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Downstream Economic Implications of Predation in the South African Red Meat Industry

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Globally, predation is an important and ongoing problem facing the livestock sector. This study estimated the downstream economic impact of predation in the South African red meat industry using a recent South African Social Accounting Matrix (SAM) and a partial equilibrium model. Due to predation the total output decreased by R 3,806 million and R 648 million for large (cattle) and small livestock (sheep and goat), respectively. The result implies that the loss of livestock due to predation reduces the number of livestock available for marketing and the presence of predators influences the level and intensity of best management practices employed by the red meat industry. The findings of this study, which looked at the macroeconomic implications of predation in the South African red meat industry, as well as the biodiversity and ecology aspects of predation, could help government and policymakers develop appropriate policies and mitigation strategies to reduce prediction and prioritize strategies that will help lessen the impact of predation.

Keywords: Social Accounting Matrix, partial equilibrium model, output, livestock, management practice, macoeconomicimplications

INTRODUCTION

Livestock producers globally have been trying to protect their domesticated animals from damage-causing predators for hundreds of years (Stadler, 2006). Predation in South Africa influence various agricultural sectors from livestock production to wildlife ranching (Badenhorst et al., 2015; Du Plessis et al., 2015; Kerley et al., 2018b; Schepers et al., 2018; Van Niekerk et al., 2021). The losses due to predation in South Africa happens against the backdrop of the livestock industry which plays a vital role in the agricultural sector. In 2019/20, primary agriculture output contributed little over 2.3 percent to South Africa's Gross Domestic Product (GDP) [Department of Agriculture, Land Reform and Rural Development (DALRRD), 2021]. The total gross value of primary agricultural production for 2019/20 was estimated at R 323,953 million, while its contribution to the GDP was estimated at R 81,337 million in 2019. Animal products, horticultural products and field crops contributed 49.2, 30.3, and 20.5% of the total gross value of agricultural production, respectively. It must however be remembered that these contributions only include primary agricultural production. When the secondary and tertiary linkages are considered the contributions become greater. The agriculture sector in South Africa does not play a growth-leading or initiating role in the economy, but rather a growth-permissive role. The agricultural industry in South Africa is tightly linked to the rest of the economy and plays a vital role in job creation, particularly in rural areas (Khapayi and Celliers, 2016).

Both the black-backed jackal (Canis mesomelas) and the caracal (Caracal caracal) are essential medium-sized predators in South African wildlife ecosystem, but they have a negative influence on the livestock farming and wildlife ranching industries (De Waal, 2009; Badenhorst et al., 2015; Schepers et al., 2018; Van Niekerk et al., 2021). The black-backed jackal and caracal are presently the main problem causing predators in most areas due to human intervention that interfered with their natural habitat and removed their significant natural competitors (Du Plessis et al., 2015; Kerley et al., 2018a).

Ample research has been done globally on the impact of predation on domesticated animals. Previous research ranges from wolverines in Norway, brown bears in Spain and black-backed jackal and caracals in sub-Sahara Africa (Yom-Tov et al., 1995; Landa et al., 1999; Van Niekerk, 2021). These predators have the ability to cause significant damage in not only domesticated animal sectors but also in wildlife ranching sector (Schepers et al., 2018). All reviewed literature founded a direct negative financial implication of animal losses due to predation, whether it was domestic animals, livestock or wildlife (Moberly et al., 2003; Zimmermann et al., 2005; De Waal, 2009; Thorn et al., 2012; Wielgus and Peebles, 2014). The majority of previous research focused on the physical losses suffered by predation and the management aspects used to reduce the level of predation. In addition to the financial implications of predation losses, and mostly overlooked, is the secondary downstream economic implications or "spill-over effects" of damage-causing animals (also known as indirect and induced effects). The downstream economic implications as explained by Shwiff and Bodenchuk (2014), include the implications of predation on interrelated industries, suppliers to industries, macroeconomic variables and the general economy (Bodenchuk et al., 2000; Jones, 2004; Pacific Analytics Inc. and Risk Reduction Strategies, 2011).

To the knowledge of the authors, no studies have been done to estimate the downstream economic implications of predation in context of the direct, indirect, and induced effects of revenue, output, GDP, labor income, employment, capital, tax, and effectiveness using GDP per capita and labor per capita as indicators. Therefore, the aim of this study is to estimate the downstream economic impact of predation in the South African red meat industry using a recent Social Accounting Matrix (SAM) of South Africa as a database and a partial equilibrium model.

The novelty of this paper lies in the incorporation of direct, indirect, and induced effects of capital, tax, and effectiveness using GDP per capita and labor per capital for both large (cattle) and small (sheep and goat) livestock. Previous research, such as that conducted by Pacific Analytics Inc. and Risk Reduction Strategies (2011), did not take into account the capital and effectiveness effects on macroeconomic variables when calculating the implications of predation. Furthermore, this study adds to current knowledge by determining which livestock industry (large or small livestock) has the highest amount of predation on crucial macroeconomic indicators. Further, except for Van Niekerk et al. (2021) who included goats in the estimation of the direct cost of predation on small livestock sector, no other national or international studies had been conducted were the goat sector has been included. This study also makes the adjusted SAM dataset available which now incorporates the large and small livestock sectors. This dataset is crucial for future researchers interested in conducting economy wide research on livestock sub-sectors. The findings of this study may be useful in assisting the government and policymakers in developing appropriate policies and mitigation methods to reduce predation and prioritize strategies that will help lessen the impact of predation.

This papier consists of five sections. It started off with a broad introduction to the implications of predation losses in the red meat industry of South Africa, including the importance of solving the research question. Section two contains the materials and methods where a Social Accounting Matrix and a Partial Equlibrium Model are used to model predation losses in the red meat industry and to understand the additional downstream implications resulting from predation losses in terms of direct, indirect and induced implications. Due to predation losses incured by livestock producers a reduction in output can be sumulated in the macroeconomic models used to obtain the results illustrated in section three. The results are duscussed in section four to put the obtained results obtained in contexts and compared to simmilar studies globally. Finally, in section five, conclusions are drawn and some recommendations made in further solving the research question.

MATERIALS AND METHODS

Social Accounting Matrix as Database

This study used a 2015 Social Accounting Matrix (SAM) of South Africa as a database and a partial equilibrium model to estimate the downstream economic impact and implications of predation in the South Africa red meat industry. We use 2015 SAM because it is the most recent available SAM for South Africa and is more appropriate for this type of analysis. The SAM was developed by Van Seventer and Davies (2019), and modified to suit this study by transforming it into a Semi-Input-Output model. The Semi-Input-Output model is a partial general equilibrium econometric model with which the magnitude of various types of multipliers are measured by calculating the sectorial contribution to the economy of South Africa in terms of inverse, open inverse, direct, indirect, and induced multipliers, as well as other concerned variables for this study. For a detailed explanation of a SAM please refer to the work done by Round (1981), King (1988), Sen (1996), and Burfisher (2011).

