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Demand-induced transition risks: A systemic approach applied to South Africa

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Résumé

Lors de l'évaluation des conséquences économiques d'une transition vers une économie à faible intensité de carbone, il peut sembler raisonnable de se concentrer sur les secteurs utilisant des technologies à forte intensité de carbone et émettant ainsi d'importantes quantités de gaz à effet de serre. Nous montrons cependant dans cette étude que les secteurs non émetteurs pourraient aussi être vulnérables aux risques de transition. Pour ce faire, nous développons une méthodologie simple qui combine des tables Entrée-Sortie avec des données financières sectorielles pour évaluer l'exposition et la sensibilité financière de tous les secteurs dans le cas scénarios stylisés pour l'Afrique du Sud. Nous soulignons comment la combinaison d'un choc de demande, de la position dans la structure de production et des caractéristiques de la chaîne de valeur détermine l'amplitude des impacts sur les différents secteurs de l'économie et leurs équilibres financiers. Dans le cas de l'Afrique du Sud et pour les deux chocs à l'exportation considérés (charbon et industrie automobile), nous constatons que les fabricants de matières premières, les services publics, ainsi que les prestataires de services financiers sont exposés et sensibles aux risques de transition. Nos résultats soulignent l'importance de prendre en compte les émissions des secteurs du scope 3 (en particulier en aval) lors des évaluations d'impact et appellent à des analyses systémiques des conséquences économiques de la transition écologique.

Mots-clés: Risques de transition, fragilité financière, analyse structurelle

Abstract

When trying to assess the economic consequences of a transition to a low carbon economy, it might seem reasonable to concentrate on the sectors using carbon-intensive technologies and thus emitting important amounts of Greenhouse gases. We however show in this study that non-emitting sectors might nonetheless be vulnerable to transition risks. To do so, we develop a simple methodology that combines Input-Output tables with sectoral financial data to assess the exposure and financial sensitivity of all sectors to simplified transition scenarios in the case of South Africa. We highlight how the combination of the nature of the demand shock, the position in the production structure and the characteristics of the value-chain determines the amplitude of the impacts on the different sectors of the economy and their financial balances. In the case of South Africa and for the two export shocks considered (coal and automotive industry) we find that raw material manufacturers, utilities, as well as financial service providers are exposed and sensitive to transition risks. Our results stress the importance of considering scope 3 (particularly downstream) sectors' emissions when conducting impact assessments and call for systemic analyses of the economic consequences of the ecological transition.

Keywords: Transition risks, financial fragility, structural analysis

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1. Introduction

Given the ambition of the Paris Agreement to maintain global warming below 2°C, a low-carbon transition will have to take place, impacting most, if not all, sectors of the economy and generating dynamics similar to Schumpeter's creative destruction (Schumpeter, 1911). The required qualitative shift in the use of consumption, intermediate and capital goods is then analogous to a structural technical breakthrough. As stressed by Schumpeter himself and more recently by Perez (2002), such industrial transformation goes hand in hand with financial counterparts. As past technological revolutions were driven by the growing profitability of new sectors, these authors put more emphasis on the risk related to the overestimation of promising assets occurring in the "frenzy" phase of such technological cycle.[1] Yet, it is mostly because of the fall in the activity of carbon-intensive industries that the low-carbon transition has been perceived as a source of various types of economic losses, including stranded assets.[2] Stranded assets in particular are prone to generate strong financial negative consequences as argued by Battiston et al. (2017), Campiglio et al. (2017b), or Spiganti and Comerford (2017) among others. For financial regulators, central banks and finance ministries it is indeed of the utmost importance to grasp to what extent the financial system in general is exposed to climate risks (Carney, 2015; Campiglio et al., 2018). Policy makers and financial investors thus require new analytical tools to understand transition risks and their macroeconomic consequences (Semieniuk et al., 2019).

Because of the interconnectedness of industrial networks, even simple transition shocks transform into complex dynamics as sector producing intermediate output for impacted sector themselves reduce production. This implies that policy makers and financial investors or regulators should consider the entire production chain when trying to assert transition risks. What is more, the characteristics of impacted sector generate various transmission mechanisms (e.g. intermediate production, employment, gross operating surplus) hence transforming the overall dynamics as the shock propagates in the production network. In this paper, we aim to respond to the following questions: How to determine which sectors will be exposed to transition shocks? How to characterize the financial sensitivity of these sectors? To do so, we propose an empirical methodology based on the combination of static Input-Output (IO) modeling and financial risk indicators. The approach focuses on demand-induced risks, i.e. those emerging out of the reduction of final demand of one or many goods and services produced in an economy. It is applied to the specific case of South Africa and considers two different demand shocks under the form of export loss of the same magnitude on either coal or the motor vehicle sector.

So far, empirical methodologies taking up these issues either adopt a holistic perspective on polluter-based transition scenarios or propose a microeconomic outlook of transition shocks propagating through demand. On the one hand, Battiston et al. (2017) for example inspect at the European scale the overall financial second-rounds effects that could emerge out of losses in high emitting sectors. Boermans and Galema (2019) utilize a stock-level holdings dataset and combine it with firm-level CO2 emissions information to measure the

[1] See Perez (2002) for more details.

[2] Following Caldecott et al. (2013), stranded assets are natural, physical or financial assets "that suffer from unanticipated or premature write-downs, devaluations, or conversion to liabilities because they are environmentally unsustainable".

portfolio carbon footprint. On the other hand, Dericks et al. (2018) assess in case studies the risks originating from the decrease in demand for real estates in "Resource-based Cities". Huxham et al. (2019) conduct a analysis at the company level assessing values at risk implied by a reduction in South African coal and oil exports.

Adapting the methodology described in Cahen-Fourot et al. (2019, 2020) for a demand shock,[3] we show how non-carbon intensive sectors are also exposed to transition risks due to inter-industry linkages. These results highlight the importance of considering "downstream" scope 3 emissions, thus adding to the existing literature which usually focuses on 'upstream" ones (embodied emissions) (Hertwich and Wood, 2018). We furthermore describe how sectoral characteristics transform production losses into financial vulnerability by combining an Input-Output demand model with financial data. The connection between the cascades of production stranding though the industrial network with financial characteristics of these sectors offers a methodology to identify financial vulnerability emerging out of a shock in the real sphere, demonstrating the importance to considering both real and financial dynamics and their combination. In our case study, we find that the transport, the utilities and the auxiliary financial sectors exhibit vulnerability relative to the coal shock, while the metal ores, basic iron and steel, glass and again the utilities sectors are concerned in the case of an automobile shock. Finally, it is worth noting that the proposed methodology is relatively light in terms of data requirement and mathematical apparatus, allowing for replication in a wide variety of countries.

The paper is structured as follows. Next section reviews the literature. Section 3 presents the methodology to measure transition risks. Sections 4 and 5 present and discuss our results while section 6 concludes.

2. Academic context

A low-carbon transition is a necessary condition to fight climate change, a mean to decouple the production of goods and services from the emission of greenhouse gases, and an opportunity to generate employment and income in various sectors. Simultaneously, it also implies direct losses, unemployment and/or stranded assets (Caldecott, 2018; Rozenberg et al., 2018) for polluting activities, see also Van der Ploeg et al. (2019) for a recent review. The existing academic and institutional literature on transition risks provides some keys to identify empirically the activities directly exposed and to assess their further economic (real and financial) consequences.

The identification of activities subject to transition risks are based either on technology and policy-based scenarios, or on "commitment accounting analysis of carbon budgets" (Davis and Socolow, 2014). The latter estimates the amount of zero carbon budget assets, i.e. fossil-fuel reserves, that cannot be extracted (McGlade and Ekins, 2015; Mercure et al., 2018) or the physical capital, mostly power plants, (Pfeiffer et al., 2016; Smith et al., 2019; González-Mahecha et al., 2019) that will not be used to respect the commitments in terms of

[3]The methodology could however easily be adapted to model specific supply shocks such as severe resource constraints, major political interventions in markets (OPEP-style actions), or locally specific supply bottle-necks.

greenhouse gas emissions. Other authors assess in a more or less aggregated fashion the indirect losses through value chains, due to the initial activities or assets at risk. Studies have notably proceeded using Input-Output analysis to analyze the real side of the economy. Choi et al. (2010) and Hebbink et al. (2018) assess the indirect effects of a carbon tax on economic sectors embodying emissions and respectively on material resources use and international competitiveness. Bastidas and Mc Isaac (2019) or Perrier and Quirion (2017) inspect changes in employment level and distribution subsequent to mitigation efforts in energy systems. Cahen-Fourot et al. (2019) are looking for the stranding cascade of physical capital following the abandonment of fossil fuel inputs.

Another strand of the literature inspects the financial side of transition risks, bringing to light the potential of fragility that could result from the industrial shift, see Semieniuk et al. (2019) for a recent overview. As highlighted by Campiglio et al. (2019), these risks materialize when real transition costs translate into balance sheet adjustments impacting banks, financial intermediaries or even the entire financial sector through changes in asset values and the deterioration of financial positions out of non-performing loans. Carbon Tracker Initiative (2011) commits the carbon budget of fossil-fuel reserves, combine them with ownership data and estimate stranding shares in company's assets. Alternatively. Battiston et al. (2017) take a wider view on the financial system and develop a climate stress-test based on portfolio data in order to capture what they call transition "second-round" effects. They concentrate their analysis on transmission channels occurring between financial institutions where some of them own liabilities emitted from a set of carbon intensive sectors. Another type of approach, more microeconomic in nature, also tries to appraise second-order effects, but this time in the non-financial network of backward linkages from sensitive sectors. It has been developed for instance by Climate Policy Initiative in its pilot country case study of South Africa (Huxham et al., 2019). In this approach, once a base case and a low carbon scenario have been defined, their relative effects are measured on the financial wealth of the large corporates that are most likely to be affected. The commercial and financial relationships and contracts between the main economic actors of the economy (including State and local governments) are then analyzed. This approach allows for the modelling of finely tuned scenarios and is well suited to respond to the needs of large corporates for analyzing their exposures to particular scenarios. It is also an efficient tool for a sovereign or sub-sovereign to identify the main sources and magnitude of the potential fiscal risk.

