems literature as well.

The article is structured as follows. First, the systems model for the different components is developed. Section 3 deals with the parametrisation of the model, distinguishing between exogenous and endogenous parameters. The results are presented in Section 4, and the results are discussed in Section 5.

2. The model

There are five components of the market model (Fig. 1). These are: (1) a population model determining the dynamics of rhino abundance; (2) a income model determining the response of rhino horn demand to changes in income; (3) a price model, evaluating the effect of price changes on demand; (4) a demand function that combines the income and price models, and (5) a supply model, consider the effect on game farm profitability of either legalised trade or no trade. We use the term ‘game farm’ in the broadest sense to include private sector and public sector management of rhinos. We will now consider each of these components in turn.

2.1. Population model

The model utilises the population model of Milner-Gulland and Leader-Williams (1992), which is in effect a density dependent logistic model.

$$f(x) = rx\left(1 - \left[\frac{x}{k}\right]^{z}\right) - h$$

Table 1
Parameters used in the model.

Parameter	Symbol	Value	Units	Reference
Endogenous variables				
Income elasticity	ϵ_y	3.445	Dimensionless	Optimisation A
Price elasticity	ϵ_P	0.1	Dimensionless	Calibration
Reference income	y_R	840	Dollar/person	Calibration
Carrying capacity	k	50000	Rhino	Calibration
Non-linear cost coefficient	α	0.026	Dollar/rhino/year	Optimisation B
Exogenous variables				
Dehorning costs		826	Dollar/rhino/year	Own calculations (see Appendix)
Mass of horn removed	W^H	1	kg/Rhino	Milner-Gulland (1999)
Share of retail price		0.11	Dimensionless	Own calculations based on Vecchiatto (2013)
Income per rhino no dehorning		364	Dollar/rhino/year	Own calculations (see Appendix)
Discount rate	δ	0.2	1/Year	Milner-Gulland et al. (1992)
Proportion rhino dehorned	γ^H	1	1/Rhino/year	Milner-Gulland (1999)
Initial price (1980)		1762	Dollar/kg	Average prices from data in Leader-Williams (1992)
Fowler (curvilinear) factor	z	7	Dimensionless	Milner-Gulland and Leader-Williams (1992)
Intrinsic growth rate	r	0.061	Dimensionless	Unpublished data

where k is the carrying capacity, r is the intrinsic growth rate, x is the rhino population, z is a density dependent term and h is the harvest (poaching) rate.

2.2. Income

There are various theories of economic growth. We need a growth theory that accurately represents the Asian economies where the demand for rhino horn is prevalent. One such theory is that of Emeritus Professor Lim Ching Yah. Professor Lim has over 40 years' experience as an academic researcher in pursuit of the goals of economic development and social upliftment (Sng, 2010). He developed the s-curve growth hypothesis (e.g. Lim, 2005), which was subsequently empirically verified through econometric analysis (Sng, 2010).

The s-curve growth theory, as the name suggests, holds that an economy grows in a sigmoid manner. A typical economy grows in three stages (Fig. 2): initially, an economy is characterised by low income and low growth (turtle economy). Over time, however, growth increases rapidly along with income (horse economy). Stage III is reached when income is high and growth slows (elephant economy). The data indicates that this growth pattern is highly indicative of East Asian economies (Lim, 2005).

The current model is developed for Vietnam, a major consumer of rhino horn products from the African continent (Milliken & Shaw, 2012). Income (y) dynamics follow a logistic function similar to the rhino population model:

$$f(y) = iy\left(1 - \frac{y}{y_{\max}}\right)$$

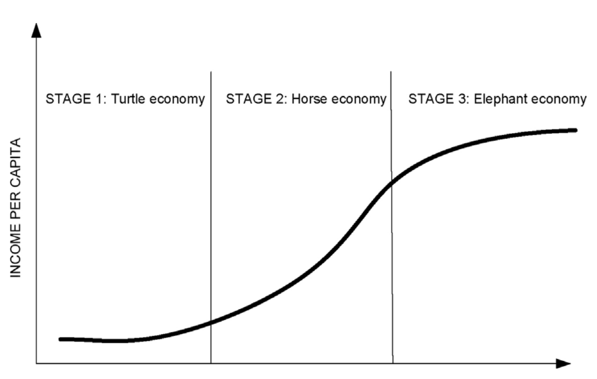

Fig. 2. s-Curve of economic development.
Source: Sng, 2010.