The SAM of South Africa was aggregated into a standard form of nine activities and nine commodities for this study, as follows: agriculture, forestry, and fisheries; mining and quarrying; manufacturing; electricity and water; construction; wholesale and retail trade; transportation, storage, and communication; financial and business services; and community services. The interest of this study is livestock; hence the livestock sector further disaggregated as large and small livestock sub-sectors from the agricultural industry.

The SAM does not provide extensive accounting for the livestock industry. The livestock industry was accounted for as part of the agriculture sector. To quantify the downstream economic impact and implications of predation in the South Africa red meat industry, the large and small livestock was disaggregated from the agricultural sector account using different data sources. The share of gross output to the total agricultural output used Department of Agriculture, Forestry and Fisheries (DAFF) (2015) data. The percentage of large livestock gross output (gross value of output) in 2015 was 12% of total agricultural output. The share of small livestock gross output (gross value of output) in 2015 was 3 % of total agricultural output. The percentage of export/import cattle as well as small livestock products to total agricultural export/import and information on import tariffs was obtained from the International Trade Centre (ITC) (2019) and United Nations Commodity Trade Statistics (UNCOMTRADE) (2020). Information on household expenditure was sourced from income and expenditure data of Statistics South Africa STATSSA (2007).

As a result of disaggregating the agricultural industry's livestock sector, data inconsistencies occur, and the SAM was unbalanced. As a matter of principle, the SAM must be balanced to continue with the analysis. A cross-entropy method was applied to balance the SAM by using a code and GAMS software (Robinson et al., 2000; Fofana et al., 2008; Bahta et al., 2014; Lee and Su, 2014).

The cross-entropy (CE) method of balancing a SAM has become a typical procedure in most SAM-based models. The CE method, according to Robinson et al. (2000), is based on Shannon's (1948) information theory, which was applied to economics by Theil (1967). The key notion is that, as indicated in equation (1), the expected information value of extra data may be expressed as a Kullback and Leibler (1951). CE distance "I" between the prior "q" and posterior "p" probability distributions of a collection of "n" occurrences:

$$- \; I\left(p:q\right) = \sum_{i=0}^{n} P_i \;\; ln\frac{P_i}{q_i} \tag{1}$$

The goal of the CE problem is to determine the set of "P_i" that minimizes equation (1) utilizing previous data knowledge. The objective in SAM estimation or updating is to construct a new SAM coefficient matrix "A*" that minimizes the CE distance between itself and the prior (or initial and likely imbalanced) coefficient matrix "A." The minimization problem can be phrased as follows if "a^*_{ij}" and "a_{ij}" are the respective elements of "A*" and "A":

$$Min\left[\sum_i \sum_j a_{ij}\ln\frac{a^*{}_{ij}}{a_{ij}}\right] = \text{Subject to}: \; \sum_j a_{ij}y^*{}_j = y^*{}_i; \sum_j a_{ji} = 1 \text{ and } 0 \le a_{ji} \; \le 1 \tag{2}$$

After setting up the Langrangian multiplier, the problem in Equation (2) does not have a closed-form solution and must be solved numerically. The ideal solution "a^*_{ij}" may, however, be expressed as a function of both the Lagrange multipliers "I" associated with the row and column sums and the initial coefficient "a_{ij}":

$$a^*{}_{ij} = \frac{a_{ij}\exp(\lambda_i y^*{}_j)}{\sum_{i.j} a_j \exp\left(\lambda_i y^*{}_j\right)} \tag{3}$$

Robinson et al. (2000), compare equation (3) to Bayes's rule, which states that the posterior distribution equals the sum of the prior distribution and the likelihood function, divided by a normalization factor to convert relative probabilities to "absolute ones." As a result, equation (3) can be viewed as an effective information processing rule that adheres to Zellner's (1962) information conservation principle. It does not ignore any of the input data, and it also does not generate any misleading data. Robinson et al. (2000), also cite Golan et al. (1996), in support of their claim that the CE estimator is consistent and possesses maximum likelihood features for some distributional assumptions.

Incorporating aggregation limitations and measurement errors into the fundamental minimization problem in equation (2) enriches the problem. A typical aggregation constraint for k restrictions can be written as follows:

$$\sum_i \sum_j g_{ij}{}^{(k)} t_j = \; y^{(k)} \tag{4}$$

where "g_{ij}" denotes an n-by-n aggregator matrix with ones for aggregate cells and zeros otherwise. Assume there are "k" aggregation constraints in total. Similarly, measurement mistakes are taken into account in the following way:

$$y = x + e \tag{5}$$

where "y" is a vector of row sums and "x" is a vector of known column sums measured with error "e." The error is calculated using a weighted average of known constants "$v_{i,w}$" as follows:

$$e_i = \; \sum_w w_{i,w}.v_{i,w}$$

$$\sum_w w_{i,w} = 1 \; and \; 0 \le \; w_{i,w} \le 1 \tag{6}$$

The weights are modeled as probabilities that are computed in conjunction with the matrix components "A*." The estimation method employed in this work is based on five symmetrical weights around zero. Equations (4), (5), and (6) are used to solve the minimization issue (Equation 2).

Partial Equilibrium Model (Multiplier Analysis)

The multiplier concept will be used to define the type and extent of the influence (effect) of an autonomous change in one economic quantity on another economic number or quantities.

The multiplier idea is defined by Sameulson (1970), as the number by which the change in investment must be multiplied to produce the corresponding change in revenue. To make the multiplier notion more generic, independent and dependent variables such as job creation can be replaced for investment and income, respectively.

Multiplier models based on SAM are fixed-price general equilibrium models that are used to evaluate the economic impact of exogenous changes. According to Arndt et al. (2002), SAM analysis is based on three sets of assumptions. First, because prices are set, judgments regarding quantities are reached based on value shares. Second, in the SAM-columns, functional relationships are assumed to be linear. This means, for example, that Leontief production functions are used in the activity columns, and that imports and domestic production are not substituted in the commodity columns (Leontief production functions are characterized by constant returns to scale as well as the absence of substitution in factor and intermediate inputs). Third and final, multiplier models are price-driven and demand-driven.