From the perspective of the financial system as a whole, a "Green Swan" (Bank for International Settlements, 2020) could take its origins from plenty of causal ramifications, and be the source of deep macroeconomic consequences (through changes in expectations or various other channels like the rationing of credit supply, see Semieniuk et al. (2019), p.13). This explains why central banks are more and more interested in that issue (Carney, 2015; Campiglio et al., 2018; NGFS, 2009). The problem is that most of existing studies, as detailed they might be, still fail to provide an integrated and complete picture of the financial fragility potential emerging from the transition implies through the real structure of the economy. A first attempt in this direction is nonetheless to find in the analysis of Vermeulen et al. (2018). They link the vulnerability of assets owned by non-financial industries embodying carbon emissions to portfolio data of financial firms in the Netherlands. They improve previous analyses usually focus on a very limited set of sectors. However, they still do not give any clue concerning the impacts across the also vulnerable sectors whose production are sold to those embodying carbon emissions. Alternatively, in this paper we illustrate empirically how productive sectors which are not necessarily lying on fossil fuel products may, through demand losses, also be source of transition-led financial distress.

The argument can be interpreted in the light of the GHG protocol's framework. The GHG Protocol Initiative[4] develops accounting standards to guide the identification and quantification of emissions. Among them, an important notion is the one of "Scopes" of emissions. From a firm's point of view, Scope 1 emissions are direct emissions from owned or controlled sources. Scope 2 emissions are indirect emissions from the generation of purchased energy. Scope 3 emissions are all indirect emissions that occur in the value chain of the reporting company, including both upstream and downstream emissions. In the case of general abatement incitation, it is then not only because of the attempt to reduce its Scope 1-2 emissions that any company is exposed to the transition, but also because of the efforts of some others to reduce their Scope 3 ones. "This is not to say that the emissions related to scopes 1, 2 and 3 are sufficient to assess the exposure of a firm. For instance, a firm with high emissions today could become decarbonized and seize many opportunities under specific transition paths. Still, focusing on scopes 1, 2 and 3 means that a comprehensive risk assessment should look at potential vulnerabilities throughout the entire value chain." (Bank for International Settlements, 2020). Indeed, worldwide for instance, "[f]or buildings, scope 3 [upstream] emissions are twice as high as direct emissions (Hertwich and Wood, 2018).

Therefore, to manage transition risks, it is of an utmost importance to track at which extent the agents in the economy are vulnerable to those channels. From an IO point of view, while studying *upstream* Scope 3 emissions of a given sector would mean to inspect the carbon footprint of its suppliers, studying its *downstream* Scope 3 ones would mean to inspect the carbon footprint of the sectors to whom is sold its products. For instance, the rubber sector contains more upstream (or embodied) Scope 3 emissions when its inputs in raw materials come from a carbon-intensive sector and more downstream Scope 3 emissions when its commodity is used in such an industry. In the first case, the rubber sector is exposed to supply transition shocks; in the latter, it is exposed to demand shocks. As illustrated in section 4, our methodology is adopted to investigate the second type of vulnerability. Analysis of more local sectoral shocks will then be conducted to address more precisely the exposure propagation and the implications for financial fragility.

3. Methodology and data

Carley et al. (2018) develop a conceptual framework where they decompose vulnerability as the combination of exposure, sensitivity and adaptive capacity, in the context of the energy transition. The higher the exposure and the sensitivity and the lower the adaptive capacity, the more vulnerable is a sector. We propose in this paper an empirical method to assess how certain sectors are exposed and sensitive to financial risks emerging out of the propagation of demand shocks throughout the industrial tissue. More specifically, we firstly

[4]https://ghgprotocol.org/

measure the indirect exposures to losses in production and employment among sectors through the usage of a demand-pull IO model. We then combine these results with financial data to determine how exposures interacts with the sensitivity of cash-flow surplus and financial conditions of the industries involved. In such a way, it is shown how the composition of the overall industrial network determines sectors exposure, and how particularities in cost-revenue structure and financial positions across sectors drives financial sensitivity to transition risks.

3.1. Real exposure to demand shock

An IO table is a matrix representing all the transactions of goods and services taking place in the economy in nominal terms[5] -see table 1 for a simplified example.[6] The first category of transaction is final demand of goods and services, composed of consumption[7] (**c**), government expenditures (**g**), investment in capital (**i**), changes in inventories (**inv**) and exports (**e**). All of them being either produced domestically or imported. The second category of transactions lie in the domestic and imported inter-industry matrix (Z^d and Z^m) where each element $z^d_{i,j}$ (resp. $z^m_{i,j}$) corresponds to the inputs produced domestically (resp. abroad) by sector i and bought by sector j to produce its own goods and services. Finally, the last category of transactions consists in the various components of value added: wages (**w**), taxes less subsidies on products and other net taxes on production (**t** and **ot**), and gross operating surplus[8] (**gos**).

An important characteristic of the IO table is that the sum of all element in a row is equal to the sum of all elements in the corresponding column, which leads to the following identities for the (column) vector of domestic gross output **x**:

$$\mathbf{x} = Z^d\mathbf{1} + \mathbf{c}^d + \mathbf{g}^d + \mathbf{e}^d + \mathbf{i}^d + \mathbf{inv}^d \tag{1}$$

$$= (Z^d)^\intercal\mathbf{1} + (Z^m)^\intercal\mathbf{1} + \mathbf{t} + \mathbf{w} + \mathbf{ot} + \mathbf{gos}, \tag{2}$$

where the use of the column vector **1** serves to sum matrix across their rows, and where the superscript $^\intercal$ indicates the transpose of the matrix.

The first identity (1) will be at the heart of our analysis and can be re-written as follows:

$$\mathbf{x} = Z^d\mathbf{1} + \mathbf{f}^d, \tag{1.A}$$

where $\mathbf{f}^d$ is the sum of all elements of final demand domestically produced. (1.A) simply states that the total production from a specific sector is equal to its final demand plus its demand as intermediary goods and services. The second identity (2) shows that value added - i.e. the difference between total sales and intermediate consumption, $\mathbf{x} - (Z^d)^\intercal\mathbf{1} - (Z^m)^\intercal\mathbf{1}$ - is

[5] Some countries also produce deflated IO tables which aim to capture the transaction in real terms.
[6] See Eurostat (2008); Miller and Blair (2009) for more details on the methodology to compile and use these tables.
[7] We use the following notation: minuscule variable are scalars (c_i is the consumption of goods and services produced by sector i), bold variables are vectors (**c** is thus the vector of consumption), and capitalised letters are matrices (Z is the inter-industry matrix). Domestic and imported elements are denoted by a d and m exponent: e.g. $\mathbf{c}^d$ and $\mathbf{c}^m$.
[8] Our data does not distinguish between gross operating surplus and mixed income.

		Using/ buying sectors					Final demand						
		Sector 1	...	Sector j	...	Sector n	Cons.	Gov. exp.	Exports	GFCF	Ch. inv.	Imports	Output
Supplying/ selling sectors (Domestic)	Sector 1	z^d_{11}	...	z^d_{1j}	...	z^d_{1n}	c^d_1	g^d_1	e^d_1	i^d_i	inv^d_i		x_i
	⋮	⋮		⋮		⋮			⋮				⋮
	Sector i	z^d_{i1}	...	z^d_{ij}	...	z^d_{in}	c^d_i	g^d_i	e^d_i	i^d_i	inv^d_i		x_i
	⋮	⋮		⋮		⋮			⋮				⋮
	Sector n	z^d_{n1}	...	z^d_{nj}	...	z^d_{nn}	c^d_n	g^d_n	e^d_n	i^d_n	inv^d_n		x_n
Supplying/ selling sectors (Rest of the world)	Sector 1	z^m_{11}	...	z^m_{1j}	...	z^m_{1n}	c^m_1	g^m_1	e^m_1	i^m_i	inv^m_i	$-m_i$	
	⋮	⋮		⋮		⋮			⋮			⋮	
	Sector i	z^m_{i1}	...	z^m_{ij}	...	z^m_{in}	c^m_i	g^m_i	e^m_i	i^m_i	inv^m_i	$-m_i$	
	⋮	⋮		⋮		⋮			⋮			⋮	
	Sector n	z^m_{n1}	...	z^m_{nj}	...	z^m_{nn}	c^m_n	g^m_n	e^m_n	i^m_n	inv^m_n	$-m_n$	
	Total expenditures (Int./final)	z_1		z_j		z_n	c	g	e	i	inv	$-m$	x
	Net taxes on products	t_1	...	t_j	...	t_n							
Value added	Wages	w_1	...	w_j	...	w_n							
	Other taxes	ot_1	...	ot_j	...	ot_n							
	Gross op. surplus	gs_1	...	gs_j	...	gs_n							
	Output	x_1		x_j		x_n							

Table 1: Structure of a single-country Input-Output table where the uses of imports are specified.

distributed among wages, other net taxes on production and gross operating surplus. In shares, it reflect how sectors are more or less labor or capital intensive.

An IO table can be used for numerous applications. A very common one is the demand-pull model of impact analysis (Leontief, 1919). The objective is to quantify the effect on all sectors of a specific change in demand (a shock) occurring in one (or more) sector(s). In practice, what we primarily need to derive is the matrix A^d of technical coefficients a^d_{ij} that represent the amounts of inputs from i that are domestically and directly needed to produce on single unit of product of industry j. In other words, "the dollars worth of inputs from sector i per dollars worth of output of sector j", (Miller and Blair, 2009, p.16). Relying on the essential assumption of constant return to scale, these coefficients are derived from values of the matrix Z^d when divided by sectoral outputs (x_j): $a^d_{ij} = z^d_{ij}/x_j$. In a matrix form, this gives:

$$A^d = Z^d \cdot \hat{X}^{-1}, \tag{3}$$

where $\hat{X}$ is the diagonal matrix of dimension $\{n; n\}$ containing the vector **x** along its main diagonal.