The growth rate i and maximum income $y_{\max}$ were unknown and so were allowed to vary until the best fit with the historical data was achieved. The effect of income on demand is given by the following function:

$$y_t^D = e^{\epsilon_y \times \ln(y_t/y_R)}$$

where ϵ_y is the elasticity of demand with respect to income, y_t is the income data emanating from the logistic growth function and y_R is a reference income that needs to be empirically determined from the data. The values of these constants are given in Table 1.

2.3. Price function

The price function uses a different approach to determining changes in prices over time, but is similar to the income function in the way that the effect of price changes on demand is modelled, except that the price elasticity of demand (ϵ_p) is negative rather than positive:

$$p_t^D = e^{\epsilon_p \times \ln(p_t/p_R)}$$

where p_t^D the retail price of rhino horn and the other parameters have the same interpretation as for the income function (see Table 1). We modelled the effect of a positive price elasticity of demand, to test for an Anthropogenic Allee Effect (AAE), but this did not fit the historical data very well, although extinction occurred much sooner than under the baseline. For negative price elasticity, demand was insensitive to changes in price so we conclude, as per Millner-Gulland (1993) that price is not an important driver of rhino horn demand.

2.4. Demand function

The demand for rhino horn is then a simple combination of price effects and income effects in the model:

$$D_t^H = D_R \Delta\omega_t^D$$

where D_R is a demand coefficient, and Δw^D is the net change in price and income effects (${y_t}^D$ and ${p_t}^D$). A consumption function that also influenced demand through an income effect was also attempted, but this also did not have a significant impact on the model dynamics.

2.5. Game reserves

Game farm profitability is estimated taking into consideration both non-horn income and horn income. Non-horn income is the

Table 2
Policy experiments conducted.

	No legalised trade			Legalised trade		
	Equilibrium		Disequilibrium	Equilibrium		Disequilibrium
	Policy	SBV ($/kg)	Policy	Policy	SBV ($/kg)	Policy
No CBM			Baseline	Policy 1A	−5,954	Policy 2A
CBM	Policy 1C	361	Policy 2C	Policy 1B	18,458	Policy 2B

Notes: Policy 1× strategies are the equilibrium scenarios, whereas Policy 2× are disequilibrium scenarios. CBM = consumer behaviour modification; SBV = Second best value.

income from trophy hunting, live sales, game products and eco-tourism. Not all rhinos encompass all these values. For example, rhinos on public land may only be used for live sales and eco-tourism, while certain private game farms may emphasise trophy hunting and game products. Averaging across all rhino uses, gives an approximate value of $364 per rhino per annum (Appendix 1).

Income from dehorning is estimated as follows:

$$I^H = \gamma^H x_t W^H p_t^W$$

where γ^H is the proportion of rhinos dehorned, x_t is the total rhino population in time t, W^H is the mass of rhino horn removed per annum and ${p_t}^W$ is the wholesale price of rhino horn in time t. Following Milner-Gulland (1999), γ^H is set at 1 as it is optimal to dehorn all rhinos and W^H is set at 1 kg.

For game farm management costs, we utilise the non-linear cost model of Allen (2002), such that management costs are modelled as a non-linear function of effort (E):

$$c(E) = \alpha E^2$$

where α is an unknown parameter that needs to be estimated. Hall (2012) provides detailed farm level cost data for rhinos, from which it is possible to calculate management costs for 2011 subject to dehorning and in the absence of de-horning. Using optimisation, α is estimated to be 0.026 under a de-horning strategy, and 0.022 under no dehorning. De-horning costs are calculated from Hall (2012), see Appendix 1.

3. Data

The data used in the model are of two sources: historical time series data was used to calibrate the model, whereas individual data points (obtained from the literature or simulated by the model) were also used to parametrise the model. Details of these data are now described. Further data are also provided in Appendix 1.

3.1. Time series data

Data on rhino population abundance was derived from two sources. Historical data until 1997 was obtained from Emslie and Brooks (1999), while data post 1999 was obtained from the latest CITES Conference of the Parties (COP16 Inf. 51), CITIES (2013). Rhino population data are not annualised and black and white rhino data were not always available for the same years so a model was fitted to the historical data, for both black and white rhino populations separately. The correlation coefficients (R^2 values) for both the black and white rhino populations were in excess of 0.99 so we are relatively confident in the historical fit of the data. The annualised black and white rhino data from the model could then be aggregated to obtain total rhino numbers.

