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Macrologistics instrumentation: Integrated national freight flow and logistics cost measurement

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Abstract

The objective of this research is to aid macrologistics decision-making through the development and interpretation of national freight flow and logistics cost measurements, i.e. macrologistics instrumentation. This provides the systemic view of the national freight logistics landscape that is required to address logistics challenges within the context of a country's socio-economic objectives. South Africa's macrologistics costs exceed that of trading partners, with road transport the dominant cost contributor. Investing in domestic intermodal solutions will reduce both transport and externality costs. This, in turn, will improve the competitiveness of domestic and international freight, and support economic and ecological development objectives. Rail branch line densification will improve market access for rural economies and reduce logistics costs while supporting social development objectives. These applications provide examples of data-driven policy development and infrastructure investments. The level of spatial and sectoral disaggregation in the freight-flow model, and the flow-level link with a logistics costs model, within the context of the national input-output model, is to the best of our knowledge unique. This link to economic aggregates bridges logistics' analytical gap to macroeconomic decision-making.

Keywords: Macrologistics instrumentation, emerging economies, disaggregated freight demand modelling, logistics costs

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1. Introduction

In the 2016 Logistics Performance Index (LPI) South Africa was ranked 20th out of 160 countries and classified as a logistics over-performer compared to its peers (World Bank, 2016a and 2016b). This logistics performance by South Africa is remarkable in an emerging economy context with a significant infrastructure backlog and long transport distances to major trading partners. However, while average gross domestic product (GDP) growth for South Africa equalled 2.1% between 2010 and 2016, only 1.3% growth was achieved in 2017, with 1.5% projected for 2018. These growth rates are in sharp contrast to those of the emerging Asian economies, with China's growth forecast at 6.6% for 2018, while growth rates in India are expected to remain around 7% (IMF, 2018).

Efficient freight logistics is one of the enablers of economic growth (Müller et al., 2012). South Africa is still one of only three countries where researchers consistently measure and publish national logistics costs, the other two being the USA and Finland (Rantasila and Ojala, 2015). Yet, logistics performance is not tracked as a regular macroeconomic indicator by the country's central bank or national statistics agency, in contrast to e.g. GDP and inflation. This situation is not unique to South Africa, or even the developing world. Huber (2017) refers to the "major need for effective and more accurate tools to support public sector decision making" within the freight transport sector, attributable to the absence of quantitative methods to enable logistics decision-making on a national scale (Tavasszy and de Jong, 2014). The latter is the essence of the emerging field of macrologistics (Delfmann et al., 2010; Gleissner and Femerling, 2013; Simatupang, 2013 and Schönberger et al., 2016).

Logistics is applied in the micro-economy to reduce the total cost of ownership of supply chains by enabling trade-offs between supply chain cost components (Ellram 1995, 2002). In essence, the total cost of ownership of economies does not differ from the total cost of ownership on a microeconomic level. The economy employs production factors such as natural resources, capital and labour (Lefevre, 2016) to produce the total output of an economy, i.e. the GDP. These production factors are the natural accounts of economies on the input side, but just as natural accounts in businesses are often deficient for decision-making when the systemic relationship between these items are not analysed (Stock and Lambert, 2001; Hälinen, 2015), the same holds true for macroeconomics. Informed by micrologistics successes, the vision for macrologistics is defined as the calculation of national freight logistics costs on a component level in order to enable trade-offs for lowering the total cost of ownership of goods on a macroeconomic scale, i.e. either enabling the same level of GDP with less inputs, thereby releasing capacity that can be used to increase future GDP or, alternatively, if the same inputs are used more productively, increase GDP directly. The instrumentation of macrologistics refers to the development of the models to enable this role. Although important contributions have been made through national logistics cost instruments (Rantasila and Ojala, 2015), as yet these do not reflect systemic interrelationships that enable trade-offs.

The objective of this research is to support the instrumentation of macrologistics through the development and interpretation of national freight flow and logistics cost measurements to aid macrologistics decision-making in an emerging economy, i.e. South Africa. To support this objective, the following research questions will be answered:

- RQ1. What are the building blocks required for the instrumentation of macrologistics?
- RQ2. Can the outputs of the instrumentation constructs be applied to inform macrologistics decision-making and, in turn, support the attainment of national socio-economic goals?

In the next section, the rationale for macrologistics measurement is discussed, followed by the methodology of South Africa's freight demand model (FDM) and logistics costs model as macrologistics instrumentation tools. In the results section, the model outputs are presented including the application of the model to facilitate macrologistics management, followed by the conclusion and identification of next steps.

At the outset, it is important to define the following concepts:

- Freight logistics is defined as "…that part of the supply chain process that deals with the transportation, warehousing, inventory holding, and administration and management of commodities between the origin (that is, where they are produced, mined or cultivated) and the destination (that is, the point of delivery to the consumer, either as input to further production processes or for consumption). By definition, this excludes the cost of passenger transport; transport, storage, packaging and handling of mail and luggage; and storage and transport tasks that occur during the production, mining or cultivation process." Botes et al. (2006: 4).

- Freight logistics costs are calculated as a bottom-up aggregation of logistics-related costs for commodity-level flows, comprising transport costs, storage and port-handling costs, management and administration costs, and inventory carrying costs (Havenga, 2010) (detailed in the methodology section).
- Transportable GDP is defined as that portion of GDP that produces a physical component requiring transportation from point of origin to point of production or consumption, specifically the agricultural, mining and manufacturing subsectors of GDP (i.e. the primary and secondary sectors of the economy).
- In South Africa, competitive or surface freight transport denotes freight transported by road and rail. (South Africa does not have inland waterways and coastal transport is negligible). For the purposes of this paper, transport costs therefore comprise of costs related to road line haul, road distribution and rail transport. The research is commodity-based, i.e. the aggregate volumes reflect total national freight flows, and therefore includes both ancillary road transport (the provision of road transport services by freight owners themselves), and road transport for reward (the outsourcing of transport by freight owners to road transport companies).

2. The rationale for macrologistics measurement

The importance of systemic logistics costs trade-offs is embedded on a micro- and meso-economic level (Nakano, 2009; Wang et al., 2016). However, limited empirical literature could be found that underscore a systemic quantitative approach to logistics as a macroeconomic production factor to enable integrated management with other macroeconomic production factors. The statistically significant relationship between logistics performance and the level of international trade (and as a result, economic growth) has been established (Hausmann et al. 2005, 2013; Portugal-Perez. and Wilson, 2012), frequently pointing to the quality of infrastructure and technology, port efficiencies and customs procedures as key enablers. The inputs for these analyses are typically existing survey-based economic and logistics performance indicators, including the World Banks' LPI data, World Development Indicators (WDI) and World Economic Forum (WEF) data. LPI data is survey-based and focus on international trade, while the WDI and WEF provide valuable insight into the health of a representative basket of indicators for national economies. In addition, the positive correlation between logistics infrastructure investment and economic growth receives research attention (Pradhan and Bagchi, 2013; Song and Van Geenhuizen, 2014).