Combining (1.A) and (3) and rearranging, the total outputs vector **x** can then be formulated as a combination of A^d and **f**:

$$\mathbf{x} = (I - A^d)^{-1}\mathbf{f^d} = L^d \cdot \mathbf{f^d}. \tag{4}$$

This is the fundamental equation at the heart of the model. The total requirements matrix $(I - A^d)^{-1} = L^d$, or Leontief inverse matrix, is such that its elements l^d_{ij} translate a unitary change of final demand in sector j (Δf^d_j) into the total change in the domestic output of sector i (Δx_i). Elements $l^d_{ij} = \frac{\Delta x_i}{\Delta f^d_j}$ are called output-to-final-demand multipliers.

Let us now define a particular transition shock $(\square_j)$ as an exogenous change in final demand faced by the domestic sector j. Then, the vector containing the amounts of output exposed to the shock (output loss) in each sector ($\mathbf{k}^{\text{out}}$) can be computed as:

$$\mathbf{k}^{\text{out}} = L^d \cdot \boxtimes_j \tag{5}$$

where $\boxtimes_j$ is the 0's column vector with its only non nul jth element equal to the exogenous shock on sector j.

Each element of the vector $\mathbf{k}^{\text{out}}$ measures the total change in output of a sector implied by the shock, including direct and indirect effects. The chain of effects are illustrated by noting that the Leontief inverse matrix can be conceived as the geometric series of the technical coefficient matrix:

$$L^d = (I - A^d)^{-1} = I + A^d + \left(A^d\right)^2 + \left(A^d\right)^3 + ... \tag{6}$$

This shows that the initial shock $\boxtimes_j$ first reduces production in sector j - this is the identity matrix I in (6) - and then propagates in the economy as direct requirements to produce the lost production in sector j are not produced $\left(A^d\right)$ and as the goods corresponding to the second round of requirements $\left(A^d\right)^2$ are not produce, etc. Given the fact that almost all sectors are interconnected, there can be many paths of different length by which a specific sector i is impacted by the loss of final demand in sector j, even if the impacted sector seems quite far from the originating sector in the industrial network.

While the Leontief model is of great interest to understand the ramifications of a specific shock in terms of production, it does not directly address the impacts on factors such as employment. Generally speaking, factors are non-intermediary goods item that are used directly or indirectly to produce goods and services. In the following sections, we will study the impact of the transition on employment and gross operating surplus (GOS) generation. To allow for their study, we define the employment and the profit content in production γ_i^{emp} and γ_i^{gos} of a sector i as the ratio between the factor quantity and the output of the sector (x_i) . For example, the employment content of production is equal to the number of jobs per unit of output in a sector. From such a measure, based on the assumption of proportionality between output level and labor use or GOS generation, we derive the "final demand to employment multiplier matrix", S^{emp}, and the "final demand to GOS multiplier matrix", S^{gos}, where elements s_{ij}^{emp} and s_{ij}^{gos} are interpreted as total changes in employment or GOS in sector i due to a unitary change in the final demand faced by sector j:

$$S^{emp} = \hat{\Gamma}^{emp} \cdot L^d, \tag{7}$$

$$S^{gos} = \hat{\Gamma}^{gos} \cdot L^d, \tag{8}$$

where $\hat{\Gamma}^{emp}$ and $\hat{\Gamma}^{gos}$ are the n-dimensional square diagonal matrix of the vectors of elements γ_i^{emp} and γ_i^{gos} respectively.

From the latter and equation (5), levels of employment or GOS at risk due to a shock of domestic final demand for j's products ($\mathbf{k}_j^{emp}$ and $\mathbf{k}_j^{gos}$), can be derived as:

$$\mathbf{k}_j^{emp} = S^{emp} \cdot \boxtimes_j, \tag{9}$$

$$\mathbf{k}_j^{gos} = S^{gos} \cdot \boxtimes_j, \tag{10}$$

Considering employment content in production for instance, this would give a picture of sectorial job losses due to a shock in sector j.

The simple Leontief model used here relies on strong assumptions. First, producers face constant returns to scale (a change in the output level will lead to a proportional reduction in inputs). Secondly, labor and capital are unlimited and available at fixed price (a change in the demand for productive factors will not induce a change in their cost). Third, inferences about the effects on employment and GOS rely on the hypothesis of strict proportionality between production factors and output (a change in the level of production will not induce a change in the needed level of factors per products).

3.2. Financial sensitivity

Together with its exposure to the shock, the financial vulnerability of a sector depends on the sensitivity of its financial conditions. This will drive the appearance of financial instability emerging out of shocks. We will differentiate and discuss two types of financial sensitivity: the "gearing sensitivity", i.e. the initial indebtedness of sectors, and the "profit sensitivity", i.e. the reaction of their cash-flow surplus to variations in their output level.

Indexes of financial fragility used in the corporate finance (see Balcaen and Ooghe, 2006; Sun et al., 2014, for recent overviews) or by macro-prudential regulators, mostly consist in gearing ratios comparing two or more variables. In this case, we thus speak of gearing sensitivity, measured by financial soundness indicators. Without multi-lateral financial data, i.e. "from-whom-to-whom" data linking debts to creditors,[9] these ratios are indications to locate and measure fragility niches. Our strategy will hence primarily consist in exploring how such ratios interact with the consequences of transition shocks. Those ratios can be uni- or multi-variate. Applied at the sectorial level as we do here, their analysis simply lies on the assumption that firms populating each sector are more likely to depict the corresponding financial pictures.

3.3. Dataset

We use a 2014 table from Statistics South Africa database (StatSA, 2017) relating 50 sectors according to the fifth edition of the Standard Industrial Classification (SIC). While it indicates the value of total imports by industries, the table does not precisely distinguish between domestic and imported contents in inputs requirements. To differentiate domestic and imported demands as illustrated on Table 1, we assume, for each sector, the level of imported goods allocated to each type of demand as proportional to the share of total imports in gross outputs.

Employment data is based on the Quarterly Labour Force Survey (QLFS) 2014's survey (StatSA, 2019c), from which we derived annual averages. We had to complement the dataset using Quarterly Employment Statistics (QES) database (StatSA, 2019b) so as to cover missing sectors from QLFS (Agriculture) as well as to include informal and self-employment which

[9] This type of data are particularly used in financial macro-network approach in the field of climate risks (Stolbova et al., 2018). An approach that ought to be naturally be coupled with ours in further study.

are not covered in QLFS.[10] We decomposed the mining sector that was initially aggregated into two Gold and Non-Gold sectors in the QLFS database, using the 2015 report[11] (StatSA, 2015).

Financial data is taken from the Annual Financial Statistics (AFS) database (StatSA, 2019a) covering the period 2006-2018. Four IO sectors are however not covered in the dataset: agriculture, financial intermediation, insurance and pensions, and education. We thus omit these sectors for all the financial analysis.

CO_2 emissions data are derived from the Eora database (Lenzen et al., 2013). To be used, we developed a concordance table between their sectorial classification and ours (see Table 2 in the Appendix).

4. Results for South Africa

The literature looking at the indirect vulnerability from a low-carbon transition mostly concentrates on the effect for sectors that *use* as input products embodying emissions (Wiebe et al., 2012; Wiedmann et al., 2015; Hertwich and Wood, 2018; Cabernard et al., 2019). These studies thus primarily answer to the question "what is the scope of sectors to influence CO_2 emissions indirectly through changes in their supply chain?" (Hertwich and Wood, 2018, p. 3). They identify risk exposures associated to the presence of upstream Scope 3 emissions. In this paper, we focus on the exposure of sectors that *sell* intermediary inputs to polluting industries. In this case, the emissions that have been mitigated correspond to downstream Scope 3 emissions of the sectors indirectly exposed. We thus answer to the question "what is the scope of sectors to be vulnerable to mitigation in CO_2 emissions indirectly through changes in their demand network?". While in the upstream case, a sector is exposed when it uses products from carbon-intensive industries, in the downstream case a sector is exposed when it provides inputs to carbon-intensive industries.

Formally, the vector of scope 1-2 sectoral direct emissions per product, denoted ϕ^{CO_2}, is defined as:

$$\phi^{CO_2} = \frac{\mathbf{kCO_2}}{\mathbf{x}} \tag{11}$$

where $\mathbf{kCO_2}$ is the vector of Scope 1 total emissions (in kilo) per sector. On the one hand, upstream Scope 3 emissions, corresponding to indirectly embodied emission in the value-chain of each sector, are calculated by pre-multiplying the indirect Leontief inverse such that:

$$\varphi_{\mathbf{U}}^{CO_2} = \phi^{CO_2} \cdot (L^d - I) \tag{12}$$

On the other hand, downstream Scope 3 emissions, corresponding to the per unit emissions of sectors that use the product of each sector, are calculated by post-multiplying the indirect Leontief inverse such that:

$$\varphi_{\mathbf{D}}^{CO_2} = (L^d - I) \cdot \phi^{CO_2} \tag{13}$$

[10] QLFS surveys firms while QES surveys households. QLFS is more disaggregated and allows for a better connection to IO sectors.

[11] http://www.statssa.gov.za/publications/P0211/P02114thQuarter2015.pdf

Figure 1 presents the values, expressed in kilo per rand of production, computed for scope 1 emissions (green bar on left hand side) and indirect scope 3 upstream (blue bar on the left hand side) and downstream (red bar on the left hand side) emissions, for selected sectors. We first observe that while scope 1 emissions are very concentrated within few sectors, primarily in the utilities,[12] transport and the non-metallic minerals industries, scope 3 upstream and downstream value are more dispersed. The Shannon (1948) information entropy, measuring the dispersion of information, of direct emissions across sectors is 2.54, against 5.41 and 4.56 for upstream and downstream emissions respectively. Furthermore, while total indirect upstream emission represents 134% of total scope 1 emissions, total indirect downstream represent only 67% of total scope 1 emission, indicating that carbon-intensive sectors are on average supplying more to other sectors than they use goods from other sectors. These results highlight that concentrating on carbon intensive sectors would be counterproductive because one might then underestimate the overall carbon intensity of the economy or not perceive the exposure of certain sectors to transition risks. For example, sectors related to financial or insurance services barely look exposed to the supply channel because they do not use many carbon intensive products, but they are vulnerable to the demand one because they provide services to the supply a network of high emitting industries.