Economic analysis is carried out using the input-output matrices that can be constructed from a SAM. The Leontief inverse matrix and the technical input coefficients are used to do this. The quantity of intermediate inputs that a given sector requires from another sector to produce each country's currency is characterized as a technical coefficient (in monetary units).

$$aij = \frac{X_{ij}}{X_j} \ (i = 1 \quad n) \ and \ (j = 1 \quad n) \tag{7}$$

Where "aij" is a production coefficient reflecting the quantity of product from sector "i" required to generate one unit of product from sector "j"; "X_{ij}" is the delivery of intermediate goods from sector "i" to sector "j"; and "X_j" is total gross input (output of the different sectors). We have the following for specific items in a transaction table:

$$a_{11} = \frac{X_{11}}{X_1}; \ a_{12} = \frac{X_{12}}{X_2}; \ X_{1n} = \frac{X_{1n}}{X_n} \tag{8}$$

A capital letter "A" is typically used to signify the technical coefficients matrix, which is a collection of technical coefficients:

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & . . . & a_{1n} \\ a_{21} & a_{22} & . . & a_{2n} \\ & & & \\ a_{n1} & a_{11} & & a_{nn} \end{bmatrix} \tag{9}$$

where (i = 1. . . n) and (j = 1 . . . n) are integers.

The amount of output required to meet a certain level of gross output can be expressed as:

$$O = A^{*}Xn \tag{10}$$

Where "X" is a vector of activity levels (in value terms) in an economy; "A" is a vector containing the intermediate demand for its output and the total final demand for its input at rates that are assumed to be independent of the levels of activity in "X" (constant returns to scale); and "O" is a vector containing the intermediate demand for its output and the total final demand for its input. Endogenous ("AX") and exogenous ("D") uses are satisfied by total activity "X." Assuming that "A" is parametric, any change in "D" must be accompanied by a change in "X":

$$X = AX + D \tag{11}$$

When you solve for "X," the relationship between "D" and the activity vector "X" is as follows:

$$A^{*}X + D = X; D = X - -A * X \tag{12}$$

Equation 12 is rearranged as

$$D = (I - A) * X \tag{13}$$

As a result,

$$X = (I - A) - -1 * D \ or \ Ma * D \tag{14}$$

The multiplier matrix or Leontief Inverse is represented by the expression "(I-A)-1" or "Ma."

The Leontief inverse and the technical coefficient matrix serve as the foundation for the multiplier concept theory. The Leontief inverse is used to construct the multiplier, and the technical coefficients matrix is part of the Leontief inverse. For this study, several types of economic multipliers (macroeconomic variables) were calculated:

- *Output/Production multipliers* – It measures the impact of a change in final demand for one sector on overall output, taking into account inter-sectoral purchases of input goods/services, income distribution, and spending behavior of local households as more (or less) income becomes available as a result of the initial injection. The entire turnover created by each sector of the economy is referred to as production. In a nutshell, "Activity (A)" production can be characterized as:

  Units generated by Activity (A) x Price per unit
  = Production by Activity (A) (15)

  As a result, production consists of the following elements:

  - Demand for intermediate inputs (materials) by Activity (A) (domestically produced and imported goods and services) and total value-added generated by Activity (A).

- *Gross Domestic Product/value-added Multiplier* – This is a measure of the value added to each product produced in the South African economy by the various economic sectors at each stage of the production process. The difference between the revenue earned by a particular industry and the amount it pays for the products of other industries that it employs as intermediary goods or manufacturing inputs is known as value-addition. It's worth noting that the notion of value-addition was created to avoid double-counting and to assign a portion of national GDP to each industry. As a result, value-addition is made up of three components:

  - Employee remuneration
  - Gross operating surplus
  - Indirect taxes net

- *Employment coefficients* – It calculates the number of full-time equivalents (FTEs) needed per unit of output for each sector.
- *Labor/Employment multipliers* – A measure of the overall number of jobs created in the economy as a result of a rise in employment in one sector, or an indication of the number of job opportunities that will be produced as a result of changes in the production of R1 million by a specific activity.
- *Capital formation multiplier* – It represents the size of change in capital required as a result of a change in a sector's production. A certain amount of capital investment is required for an economy to operate at a certain level of activity. Capital, along with labor and entrepreneurship, are the three essential variables required for economic output.
- *Effectiveness criteria* - The activity's macroeconomic impact is assessed using effectiveness criteria. These criteria assess how effectively the sector makes use of its resources. Because capital is a finite resource in South Africa, the criteria assess the efficiency with which capital is utilized in terms of labor and GDP generation in relation to the whole South African economy.
  - Two essential multipliers/ratios have been calculated to make these comparisons: the Gross Domestic Product/Capital ratio (GDP/Capital ratio) and the Labor/Capital ratio. These ratios can be used to calculate the contribution to economic growth and job creation in relation to the capital used in the process. Assume that long-term economic growth is valued more than short-term employment creation. The GDP/Capital ratio is the more important of the two macroeconomic metrics in this scenario. The Labor/Capital ratio, on the other hand, is more significant if job creation is a priority, especially in the short term.

Direct, Indirect, and Induced Economic Multipliers

In the red meat sector, predation losses have direct, indirect, and induced effects. Direct effects indicate influences in the livestock sector on all other sectors that offer inputs to the red meat sector, while indirect effects reflect impacts in the livestock sector on all other industries that supply inputs to the red meat industry. The direct multiplier measures the direct influence of a given sector, in this example the livestock sector. The direct multiplier, for example, will determine how an increase in livestock sector production affects employment in the same industry. These direct effects are the most intimately tied to the sector and, as a result, are most likely the most significant repercussions from a strategic and planning viewpoint.

Indirect multipliers reflect the effects that a red meat sector has on all other industries that provide inputs for the sector's operations. These 'backward links' are critical because they assess the direct sector's overall impact on the economy. These indirect effects are frequently large and may even outweigh the direct effects.

Induced effects relate to the economic impact of paying salaries and wages to people who work in the red meat industry, as well as the salaries and wages paid by firms in sectors that are indirectly tied to the livestock industry due to the supply of inputs. These higher incomes and wages raise demand for a variety of consumable commodities, which must be provided by a variety of economic activities across the economy.

The induced effect of predation can thus be describe as the lower demand for goods and services from the livestock industry, and the lower supply of products for processing that reduce the employment numbers in die wider economy and thus reduce the amount of salaries and wages which, in turn, should have created demand for goods and services. The induced effect of predation can thus be described as a decrease in the demand for goods and services from the livestock industry, as well as a decrease in the supply of products for processing, which reduces employment numbers in the wider economy and, as a result, lowers the amount of salaries and wages, which, in turn, should have increased demand for goods and services.

Simulating Predation Losses in the Red Meat Industry of for South Africa

Predation losses in the red meat sector are estimated using two scenarios: one with, and one without predation losses. Predation rates for large and small livestock at national level were estimated to be 0.31 and 8.16%, using a 2015 values respectively, based on the studies by Van Niekerk et al. (2021) and Badenhorst et al. (2015). Predation percentage is computed by dividing the total number of livestock lost due to predation by the entire national livestock herd utilizing several data sources, including the National [Department of Agriculture, Land Reform and Rural Development (DALRRD), 2021].

RESULTS

The result presents first, the economy of South Africa from 2015 SAM perspectives followed by predation losses by damage-causing animals incurred in the large and small livestock sectors froming the red meat industry with and without predation.