The above-mentioned research is invaluable for benchmarking and policy development. The underlying data however does not allow in-depth analysis of the spatial and commodity characteristics of freight transport to facilitate targeted investments and efficiency initiatives. In a comprehensive summary of national freight-flow models, Ivanova (2014) maintained that empirical literature on freight demand modelling focuses on aggregate trade flows, hampering the development of policy-relevant conclusions related to particular industries. Three decades ago Raza and Aggarwal (1986) understood that aggregate freight-flow analysis cannot reflect the diversities of and the disparities in either the production or consumption processes, nor can they reflect the regional structure of an economy. Disaggregation on the level of industry and geography informs a deep understanding of the current and possible future states of a nation's freight transport system, and enables the design and implementation of freight policies and investments to deliver on a chosen future state within the context of the macro economy (Tavasszy, 2006; Tavasszy and De Jong, 2014).

Freight-flow modelling that is based on an understanding of this underlying economic activity is therefore a logical next step as freight transport is both an outcome and enabler of economic interactions (Tavasszy and De Jong, 2014; Khan and Machemelh, 2015; Stinson et al., 2017). There are two main approaches to develop spatially and sectorally disaggregated freight-flow data: a survey approach and a demand-side approach.

A survey approach involves estimating the characteristics of total freight through analyses of the responses to a commodity-flow questionnaire distributed to a representative sample of freight logistics stakeholders, combined with other data sources. A small number of countries (mainly the USA and Sweden) conduct commodity flow surveys (CFS) regularly as the basis for their freight demand models. A CFS was conducted in Sweden in 2001, 2004/05 and 2009 (De Jong et al., 2016). The United States CFS is conducted every 5 years, the latest data is for 2012 with the 2017 CFS being conducted in 2018 (United States Census Bureau, 2018). Comprehensive freight-flow surveys are extremely resource intensive and still require significant analysis post-survey to estimate the total freight market. In addition, survey-based research suffers from sampling biases and non- or partial responses (Kockelman et al., 2009), as well data continuity challenges due to time lapses between surveys and changes in scope (Bergquist et al., 2016).

A demand-side approach develops freight flows based on interactions between supply and demand as informed by the macroeconomic input-output (I-O) model, which describes interdependencies between industries in terms of intermediate inputs, driven by developments in final household demand. The country-level multi-sectoral I-O framework was developed by Leontief (1986) in the 1930s, based on the theory of Keynes who postulated that production is determined by consumption, i.e. market equilibrium, expanded to multiregional or spatial I-O models in the 1950s (Ivanova, 2014).The use of I-O tables (or subsets thereof) to model linkages between economic activity and freight transportation has been confirmed recently by Müller et al. (2015) (for Germany) and Alises and Vassallo (2016) (for Spain and the UK).

There is no CFS in South Africa that provides a spatial and sectoral view on freight transport flows. A number of surveys were attempted during the 20th century. The surveys were discontinued due to low response rates and limited macroeconomic applicability (Havenga and Pienaar, 2012). In an attempt to improve the continuity and application of its country-level FDM, a demand-side modelling approach was selected, driven by a multiregional and multi-sectoral I-O model of the economy due to its comprehensive nature and resulting application possibilities. The volumetric outputs from the I-O model are then used in the flow model to ensure both internal alignment between these models and alignment with national I-O aggregates. The model outline is discussed below.

3. Methodology

The basic modelling components of South Africa’s freight demand and logistics costs models are illustrated in Figure 1, while Figure 2 summarises key data sources and the process detail of South Africa’s freight demand model, the detail of which are described in subsequent sections.

3.1. Supply and demand per commodity on a geographical basis

South Africa’s FDM estimates supply and demand of commodities in pre-defined geographical areas as per Equations (1) and (2), the aggregate of which reflects total national supply and demand.

$$Total\ demand\ (outputs) = Intermediate\ domestic\ demand + Final\ domestic\ demand + Exports \tag{1}$$
$$Total\ supply\ (inputs) = Production + Imports \tag{2}$$

The main inputs for South Africa’s FDM are actual data. As part of the data gathering process to populate a disaggregated supply and demand table, research is conducted on a commodity-by-commodity basis to collect actual supply and demand data, where possible on a magisterial district level, otherwise on provincial level. Key sources of actual data are government departments, industry associations, general industry reports and news articles. This process facilitates a realistic reflection of the real economy (i.e. reducing the modelled I-O component), while the I-O table is rebalanced when actual data is added to maintain I-O interdependencies and overall supply and demand equilibrium. Horridge et al. (2005) introduced the use of published sectoral statistics to improve national input-output table data. This hybrid data collection approach is also evident in the freight models of Norway (Hovi et al., 2013), Germany (Müller et al., 2012), and Belgium (Mommens et al., 2017). The Freight Analysis Framework in the USA also integrates data from a variety of sources (their CFS, international trade data, and data from industry) to create a comprehensive picture of freight movement among states and major metropolitan areas by all modes of transportation (Fullenbaum and Grillo, 2016).

Challenges with the conversion of trade data in monetary terms to volumetric data (Müller et al., 2012) is largely circumvented through developing bottom-up volumetric supply and demand tables from the hybrid data. Similarly, the regionalisation of supply and demand is based on the development of disaggregated supply and demand tables commencing from the most granular spatial disaggregation at which national data is available, in the case of South Africa this is magisterial district level (these districts are a remnant of local Magistrate’s Courts, and are being aligned with municipal boundaries). Where data is not available on a magisterial district level, secondary keys such as population or household income are used for apportionment. The ultimate objective is therefore to populate the district level supply and demand tables, but the input into this population is dynamic and is expected to change from economy to economy, depending on data sources. In this regard, for South Africa’s tonnage data, 48% of the magisterial district-level data was actual data, 13% was provincially available and required further disaggregation to district level and 39% was disaggregated to district level using input-output modelling

The supply and demand data is developed for 83 commodities in 372 geographical areas, culminating in a 30-year forecast at 5-year intervals for three scenarios. The methodology has been applied annually since 2006 (Havenga, 2013). The interaction between the supply and demand data is translated into freight flows through gravity modelling, as described below.