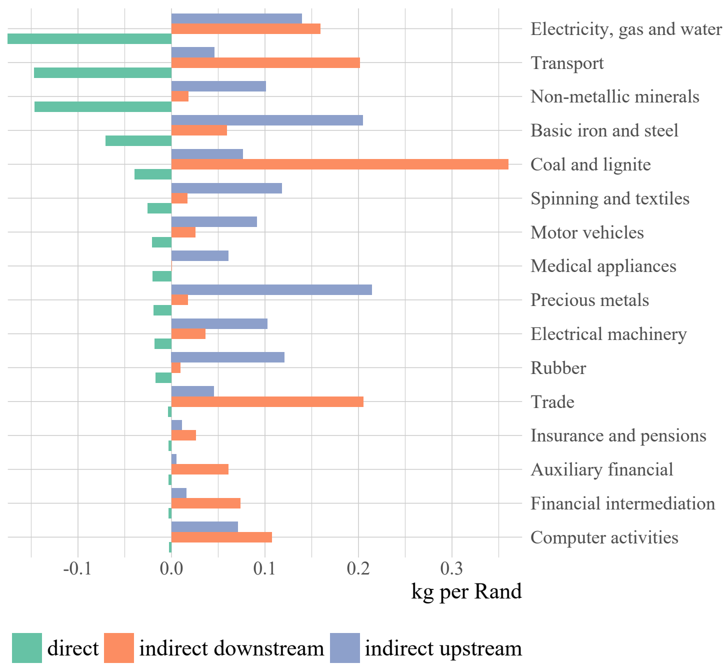

Figure 1: Selected sectorial emission intensity in South Africa, Direct scope 1 in left hand side, indirect upstream and downstream scope 3 in right hand side. Source: StatSA (2017), EORA (Lenzen et al., 2013) , and authors' computations.

[12]Note that for readability motives, we have truncated the utilities scope 1 bar plot, in reality it should show a value of 1.9 $ktCO_2/R$

4.1. Defining sectorial transition shocks

The two shocks we calibrate do not intend to represent a comprehensive scenario of a low-carbon transition but are used for expositional purposes. Our main shock, a loss of coal exports, is based on the study of Huxham et al. (2019) and relates to international trends that could hamper the South-African economy in the perspective of a global transition. With 9.9 million tons of proven coal reserves at the end of 2017, South Africa has 1.0% of the world's proven reserves. The coal industry represented 1.52% in the domestic output in 2014 (the year of our IO table) and 6.42% of South African exports. Over the period 2001-2017, around 28% of extracted tons of coal were exported (Minerals council South Africa, 2018), making South Africa the 6th bigger exporter in 2017 (International Energy Agency, 2019b). However, according to Holz et al. (2018), relatively small declines in Chinese and Indian demand of 5-10% could suffice to displace demand for imports entirely and would "first and foremost hit South African coal exports hardest" (p.5). We use a shock of the same magnitude than the scenario 2°C 2014-2025 analyzed in Huxham et al. (2019). In their scenario, South Africa losses around 70% in coal exports, corresponding to a decrease in final demand of 44 507 Million Rand or 0.59% of the country's gross output.[13] We model this shock as a single one-time drop, rather than as series incremental reduction in exports.

In order to compare and contrast the transition risks caused by a loss in coal exports, we also simulate an export loss in the motor vehicles sector. South Africa is indeed well inserted within the global value chain of the motor industry (Barnes and Morris, 2008) and it is reasonable to assume that a global transition to a low carbon economy will lead to a reduction in demand for internal combustion engine vehicles. The total output of this sector represents 2.77% of the South African domestic product. For the sake of comparison, we use a shock of the same magnitude than in the coal case (44 507.33 Million Rand, 0.59% of the country's output).

4.2. Real propagation of the shocks

As previously highlighted, it is important to understand that a reduction of demand for a specific sector will lead to reduction in production in other sectors as well because of the propagation of the shock. Figure 2, constructed using the methodology[14] described in Cahen-Fourot et al. (2020) illustrates how the coal shock propagates from sector to sector. Each node in the network is a sector while each vertex connecting two nodes corresponds to the supplier-user relationship between these two sectors. We can observe different supply chains such as the trade industry chain, relying on telecommunication, real estate activities and financial intermediation. One can also note that some sectors such as telecommunication, financial intermediation, or real estate activities, are central to various supply chains. A first implication that might be derived from the figure is that case studies à la Huxham et al. (2019) should also envision sectors other than transports in order to appraise transition risks.

[13] We do not consider differences in price between domestic and exported sales

[14] Cahen-Fourot et al. (2020) describe a supply shock where we consider a demand choc, the algorithm had thus to be adapted to account for this difference.

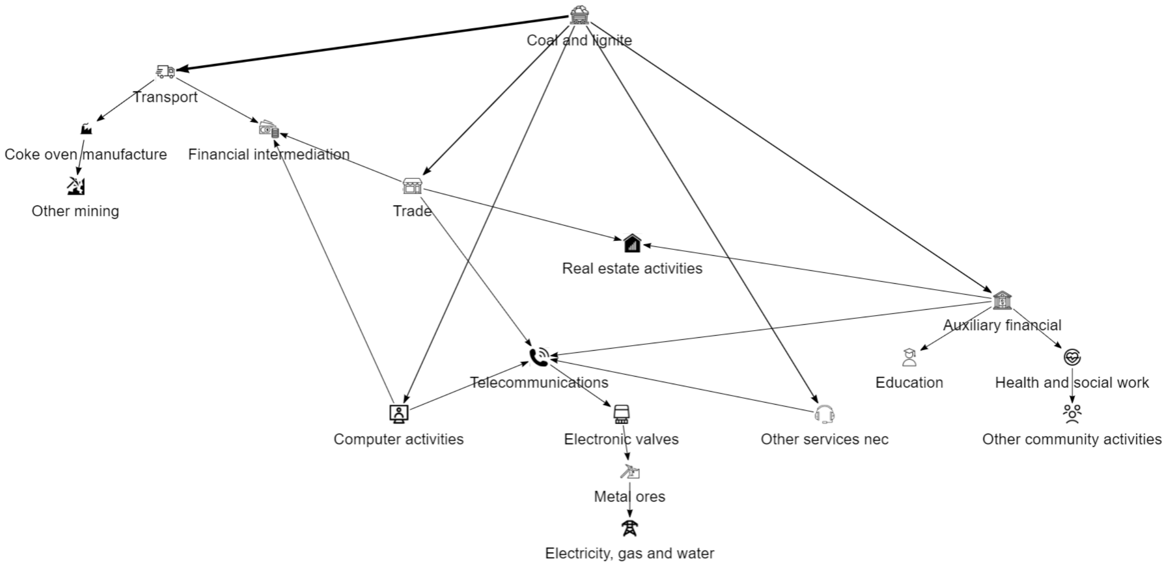

Figure 2: Network of output stranding due to a unitary loss in final demand in the coal and lignite sector. Source: StatSA (2017) and authors' computations.

In order to produce a specific good, one needs intermediary inputs but also labor and capital. Once we determine the quantity of output lost in each sector, it is possible to pursue the analysis and compute the quantity of profits, taxes or wages being lost. Depending on the sectorial intensity of each of the production factor, the impacts of a loss of demand will yield different results. As expressed in the methodology section, it is possible to measure the impacts on different factors by using complementary information either directly from the IO table (value added, inputs, gross operating surplus) or via auxiliary datasets (employment, financial flow, assets or liabilities). Figure 3 shows the loss of output, employment and gross operating surplus for each of the two shocks. The bar plots have been normalized to one, for ease of reading, but the aggregate loss is indicated under each bar plot as a percentage of total output, employment or GOS in the South African economy. The direct effect, i.e. the level of the original shock, has been highlighted in black.

In both cases, we remind that the initial loss in demand corresponds to 0.59% of total output. In the case of the coal shock in panel (a), it leads to a total decrease of 0.93%. The main sectors indirectly affected in terms of production are transport and trade. The picture however change significantly when looking at the two other variables. We find roughly similar industries, but with different weight, reflecting their characteristics in terms of jobs or GOS contents. On the one hand, as the coal sector is relatively not intensive in labor and as some of its suppliers are conversely labor-intensive (like the computer activities sector), the indirect loss of employment represents roughly 200% of the direct loss in employment. This means that for every job at risk in the coal sector, there are actually two other jobs at risk in the rest of the economy. On the other hand, coal and lignite sector being capital intensive, one sees that the indirect effect on GOS is very limited (roughly 1/3 of the total effect) but the share of South African GOS lost is nonetheless more important than for output.