Time series data on rhinos poached in South Africa were obtained from the official poaching statistics released by the Department of Environment Affairs (DEA). We utilised data up to the 28 May 2014 release.

Historical data on rhino horn prices is difficult to obtain, since CITES established a ban on the trade in rhino horn in 1977, and most Asian countries banned rhino horn in the use of traditional medicines since the mid-1990s (Shaw, 2012). Historical data was obtained from Leader-Williams (1992), and averaged to obtain an average retail price for African rhino horn. This was supplemented by recent and now well established market data from the internet. Again, a model was fitted to the historical data to account for missing data. The model fit gave an R^2 value of 0.94, again suggesting a good fit with the historical data. Time series data for per capita income for Vietnam was obtain from the International Monetary Fund (IMF, 2014).

3.2. Parameterising the model

The parameters used in the model are summarised in Table 1. Here we differentiate between parameters that are exogenous to the model, and parameters that are endogenous. Endogenous data represents data generated by the model itself, and represents two kinds: data through calibrating the model to find the best fit using the Vensim software, and data derived through optimisation, either from within Vensim (Optimisation A) or by using Excel Solver (Optimisation B). Calibration is used where a more imprecise fit is sufficient, whereas optimisation is required to obtain a more precise fit, for example for the estimation of elasticities.

4. Results

4.1. Elasticities

The system dynamics model we developed (Fig. 1) indicates that demand is not sensitive to changes in the price of rhino horn. This is consistent with the observations of Millner-Gulland (1993). The implication of this is that lifting the trade ban, even if it results in a reduction in rhino horn price, will not alleviate demand.

Income elasticities are positive, and greater than those estimated by Millner-Gulland (1993). We estimate an income elasticity of 3.445, which indicates that rhino horns are more of a luxury good, with consumption rising with increased income. This suggests that income policies may be successful in managing the rhino horn trade.

We therefore use the systems dynamics model to examine two models. The first (Policy series 1×) is an equilibrium model based on Allen's (2002) non-linear property rights model, and the second (Policy series 2×) is a disequilibrium model to investigate the effect of changes in market demand on game farm profitability. Table 2 summarises the different policies examined. These include: a baseline simulation (no legal trade, no income reduction); policy simulation 1A, 2A (legalisation of the trade, no income reduction); policy simulation 1B, 2B (legalisation of the trade, income reduction); and policy simulation 1C, 2C (no legalised trade and income reduction in consumer nations). For each of these policies we look at the effect on rhino abundance and the profitability of game farming, as measured by the net present value of game farms between 1980 and 2050.

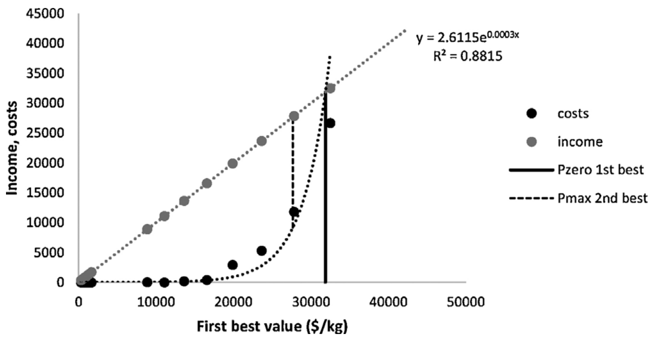

Fig. 3. Game farm profitability.

4.2. Equilibrium model

One way of exploring the implication of a legalisation of the trade is to consider Allen's non-linear property rights model (Allen, 2002). The model, populated with data from our study, shows the different values and costs associated with game farming subject to poaching (Fig. 3). The 45 degree line indicates the benefits from wildlife management, whereas the curvilinear line indicates the management costs subject to poaching. Where costs and revenues intersect (the solid black line in Fig. 3, which we will call V^H), is the maximum value that would make private ownership viable. To the right of this intersection, public ownership is the preferred management strategy as management costs would exceed benefits. We use Allen's model to consider in greater detail the policy option of legalising the trade with and without income reduction.

