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A dynamic, stochastic, Bayesian, provincial input–output model for the South African economy

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Background: The green economy has long been important in public discourses, as has been the forecasting of macroeconomic phenomena.

Aim: The purpose with this study was to construct a regional input–output model for the South African economy.

Setting: The model is a coupled input–output/system dynamics model. It is dynamic in the sense that sector growth follows the 'limits to growth' hypothesis. The model is used to explore the impact on the green economy, and also on poverty indices.

Method: It was constructed using Vensim®, a system dynamics modelling package. Bayesian methods were utilised to estimate realistic values for the multipliers. Type I multipliers for output, income, employment and gross value added (GVA) are estimated. The model was then 'tested' by forecasting various resource sectors' GVA (i.e. agriculture, mining, water, electricity).

Results: The model fits the historical data well, replicating provincial GVA as well as national GVA to an acceptable standard. The multipliers fell within appropriate ranges, and followed a priori expectations.

Conclusion: The model provides 'highly accurate' forecasts of various macroeconomic parameters, including the resources sectors. The impact of different multipliers in the three resources sectors on various poverty indices in South Africa was also assessed.

Contribution: The model has great potential for further use in the agricultural, energy and resource sectors, but also has wider application since it provides a means for generating an input– output table for any specific year based on the forecasting of input – output elements.

Keywords: Vensim; input– output; limits to growth; forecast accuracy; poverty indicators; resources; multipliers; System dynamics.

Introduction

The Green Economy has become an increasingly important topic in policy discourses (Barbier 2012; Loiseau et al. 2016). The United Nations Environment Programme (2011) defined the Green Economy as one that:

> … results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. In its simplest expression, a green economy can be thought of as one which is low carbon, resource efficient and socially inclusive. (p. 9)

In South Africa, the Green Economy accord was signed in 2011, with the intention to create at least 300 000 green jobs (Borel-Saladin & Turok 2013).

One of the main methods for facilitating a transition to a green industrial policy is input–output analysis (eds. Altenburg & Assmann 2017). But many of the existing tools for conducting an input–output analysis are not geared towards addressing the poverty alleviation aspect of the Green Economy definition. For example, the World Input–Output Database (WIOD) (Timmer et al. 2015), 2016-release, contains data on 28 European Union (EU) countries and 15 other major economies from 2000 to 2014. Although this is an extremely important and useful dataset, significant to the present study, there is to date no disaggregation for any African country in the dataset (Gouma et al. 2018).

The forecasting of macroeconomic phenomena has long been important in South Africa (Gupta & Kabundi 2010). Most previous analyses have focused either on a provincial disaggregation

(Majory & Stephen 2011; Van Seventer 1999), on using input–output methods (Boshoff & Seymore 2016; Kavese & Phiri 2020; Park & Chan 1989), on utilising Bayesian methods (Kim & Hewings 2019), or on combining input– output analysis and system dynamics modelling (Uehara, Cordier & Hamaide 2018). In this paper, all these elements are combined in order to forecast not only national gross value added (GVA), but also provincial GVA, and estimate the relevant provincial multipliers.

The use of input–output tables to investigate poverty alleviation is well documented in Asia (e.g. Fu et al. 2021; Hardiwan et al. 2019; Murthy, Panda & Parikh 1997). This linkage, however, has been less well studied in Africa. We are particularly interested in studying the effect of poverty reduction strategies on the resource sectors, given that these are useful for poverty reduction in Africa (e.g. Zimbabwe: Cavendish 2000; South Africa: Crookes 2003; Ghana: Crookes et al. 2007). This is especially important to ensure inclusive, and green growth and development (Bowen 2011).

Therefore, we consider as a case study the impact of multipliers in the resource sectors on poverty alleviation. In order to do this, we propose a multi-regional input– output model. At present, most multi-regional economic analyses using multipliers are only available in South Africa on a subscription basis. The aim of this study is to demonstrate a method for deriving provincial multipliers and forecasting macroeconomic variables such as GVA in a robust and scientific manner. The input–output model is then used to evaluate the impact of this forecasting methodology, focusing specifically on the various resource sectors (agriculture, mining, electricity and water).

In summary, the primary aim is to develop a regional input–output model for the South African economy using Bayesian methods, as well as system dynamics modelling tools. The model is, therefore, a hybrid model that draws from the mathematics, economics and simulation modelling fields. Sub-objectives include exploring and forecasting macroeconomic phenomena using the model, as well as investigating the impact on the green economy sectors and poverty indices. Finally, the model makes it possible to generate input–output tables for any year in question, by forecasting the input–output elements in Vensim. A regional input– output table for the year 2022 is included in the supplementary material (Online Appendix 1).