The Economy of South Africa From 2015 SAM Perspectives

Figure 1 depicts the sectoral contributions to value addition and output from a SAM perspective. Agriculture contributes about 2.34% to the GDP of the South African economy at factor cost (R 185,603 million). The livestock sector contributes about 0.33% (R 26,202 million) for cattle and 0.08 % (R 6,551 million) for sheep and goats to the GDP of the South African economy at factor cost. As indicated from **Figure 1**, the manufacturing sector (24%) is the highest contributor to GDP for the South African economy

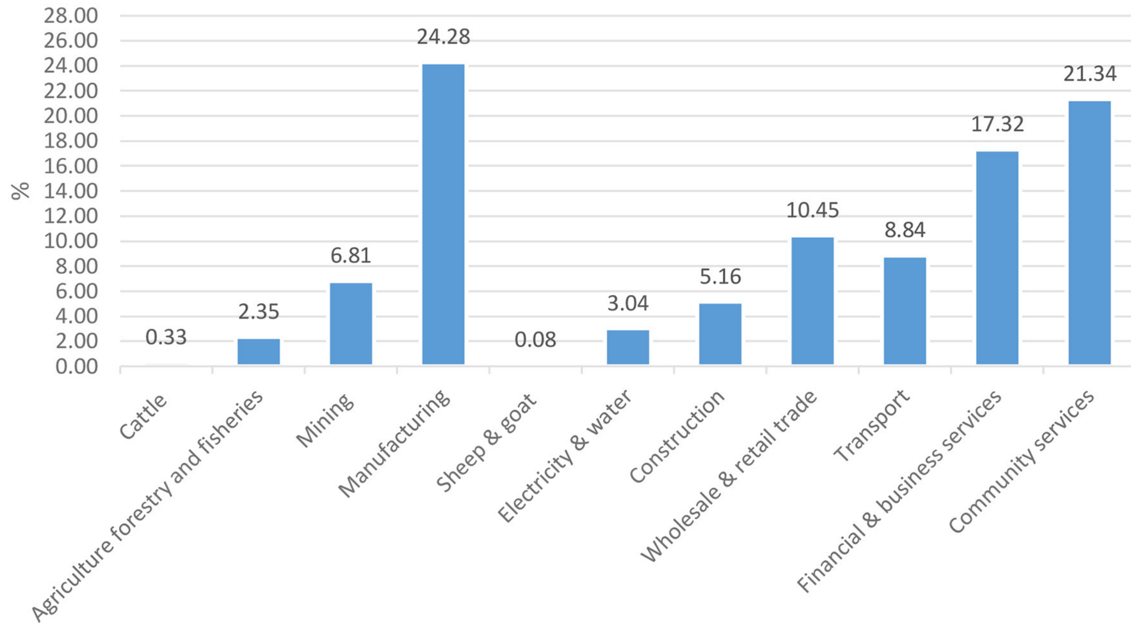

FIGURE 1 | Sectoral contributions to value-added (GDP) at factor cost for South Africa economy. Source: Authors' calculation from SAM.

TABLE 1 | Impact of predation on revenue and output in the large livestock sector.

	Total economic contributions from the large livestock sector, simulating no predation losses (scenario one)				Total economic contributions from the large livestock sector, simulating predation losses (scenario two)			
	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total
	R million				R million			
Revenue	26,255			26,255	26,173			26,173
Output	26,255	9,525	36,645	72,425	26,173	8,590	33,856	68,619

Sources: Author's calculation.

at factor cost, followed by community service (21%) and financial and business services (17%).

Predation Losses in the Red Meat Industry

The levels of predation losses, from which downstream economic implications are experienced, are 0.31 and 8.13% for the large and small stock sectors, respectively.

Impact of Predation Losses of Large Livestock in the Red Meat Industry

Impact of Predation on Revenue and Output in Large Livestock Sector

Table 1 shows the economic contributions of the cattle sector in two scenarios: with and without predation. Total revenue earned directly by the large livestock sector declined by R 82 million, from R 26,255 million to R 26,173 million, due to predation. The reduction in economic activity by the large livestock sector also has spin-off impacts on their supplying industries (the indirect impacts). When one considers direct, indirect, and induced aspects, the total output decreases from R 72,424 to R 68,619 million due to predation. The total reduction in output is 5.3% with the direct, indirect and induced effects contributing 0.31, 9.8, and 7.1%, respectively.

Impact of Predation on Macroeconomic Variables in the Large Livestock Sector

Changes in macroeconomic variables (economic multipliers) that are attributable to predation losses were measured in terms of GDP contributions, labor income, capital, and taxes paid to government. Due to predation, a comparatively large reduction of R8 million in GDP contributions made by the large stock industry are observed. The total contribution to GDP thus decreased by 0.37%, as a result of the direct (0.40%), indirect (0.33%), and induced (0.37%) effects. Furthermore, total

TABLE 2 | Direct, indirect, induced, and total effect with and without predation in the large livestock sector on selected macroeconomic variables.

	Total economic contributions from the large livestock sector, simulating no predation losses (scenario one)				Total economic contributions from the large livestock sector, simulating predation losses (scenario two)			
	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total
	R million				R million			
GDP	504	307	1,337	2,148	502	306	1,332	2,140
Labor income	61,056	2,704	2,169	65,929	60,866	2,695	2,163	65,724
Capital	551	1	1,134	1,686	549	0.99	1,129	1,679
Total Tax	52	19	73	144	51.83	18.93	72.96	143.72
Effectiveness criteria								
GDP/Capital	0.018				0.017			
Labor/capital	0.001				0.0009			
Employment coefficient*	4.401				4.338			

**FTEs per Million Rand change in final demand.*
Sources: Author's calculation.

TABLE 3 | Impact of predation on revenue and output in the small livestock sector.

	Total economic contributions from the small livestock sector, simulating no predation losses (scenario one)				Total economic contributions from the small livestock sector, simulating predation losses (scenario two)			
	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total
	R million				R million			
Revenue	6,564			6,564	6,028			6,028
Output	6,564	590	2,234	9,388	6,028	566	2,146	8,740

Sources: Author's calculation.

labor income in all labor categories reduced from R 65,929 million to R 65,724 million due to predation, with the direct effect contributing a reduction of 0.31%, the indirect effect a reduction of 0.33% and the induced effect a reduction of 0.28% (**Table 2**).

Capital contributions in the large stock sector decreased by an estimated R 7 million due to predation as less capital is needed in order for the economy to function at a specific level. This reduction can be divided between lower direct (0.36%), indirect (1%), and induced (0.44%) contributions. Tax is important for the economy of the country, and so is the contribution of the livestock sector's tax. However, the contribution of the livestock sector to tax reduced with 0.19% from R 144 million to R 143.72 million when predation occurs. This reduction can be categorized as direct (0.33%), indirect (0.37%) and induced (0.05%) effects (**Table 2**).