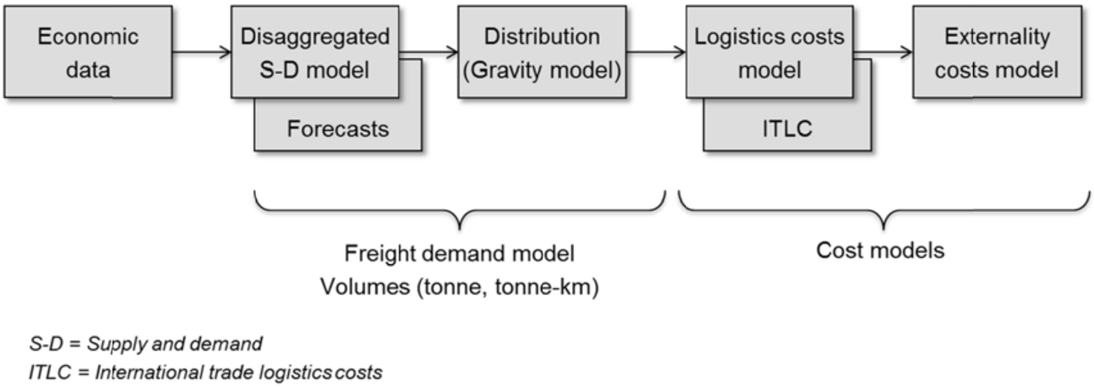

Figure 1: Basic modelling components of South Africa’s freight demand and logistics costs models (Havenga and Simpson, forthcoming)

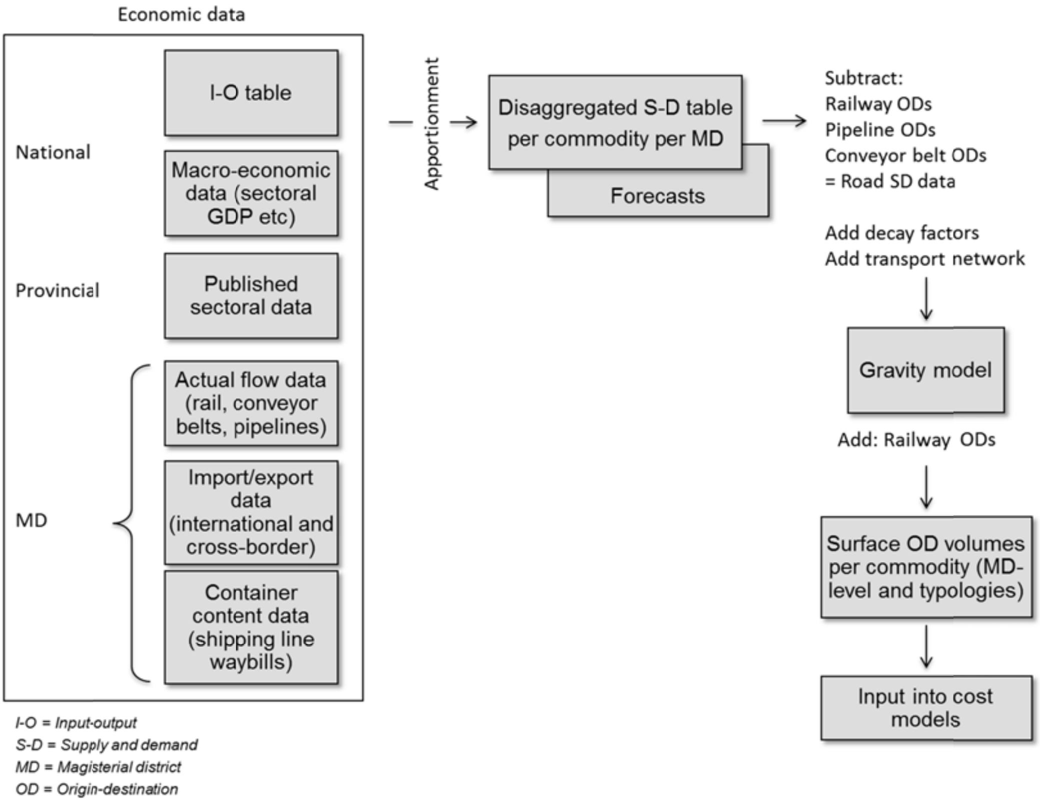

Figure 2: Key data sources and process detail of South Africa’s freight demand model (Havenga and Simpson, forthcoming)

3.2. Distribution: Freight-flow estimates via gravity modelling

As with the I-O data, the objective was to populate flows between districts with actual data as far as possible. These inputs can differ amongst economies, depending on the availability of data. For South Africa 48% of origin and destination tonne-km flows were available, i.e. all railway, pipeline and conveyer belt flows in the economy. The input data for the flow modelling is created by subtracting the origin and destination data of these known flows from the supply and demand data respectively. The balance of supply and demand data is modelled as road flows via a gravity model. Historical modal interaction therefore does not need to be modelled due to the availability of data on non-road modes. Correlation with the national I-O table ensures that traffic volumes are not over- or under-reported (Liu et al., 2006).

The most commonly-used approach to distribute freight between regions is the gravity model (Ivanova, 2014; Arbués and Baños, 2016). The gravity model assumes that bilateral trade flows are directly proportional to the volumes of supply and demand of the regions under consideration and inversely proportional to a measure of transport resistance. Distance is a common measure of transport resistance as it is an objective, readily-available variable. Road cost components, such as diesel consumption and truck wear-and-tear, also typically have a linear relationship with distance (Martinez-Zarzoso and Nowak-Lehmann, 2007; Giuliano et al., 2013). A distance-decay function describes the attraction value between origins (supply) and destinations (demand) (Smith, 1970). The decay parameter determines the slope of the decay function. Distance decay varies from one commodity to another based on its nature and utility. Low value, bulk commodities generating a transport demand disproportionate to their value tend to have a sharp rate of decay, while for higher-value commodities the impact of distance is smaller suggesting low decay parameters (UK Department for Transport, 2002). These commodity characteristics translate into two distance decay functions, namely (de Jong and Van der Vaart, 2010):

- An exponential function representing quickly declining distance decay, i.e. with very little or no long distance flows (mostly used for bulk commodities or homogenous goods); and
- A power function representing more gradually declining distance decay with high flows over short distances, but considerable longer distance flows (mostly used for manufactured and end-use agriculture commodities, i.e. heterogeneous agglomerations).

The above parameters are operationalised in a gravity model as per Equations (3), (4) and (5) (de Jong and Van der Vaart, 2010).

$$Tij = Ai.Bj.Oi.Djf(Cij,ß) \qquad (3)$$
$$Ai = 1/(\Sigma j.Bj.Dj.f(Cij,ß)) \qquad (4)$$
$$Bj = 1/(\Sigma i.Ai.Oi.f(Cij,ß)) \qquad (5)$$

Where:
Tij = the estimated volume of freight flows between origin i and destination j
Ai = the balancing factor for origin i that ensures compliance to Oi
Bj = the balancing factor for destination j that ensures compliance to Dj
Oi = the constraint value for origin i (i.e. total supply)
Dj = the constraint value for destination j (i.e. total demand)

f is the decay function

Where:
$f(Cij,ß) = exp(-ß.Cij)$ in case of an exponential function
$f(Cij,ß) = Cij^{-ß}$ in case of a power function

Where:
Cij = the distance between origin i and destination j (the resistance measure)
$ß$ = the decay parameter

The availability of supply and demand data enables the use of a doubly-constrained gravity model (de Jong and Van der Vaart, 2010) where total flows from a district equal the total supply from that district, while flows to a district equal the total demand at that district.