The next section presents the literature reviewed. Thereafter the methodology is described, and the results and conclusions are presented.

Literature review

South Africa has a long history of developing economy-wide models by also incorporating the environmental and energy sectors. These models fall into various categories, such as (1) input–output models; (2) social accounting matrix (SAM) models; (3) computable general equilibrium (CGE) models; and (4) system dynamics models (Table 1). Although this is not an exhaustive review of all the models that have been published (a task too laborious to undertake), a notable feature of these models is that most are national level models. Exceptions include Van Seventer (1999), the PROVIDE project (2006), and some individual provincial disaggregations. None of the models considered a provincial disaggregation by also incorporating dynamic feedbacks through a system dynamics model. And no economy-wide models of the South African economy, as far as we are aware, have incorporated Bayesian elements in the analysis.

Internationally, Moffatt and Hanley (2001) modelled an environmentally extended input–output model for Scotland that takes into consideration system dynamics. More recently, Cordier et al. (2017) developed one for the Seine Estuary in France. Other hybrid approaches include combining the dynamic simulation approach with input–output modelling in Mexico (Fuentes & Martínez Pellégrini 2021). A novel feature of the paper is that the authors also tested the validity of the model by comparing values estimated by the model with actual data. The simulated values compared well with the actual values over the validation period of the model (7 years). More recently Abdolabadi, Amaya and Little (2023) developed a coupled input–output system dynamics model, also using the modelling software Vensim. It included an exogenous hydrological model. In a number of studies system dynamics and Bayesian networks have also been coupled (Crookes 2017; Sušnik et al. 2013). No examples were found in the international literature that coupled system dynamics, input– output modelling and Bayesian methods in a multi-regional setting.

TABLE 1: Summary of selected economy-wide models that have considered environmental effects.

Institution	Type of model	Environmental sectors	Scale
DBSA†	CGE	One sector model	National
CSIR‡	CGE	Water sector	National
University of Pretoria§	CGE	Energy	National
IPRI¶	CGE	Multiple	National
Elsenburg††	SAM	Agriculture	Provincial (all nine provinces)
University of Venda‡‡	Input – Output	Agriculture	Provincial (Limpopo)
National Treasury§§	CGE	Energy	National
UNEP¶¶	System dynamics	Green economy (agriculture, natural resources, transport and energy)	National
University of Pretoria†††	CGE	Water	National
GreenCape‡‡‡	SAM	Energy, water	Provincial (Western Cape)

†, Gelb et al. (1994).
‡, Crookes and Van der Merwe (2000).
§, Van Heerden et al. (2006).
¶, Thurlow and Van Seventer (2002).
††, PROVIDE (2006).
‡‡, Majory and Stephen (2011).
§§, Alton et al. (2014).
¶¶, Musango, Brent and Bassi (2014).
†††, Hassan and Thiam (2015).
‡‡‡, Janse van Vuuren (2015).

Methods

This study is a coupled system dynamics, regional input–output model for the South African economy, using a Bayesian analysis in order to estimate realistic values for the multipliers (the SD R-IO model).

Input–output theory

Excellent treatment of input–output theory is given in Miller and Blair (2009), and more recently Mahajan et al. (2018). Under the production approach for measuring gross domestic product (GDP) (see UNSTATS 2018): 'GVA at basic prices is equal to output at basic prices less intermediate consumption at purchasers' prices' (p. 60). Gross domestic product at basic prices then equals 'GVA at basic prices plus taxes on products, less subsidies on products' (p. 60). This source goes on to note that 'GDP is also the balancing item of the production account for the whole economy' (p. 60) when the input–output table is considered.

Wassily Leontief (1905–1999) is often regarded as the pioneer of input–output analyses (e.g. Bjerkholt & Kurz 2006). In matrix terms, his approach may be described as follows: we define A (nxn) as the matrix of input coefficients as the production in sector nn divided by total output, I (nxn) as the identity matrix, y (nx1) as the vector of final demands and x (nx1) as the vector of total outputs. The equation can be written as follows:

$$x = (1 - A)^{-1} y \qquad \text{[Eqn 1]}$$

where (I-A) is the Leontief matrix (nxn) and $(I\text{-}A)^{-1}$ is the Leontief inverse. Once this equation is solved for a relevant input–output table, various multipliers may be derived (for example, output, income, employment and GVA). There are two types of multipliers (UNSTATS 2018): in Type I multipliers 'household final consumption expenditure and private household activities are exogenous' (p. 629), while Type II multipliers treat the household sector as endogenous. As a result, Type II multipliers are typically larger than Type I multipliers:

- An output multiplier for an industry nn is defined as 'the total value of production in all industries of the economy that is necessary for all stages of production in order to produce one unit of product nn for final use' (UNSTATS 2018:629). In the example above, 'the output multiplier corresponds to the column sum of the Leontief inverse' (op. cit.).
- A GVA multiplier measures the impact of changes in final demand on economic growth. Here, GVA at basic prices is used.
- An employment multiplier measures the effect of changes in final demand on physical employment (jobs). Sometimes these are expressed as number of jobs per monetary unit of output, but here we use total number of jobs created per sector.
- An income multiplier is similar to the employment multiplier, except that wage rates per unit of output are used instead of physical employment.