The effectiveness criteria were also measured by making use of two ratios; GDP/Capital and Labor/Capital. These ratios indicate how effective resources are used in the economy. GDP/Capital ratio decreased from 0.018 to 0.017, resulting from R28 million less GDP efficiency gains. The same principle was applied to the Labor/Capital ratio. A decrease of 0.0001 is observed since predation losses caused R^2 million less efficiency gains as shown in **Table 2**. Last, but not least, the employment coefficient was calculated for the large stock sector, and due to the reduction in total output a decrease of 361 jobs.

Impact of Predation Losses of Small Livestock in the Red Meat Industry

Impact of Predation on Revenue and Output in Small Livestock Sector

The South African small livestock sector is a comparatively smaller industry than the large livestock industry in terms of revenue generated and value-addition to products. Small livestock production in South Africa are mainly practiced in semi-arid areas where the available natural resource availability cannot sustain cattle production. In this section, we focus on the impact of predation on small livestock. The effect of predation in the small livestock production sectors is shown in **Table 3**, where the total contributions of the sheep and goat production sectors are illustrated in terms of a baseline scenario (without predation) and the scenario with predation.

Total revenue generated as a direct effect by the small stock sector reduced by R536 million from R6,564 million to R6,028 million due to predation. Output's direct effect reduction is the same as that of revenue, but it also exhibits indirect (0.41%) and induced effect (0.04%) reductions, as illustrated in **Table 3**.

TABLE 4 | Direct, indirect, induced, and total effect with and without predation in the small livestock sector on selected macroeconomic variables.

	Total economic contributions from the small livestock sector, simulating no predation losses (scenario one)				Total economic contributions from the small livestock sector, simulating predation losses (scenario two)			
	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total
	R million				R million			
GDP	30	19	50	99	27.50	16.69	48.90	93.09
Labor income	3,744	172	136	4,052	3,438	157.94	119.38	3,715.32
Capital	35.80	0.08	70.87	106.75	32.88	0.07	65.09	98.04
Total Tax	13.30	1.19	4.53	19.02	12.20	1.09	4.16	17.45
Effectiveness criteria								
GDP/Capital	0.001				0.00091			
Labor/capital	0.005	0.0046						
Employment coefficient*	4.777				4.387			

**FTEs per Million Rand change in final demand.*
Sources: Author's calculation.

Impact of Predation on Macroeconomic Variables in the Small Livestock Sector

The impacts of predation on the macroeconomic variables in the small livestock sector are illustrated in **Table 4**. Lower contributions made to value-added products caused the GDP to decreased by R 5.9 million (5.97%) in total with predation being present. This reduction in the GDP can be divided between reduction of 8.33% as a direct effect, 12.16% as an indirect effect, and 2.20% as an induced effect. Furthermore, total labor income in all labor categories reduced from R3,744 million to R3,438 million due to predation as a direct effect, while the indirect and induced effects were, respectively, 8.17 and 12.22% lower (**Table 4**). Due to predation in the small livestock sector, R8.7 million less capital is needed for the economy to function at a specific level, this reduction can be distributed between direct (8.16%), indirect (8.75%), and induced (8.16%) effects. The total tax contributions reduced from R19.02 million to R17.45 million, an 8.25% decrease with the direct, indirect and induce effects contributing 8.27, 8.40, and 8.17%, respectively, as illustrated in **Table 4**.

The effectiveness criteria were measured by GDP/Capital and Labor/Capital. The GDP/Capital ratio decreased from 0.001 to 0.00091 due to an R5.9 million reduction in GDP contributions. In terms of the Labor/Capital ratio, a decrease from 0.005 to 0.0046 is observed, resulting from an R306 million reduction in Labor. Lastly, the Employment coefficient was calculated, and due to a decrease in total output for the small livestock production sector, a decrease of 2,561 jobs can be simulated in the economy from an R 536 million reduction of the revenue earned from production (**Table 4**).

Total Impact of Predation Losses on the Red Meat Industry

The combined results of the impacts of predation on revenue, output and the macroeconomic variables in the large (cattle) and small (sheep and goats) livestock sectors are presented in this section.

TABLE 5 | Total decline in revenue and output due to predation in the red meat industry.

	Direct	Indirect	Induced	Total
	R million			
Revenue	618			618
Output	618	959	2,877	4,454

Sources: Author calculation.

Total Impact of Predation Losses on Revenue and Output in the Red Meat Industry

The total estimated impacts of predation on revenue and output for the red meat industry are illustrated in **Table 5** below. Predation in the red meat industry led to a direct decline of R618 million in revenue, and thus in output as well. The indirect and induced effects caused output to decline by R959 million and R 2,877 million, respectively, bringing the total reduction in output to R 4,454 million.

The above-described effects of predation on revenue and output may seem to represent substantial financial amounts, but they must be evaluated in terms of the total economic contributions to the red meat sector and economy. When the direct losses are compared with the factor cost contributions to the economy, as used in the SAM, they represent only 0.33% of the total value of the agricultural, forestry and fisheries sector. However, when the impacts of predation are considered in the livestock sector only, the direct losses reduce the factor cost contribution of this sector by 1.9%. The total losses in output (direct, indirect, and induced) attributable to predation account for a 2.4% reduction of the value of the agricultural, forestry and fisheries sector, and 17.0% of the livestock sub-sector.

TABLE 6 | Direct, indirect, induced, and total effect with and without predation in the livestock sector on selected macroeconomic variables.

	Direct	Indirect	Induced	Total
	R million			
GDP	4.50	3.31	6.10	13.91
Labor income	496.00	23.06	22.62	541.68
Capital	4.92	0.02	10.78	15.72
Total Tax	1.27	0.17	0.41	1.85

Sources: Author calculation.

TABLE 7 | Change in effectiveness criteria due to predation losses.

	Effectiveness criteria without predation losses	Effectiveness criteria with predation losses
Large livestock		
GDP/Capital	0.018	0.017
Labor/Capital	0.001	0.0009
Small livestock		
GDP/Capital	0.001	0.00091
Labor/Capital	0.005	0.0046

Sources: Author calculation.

Total Impact of Predation Losses on Macroeconomic Variables in the Red Meat Industry

The combined results of the impacts of predation on the macroeconomic variables in the large and small livestock sectors are presented in **Table 6**. Although the cattle industry contributes more in terms of output and contributions to the agricultural sector's GDP than the sheep and goat industry does, it has a lower level of predation. The loss of small and large livestock due to predation reduces the number of livestock for marketing, and the presence of predators influences the level and intensity of best management practices employed by the red meat industry. Total GDP contributions decreased by R13.91 million, labor income by R541.68 million, capital requirements by R15.72 million, and taxes to government by R15.50 million.