Equations (4) and (5) hold for a doubly-constrained gravity model if the constraint Equations (6) and (7) below are satisfied (through an iterative procedure):

$$\sum_j Tij = Oi \tag{6}$$
$$\sum_i Tij = Dj \tag{7}$$

At the outset of the South African gravity-modelling exercise, distance-decay parameters were informed by the decay parameter principles discussed above as well as known flows such as rail flows and large industry flows (e.g. barley inputs to beverage plants). The 'best-fitting' distance-decay parameters were selected; an approach in line with the UK Department for Transport (2002) and Wittwer (2017). In the FDM, a distance-decay parameter is developed for each commodity group individually to account for the varying nature and utility of the commodity.

The gravity modelling is done using software called FlowMap® which was developed at Utrecht University. The spatial planning software has been applied successfully in South Africa for various spatial planning purposes since 2000. FlowMap® expands typical GIS functionality to allow for the management and analysis of data that depicts spatial relations such as distances, flows, travel times and travel costs (Utrecht University, 2013).

3.3. Typologies

Once freight flows have been modelled, they are aggregated into typologies to facilitate analysis and recommendations. The primary typology refers to ring-fenced logistics systems that are by nature mode-monopolistic of which flows are known, i.e. export coal and iron ore; conveyor belt power station coal; and energy pipelines. The competitive surface freight transport market refers to corridor, metropolitan and rural freight flows. Corridor flows typically constitute higher value manufactured goods converging over long distances, with a multitude of endpoint ODs. Metropolitan flows are the diverse distribution flows in often congested cities, while rural flows have many medium and short distance flows, mostly serving the agricultural market.

3.4. Calculating logistics costs

The logistics costs model is a bottom-up aggregation of logistics-related costs for commodity-level flows received from the FDM, comprising transport, storage and port-handling costs, management and administration costs, and inventory carrying costs (Havenga, 2010).

Inland transport costs are calculated as a mode-dependent (rail, road, pipeline) cost per tonne-km. Using actual tariff data for rail and pipelines and a highly detailed road tariff model, the cost per tonne-km is unique for each commodity travelling on each origin–destination pair. The different cost elements of road transport are determined by vehicle type; vehicle types, in turn, are determined by the commodity type, typology and route of travel. The commodity's 'preferred' vehicle type will change with changes in each of these variables. Once the vehicle type and volume are known, the cost elements are assigned. The core drivers of transport costs, i.e. weight in tons and distance travelled, form the basis of the approach. Inventory carrying costs take into account the repo rate (the central bank's interest rate) and the average time each commodity is kept in storage. This cost per ton is unique for each commodity, but is independent of origin-destination pairs. Warehousing costs include all costs associated with keeping a commodity in storage, including rent, equipment costs, direct labour costs and insurance. It is calculated per ton taking into account the average time in storage and the cost per ton for storage for a specific commodity. The storage cost depends on the packaging type and density of the product. This cost per ton is unique for each commodity, but is independent of origin–destination pairs. Management and administration costs is a cost per ton, which takes into account the cost of indirect labour, administration and other indirect costs.

An externality cost extension to the logistics costs model was developed to quantify all non-charged costs, which include emissions, accidents, congestion, policing, noise pollution and land-use (refer Havenga (2015) for the detailed methodology). However, the ultimate goal is to understand the drivers behind these cost elements and the relationship between them on a flow level. This will be showcased through describing the overarching outputs of the model and identifying macrologistics improvement opportunities for South Africa.

3.5. Integration of the body of knowledge

The final step is to integrate all results from a component to integrated model view in order to facilitate macrologistics decision-making to enable infrastructure, policy and spatial organisation decision-making (refer Figure 3). The current modelling endeavours are still focused on optimising logistics as a production factor given the relative infancy of the macrologistics discipline. The vision is to be able to understand the macrologistics trade-offs of specific interventions in the macroeconomic realm and vice versa.

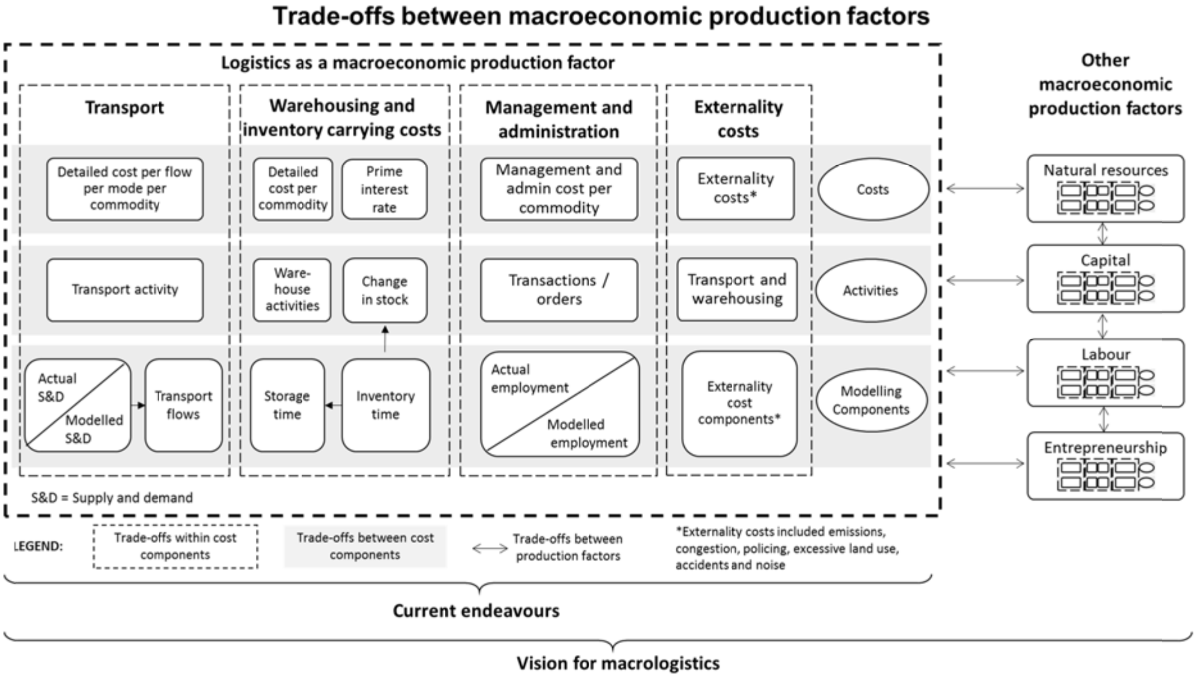

Figure 3: Cost trade-offs within logistics and between logistics and other macroeconomic production factors

4. Results

4.1. Logistics costs

South Africa's freight logistics costs totalled R429 billion in 2014, or 11.2% of GDP, compared to North America's 8.6% and Europe's 9.2% in 2014 (Armstrong and Associates Inc., 2016). Logistics costs however amount to 51.5% of transportable GDP (i.e. those sectors that create a demand for freight transport, namely agriculture, mining and manufacturing) (refer Figure 4).