Although all multipliers use the Leontief inverse, these multipliers are calculated in different ways. Output and GVA multipliers find information contained in the input–output tables, whereas the employment and income multipliers may use other data from external sources.

Usually, an Excel approach is used to estimate input–output coefficients, Leontief inverse and multipliers (such as employment, value added and output). The above approach also usually only requires data for a specific year, as well as the construction of an input–output table. Most input– output analyses are not dynamic in nature and consider only impacts for one particular year.

In South Africa, Statistics South Africa (Stats SA) has constructed input– output tables for a number of years, but these have not been updated since 2014. Also, no official provincial input–output tables have been published in South Africa by Stats SA.

Regional input–output model

The SD R-IO model is a 22 sector input–output model (Table 2), based on a partial input–output model constructed by the now defunct Central Economic Advisory Services (CEAS). This dataset was also used by Van Seventer (1999). The base year of the input–output table is 1993 and we completed the table using data on value-added per sector from Stats SA. The model, therefore, has nine provinces with 22 sectors in each, totalling 198 sectors.

In the model, we estimate both Type I and Type II multipliers. Type I multipliers consider both direct and indirect effects, whereas Type II multipliers consider induced effects as well:

TABLE 2: Description of sectors in SD R-IO model.

Sector	Description
S1	Agriculture, forestry & fishing
S2	Coal mining
S3	Gold mining
S4	Other mining
S5	Food, beverage & tobacco
S6	Textiles, clothing, leather & footwear
S7	Wood & wood products
S8	Paper, paper products, printing & publishing
S9	Chemical products
S10	Non-metallic mineral products
S11	Basic metal industry
S12	Fabricated metal products
S13	Other fabricated products
S14	Electricity, gas & water
S15	Building construction & civil engineering
S16	Trade (wholesale, retail & motor)
S17	Catering & accommodation
S18	Transport services
S19	Storage & communication
S20	Financial services
S21	Community services
S22	Other services

- Direct effects: effects on the sector itself resulting from a change in final demand.
- Indirect effects: considers how an exogenous shock affects the household sector.
- Induced effects: considers the feedback effects of household income on commodity consumption.

Some studies (e.g. Hanson 2010; Rickman 2002) also report Type III and Type IV multipliers. Type III multipliers include intensive and extensive effects, while Type IV multipliers include intensive, extensive and redistributive effects. Intensive effects consider indigenous workers and marginal consumption coefficients. Extensive effects consider in-migrants and average consumption coefficients. Redistributive effects consider unemployed residents and their consumption propensities based on benefit payments. These latter effects are beyond the scope of the present study.

System dynamics model

System dynamics modelling is a useful tool for considering linkages and feedback in systems characterised by complexity (Sterman 2000). The steps in the modelling process are to develop a causal loop diagram; develop a stock flow diagram; populate the model with equations, parameters and data; validate the model; perform sensitivity analysis checks on the model; and then use the model.

A causal loop diagram shows the different elements in the model, the linkages between these elements, the direction of causality, and the polarity of the causality (either positive or negative). A positive polarity implies that an increase in the element results in a same-direction change in the element that is being targeted. For example, if interest increases, then savings increases; this is a positive causality. A negative causality is when a change in an element results in an opposite change in the targeted element. For example, an increase in depreciation results in a decrease in the value of the asset. A reinforcing loop (R) denotes the case in which there is an even number of positive elements in the loop, and emphasises an increasing or exponential dynamic action. A balancing loop (B) indicates the case in which there is an odd number of positive elements in the loop, and emphasises exponential decline or goal-seeking behaviour.

Causal loop diagrams are usually constructed in soft systems or qualitative analyses. Hard systems or quantitative analyses, such as the present case, require the construction of a stock flow diagram in addition to the causal loop diagram. The stock flow diagram also shows the elements in the system along with the interactions between the different components, but instead of polarities on the arrows, equations behind each element describe the relationships between the different components. The elements can therefore be a constant, an auxiliary variable, or a stock. Auxiliary variables are equations, whereas stocks are represented by boxes in the stock flow diagram and have rate variables flowing into them. A stock is represented as a bath tub filled with water, and the rate variable is the tap allowing a flow of water into the bath.