The results are strikingly different in the case of a shock on the motor vehicles industry,

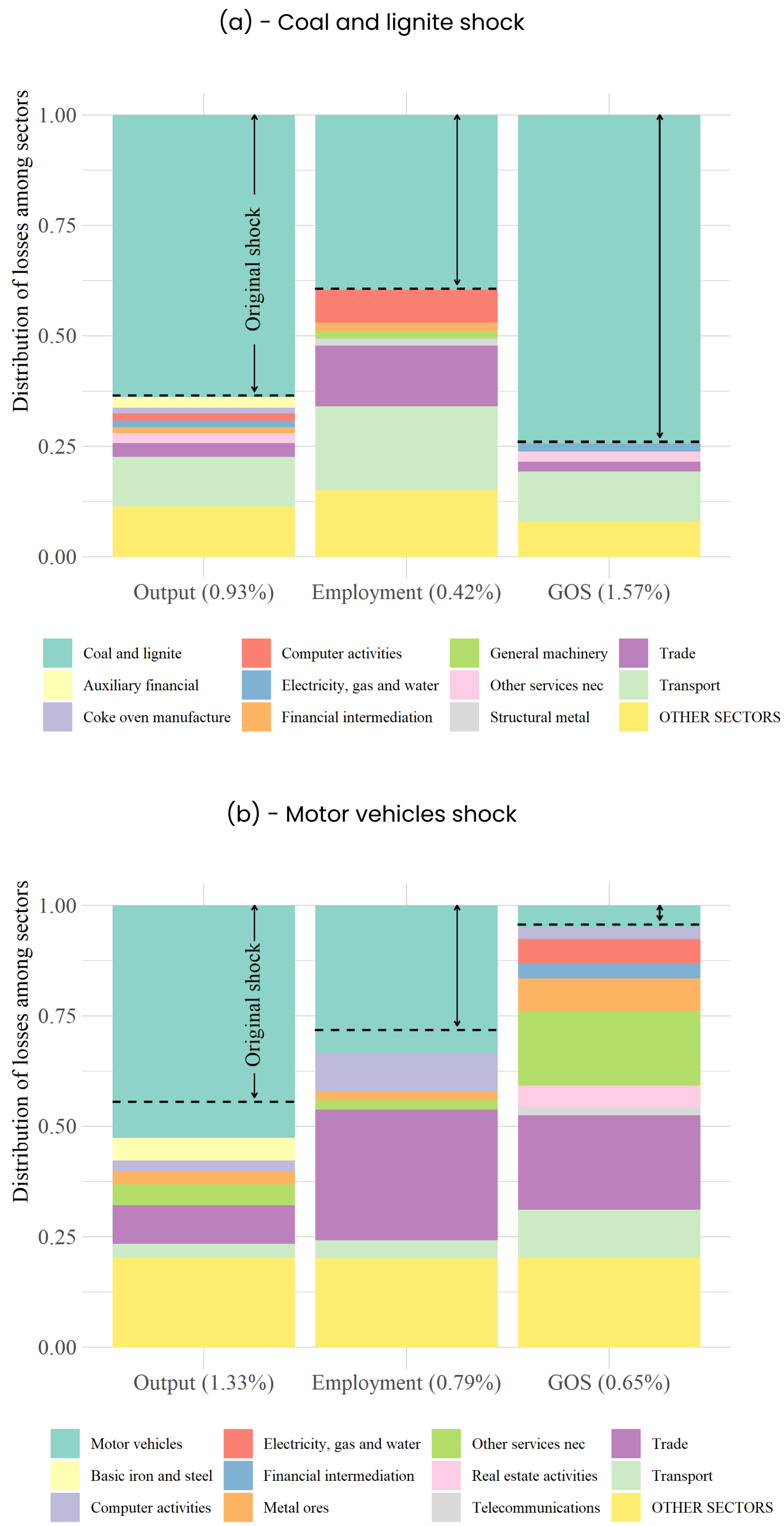

Figure 3: Sectorial stranding components, i.e. output, employment and GOS, due to a loss in demand in the coal sector (panel a) or in the motor vehicle sector (panel b). Value in parenthesis represent share of total output, employment or GOS in South Africa. Source: StatSA (2017, 2019c,b) and authors' computations.

see panel (b). While the original shock to the two sectors are by construction identical in magnitude, they lead to different total stranding impacts in output (0.93% of domestic output in the case of coal vs. 1.33% in the case of motor vehicles), employment (0.37% vs. 0.59%) and GOS (1.56% vs. 0.63%). Delving deeper on the impacts of the car shock, we find that the indirect effects more than double the initial output loss. And contrary to the coal shock, a significant part of the impact occurs indirectly in the motor vehicle sector itself. In terms of employment, the loss is approximately tripled (as in the coal shock) and highly concentrated in the trade sector. Regarding GOS at last, 96% of the total loss lies in indirect effects. Sectors such as trade, other services or transports are even experiencing a greater decline in GOS than the automotive industry initially affected.

We can thus conclude that the structure of the economy is not neutral in driving how different shocks spread through the economy and affect different sectors and indicators. In order to understand the motives behind such large differences, one has to look deeper into sectorial characteristics, both for the originating sector and for the downstream sectors. An important characteristic explaining the heterogeneity in multipliers lies in the expenditure structures of involved industries. Figure 4 shows the repartition of expenditures as shares of total output for some sectors. It helps for instance to understand why the motor vehicles sector is likely to have a larger output multiplier. Indeed, more than 50% of its output is produced using domestic intermediary goods, while it is around 30% in the case of the coal and lignite sector. Note that the domestic nature of intermediary product is also important to explain large multipliers. Overall, we understand that the sectoral expenditures of the industrial network - itself mainly explained by the nature of the production of each sector (as technological, material and organizational constraints), constitute a central feature explaining the expansion of demand-induced exposures to transition risks.

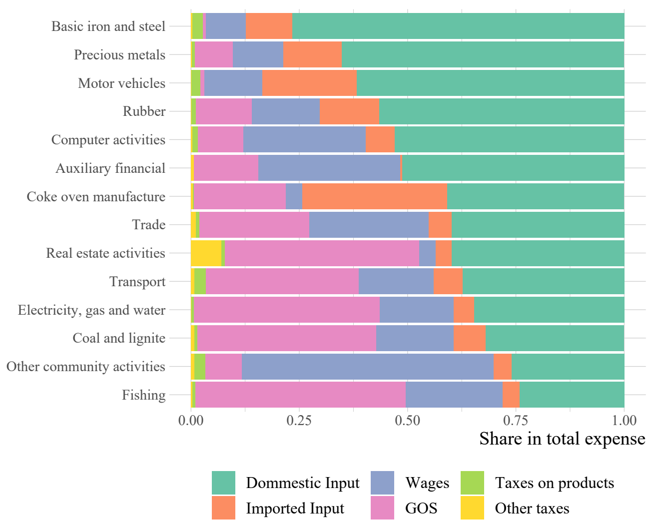

Figure 4: Type of expenditure as a share of total expenses for selected sectors. Source: StatSA (2017) and authors' computations.

4.3. Financial fragility

To address the impact of transition shocks on financial stability, it is first interesting to assess the outstanding financial obligations incurred by the sectors under scrutiny. Figure 5 combines output backward linkages with balance sheet sizes of main sectors affected by a coal export shock. Liabilities present in those balance-sheets are composed by short and long-term loans and other obligations. The figure illustrates the real channels through which the various cascades of stranding output may affect producers' financial balances in what Battiston et al. (2017) calls a "first round". It is interesting to note that seven out of the top ten sectors (and all of the top five sectors) in terms of balance sheet size are among the most impacted sectors presented in section 4.2. In fact, the coal, transport, trade, utilities, auxiliary financial, computer activities, metal ores and real estate sectors account for 67.5% of the whole stock of liabilities contracted by the South African industries covered by ASF data, while accounting for 56.9% of total sales (StatSA, 2019a). Nevertheless, this picture only provides information on exposure and not on the vulnerability of financial obligations to transition shocks.

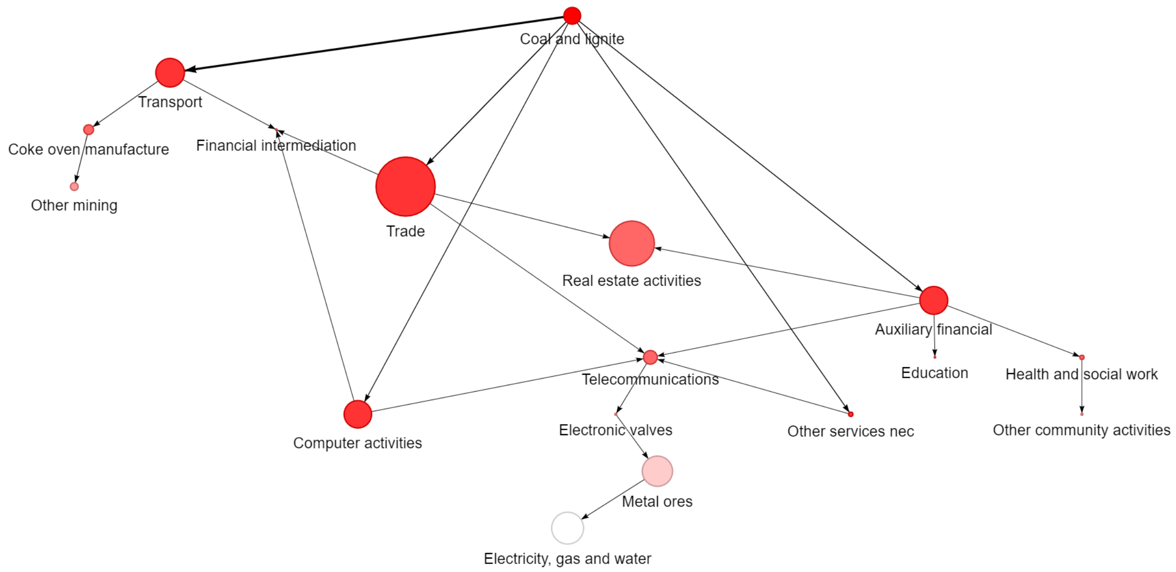

Figure 5: Network of stranding output following a shock in the coal sector. Bubbles represent sectorial liability size. Source: StatSA (2017, 2019a) and authors' computations.