4.2.1. Policy 1A: trade, no CBM

The first best threshold value below which private sector game farms are viable (V^H) is $31,870/kg, which is marginally lower than the 2013 wholesale price of rhino horn ($32,500/kg) (Fig. 3). This suggests that a legal trade would not result in a viable and profitable private sector at the prevailing market price once management and enforcement costs are taken into consideration. However, the actual value accruing to game farms (the so called second best value) is negative, −$5,950/kg, since the cost of enforcement at that price is higher than the income earned (cost = $38,450/kg). The net present value of game farming under this scenario is −$137 million at a discount rate of 0.2 and −$172 million at a discount rate of 0.17 (Fig. 4).

4.2.2. Policy 1B: trade, CBM

Our analysis (Fig. 3) indicates that a legalisation of trade would increase game farm profitability compared with no price reduction. A shift in the wholesale price of rhino horn from $32,500/kg down to $27,665/kg would result in the profit maximisation solution for game reserves (Fig. 3). At this level, the costs of enforcement are reduced as a result of dehorning, and the reduction in costs exceeds the reduction in price, making this the optimal de-horning strategy. The value accruing to game farms from this (the so called second best value) would be $18,460/kg (the dotted line in Fig. 3). The cost of management and enforcement would be $9,205/kg at this price.

4.2.3. Policy 1C: no legalised trade, CBM

A third strategy, involves CBM without legalisation of the trade. Under Allen's model, this would reduce the first best value to $364/kg, and would reduce the management costs significantly. Our analysis suggests that this would produce a viable private sector. The NPV under this scenario is $8 million at a discount rate of 0.2, and $10.5 million at a discount rate of 0.17 (Fig. 4).

4.3. Disequilibrium model

4.3.1. Status quo: no trade, no CBM

Under the baseline, income rises and so does expected demand for rhino horn products, and rhino abundance declines to zero. This is consistent with the findings of Di Minin et al. (2015). The effect of these declines on the profitability of game reserves is ambiguous, and depends on the discount rate (return on capital). For low discount rates (i.e. $\delta < 0.18$), profitability declines (NPV < 0) over the next 5–10 years. However for higher returns on capital (e.g. $\delta = 0.2$), total NPV of rhino farming stabilises at around $6 million (Fig. 4).

4.3.2. Policy 2A: trade, no CBM

Under a policy of legalising the rhino horn trade (but without consumer behaviour modification), rhino abundance continues to be driven to extinction, while game farm profitability is positive for all values of the discount rate (Fig. 4). The incentive therefore for game reserves to harvest rhino horn to extinction, while maximising profits by taking the maximum amount of rhino horn from each animals.

4.3.3. Policy simulation 2B: legalisation of trade and CBM

A reduction in income in consumer nations and a legalisation of the trade could have "win–win" implications for conservationists as well as game farmers, however it is a risky strategy as the income reduction would need to be sufficient to reduce demand, while legalising the trade may actually stimulate demand. Furthermore, the NPV for Game Reserves from without CBM (Policy simulation 2A) is greater than the NPV for trade legalisation with CBM (Policy 2B, see Fig. 4), therefore encouraging a switch to a 'banking on extinction' scenario (Mason, Bulte, & Horan, 2012). Under CBM, rhino abundance stabilises at around 0.5K, whereas without CBM extinction is likely (Fig. 4).

4.3.4. Policy simulation 2C: no trade, CBM

This strategy assumes no trade, but models the effect of CBM to induce the shift in price. A reduction of income has the effect of improving the sustainability of rhinos, while game farm profitability stabilises at between $8 and $9 million (Fig. 4).

4.4. Optimal de-horning strategy

The previous section has indicated that, under certain conditions, NPVs accruing to game farms under a legal trade may be higher than under an illegal trade. However, the analysis ignores the effect of poaching. In order to shed more light on this we need to consider the optimal de-horning strategy for the poacher and the game farm.

Using the optimal de-horning model of Milner-Gulland, Beddington, & Leader-Williams (1992), we estimate the optimal dehorning strategy of game farmers and poachers. Following these authors, horn growth follows Von Bertalanffy growth function and game farms and poachers seek to maximise profits subject to a Faustmann growth model, where $PV = (V(T) - c)/(e^{rT} - 1)$ is the site value, where $V(T) - c$ is the net stumpage value and $V(T) = p \times w(t)$ is the value of horn at a specific weight. Fig. 4 indicates the optimal harvesting strategy for both game reserves and poachers, using data from our study. The results indicate that, while it is optimal for game farms to harvest after $T = 1.5$ years, for poachers it is optimal to kill a rhino and harvest its horn, even at very low rotation intervals (Fig. 5). This suggests that, even if a poacher encounters a dehorned rhino, it is still optimal to kill the rhino and take what is left of the stump. This casts further doubt on the effectiveness of a legalised trade, and highlights the importance of further research on farm level interventions.