System dynamics modelling provides a means of adding dynamics to input–output models. Specifically, we wish to use the model to forecast national and provincial GVA. The input – output model was constructed in the system dynamics modelling package Vensim®, using subscripts to account for the different sectors and provinces. There are therefore 198 subscripts in the model to account for each sector and province, plus subscripts for the final demand, gross value added and final output. The supplementary material (Online Appendix 1) provides the stock flow diagrams of the system. Because subscripts were used, the elements in the stock flow diagrams were vastly simplified. For example, it was not necessary to represent the 198 sectors individually as separate elements in the model. Growth in the sectors is assumed to follow the 'limits to growth' hypothesis (Meadows, Meadows & Randers 1992), where initially growth is exponential but as resource constraints are reached, growth in the future is dampened. The economist Thomas Malthus (1766–1834) was first to hypothesise this (Mebratu 1998). The model was run from 1993 to 2023, a period of 30 years.

Bayesian multipliers

The system dynamics model generates the magnitude of the 198 multipliers, using the methodology of the Leontief inverse matrix, which is an established methodology in the input–output literature (Miller & Blair 2009). In order to calibrate the model to ensure that the multipliers all fall within designated ranges, a Bayesian methodology is employed. In a Bayesian analysis, the posterior function is equal to the likelihood function multiplied by the prior distribution. We assume as prior a uniform distribution in the expected range of the multiplier, while the likelihood function is the normal distribution with mean and standard deviation determined from a Monte Carlo simulation. The maximum likelihood of the posterior distribution then gives the (new) value of the multiplier. Figure 1 illustrates this.

Model validation and sensitivity analysis

The model was constructed from 1993 data and then a training dataset was constructed from data available between 1993 and 2012 by comparing model estimates of GVA with national and provincial GVA published by Stats SA. The data in this range were used to derive growth rates for the different sectors that best calibrated the model with the historical data. These parameters were then used to forecast the model forward to 2019 (first step), and then to 2021 (second step). In all cases, the forecast accuracy was assessed. A final forecast period was from 2022–2023, a period with no data currently available to assess the accuracy of the model.

A second stage of validation was then constructed for the multipliers. A Monte Carlo simulation is a form of sensitivity analysis, in which outliers are removed. The Bayesian analysis was used to 'force' the multipliers within the appropriate range. These two methods of validation and sensitivity analysis improved the usefulness of the model.

Forecast accuracy

We use the mean absolute percentage error (MAPE) statistic to assess the forecast accuracy of the model. The formula for the MAPE is as follows:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{A_i - F_i}{A_i}\right| \quad \text{[Eqn 2]}$$

Where:

MAPE = mean absolute percentage error

n = number of forecast periods

A_i = actual value

F_i = forecast value

The provincial GVA model was calibrated with data from 1993 and 2012, and then forecast from 2013 to 2019, a period of 7 years. The national GVA model was constructed based on data up to 2017, and then tested on data from 2018 to 2021, a period of 4 years. The model-generated data were compared with GVA data published in Stats SA's regional GVA spreadsheets available on their website.

Poverty indices

The multipliers from resource sectors (the agriculture, forestry and fishing, water and electricity sector, and other mining) are compared with two poverty indicators (the poverty headcount measure and the poverty incidence measure) in order to ascertain the impact of the resource sectors on poverty reduction.

The poverty headcount ratio is the share of total population whose income or consumption is below the poverty line; in other words, the proportion of the population that is unable to meet basic needs.

The poverty incidence measure is similar to the poverty headcount ratio, except that the data are estimated on a household basis rather than on an individual basis. The data were obtained from the Stats SA (2018) poverty report, where the poverty headcount measure is based on an upper bound poverty line (R992 per capita per month, which equates to approximately US$2.6 per capita, per day). The data are for 2015.

Pearson's product moment correlation coefficient was used to compare the resource sectors' Type II multipliers (output, GVA, income and employment) with these two poverty measures. The formula for the correlation coefficient is as follows:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad \text{[Eqn 3]}$$

Where:

r = correlation coefficient

x_i = values of the x-variable in the sample

$\bar{x}$ = mean of the values of the x-variable

y_i = values of the y-variable in a sample

$\bar{y}$ = mean of the values of the y-variable

Ninety-five percent confidence intervals are estimated using the statistical package R. The resource sectors modelled include agriculture, forestry and fishing (S1), other mining (S4) and water and electricity (S14). Other mining sectors (gold, coal) are not modelled as these only occur in some of the provinces.

Ethical considerations

The Stellenbosch University Social, Behavioural and Education Research Ethics Committee (REC: SBE) has given full approval for this study to be conducted (Project number 27354).