We now combine our previous results with an analysis of financial sensitivity in order to appraise the potential of financial fragility ensuing from the transition shocks. Formerly, we build on the GOS analysis presented before to assess of gearing sensitivity based on uni-variate ratios. GOS indeed represents the inflow generated by the production process to service liabilities, in the form of interest payments or capital amortization. GOS losses will thus be compared to two types of ratios capturing financial fragility: debt to GOS ratio capturing the ability of firms to meet their repayment obligations through cash-flow and the leverage ratio (i.e. debt over assets) capturing the intrinsic fragility of the balance sheet. A combination of large profit losses and high value for one or both financial ratios will be regarded as a warning for the presence of firms likely to sustain financial distress subsequently to our transition shocks. It should however be noted that depending on the market and financial structure of each sectors (number of firms, degree of competition or participation of the state...), inferences about further financial implications remain limited. Our results can be viewed as first evidences paving the way for more precise investigation into highlighted sectors.

Figure 6 combines the two gearing ratios with the percentage share of GOS losses where bubble sizes represent the indebtedness level of industries.[15] In other words, exposure in GOS is depicted on the x-axis and gearing financial sensitivity on the y-axis, either in terms of debt to GOS (panel a) or in terms of leverage ratio (panel b). In the case of the coal shock (red bubbles), two sectors appear particularly fragile: the auxiliary financial sector combines a high leverage and a significant debt burden over GOS with a marked level of profit loss subsequent to the shock while the transport sector shows high leverage and high profit losses, although not depicting a large debt burden on GOS.[16] The motor vehicles shock (blue bubbles) has stronger effects on more sectors and concerns industries displaying more financial fragility. The motor vehicle sector[17] along with the basic iron and steel and the precious metal ones show GOS losses of more than 3% combined with substantive debt burden over profit and assets. We also find that trade, electricity and gas, structural metal, spinning and textile, glass, plastic, and rubber sectors are standing out. They represent sectors that certainly include some firms susceptible to display financial distress.

One way to synthesize our findings in general terms could then be as follows. While we illustrated earlier how the (external) position of sectors in the productive network and the expense structures of its participants determine the exposure of industries to transition risks, we now observe how differences in their (internal) cost, revenue and financial structure drive their sensitivity to such risks. The financial failure of any economic entity depends on several aspects of its situation and the interpretation of isolated ratios is not as straightforward as it has been hinted here, indicating the importance of comparing various indicators when doing our analysis of financial fragility. To address these concerns, financial indexes may be combined to each other. That is why we propose in appendix a complementary analysis using the Z-score of Altman (1968) which broadly confirm our results.[18]

5. Discussion

5.1. Implications for investors and policymakers

The main policy implication from this study relates to the sectorial scope that policymakers should account for in coping with transition risks. It is not only the activities of carbon-

[15]For readability reasons, have excluded the leather and luggage from the two graphs and the electrical machinery sectors from the first one as the leather and luggage sector has a large share of GOS loss (around 9%) and the electrical machinery sector has a high debt burden (around 450).

[16]It can also be noted that if some of its physical assets reveal themselves definitely unusable as Huxham et al. (2019) find for the company Transnet, then the leverage ratio would become even higher, indicating the presence of "demand-induced stranded assets" (see section 5).

[17]The motor vehicles bubble that is shown only accounts for indirect effects on the industry.

[18]The index uses multiple corporate income and balance sheet values to predict the probability that a firm will go into bankruptcy within two years.

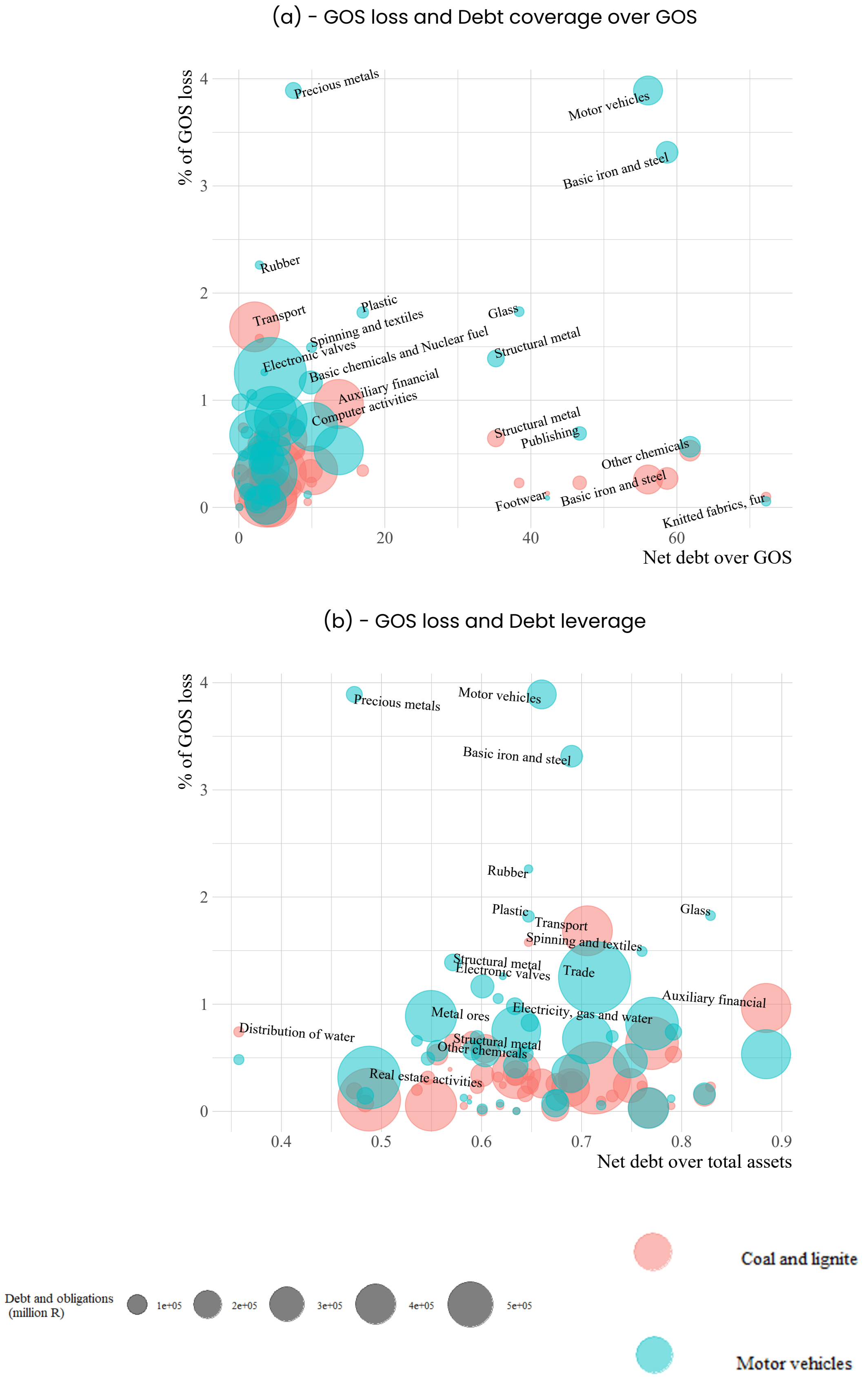

Figure 6: Stranding GOS (y-axis) following a shock in the coal sector (red bubble) or in the motor vehicle sector (blue bubble) and financial fragility (y-axis): net debt over GOS in panel a or debt over assets in panel b. Bubbles represent liability size. Source: StatSA (2017, 2019a) and authors' computations.

intensive sectors that would be affected in the case of ambitious low-carbon transformations, but also some of their industrial counterparts. These “stranded networks” should thus be taken into consideration when designing employment programs or financial policies aiming at mitigating the damaging effects of the transition.

Monetary institutions and financial or insurance businesses should also care about the assets relying on stranded networks. The majority of analysis on transition risks focuses too exclusively on polluters. As an example, the Taskforce on Climate-Related Financial Disclosure likes to recall that “The non-financial groups identified by the Task force account for the largest proportion of GHG emissions, energy usage and water usage” in its overview (TCFD Status Report, 2019).What we have shown here is that financiers wanting to prevent transition risks should scrutinize the entire industrial structure as well. In that sense, disclosures must not limit themselves to emitting activities but also to all the enterprises that economically depend on them. As another example, Monasterolo et al. (2017) proposes two indices capturing either the exposure of single investors’ portfolios to climate transition risks, or the market share of each financial actor weighted by its contribution to GHG emissions. In both cases, the “real” source of financial fragility exclusively lies on carbon embodiment[19].

The literature on policies aiming to mitigate financial instability should also take into account demand-induced vulnerabilities. For instance, Spencer et al. (2017), among others, suggest that “bad banks” could be set-up to purchase carbon-intensive assets from financial intermediaries’ balance-sheets. The case outlined in this paper makes clear that such institutions should also purchase some of the assets underlying demand-induced stranded networks in order to exhaustively handle transition risks. One should thus identify the owners of the assets affected by demand-induced effects to determine which agents to put under scrutiny. Here, due to data limitation, we are not able to conduct this estimate. We can nonetheless provide preliminary insights in two ways.

When it is straightforward, we can allocate the liabilities contracted by vulnerable sectors to the type of their owners. Figure 7 displays the nature of the sector exposed to transition risks because it owns a certain type of liability: e.g. loans are assets for banks while payables (i.e. trade credit) are assets for other non-financial companies. Different types of asset owners thus appear exposed depending on the industry losing production in the transition shock. For example, the glass sector heavily relies on loans indicating banks would be more exposed than other investors would if the glass sector where to be impacted by a transition shock. On the other hand, equity shareholders look more exposed to underperformances in the metal ore or in the precious metal sectors.

The other way to determine the financial exposure to demand-driven risks is to examine the extent to which portfolios contain assets issued by the affected sectors. As a first step in this direction, we examine the credits granted by the main South African banks to the institutional and industrial sectors. Data has been obtained from the annual reports of the 4 major banks of the country, accounting for more than 80% of total banking assets in 2014 (The Banking Association South Africa, 2014). Overall, one third of bank ”advances” (term used in the reports) are directly lying on non-financial firms, with wholesales and other services

[19] It should be noted that in other work, the range of sectors considered as vulnerable by these authors is broadened, for example using the carbon leakage risk classification of the EC 2015 directive (European Commission, 2014).