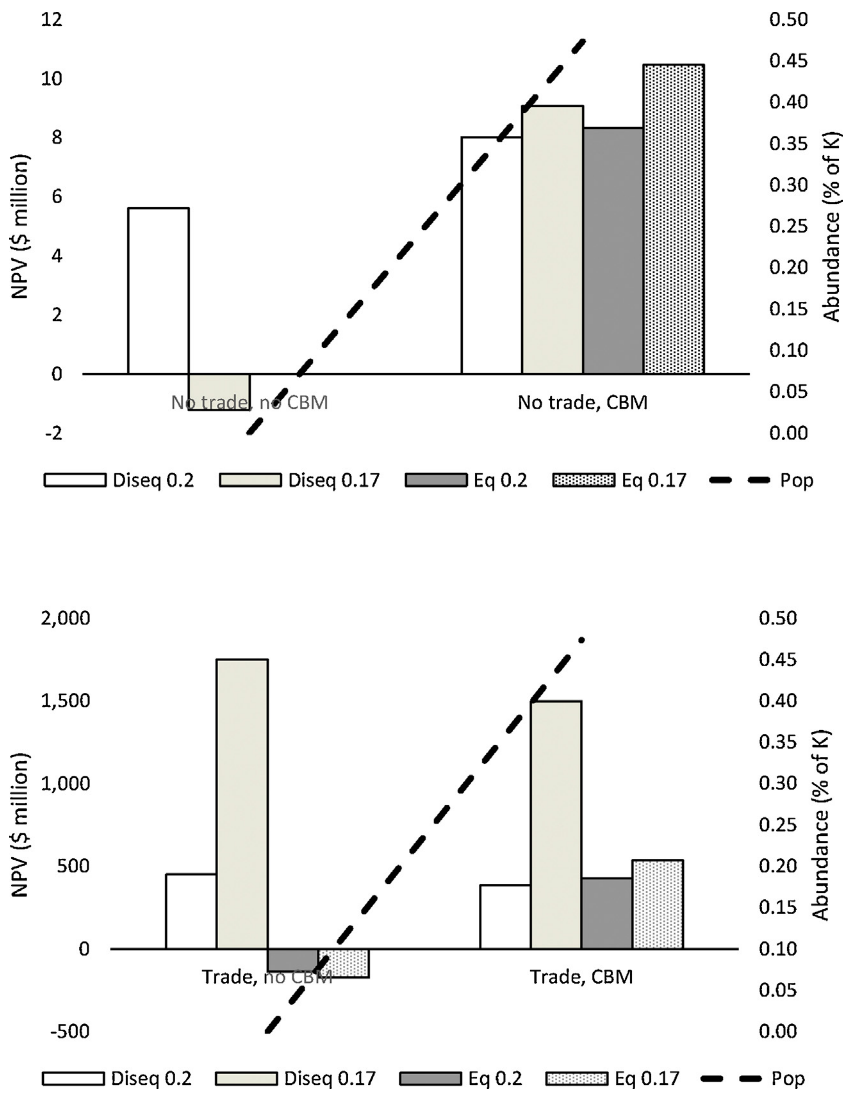

Fig. 4. Game farm profitability and rhino abundance under different policies.

5. Discussion

Conventional wisdom holds that demand reduction strategies would be effective in reducing supply, where demand is downward sloping. Our study shows that, even if the demand curve is negative and inelastic as hypothesised by Biggs et al. (2013), conventional demand reduction strategies that influence the price of rhino horn to the market may not be successful in curbing supply. Our model indicates that less conventional demand management strategies (such as consumer education, behaviour modification), appear to be more effective strategies in managing rhino horn demand than legalising the trade in rhino horns. In making this bold claim, we need to look broader than this study for evidence to substantiate this. First we consider the theoretical basis for this claim by considering what is hypothesised from Lim's growth theory, and secondly, we consider the supporting evidence for non-conventional demand reduction strategies.