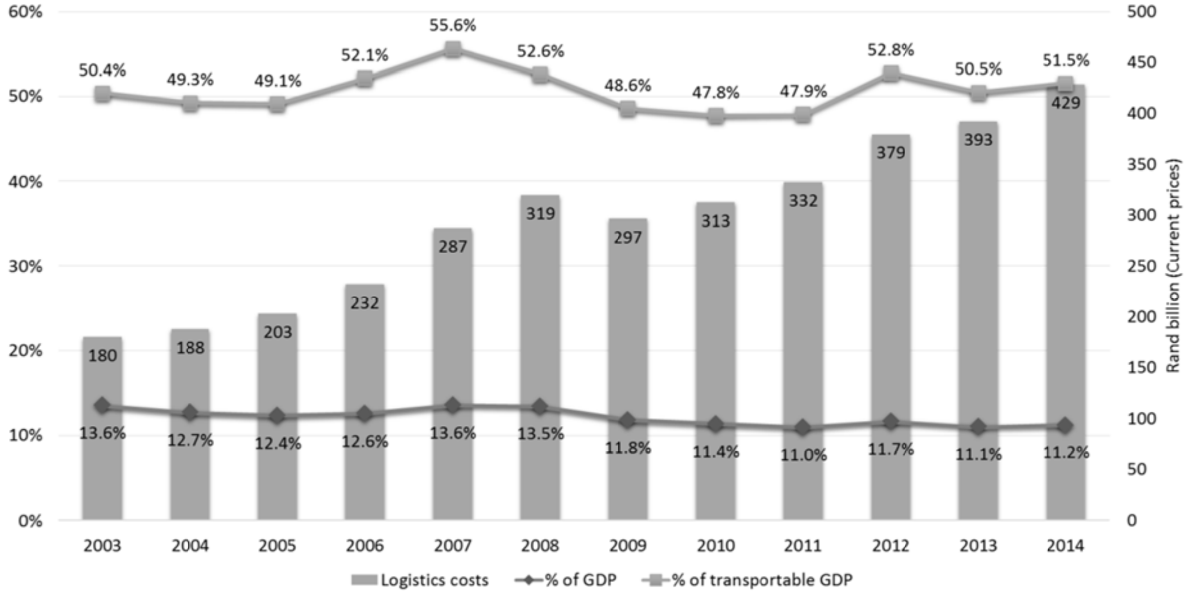

Figure 4: Trends in South Africa’s logistics costs (Havenga et al., 2016)

Transport costs are the dominant contributor to logistics costs (Figure 5), amounting to 57% of the total in 2014 (compared to the estimated global average of 39% [Rodrigue et al., 2009], most recent estimate available), followed by inventory carrying costs (15.2%), warehousing (14.6%) and management and administration costs (13%).

The availability of the aggregate cost data and its underlying drivers, enable an understanding of how microeconomic trade-offs impact national logistics costs. The contribution of transport costs to total logistics costs is expected to decline to 55% in 2016 mainly due to lower fuel prices (fuel costs made up 40% of road transport costs in 2014). This is the lowest contribution level it has reached since 2010. Transport costs showed a moderate increase of 3.7% between 2013 and 2014, driven by efficiency gains from logistics service providers. The trade-off was that inventory carrying costs increased by 22% between 2013 and 2014. The increase in the prime interest rate from 9.0% at the start of 2014 to 9.25% at year-end, compared to 8.5% in 2013, contributed to the higher inventory carrying costs, but external factors such as economic uncertainty and a volatile currency have led to increased inventory levels and are forecasted to have the same effect in 2016. On the back of these higher inventory levels, warehousing costs (which include storage and handling costs) increased by 12.1% between 2013 and 2014, following on nominal growth the previous two years, and is estimated to have grown above inflation in 2015.

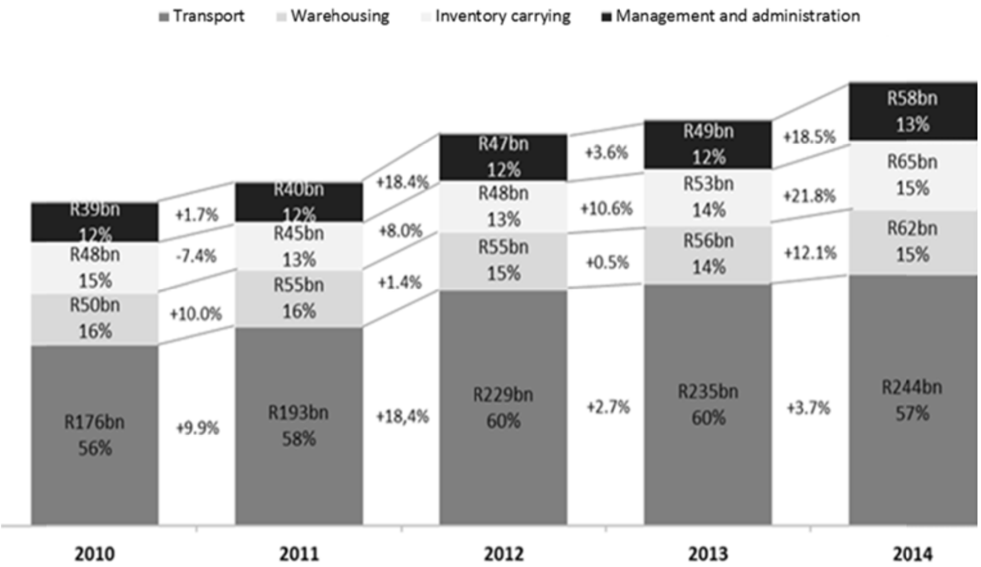

Figure 5: Trends in South Africa’s logistics costs stack elements (Havenga et al., 2016)

Road transport costs comprised the bulk of surface freight transport costs, with a contribution of 83% in 2014, while rail contributed 15% and pipelines 2% (refer Figure 6).