Impact of Predation on Effectiveness Criteria in the Red Meat Industry

The macroeconomic impact of predation is evaluated in terms of effectiveness criteria in which the sector utilizes resources. The effectiveness criteria are shown in **Table 7** for the large and small livestock sectors.

In the case of large livestock, the GDP/Capital ratio decreased from 0.018 to 0.017 due to predation. Since capital is used less effectively when predation is present, and since the total output also decreases in the presence of predation, this results in R28 million less in GDP efficiency gains. The same principle was applied to the Labor/Capital ratio, and a decrease of 0.0001 is observed in the effectiveness criteria. The lower effectiveness and reduction in output reduce the labor efficiency gains by R2 million in the presence of predation.

TABLE 8 | Change in employment utilized in the red meat industry due to predation losses.

	Employment coefficient without predation losses	Employment coefficient with predation losses
Large livestock		
Employment coefficient*	4.401	4.338
Small livestock		
Employment coefficient*	4.777	4.387

**Full-time equivalents per R1 million change in final demand.*
Source: Author calculation.

In the case of the small livestock sector, the GDP/Capital ratio decreased from 0.001 to 0.00091, resulting in a R5.9 million reduction in GDP contributions when the lower output due to predation is considered. The Labor/Capital ratio for the small livestock sector decreased from 0.005 to 0.0046 and results in a R306 million reduction in labor efficiency, since the output is lower.

An interesting observation is that the GDP/Capital ratio is higher than the Labor/Capital ratio is in the large livestock sector. This means that in terms of beef production, more value is added to the product through the value chain, while less labor is needed. The small livestock sector reveals the opposite, with the Labor/Capital ratio being higher than the GDP/Capital ratio is. This proves the common fact that sheep production is more labor intensive than cattle production is, while less value adding occurs through the value chain to deliver the final product (lamb and mutton) than in the case of beef.

Impact of Predation on Employment in the Red Meat Industry

The employment coefficient without predation is calculated at 4.401 for the large livestock sector. The coefficient indicates that 4.401 jobs will be created when output in the industry increases by R1 million. Predation in the large stock industry, however, reduces the coefficient by 0.014 to 4.338. The decrease in the employment coefficient, combined with the reduction in total output due to predation, result in 360.92 job opportunities being forfeited in the sector (**Table 8**).

Predation in the small stock industry reduces the labor coefficient by 0.39, from 4.777 to 4.387. In the absence of predation, 28,800 jobs, in total, are used to produce direct output worth R6,564 million. The decrease of R536 million in direct output from the small livestock sector due to predation, in combination with the lower labor coefficient, results in the loss of 2,561 jobs in the economy (**Table 8**).

DISCUSSION

Predation is an important and ongoing problem facing the livestock sector. There has been no attempt previously to estimate the total economic cost of predation in the livestock sectors of South Africa. This study is a first attempt at making these estimates. Therefore, this study assessed the downstream economic impact of predation in the South African red meat industry using a recent Social Accounting Matrix (SAM) of South Africa as a database and a partial equilibrium model.

The result indicates that the economic contributions of large and small livestock in two scenarios: with and without predation. Even though the large livestock industry contributes more in terms of output and contributions to the agricultural sector's GDP, it has a lower level of predation compared with the level of predation in the large and small livestock industries. The loss of large and small livestock due to predation reduces the number of livestock for marketing and the presence of predators influences the level and intensity of best management practices employed by the red meat industry.

Total output; the total contribution to GDP, the contribution of the large and small livestock sector to tax declined due to predation. Furthermore, a loss of jobs was observed due to predation in the large and small livestock sectors. The reduction in economic activity by the large and small livestock sector also has spin-off impacts on their supplying industries (the "indirect and induced impacts"). Our findings were consistent with those of Pacific Analytics Inc. and Risk Reduction Strategies (2011), who found that predation caused to a cattle industry resulted in a direct loss of $2.3 million in Gross Domestic Product (GDP) and in the loss of 35 jobs and $730 000 in income in the cattle ranching industry in British Columbia. Besides, the cost of "downstream" impacts (also known as "indirect" impacts or "spin-off" impacts) was estimated at $2.1 million in GDP, $580,000 in labor income, and 18 jobs. Similarly, the loss in wages translated into a reduction in consumer spending. After accounting for taxes, the loss was estimated at $670 000 in GDP, $390 000 in labor income, and another 7 jobs. Further, Jones (2004) indicated that due to the value of all sheep and lambs lost due to predation in the USA in 1999 a total of 951 jobs were lost.

Further, our findings for the small livestock sector also concurred with the results of Pacific Analytics Inc. and Risk Reduction Strategies (2011). They found that due to predation the loss in sheep farming revenues decreased with $365,000. When including the economic losses due to the reduction in supplier activity and the loss in personal consumption due to lower wages and salaries, GDP reduced by $345,000, labor income by $150,000 and jobs by 5. Further, our findings concurred with Kerley et al. (2018a), they found that the impact of predation on the economy is relatively small. When the total downstream impact of predation, including the indirect and induced effects, is considered, however, this paints quite a different picture, as a 2.4% reduction in the factor cost of agricultural, forestry and fisheries, and a 17% reduction in the factor cost of the livestock sector, can be seen as substantial impacts.

Capital contributions in the large and small livestock sector decreased and the effectiveness criteria were also measured by making use of two ratios; GDP/Capital and Labor/Capital. These ratios indicate how effective resources are used in the economy. GDP/Capital ratio and Labor/Capital ratio decline as a result of predation. However, contrasting or supporting the findings of capital and effectiveness criteria with similar international and national studies proved more difficult. The only international studies similar to our study was the one by Pacific Analytics Inc. and Risk Reduction Strategies (2011), but the authors did not incorporate capital and effectiveness. Further, to the knowledge of the authors, no studies have been done to estimate the downstream economic implications of predation in South Africa. As a result, the novelty of this paper lies in the incorporation of direct, indirect, induced effects of capital and effectiveness using GDP per capita and labor per capital for both large and small livestock. Furthermore, this study adds to current knowledge by determining which livestock industry (large or small livestock) has the highest amount of predation on crucial macroeconomic indicators; no national or international studies on the goat sector have been conducted.

Even if the large livestock industry contributes more in terms of output and contributions to the agricultural sector's GDP, it has a low level of predation compared with the level of predation in the small livestock industries. The study also reflected the indirect and induced effects of predation in the red meat industry for purposes of understanding the downstream economic implications of predation in the red meat industry. This is important because the industry, in its entirety, contributes fundamentally to the overall output of the agricultural sector and the economy of South Africa. If all the downstream effects are taken into account, predation reduces the total output generated by the red meat industry by over R4,400 million, including direct, indirect and induced effects of predation, although not taking into account reduction in GDP, labor income, capital and taxes paid to government.