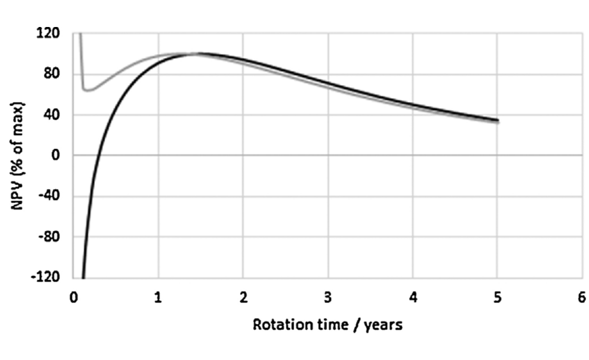

Fig. 5. Optimal de-horning rotation time for poachers and game farmers.

An extension of Lim's s-curve hypothesis is his theory of the drivers of growth (the so-called EGOIN theory). He identifies 5 drivers: entrepreneurship (E) government (G), ordinary labour (O), investment in physical capital (I) and natural resources (N). As far as natural resources are concerned, he states that:

> "here, we refer to utilized N. Unutilized N remains unutilized, and does not contribute to GDP growth level and growth rate. Natural resources normally refer to wasting assets like fossil oil, gold, tin, coal, iron-ore and diamond mines, and non-wasting or renewable natural resources like palm oil, rubber, sugar, wheat, rice, soya beans, corn, etc. However, we must also include location as a natural resource. Locational advantages like proximity to a river mouth or the cross-roads of shipping routes also confer

certain advantages to the economic centres concerned." (Lim, 2012; p.7).

Rhino horn products could potentially fall under wasting (non-renewable) or non-wasting (renewable) commodities, depending on how the horns are harvested. He argues that development results in better use of natural resources. Natural resources under turtle economies are not well utilised or lacking, under horse and elephant economies well utilised (see Sng, 2010). Although the focus of the theory is on more efficient use of natural resources, a feature of many developed economies in the West is a shift to more sustainable use of natural resources. This is the challenge for Asian economies that are focussed more on efficient resource extraction aimed at maximising growth, and focussed less on sustainable harvesting practices. Education at all levels of society is therefore very important in this regard.

Secondly, we consider the empirical evidence of non-conventional demand reduction strategies. The idea of consumer behaviour modification is not new. Already in 2012, Miliken and Shaw made the following appeal:

> "There is a compelling need to develop options for a campaign-type approach to demand reduction in Viet Nam. In this regard, well-researched strategies that target specific consumer groups with appropriate messages and influential delivery mechanisms need to be identified and implemented with the objective of influencing consumer behaviour away from rhino horn use. In particular, the evolving role of rhino horn as a non-essential lifestyle attribute needs to be directly challenged as an unacceptable form of social behaviour. Demand reduction should focus on dispelling obvious myths about the efficacy of rhino horn, promote acceptable alternatives if appropriate and create awareness of the consequences of illegal trade and usage and the conservation implications of continued rhino horn trade." (Milliken & Shaw, 2012, p.148).

Apparently in response to this appeal, a public education and awareness campaign jointly implemented under a partnership between Humane Society International and the Viet Nam Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Management Authority has been in operation in Vietnam since August 2013. There is some evidence for its success in reducing demand (HSI, 2014), although other studies have appealed for more monitoring data to confirm this (Roberton, 2014).

Our study reinforces the findings of Millner-Gulland (1993) that price is an insignificant driver for demand and that demand is income responsive, except that rhino horn is now more of a luxury good than observed in her study more than 20 years ago. The article develops a structural model that integrates many components mathematically, including both producers and consumers. The model is therefore able to test the effects of a rhino horn trade liberalisation would have on both rhino populations as well as the profitability to game farms. This is important since proponents of trade liberalisation argue that selling rhino horns would increase profitability in the sector. We find that a legal trade will increase profitability, but not the conservation of rhino populations. It is only through education in consumer nations that this trend could be reversed. Lifting the trade ban seeks to influence demand through the price mechanism, and is likely to be less effective than non-price policies. International pressure to change perceptions from status symbol to pariah could well be decisive in conserving rhino populations.

Our results suggest the importance of shifting from a conventional (sectoral) conservation model to a more non-conventional (sustainable) approach that models the interactions between the different components. While the results of the no trade scenario are similar for both the equilibrium and disequilibrium, under the trade scenario results were sometimes quite disparate. This highlights the importance of taking the type of model into consideration, as well as indicating the uncertainties associated with pursuing a trade liberalisation route. This study finds that sometimes second best solutions from an economic perspective may be optimal if conservation interests are to be achieved.