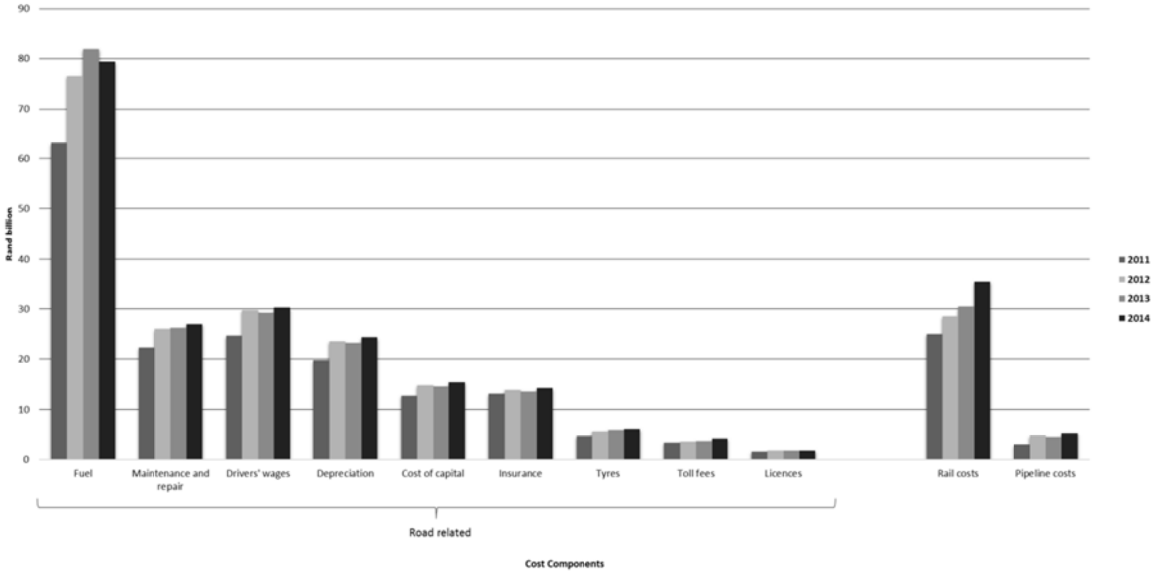

Figure 6: Cost contribution per freight transport mode in South Africa (data from South Africa’s logistics costs model – refer methodology)

4.2. Freight transport volumes

South Africa's surface freight transport volumes amounted to 848 million tonnes in 2014, an increase of 8.4% from 2013. The primary economy (i.e. the agricultural and mining sectors) contributed 76% of surface freight volumes while only contributing 44% to the transportable GDP (i.e. in value terms). In contrast, the secondary economy (i.e. the manufacturing sector) contributed the remaining 24% of volume, while amounting to 56% of transportable GDP.

Maps of the freight movements for agriculture, mining and manufacturing are shown in Figure 7. Agricultural freight volumes are low compared to the other sectors (in line with its GDP contribution); mining dominates, consisting mostly of the dedicated export lines of coal (through Richards Bay) and iron ore (through Saldanha). Manufactured commodities are highly densified along the country's two key general freight corridors, namely Gauteng-Cape Town and Gauteng-Durban. The flow densities South Africa therefore needs a dual focus in freight flow optimisation: (1) in terms of volume to continue leveraging the country's natural endowment of and infrastructure investments in bulk mining exports and (2) in terms of value in order to enable local beneficiation opportunities and to support export competitiveness to stimulate inclusive economic growth and employment. In addition, this geographical representation highlights the marginal participation of rural areas in the national economy (as indicated by the low density of non-corridor freight flows). The 848 million surface freight transport volumes mentioned above resulted in a demand of 379 billion tonne-km, an increase of 4.9% from 2013 (refer Figure 8). Tonne-km increased by 31%, and tonnes by 17%, between 2010 and 2014.

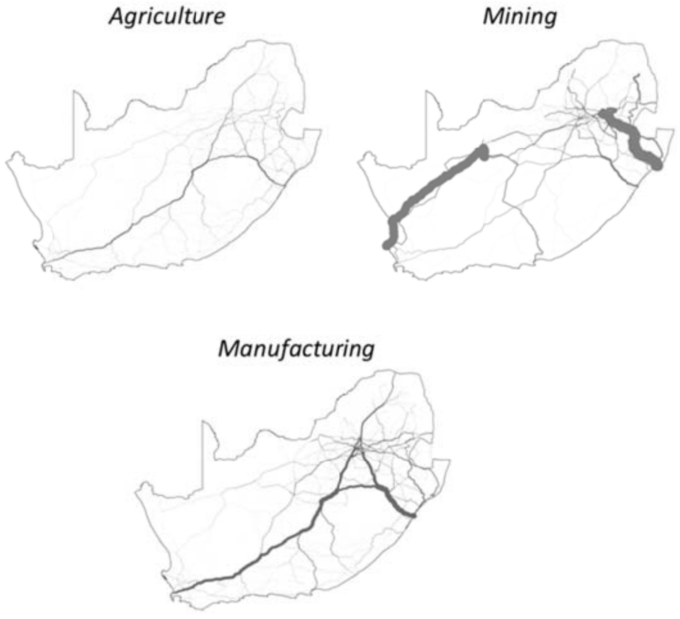

Figure 7: South Africa's aggregate sectoral freight flows in 2014 (Havenga et al., 2016)

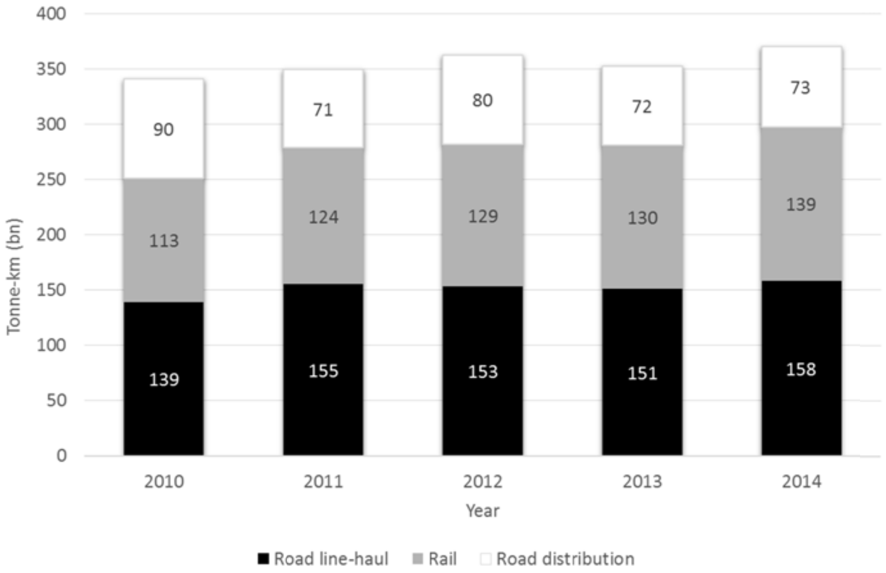

Figure 8: Tonne-km per mode in South Africa for 2010 to 2016 (data from South Africa's freight demand model – refer methodology)

South Africa's tonne-km demand economy is disproportionate to the size of the economy. The world requires about 32 trillion surface freight tonne-km, i.e. road and rail, (International Transport Forum, 2017) to generate $75 trillion of GDP (World Bank, 2017), i.e. approximately 2.4 dollars return for every tonne-km provided. The South African GDP amounts to $317-billion (World Bank, 2017), requiring 379 billion surface freight tonne-km (as stated earlier), i.e. the country's return is less than $1 for every tonne-km provided. The country's tonne-km demand is therefore almost three times less competitive than the world average; an extraordinary backlog from the outset.