When looking at the results from the sheep/goat production sector, the observation can be made that the largest magnitude of the impact of predation is experienced through the direct and indirect effects, and to a lesser extent, the induced effect, with the exception of labor income. The small livestock industry employs, percentage wise, more labor than the large livestock sector does in primary production or direct effects. A further observation is made when looking at results from the cattle production sector, when compared with the sheep/goats sector, which is that the induced effects of GDP and capital are higher for cattle than those for sheep/goats. On the other hand, labor income is higher in the case of sheep/goat production. This indicates that more value is added in cattle production, which uses more capital, while sheep/goats require more labor for producing output.

When the results of this study are put into context, the real magnitude of the implications of predation losses can be comprehended. The research reviewed indicated that, on average, it is possible for a livestock producer to lose 0.31 and 8.16% of large and small livestock, respectively, due to predation. The losses incurred by livestock producers can, in some instances, be seen as small enough to disregard. However, when these losses are combined with the existing losses (including those caused by drought and theft) experienced by livestock producers, these added losses become problematic and, to a large extent, could thus combine to threaten the financial sustainability of the livestock enterprise. When predation losses are articulated at an industry level and valued in terms of contributions made to the general economy of South Africa, the implications can be presented as being very small, when compared with the economy as a whole. However, when the impact of predation is considered only for the livestock sector, the direct losses reduce the factor cost contribution of this sector by 1.9%. The total losses (direct, indirect, and induced) attributable to predation account for a 2.4% reduction in the value of the agricultural, forestry, and fisheries sector, and for 17.0% in the livestock sub-sector.

The South African agricultural sector is largely labor intensive, especially the livestock sector. The primary agricultural sector has an estimated economically active population of 960 000 people. In total, the red meat industry employs over 140,000 laborers who are directly linked to the production of livestock. In total, it is estimated that, because of predation in the red meat industry, it is possible that there might be a reduction of over 2,900 jobs, lost due to predation, which accounts for almost 2% of the labor used in the red meat industry. The implications of predation in the red meat industry can be expressed in various ways, depending on the context and the particular point that one wants to make. When losses are compared with the GDP of South Africa, the losses associated with predation are insignificant. However, when considered for only the red meat industry or the agricultural sector, the losses suddenly become a problem that could threaten the sustainability of these sectors.

CONCLUSIONS

Predation damages in the red meat industry of South Africa can have significant economic implications not only in the red meat sector but also to contributions made by the red meat industry to the South African economy due to a multiplier effect. The multiplier effect is also known as "spin-off" impacts but is more technically referred as "indirect" and "induced" impacts. The results found that, due to predation in the livestock sector (large and small), revenue, output, employment, GDP, capital, tax, and efficiency reduce compared to the scenarios without predation. This implies that the loss of large and small livestock due to predation reduces the number of livestock for market and the presence of predators influences the level and intensity of best management practices employed by the red meat industry.

The black-backed jackal and the caracal are not restricted by borders or, to a certain extent, by physical fences. The coordinated approach should, therefore, be preferably taken on the national level. The extent and resource requirements for such a management strategy largely depend on, and should be justified by, the overall scale of the problem in hand. Findings of this study will add value to the policymakers to understanding the extent of predation losses experienced by the red meat industry. Predation is a problem affecting the primary producer in terms of losses of output that can be sold, influencing profitability; on industry level, it effects a reduction of output produced by the red meat industry resulting in spillover implications to the economy of South Africa.

Further, the study highlighted that the predation impact is very significant. The government should (continue to) address the predation concern comprehensively and bring in the livestock farming community in its endeavors more effectively. This study's findings could help government and policymakers to develop suitable policies and mitigation strategies to reduce prediction and get actively involved in meaningful policies and extenuation strategies to find an optimal solution that will consider all aspects of predation implications in order to reduce the predation losses experienced by the South African livestock producer to a generally acceptable level.

The study recommends that a more holistic approach is needed to comprehend the entire consequence of predation in the red meat industry and future predation research in the livestock industry should focus on the following aspects: First, the economic implications of predation on products that are associated with livestock production or by-products of production, including wool and mohair; Secondly, estimating the upstream economic implications of predation, and if a coordinated management plan is implemented, what the benefit would be in terms of more numbers of animals (additional livestock slaughtered) being produced and contributing to the output of the red meat industry; and finally, what the cost would be of different management strategy, and when implemented, what will the benefit be of the implemented strategy in terms of a cost-benefit analysis and more particular as to what will be an expectable level of cost vs. the benefit from such management programs.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

HN was involved in conceptualization. YB and FM were supervisors aided in the study design and contributed to data analysis and drafting the article. All authors made a significant contribution to the present manuscript preparation.

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REFERENCES

Arndt, C., Tarp Jensen, H. T., and Tarp, F. (2002). Structural characteristics of the economy of Mozambique: A SAM-based analysis. *Rev. Dev. Econ*. 4, 292–306. doi: 10.1111/1467-9361.00096

Badenhorst, C. G., Van Niekerk, H. N., Jordaan, H., and Strydom, D. B. (2015). *Factors Affecting Large Livestock Predation in the North West Province of South Africa. 20th International Farm Management Congress*. Qu9bec City, QC: Laval University.

Bahta, Y. T., Willemse, B. J., and Grove, B. (2014). The role of agriculture in welfare, income distribution and economic development of the Free

State Province of South Africa: A CGE approach. *Agrekon* 53, 46–74. doi: 10.1080/03031853.2014.887905

Bodenchuk, M. J., Mason, J. R., and Pitt, W. C. (2000). Economics of predation management in relation to agriculture, wildlife, and human health and safety. *Human Conflicts Wildlife: Econ. Considerations*. 2000:9.

Burfisher, M. (2011). *Introduction to Computable General Equilibrium Models*. Cambridge: Cambridge University Press.

De Waal, H. O. (2009). Recent advances in coordinated predator management in South Africa. *Merino SA Focus*. 2009, 44–46.

Department of Agriculture, Forestry and Fisheries (DAFF) (2015). *Abstract of Agricultural Statistics*. Department of Agriculture, Forestry and Fisheries, South Africa, Pretoria.

Department of Agriculture, Land Reform and Rural Development of South Africa (2021). *Economic Review of South African Agriculture*. Pretoria, South Africa,

Du Plessis, J. J., Avenant, N. L., and De Waal, H. O. (2015). Quality and quantity of the scientific information available on black-backed jackals and caracals: Contributing to human-predator conflict management? *Afr. J. Wildl. Res*. 45, 1–20. doi: 10.3957/056.045.0138

Fofana, I., Mabugu, R., and Chitiga, M. (2008). *Analyzing impact of alternative policy responses to high oil prices using an energy-focused macro-micro model for South Africa*. Financial and Fiscal Commission, Pretoria, South Africa.

Golan, A., Judge, G., and Miller, D. (1996). *Maximum Entropy Econometrics. Robust Estimation With Limited Data*. New York, NY: John Wiley and Sons.