Results

Causal loop diagram

Figure 1 from Online Appendix 1 in the supplementary material, provides the causal loop diagram for the model. The main structure of the model is the limits-to-growth archetype (an archetype is a stylised systems representation

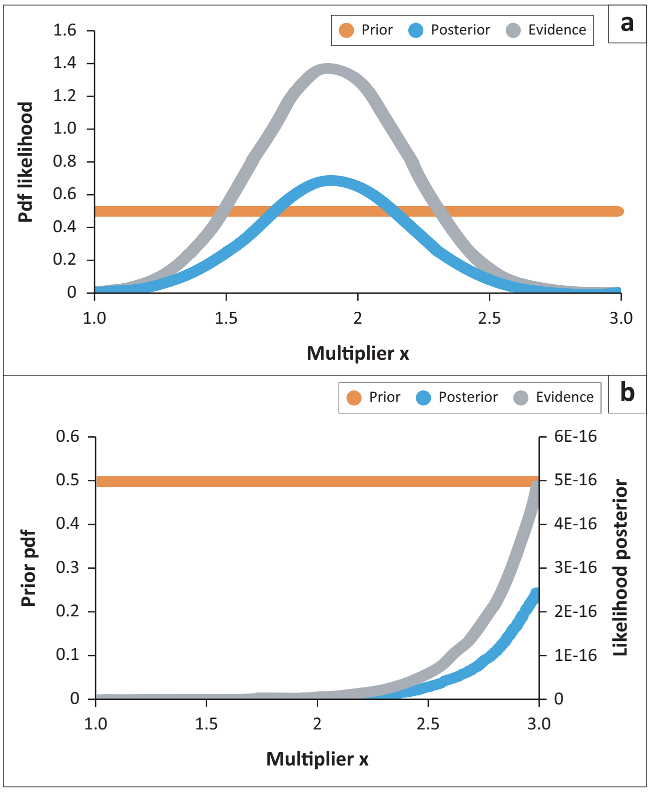


FIGURE 1: Prior, posterior and evidence for two different values of the multiplier (x). Figure 1a [top] shows that the maximum likelihood of the posterior distribution is the same as the likelihood function. Figure 1b [bottom] shows that the maximum likelihood of the posterior distribution is a corner solution. The value of x (the multiplier) outside those ranges is zero.

that is common in the systems literature; see for example, Senge 1990). The limits-to-growth archetype has as its features a growing action (represented by the economic growth loop, left-hand side diagram), and a balancing loop (economic decline loop, right-hand side diagram) which is driven by resource scarcity. This limits-to-growth model then links into the input–output model which estimates the Type I and Type II multipliers for income, GVA, employment and output. The model, therefore, combines dynamic and static elements. The model is then used to forecast provincial, sectoral and national GVA and sector multipliers.

Provincial gross value added

The provincial GVA data generated varying degrees of forecast success (Table 3). The model's most successful forecasts of the GVA data were for the Western Cape, Free State, Eastern Cape, KwaZulu-Natal and Gauteng. All other provincial forecasts were at least in the 'reasonable' category, suggesting that the model could be useful for forecasting provincial GVA for all provinces.

Provincial multipliers

The Bayesian provincial multipliers (output, income, employment and GVA) are given in the supplementary material (Online Appendix 1). We only report on Type I output multipliers in the main text, although the SD R-IO model allows for the estimation of Type II multipliers as well.

Figure 2 in Online Appendix 1 from the supplementary material, shows the count for Type I output multipliers greater than 2, per province. The provinces with the highest Type I output multipliers are KwaZulu-Natal, Gauteng, Free State and Western Cape. These are the provinces with the largest economies, so it is expected that the provincial multipliers would be higher there. Gauteng and KwaZulu-Natal have 15 of the 22 sectors with sector Type I output multipliers in excess of 2.

Sector multipliers

A count of the sectors (out of nine provinces) with Type I output multipliers in excess of 2 is given in Figure 3 in Online Appendix 1 from the supplementary material. Sectors with all nine provinces having multipliers in excess of 2, include S22 (other services), S15 (building construction and civil engineering), and S5 (food, beverage and tobacco). Sectors with eight (out of nine) provinces with Type I output multipliers in excess of 2 include S17 (catering and accommodation) and S6 (textiles, clothing, leather and footwear). Sectors with seven (out of nine) provinces with multipliers in excess of 2 include S1 (agriculture), S8 (paper, paper products, printing and publishing) and S9 (chemical products). At the other end of the spectrum, sectors with no Type I output multipliers in excess of 2 include S16 (trade [wholesale, retail and motor]), S19 (storage and communication) and S20 (financial services).

TABLE 3: Forecast accuracy of provincial gross value added.