From an economic structure perspective, one reason for this is that South Africa is a spatially challenged country, i.e. a relatively small economy in relation to a large land mass, with mineral deposits and surrounding developments located far from ports and coastal demand areas. The country also has a historical reliance on bulk exports, increasing the pressure on logistics infrastructure at low returns, pointing to a need for increased beneficiation.

From a transport provision point of view, the country's modal structure is a key contributing factor. The country's dedicated ring-fenced transport systems (i.e. the rail export lines, pipelines and conveyer belts) contributed 28% of total surface freight tonne-km in 2014. The remaining 272 billion tonne-km (or 72% of total flows) is categorised as general freight, comprising three distinct typologies namely corridor, metropolitan and rural freight, as delineated in Figure 9. Approximately half of general freight is long-distance corridor freight.

As mentioned, road transport continues to be the major transport cost element at 83% in 2014 (refer Figure 6), contributing 80% of corridor tonne-km. Historically, road increasingly served the growing economy due to rail's investment backlog, with social accountability preventing rail rationalisation, resulting in an inability to provide required service levels. Road transport's dominant long-distance market share comes at the expense of high national logistics and externality costs, with transport externalities adding an additional 18% to already high transport costs; the contribution of non-road modes to these externality costs is negligible (Havenga, 2015).

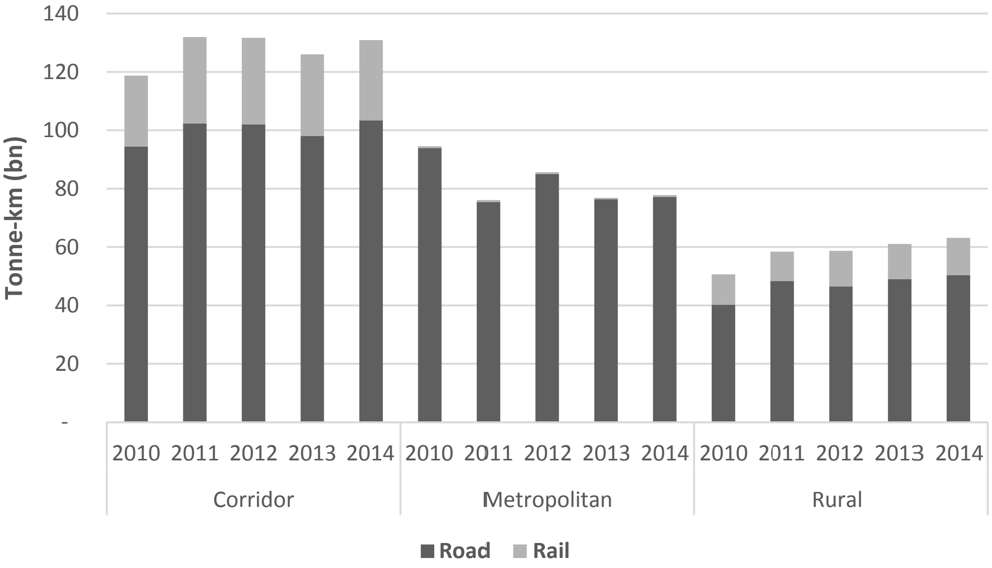

Figure 9: South Africa's general freight typologies for 2010 to 2014 (data from South Africa's freight demand model – refer methodology)

In summary, the instrumentation of macrologistics has enabled the identification of pressing macrologistics challenges in South Africa. The country's logistics costs, as percentage of GDP and transportable GDP, exceeds that of key trading partners, impacting national competitiveness. Transport contributes almost two thirds to national logistics costs. The modal balance in favour of road on dense, long-distance corridors is the key driver of high transport costs which, in turn, exacerbates externality costs. Lastly, the marginalisation of rural economies in the volumetric economy needs to be addressed. In the next section, the application of South Africa's macrologistics instrumentation outputs highlights actions to address these challenges.

5. Discussion

South Africa's macrologistics challenges persist because they have not been viewed within a macrologistics context and managed in conjunction with other macroeconomic production factors. Workable cross-functional proposals to solve these challenges are only possible if, given the nature of logistics, these proposals are made within the context of total logistics costs for the nation (refer Figure 10).

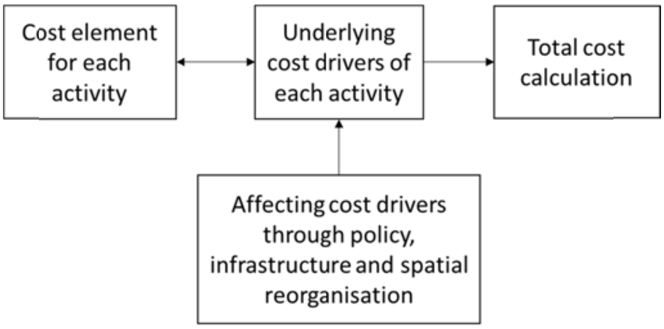

Figure 10: Relationship between logistics cost drivers and macrologistics interventions

The outputs of the macrologistics instrumentation described in this study can be applied to facilitate such a macrologistics management approach to the country's identified logistics challenges.

The current structure of freight flows in South Africa, with the modal balance in favour of road on dense, long-distance corridors, provides a clear primary priority. Dense, long-distance flows are the ideal market for intermodal freight transport solutions (Slack, 2016), which is still lacking from the country's freight transport service offering. The commodity-level segmentation within the FDM enabled the identification of the target market for the country's domestic intermodal business case. More than half of South Africa's potential intermodal freight moves on the country's two most-dense freight corridors, i.e. Gauteng-Durban and Gauteng-Cape Town. Building three intermodal terminals to connect the three major industrial hubs could enable modal shift to rail, increasing rail densities and thereby reducing logistics costs (including externalities) for the identified intermodal freight flows on these two corridors by two-thirds (Havenga et al., 2012).

Such a shift of rail-friendly traffic on road to rail can be induced through internalising externality costs. Havenga and Simpson (2018) demonstrated that the increase in rail density will reduce the cost per tonne-km for general freight on rail by 18%. The full cost in the shift-to-rail-scenario (i.e. including the internalised externality costs) amounted to a 13.6% cost saving compared to the internal costs prior to internalisation. The negative (external) effects of transport in South Africa can therefore be negated without incurring additional costs on the macroeconomic freight bill, due to the returns to density achieved by shifting rail-friendly freight back to rail.

Further impetus for the development of domestic intermodal solutions is provided by the potential impact on international trade competitiveness. Havenga et al. (2017) calculated that, for import and export commodities, 70% of the logistics costs (excl. maritime shipping costs) are attributable to inland logistics costs, i.e. the hinterland feeder system. The results suggest that collaboratively confronting the hinterland feeder system could unlock much more value for stakeholders in the short to medium term, instead of allocating scarce resources to port reform, which is frequently the first action called for to increase the competitiveness of international trade.