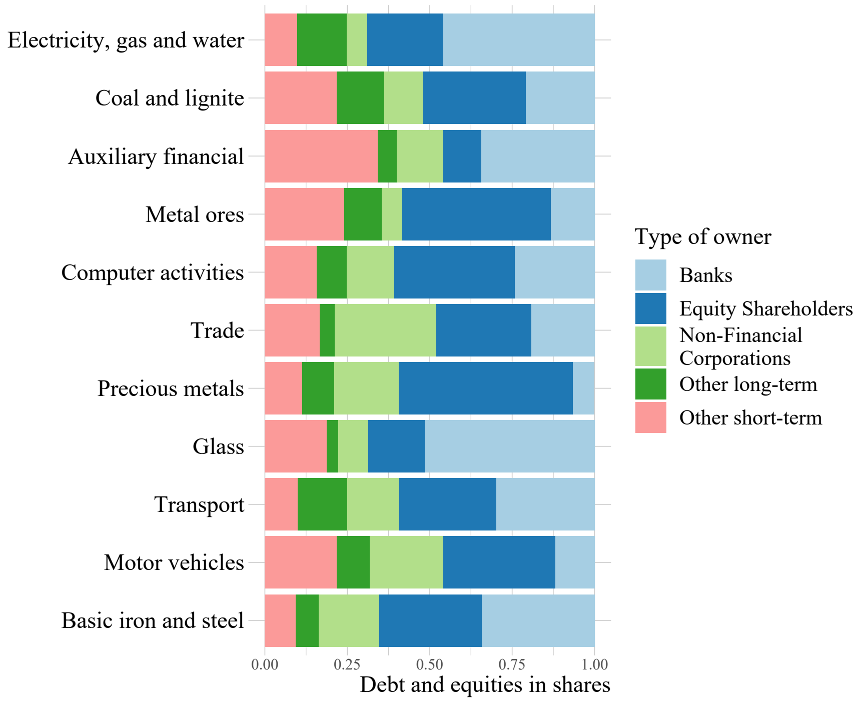

Figure 7: Probable owners of vulnerable assets for selected sectors. Source: StatSA (2019a) and authors' computations.

as the main sector involved, see figure 8. For example, First Bank looks less exposed to trade and other services sectors but more to manufacturing one. The majority of loans still consists of loans to households and other financial intermediaries. On the one hand, loans to households could also be exposed to transition shocks through stranded jobs. On the other hand, the exposure in the 'Bank, Finance and Real Estate' might as well represent an indirect vulnerability through second-round dependencies as described in Battiston et al. (2017). An obvious policy implication is thus the need for more transparent and detailed disclosure of bank's advances within productive sectors and types of household.

5.2. The importance of adaptive capacities

In any case, risky assets identified in the study cannot be considered at his point as definitely stranded. While it has been shown that some sectors probably locate niches of financial stress, our analysis is not sufficient to assert any structural implications for the underlying physical capital. Indeed, what we considered in this paper is a single decrease in capacity utilization. If these capacities were used for other purposes, the capital would still bring returns. "Demand-induced stranded assets" would materialize only where a stock of capital become definitely unusable.

For instance, Huxham et al. (2019) identify Transnet's physical assets as rail lines that would

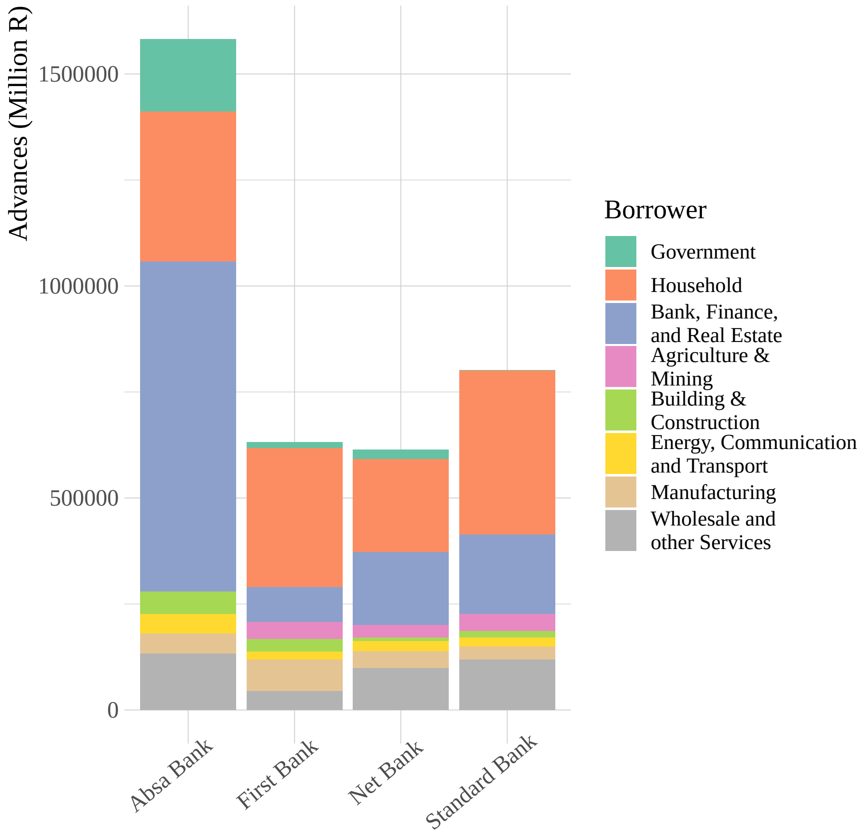

Figure 8: Banks advances per sectors. Source: banks' annual reports and authors' computations.

be let structurally unused if coal mines were closed. Real estate assets in resource-based cities (Dericks et al., 2018), or computer software specialized in services to stranded processes face the same issue. The extent to which they will actually be stranded could be evaluated if and only if we had information on the degree of capital specialization towards the processes (exclusively) involved in the supply of stranded networks. To have a better understanding of stranding dynamics, one should thus relax the hypothesis of homogeneous goods/processes per sector and detail the generic or specific nature of production. Developing ways to systematically appraise specialized capital thus appears as a critical avenue for further researches aiming at assessing the complete cascade of physical and financial assets stranding due to a low-carbon transition.

Adaptive capacities are a key factor in the (non-)materialization of transition risks, as highlighted by Carley et al. (2018). Innovation could play a central role in fostering adaptive capacities. Instead of reducing the production and use of capital in the sectors concerned, the transition could encourage innovation and open up new avenues for development. This would rely on the capacity of the underlying national innovation system to respond appropriately to these new tensions. The "production and linkage structure" dynamic approach proposed by Andersen (2010), particularly the principle of "commodity abstraction", is an

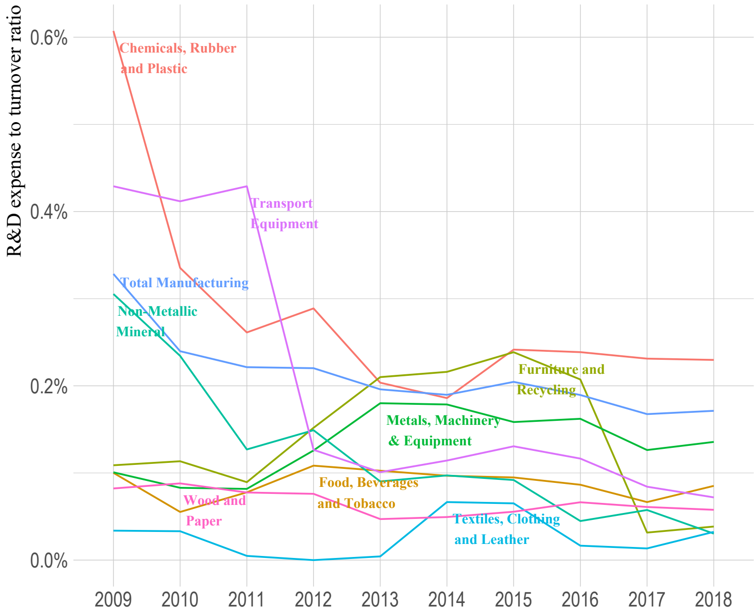

Figure 9: R&D to turnover ratio for selected sectors. Source: Bailey et al. (2019); StatSA (2019a) and authors' computations.

interesting avenue in this regard. "According to this principle, standardized and information poor seller-buyer relationships should be constructed in order to reduce the information burden put upon the parties" (Andersen, 2010, p.86). When the principle operates, adaptive behaviour can occur between sectors. For example, if the automotive industry were to turn to the manufacture of electric vehicles, the upstream links with glass, plastics and textiles could be preserved, as these sectors would be able to adapt to valid characteristics of the automotive sector. The connection to chemicals and some machine parts might not, but new connections could be created (e.g., developing capacity for battery production). We can thus argue that our static IO calculation highlights the potential for structural tension that is reflected in risk as well as the sources of innovation, which would be grasped in a dynamic framework. Tensions can then be positively overcame if the national innovation system is able to resolve them.

Adaptive capacity is thus subject to strategic intervention. A policymaker or investor might be interested to learn that fostering opportunities for learning between sectors could yield positive benefits, rather than just mitigating harm. In fact, fostering dynamic linkages is the main motivation for introducing high-tech export-oriented sectors like automobiles. As noted, that sector is well inserted in the global value chains. From a development perspective, it is a success if it is also inserted into the domestic economy, as measured by domestic backward (and possibly forward) linkages. In a way, the risk identified for this sector is the other side of past success in inserting the sector into the domestic economy. This success could be strengthened by responding adequately to new tensions. To this end, a key element is the capacity for innovation, which is essentially based on the efforts made in Research and Development (R&D from now on) activities. In our case study, a first glimpse at the data from the South African National Survey of Research and experimental Development (Bailey et al., 2019) seems to indicate that the financial effort in this area has been limited and decreasing over the last decade (see Figure 9). Indeed, all manufacturing sectors show a declining R&D spending to total sales ratio over this period, with the exception of the manufacture of electrical machinery sector (not shown in the figure) - from 0.5% to 1.2%).[20] Of particular interest in our analysis, the transport equipment sector sees a decrease from 0.43% to less than 0.1%.