Province	MAPE (%)	Forecast accuracy
Western Cape	5.7	Highly accurate
Northern Cape	25.0	Reasonable
Free State	7.0	Highly accurate
Eastern Cape	5.5	Highly accurate
KwaZulu-Natal	8.5	Highly accurate
Mpumalanga	30.2	Reasonable
Limpopo	26.0	Reasonable
Gauteng	4.6	Highly accurate
North-West	21.1	Reasonable

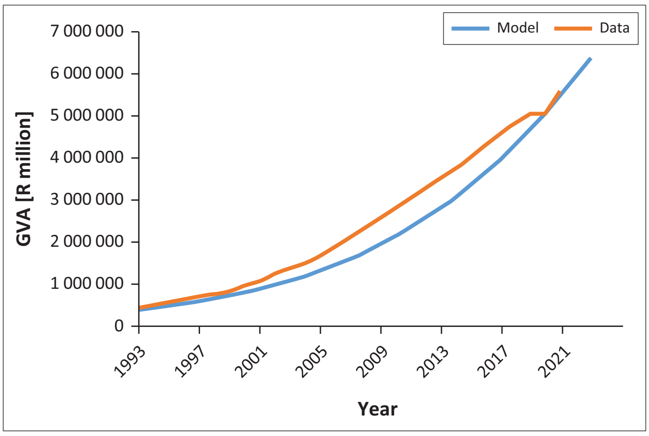
MAPE forecast accuracy: 0–10% – highly accurate; 10–20% – good; 20–50% – reasonable; 50–100% – poor.

The resource sectors (highlighted in black in Figure 3 in Online Appendix 1, feature in the middle ranges of the count data. The highest is S1 (agriculture, forestry and fisheries) with seven out of nine provinces having multipliers in excess of 2, followed by S14 (water and electricity). The mining sectors S2 (coal mining) and S3 (gold mining) have fairly low proportions of province multipliers in excess of two. This is partially because this type of mining is not done in all provinces.

Figure 4 in Online Appendix 1 from the supplementary material, provides the range of Type I output multiplier, based on the variability in that sector across provinces (ranked from low to high in terms of standard deviation of the output multiplier). A number of multipliers exhibit very low variability across provinces. These include S22 (other services) and S5 (food, beverages and tobacco). This is expected, since these sectors are likely to be inelastic in relation to price and income. The highest volatility included S2 (coal mining) and S13 (other fabricated products), S3 (gold mining) and S11 (basic metal industry). One reason for this volatility, as was indicated previously, is that these goods are not produced in all provinces. But the reality is that many sectors are highly variable across provinces, even sectors that are active in all nine provinces. Examples include S18 (transport services) and S21 (community services).

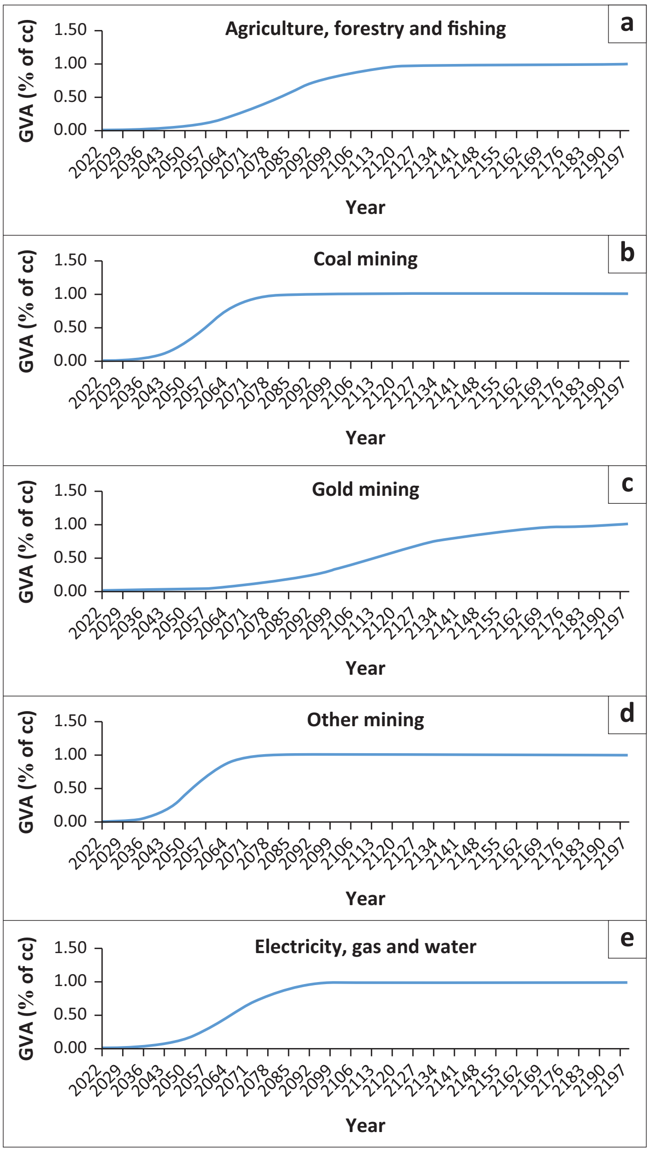
National gross value added

The model follows the historical time series of GVA at current prices well (Figure 2), supporting the hypothesis of limits to