The spatial disaggregation in the FDM allows for the analysis of opportunities for a revival of rail branch lines in South Africa, reducing transport costs and externality charges in rural areas, and increasing equitable access to the core transport network. This provides a social dimension to research in support of inclusive economic development (Simpson and Havenga, 2010).

These initiatives will require significant investment in port and rail infrastructure, and the FDM is a key input to inform Transnet's infrastructure investments in rail, ports and pipelines this century, estimated at R500 billion up to 2027 (Njobeni, 2016).

The research outputs also strengthen the institutional environment within which freight flows take place by facilitating evidence-based policy development. The depth of data has enabled on-going involvement in policy development efforts, including strategic corridor management (Department of Public Enterprises, 2016; Havenga et al., 2015); informing the development of a domestic intermodal strategy (Havenga et al., 2012) and confidential input to the national rail policy to encourage development and investment (Smith, 2012).

The macrologistics relevance of the applications described above are underscored by its relevance to the broad objectives of the South African government's transport policy (Department of Transport, 2017) which have been developed to support the attainment of South Africa's national socio-economic objectives (National Planning Commission, 2015). The latter, in turn, are aligned with the typical socio-economic goals of emerging economies as identified by the World Bank (Lee and Hine, 2008) (refer Table 1).

Table 1: Relevance of the macrologistics research outputs to national transport and socio-economic objectives

Typical national socio-economic objectives of emerging economies (Lee and Hine, 2008)	**South Africa's socio-economic objectives (National Planning Commission, 2015)**	**South Africa's transport policy objectives (Department of Transport, 2017)**	**Contribution of macrologistics instrumentation outputs**
Sustained economic growth	Decent employment through inclusive economic growth enabled by a skilled workforce	To support national development goals of accessibility, economic growth, human resource development and stakeholder involvement in decision-making	• Intermodal solutions • Internalising externality costs • Hinterland feeder system • Revival of rail branch lines • Infrastructure investments
	South Africa-centric regional and global integration		
Poverty reduction, equitable access and affordability	Vibrant, equitable and sustainable rural communities contributing to food security for all		• Revival of rail branch lines
Efficient and demand-responsive services	An efficient, competitive and responsive economic infrastructure network	To satisfy customers' mobility criteria	• Intermodal solutions • Hinterland feeder system • Infrastructure investments
		To improve the effectiveness and efficiency of the transport system to meet customer needs in support of the nation's competitiveness	
		To improve the safety, security, reliability, quality, and speed of goods transport	
Sustainable financing and maintenance of public infrastructure		To invest in infrastructure or transport systems in ways that satisfy social, economic or strategic investment criteria	• Intermodal solutions • Hinterland feeder system • Revival of rail branch lines • Infrastructure investments
Mitigating safety and environmental risks.	Protecting and enhancing our environmental assets and natural resources	To achieve these objectives in an economically and environmentally sustainable manner	• Intermodal solutions • Internalising externality costs
Efficient, effective and responsive public administration	A responsive, accountable, effective and efficient developmental state		Evidence-based policy development

6. Conclusion

This research supports the instrumentation of macrologistics through the development and interpretation of national freight flow and logistics cost measurements in an emerging economy context. The building blocks of the instrumentation construct are a commodity-level, spatially disaggregated freight flow model, informing a bottom-up logistics costs model. The outputs of these models aid macrologistics decision-making through evidence-based policy discussions and infrastructure investment planning which, in turn, support the attainment of national socio-economic goals.

South Africa’s key macrologistics challenges are evidenced in high logistics costs with a disproportionate contribution from transport costs, in large part due to the majority of dense, long-distance flows being on road with resulting high transport and externality costs. The commodity-level, spatially disaggregated freight-flow and related logistics costs data enable in-depth analyses to inter alia aid with the identification of intermodal hub locations, incentives for the internalisation of externalities, and priorities to reduce the costs of international trade, while providing systemic support to the nation’s port and rail infrastructure investment program through a disaggregated national view of flow densities per commodity, and strengthening the institutional capacity through factual analyses.

This systemic analysis is enabled by a multiregional and multi-sectoral I-O model of the economy which enables the development of inter-related national freight flow and logistics costs data within the context of the national economy. Although systematic publicly available, spatially-disaggregated commodity-level data is limited in emerging economies, there is often a wealth of information collected by rail and port operators, government departments, national statistics offices and industry associations. The iterative hybrid modelling approach utilised in the research presented here, provides impetus to create an appreciation of the intrinsic value of such information. This approach allows for the synthesising and leveraging of these disparate data sources to either populate or enhance supply and demand data, which will improve freight demand modelling in emerging economies. The freight-flow model has already been extended on a more aggregate level to all 17 countries of sub-Saharan Africa (Havenga et al., 2012; King et al., 2016). The freight flow model and transport cost component of the logistics costs model has been applied in India (Simpson et al., 2016; Dash, 2017). In both cases, the hybrid development of spatially-disaggregated supply and demand tables were possible based on actual data available from various sources, followed by established apportionment approaches to fill data gaps using proxies such as employment, population and income, while controlling against known sectoral aggregates.

7. Next steps

- Design and implementation of a verification and validation approach for the flow results from the FDM.
- Refinement of decay factors: (1) A sensitivity analysis to establish the impact on flow outputs of changes in supply and demand data vs. the impact on flow outputs of alternative decay factors in order to determine priorities for future research. (2) The use of a combination decay factor is being considered for specific homogenous goods, with distance decay up to a set distance, combined with a biased attraction point from the set distance to allow for higher flows on key trades, while variable decay factors for exports vs. domestic demand are being developed. (3) Variable centroids per geographical area are being investigated to account for the location of agriculture production vs. the location of intermediate and final demand in the same geographical area. (4) An addition to FlowMap® is being explored to incorporate the distribution of known flows during the flow modelling process as the attraction between these flows will impact the iterative flow modelling process
- In terms of testing the validity of the instrumentation construct, funding is being raised to increase the number of countries where the research is applied. As mentioned, elements of the instrumentation construct have been successfully applied in SSA and India. The next step for SSA is to improve the level of disaggregation and calculate logistics costs. The next step for India is to quantify the other logistics costs components (in addition to transport costs that have already been quantified). Applications of this approach are currently being investigated for Vietnam and China, which will be funded by the World Bank.
- As part of developing the instrumentation construct, a synopsis will be developed to depict the system of mutually consistent models and observations, as well as an explanation of the interrelationship between the dynamic modelling approaches to develop hybrid supply and demand tables (which will differ from country to country) and standard outputs of the instrumentation construct (i.e. detailed freight flows and related logistics costs for the economies under consideration).

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- The analysis and interpretation remain the authors' own.

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