International Trade Centre (ITC) (2019). *International Trade Centre*. Available online at: https://www.intracen.org/ (accessed April 18, 2019).

Jones, K. (2004). Economic impact of sheep predation in the United States. *Sheep Goat Res. J.* 19, 6–12. Available online at: https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1009&context=icwdmsheepgoat

Kerley, G. I. H., Behrens, K. G., Carruthers, J., Diemont, M., du Plessis, J., Minnie, L., et al. (2018a). "Summary for policymakers," in *Livestock Predation and Its Management in South Africa: A Scientific Assessment*, eds G. I. H. Kerley, S. L. Wilson, and D. Balfour (Centre for African Conservation Ecology, Nelson Mandela University, Port Elizabeth, South Africa).

Kerley, G. I. H., Wilson, S. L., and Balfour, D. (2018b). *Livestock Predation and its Management in South Africa: A Scientific Assessment*. Centre for African Conservation Ecology, Nelson Mandela University, Port Elizabeth.

Khapayi, M., and Celliers, P. R. (2016). Factors limiting and preventing emerging farmers to progress to commercial agricultural farming in the king william's town area of the eastern cape province, South Africa. *S. Afr. J. Agric. Ext*. 44, 25–41. doi: 10.17159/2413-3221/2016/v44n1a374

King, B. B. (1988). "What is SAM?" in *Social Accounting Matrix: A Basis for Plannin*g, eds G. Pyatt and J. I. Round (Washington, DC: The World Bank).

Kullback, S., and Leibler, R. A. (1951). On information and sufficiency. *Ann. Math. Stat.* 22, 79–86. doi: 10.1214/aoms/1177729694

Landa, A., Gudvangen, K., Swenson, J. E., and Røskaft, E. (1999). Factors associated with wolverine Gulo gulo predation on domestic sheep. *J. Appl. Ecol.* 36, 963–973. doi: 10.1046/j.1365-2664.1999.00451.x

Lee, M. C., and Su, L. E. (2014). Social accounting matrix balanced based on mathematical optimization method and general algebraic modeling system. *Brit. J. Econ. Manag. Trade.* 4, 1174–1190. doi: 10.9734/BJEMT/2014/8942

Moberly, R. L., White, P. C. L., Webbon, C. C., Baker, P. J., and Harris, S. (2003). Factors associated white fox (Vulpes vulpes) predation of lambs in Britain. *J. Environ. Manage*. 70, 129–143. doi: 10.1016/j.jenvman.2003.11.005

Pacific Analytics Inc. and Risk Reduction Strategies, (2011). *An Economic Assessment of Wildlife Predation in British Columbia (B.C)*. Report prepared for B.C. Agricultural Research and Development Corporation Wild Predator Loss Prevention Pilot Project. Victoria, British Columbia, Canada.

Robinson, S., Cattaneo, A., and Said, M. (2000). Updating and estimating a social accounting matrix using cross entropy methods. *Econ. Syst. Res.* 13, 47–64. doi: 10.1080/09535310120026247

Round, J. I. (1981). *Social Accounting Matrices and Development Planning: A Fixed Price Multiplier Model*. Development Economics Research Centre, University of Warwick, Discussion paper, No. 11.

Sameulson, P. A. (1970). *Economics, Eighth Edition*. Kogakusha: Mcgraw-Hill Inc.

Schepers, A., Matthews, N., and Van Niekerk, W. (2018). Exploring wildlife prediation in Limpopo province of South Africa: A Double-Hurdle Approach. *Afr.J.Ecol*. 56, 301–311. doi: 10.1111/aje.12452

Sen, H. (1996). *Social Accounting Matrix (SAM) and Its Implications for Macroeconomic Planning*. Bradford University, Development Project Planning Centre (DPPC), Bradford, UK.

Shannon, C. E. (1948). A mathematical theory of communication. *Bell Syst. Tech. J*. 27, 379–423. doi: 10.1002/j.1538-7305.1948.tb01338.x

Shwiff, S. A., and Bodenchuk, M. J. (2014). Direct, spillover, and intangible benefits of predation management. *Sheep Goat Res. J*. 16, 50–52. Available online at: https://digitalcommons.unl.edu/icwdmsheepgoat/16

Stadler, H. (2006). *Historical Perspective on the Development of Problem Animal Management in the Cape Province*. In Prevention is the cure. Proceedings of a workshop on holistic management of human-wildlife conflict in the agricultural sector of South Africa.

Statistics South Africa (STATSSA) (2007). *Income and Expenditure of Households 2005*. Pretoria: Statistics South Africa.

Theil, H. (1967). *Economics of Information Theory*. Amsterdam: North.

Thorn, H., Green, M., Dalerum, F., Bateman, P. W., and Scott, D. M. (2012). What drives human–carnivore conflict in the North West Province of South Africa? *Biol. Conser*. 150, 23–32. doi: 10.1016/j.biocon.2012.02.017

United Nations Commodity Trade Statistics (UNCOMTRADE), (2020). *United Nations Commodity Trade Statistics*. Available online at: http://comtrade.un.org/data (accessed June 16, 2020).

Van Niekerk, H. N. (2021). *An Estimation of the Downstream Economic Implications of Predation in the South African Red Meat Industry*. PhD thesis in progress, The University of the Free State, Bloemfontein, South Africa.

Van Niekerk, H. N., Bahta, Y. T., and de Waal, H. O. (2021). A review and estimation of the financial implications of livestock prediction in South Africa. *SAMAB (INDAGO)* 37, 1–11. Available online at: https://nationalmuseumpublications.co.za/wp-content/uploads/2021/05/Indago-36_Web.pdf

Van Seventer, D., and Davies, R. H. A. (2019). *Social Accounting Matrix for South Africa With an Occupationally Disaggregated Labour Market Representation* (No. 2019/56). WIDER Working Paper, 2019. doi: 10.35188/UNU-WIDER/2019/690-6

Wielgus, R. B., and Peebles, K. A. (2014). Effects of wolf mortality on livestock depredations. *PLoS ONE* 9, e113505. doi: 10.1371/journal.pone.0113505

Yom-Tov, Y., Ashkenazi, S., and Viner, O. (1995). Cattle predation by the golden jackal Canis aureus in the Golan Heights, Israel. *Biol. Conser*. 73, 19–22. doi: 10.1016/0006-3207(95)90051-9

Zellner, A. (1962). An efficient method for estimating seemingly unrelated regressions and tests or aggregate bias. *J. Am. Stat. Ass*. 57, 348–368. doi: 10.1080/01621459.1962.10480664

Zimmermann, A., Walpole, M. J., and Leader-Williams, N. (2005). Cattle ranchers' attitudes to conflicts with jaguar Panthera onca in the Pantanal of Brazil. *Cambridge University Press Oryx.* 39, 406–412. doi: 10.1017/S0030605305000992

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