Many of the problems of the illicit trade in rhino horns are caused by weak institutions and financial constraints in developing countries. An appeal is therefore made to the developed community to continue supporting rhino conservation programmes, both in country, as well as in consumer nations. It is only through a collaborative effort that Africa's rhino populations can be conserved.

Acknowledgements

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Appendix 1.

Estimating the dynamics of game farm income and de-horning costs.

The value of rhinos comprises legal trophy hunting, live sales, game products and ecotourism.

A. Trophy hunting. In 2012, the value of rhino hunting dropped dramatically, from $11.7 million to $6 million (Table A1). This represents a decrease of almost 50% in value from 2011.

B. Live sales. Live auction sales of rhinos indicates a value of R9.17 million in turnover for 2012, or $1.07 million (Table A2).

C. Game products. Game products from rhinos could potentially include a range of products, such as meat, skins, and ornamental objects. Van der Merwe and Saayman (2003) estimate that the value of game products in total is R20 million (2000 values). Rhino sales represent roughly 1.27 percent of total game sales (2012), so game products from rhinos are approximately $58,556 after adjusting for Consumer Price Index (CPI) inflation from 2000 to 2012 (CPI 2012 = 97.8; CPI 2000 = 49.6).

D. Ecotourism. We estimate that 12,857 rhino were in Kruger National Park (KNP) in 2012, or approximately 61.3 percent of the

Table A1
Hunting data.

	Numbers killed		Price		Total value		
	White	Black	White ($/rhino)	Black ($/rhino)	White ($)	Black ($)	Total ($)
2011	137	1	85, 000	80,000	11, 645, 000	80,000	11,725,000
2012	67	1	85, 000	300,000	5, 695, 000	300,000	5,995,000

Source: DEA data.

Table A2
Average auction prices 2012.

Rhino	Average price (Rand)	Number	Turnover (Rand)	Value ($)
White				
Young bull	169,090.9	11	1,860,000	
Cow	317,500	8	2,540,000	
Heifer	247,000	5	1,235,000	
Family group	207,941.2	17	3,535,000	
Total			9,170,000	1, 072, 138

Source: S A Game & Hunt January 2013, converted to US dollars assuming a 2012 exchange rate of 1$ = 8.553 rand (www.irs.gov.za).

Table A3
Total value of rhino products.

	Value of rhinos (2012 US$)	$/Rhino	% Share
Hunting	5,995,000	286	72
Sales	1,072,138	51	13
Game products	58,556	3	1
Ecotourism	1,206,544	57	14
Total	8,332,239	397	100

Table A4
De-horning cost and income, 2011–2014.

	Revenue ($/rhino)	Costs ($/rhino)	Difference ($/rhino)
2011		926	
2012	397	864	−467
2013	358	779	−421
2014	337	735	−397
Average	364	826	−429

Source: Own calculations based on www.irs.gov (exchange rates) and www.statssa.gov.za (inflation rates).

total rhino population. Eco-tourism values are difficult to arrive at, and difficult to apportion to rhino populations. However, rhinos are one of the big five and big five tourism would attract a greater economic rent than non-big five tourism. The approach we use is to utilise the value of eco-tourism expenditure from Kruger National Park as a basis, given the large share of rhinos in this reserve. Turpie and Joubert (2001) estimate that total tourism expenditure at KNP was R136 million (2000 values). Converting to US dollars assuming an exchange rate in 2000 of R4.60796 dollar and inflating to 2012 values using an exchange gives a value of $58,195,229.63. We then need to work out rhinos share of this value. Using the share of rhino sales to total game sales (2012) as a proxy for rhinos share of value, gives $739,079 ($58,195,229.63 × 0.0127). Dividing by the total number of rhinos in KNP gives a value per rhino of $57,48. Multiplying by the total number of rhino in 2012 (20,989) gives the total value of ecotourism.

E. Total value of rhino products. Table A3 indicates that 72%, or roughly $6 million, of total rhino income comes from hunting. Relatively little comes from sales and ecotourism. The total value of income equates roughly to $39 7 per rhino.

F. The dynamics of income and de-horning costs. The cost of de-horning a rhino is R7000 (2011 values, Hall, 2012). This equates to a value of $926 per rhino at a R/$ exchange rate of 7.562. Using prevailing R/$ exchange rates, as well as adjusting for inflation, gives the values and cost and income dynamics over time (Table A4). The rand has devalued against the US dollar over the past few years, hence the declining values over time, as shown in the Table.

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