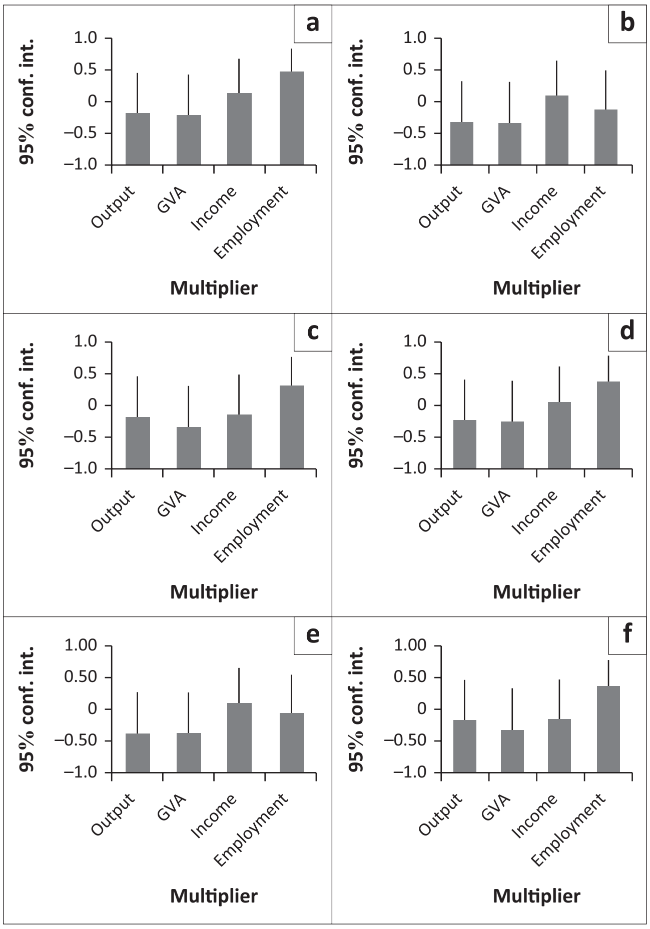
GVA, gross value added.

FIGURE 2: Change in national gross value added [at current prices], 1993–2021.



GVA, gross value added; CC, carrying capacity.

FIGURE 3: Changes in resources gross value added (2022–2200).



GVA, gross value added.

FIGURE 4: Ninety-five per cent confidence interval for Pearson's product-moment correlation coefficient. Correlation between poverty head count (a-c) and poverty incidence (d-f) and agriculture, forestry and fishing (a, d), water and electricity (b, e), and other mining (c, f) Type II multipliers.

growth. The MAPE for 2018–2021 was 5%, indicating a 'highly accurate' forecast accuracy. Although not shown in the historical data plot, resource constraints could be reached in the future and the economic performance is likely to reflect this in the future.

Resources sector forecasts

Our forecasts of the resource sectors indicate that the economy could experience limits to growth in the next 50–125 years (Figure 3). Specifically, agriculture, forestry and fisheries could experience constraints in carrying capacity during the next 100 years; coal mining in the next 50 years; gold mining in the next 125 years; other mining in the next 50 years; and electricity, gas and water in the next 70 years. This is due to environmental limits regarding carrying capacity being reached.

It should be noted that these estimates are quite different to forecasts for the resources sectors in the literature. For example, Stats SA (2017) estimated that the number of years to depletion from the current year (2023) was 247 years for coal, and 30 years for gold. This may highlight a flaw in the model (which may be rectified in future iterations of the model), but time will tell whether or not these forecasts are accurate.

The point, however, is that the model does take into consideration resource constraints, a feature of many green economy elements, highlighting the need to better manage these resources.

Links between poverty indices and multipliers

Two poverty indices (poverty head count and poverty incidence) are compared with four multipliers: output, GVA, income and employment multipliers (Figure 4). The 95% confidence intervals are quite broad due to the small sample size ($n = 9$). Therefore, we cannot conclusively reject the null hypothesis that the correlation is zero. Nonetheless, much of the data for the resource sectors (agriculture, forestry and fishing, water and electricity, and other mining) indicates that it is more likely that there is a negative correlation between the multiplier and the poverty measure (Figure 4). This means that the higher the multiplier, the lower the incidence of poverty. This observation is most noticeable in the output multipliers and the GVA multipliers. The employment and income correlations generally performed less well.

Discussion

It is worth bearing in mind that the multipliers are based on 1993 economic activity, so some of the dynamics of power may have shifted since then. South Africa had changed to a democratic government since then, which may have resulted in structural changes in the economy. Unfortunately, the reality is that more recent data at a provincial level are simply not available to conduct a more contemporaneous analysis. Most economists, therefore, have to rely on modelling efforts to forecast macroeconomic phenomena, particularly when it comes to provincial data. It is worth highlighting here that no model is perfect. Box and Draper (1987) state that all models are wrong, but some are useful. They go on to add that the question is only *how* wrong a model should be to not be useful. This does not provide an excuse for poor modelling work, but rather emphasises that models need not be perfect in order to be useful.

So, is this model an appropriate tool to forecast macroeconomic phenomena, especially if the base data is so dated? Provincial forecasts of GVA are accurate based on the MAPE statistic, adding confidence in the usefulness of the input–output dataset. Also, the literature indicates that these types of hybrid models are suitable in long-term forecasting (Crookes 2022; Crookes & Blignaut 2016; Rickman 2002). The model is such that an input– output table can be generated for any year in question (even a time period in future). This enables a comparative static type analysis to be conducted.

A key result from the analysis is that multipliers generated from input–output tables can be used to assist with poverty alleviation efforts in developing countries. Sectors with high multipliers provide the means to reduce the incidence of poverty and could be targeted for development work, since these have good 'payoffs' in terms of poverty alleviation. However, our analysis indicates that a number of these sectors could experience growth constraints in the next 50–125 years, and therefore sound management is required in order to maximise benefits from these sectors and ensure sustainability of resource use.

Provinces that are most likely to benefit from poverty-reduction strategies (those with the highest multipliers across numerous sectors) include KwaZulu-Natal, Gauteng, Western Cape and Eastern Cape. Other sectors (apart from resources) in which economic stimulus packages would benefit households with a low income include S5 (food, beverage & tobacco), S6 (textiles, clothing, leather & footwear), S15 (building construction and civil engineering), S17 (catering & accommodation), and S22 (other services).

Of the resources sectors, the mining sector showed a low proportion of provinces with a type I output multiplier in excess of 2, and high variability in output multipliers. Also, resource constraints in future could limit the possibility of this sector providing poverty alleviation over the medium to long term. At the other end of the spectrum, agriculture shows strong potential to provide poverty alleviation, based on the multiplier analysis.

The input–output table is an important tool for facilitating structural change towards a Green Economy. It can be used to model how regulations, market-based instruments such as environmental taxes, tradable permits, and subsidies, regulatory instruments and financial incentives can be used to promote human well-being and economic growth in an environmentally sustainable manner (eds. Altenburg & Assmann 2017). There is potential to extend the model in future revisions to incorporate energy, climate and environmental resource flows, as well as mitigation and adaptation scenarios (De Wit, Heun & Crookes 2018), and also further agricultural and water-use scenarios. For example, in Brazil, Martínez et al. (2013) use input–output models to forecast future developments in biofuel production. The model was a multi-regional model that took in consideration the impact on value-added imports and employment of different scenarios by taking into account both direct and indirect effects. A similar analysis could be undertaken with the present database.

The model demonstrates the potential to couple neoclassical type economic tools with systems dynamics modelling (e.g. Crookes & De Wit 2014). Hybrid systems methodology (HSM) is an emerging field in the operational research (OR) discipline (e.g. Brailsford et al. 2019; Powell & Mustafee 2014), and this model contributes to the literature. This is the first hybrid system dynamics model, as far as we are aware of, for the South African economy using input–output data. These models are still very scarce internationally as well, and it is not clear whether or not anyone else has constructed one incorporating Bayesian methods. In that sense the model is novel.

Conclusion

We constructed a stochastic, dynamic, regional, input – output model for the South African economy (the SD R-IO model). It comprises 22 sectors. Although the data, on which the model is constructed, are now almost 30 years old, the model provides 'highly accurate' forecasts of national GVA, even for as recent as 2018–2021. The provincial GVA forecasts are also all at least 'reasonable' and in many cases even 'highly accurate'. The provincial and sectoral multipliers all fall within the appropriate ranges in the literature, and follow expectations with regard to dominant economic sectors and provinces. The model may be useful for conducting economic analyses, and the results are likely to be applicable well into the future.

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Competing interests

The author has declared that no competing interests exist.

Author's contributions

D.C. is the sole author and therefore contributed to all aspects of the manuscript

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Data availability

The data are either to be found in the supplementary material (Online Appendix 1), or is available on request from the author.

Disclaimer

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