6. Conclusion

The main goal of this paper is to offer a useful methodology to assess the production losses and the financial fragility emerging out of transition shocks propagated through the industrial network. The approach is based on the combination of static demand-driven Input-Output analysis and financial fragility indicators. We use South Africa as a case study and simulate two different export shocks on the coal and lignite and on the motor vehicles sectors.

Aside from the methodological contribution, we highlight that and show how, non-carbon intensive sectors (especially those containing Scope 3 downstream emissions) might indirectly be impacted and hence contribute to financial instability. We show that the exposure of sectors depends on their position in the surrounding industrial network and on the overall structure of expenses in this network. The financial sensitivity depends on internal cost and revenue structures, as well as on the financial health of exposed industries. The sectoral vulnerability ensues from those characteristics (exposure and sensitivity).

In the case of the coal shock, the transport, trade, and financial and technological business-to-business services are sectors the most exposed. The South African economy appears more exposed in general if production loss where to happen in the automotive industry. Furthermore, the number of affected sectors (including the shocked one) owe substantial amounts of financial liabilities. We observe that the financial vulnerability of exposed sectors appear critical for some of them, mainly metal ores, basic iron and steel, glass, auxiliary financial services and utilities sectors, indicating further research agendas to detail the particular situations of the companies composing these sectors.

While the proposed approach allows capturing direct and indirect effects of transition shocks, highlighting the systemic nature of the low carbon economy, the methodology presented here could be improved in order to strengthen the results. The exposure and sensitivity analysis presented in this paper must also be complemented by adaptation capacity analysis. In this way, we might for instance find that the adaptive capacity of the utilities sector is quite high, given its strategic position and its public nature. Further analysis might nonetheless point out the increase the fragility of the public sector in the case the utilities would have to recapitalize the industry. We would also need more recent and more detailed IO data to be able to distinguish precisely imports and exports goods by sector as well

[20] The aggregate ratio decrease from 0.33% to 0.17%. For readability reason we do not show communication and optical equipment sector which sees its ratio decreasing from 4.6% to 1.7%.

as sectoral investment decisions for example. Including dynamics (either via incremental shocks or adjustment mechanisms for example) would allow for more precise analysis. Incorporating substitution effects would also increase the realism of our scenarios. For instance, the development of renewable energy capacities might constitute a beneficial economic opportunity (Merven et al., 2019). Finally, the impossibility to link debts to creditors sharply curtails our capacity to address the interdependency of portfolio vulnerabilities, and then to infer about further financial implications.

These improvements pave the way for a comprehensive macro-model of transition risks assessment including feedback loops between variables such as financing conditions and costs, income and wealth distribution, investment and innovation dynamics. We believe that the Stock-Flow Consistent models such as those presented in Berg et al. (2015); Bovari et al. (2018); Dafermos et al. (2018); Monasterolo and Raberto (2018); Dunz et al. (2019); D'Alessandro et al. (2020); Godin et al. (2020), see Caverzasi and Godin (2015); Nikiforos and Zezza (2017) for two recent surveys, are good founding stones of such a model.

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A. Z-score

The Z-score of Altman (1968) is one of the most commonly used multivariate indicator of financial fragility. It has been constructed as a linear combination of variables supposed to provide the best distinction between the failing and non-failing firms. We employ here its last formula (Z') expressed as follows (Altman and Hotchkiss, 2006):

$$Z'_i = 0.717X1_i + 0.847X2_i + 3.107X3_i + 0.420X4_i + 0.998X5_i \tag{14}$$

where:

- $X1$ = (Current Assets - Current Liabilities) / Total Assets,
- $X2$ = Retained Profit / Total Assets,
- $X3$ = EBITDA / Total Assets,
- $X4$ = Book Value of Equity / Total Equity,
- $X5$ = Sales / Total Assets.

The lower the score, the more likely the company is to face bankruptcy, with limit-values of 1.23 being equated to a default (D) rated bond. Albeit the indicator is initially constructed to be applied to firms data, we use it at the sectoral scale, simply assuming that weak sectors are more likely to contain weak firms.

We can then compute the deterioration of the Z-score following the two exports shocks (resulting from losses in retained profit, EBITDA - both set proportionally to the share of GOS loss - and sales) to appreciate which sectors combine low Z'-score (initial fragility, or gearing sensitivity) and high deterioration in the indicator (high exposure and profit sensitivity). Results are drawn in Figure 10. In order to avoid clogging the figure, we only show sectors having a Z-score below 2.5. While we find some of the previously mentioned sectors standing out again (mainly basic iron and steel, glass, metal ores, precious metal, utilities, transport, computer activity and auxiliary financial), the others however display a relatively high Z-score. This comforts our identification of vulnerable sectors.

a - Z′

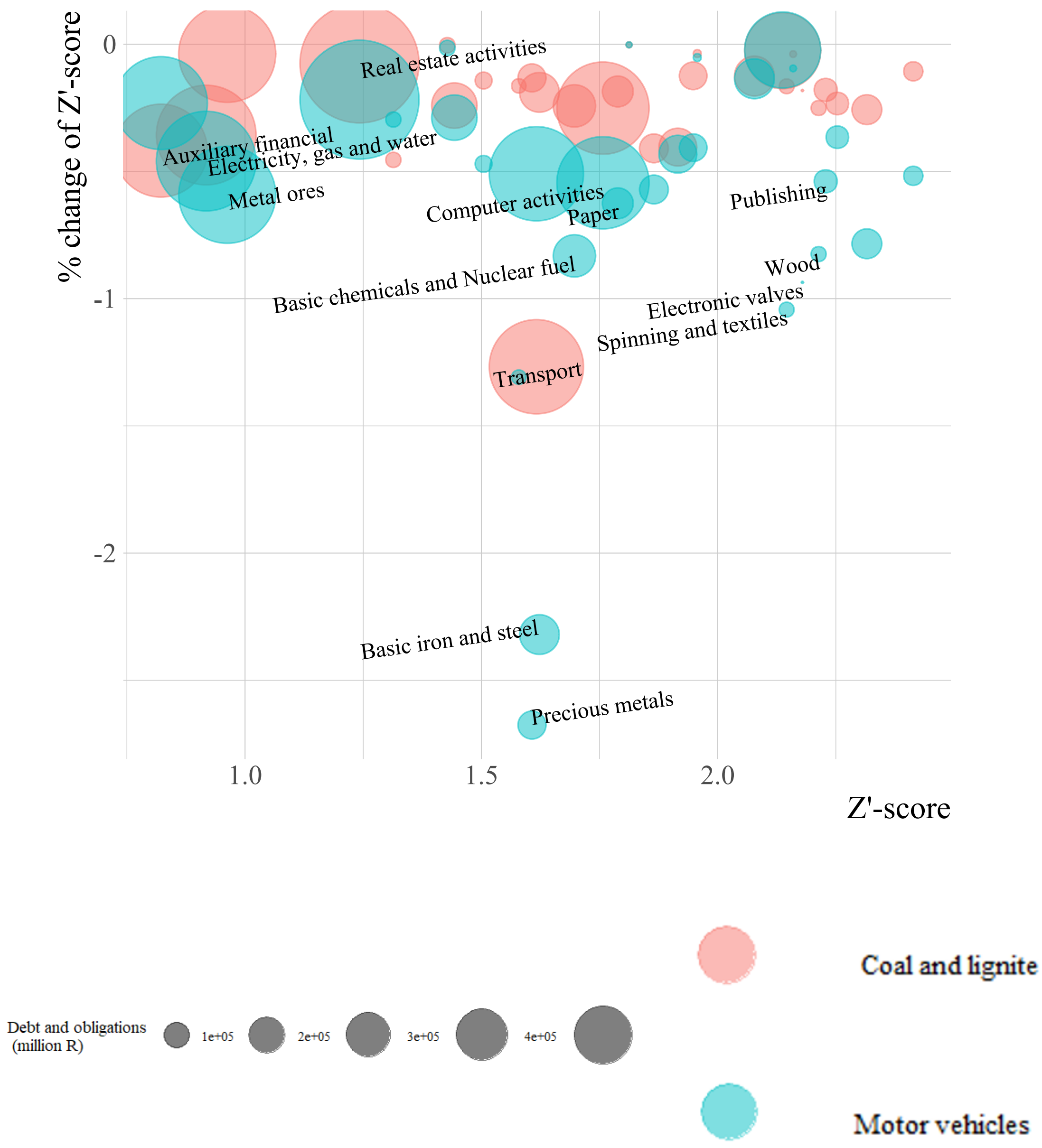

Figure 10: Z′-scores (x-axis) and variation in Z′-score (y-axis) for the coal shock (red) and motor vehicle shock (blue) for selected sectors. Bubble size represent sectorial liability size. Source: StatSA (2017, 2019a) and authors' computations.

B. Concordance table SIC-Eora South-Africa

	SIC	Eora
1	11	1
2	12	1
3	13	1
4	21	2
5	23-24	(3, 4)
6	25	4
7	301-4	(5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15)
8	305-6	16
9	311-2	(17, 18, 19, 20)
10	313-5	(21, 22)
11	316	(23, 24)
12	317	25
13	321-2	26
14	323	(27, 28, 29)
15	324-6	(30, 31)
16	331-2	32
17	333-4	(32, 33, 34, 35)
18	335-6	(36, 37, 38, 39, 40)
19	337	(41, 42)
20	338	43
21	341	44
22	342	(45, 46, 47, 48)
23	391	78
24	392_395	(79, 80)
25	351_353	(49, 50)
26	352	50
27	354-5	(51, 52, 53, 54)
28	356-9	(52, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66)
29	36	(67, 68, 69, 70, 71, 72)
30	371-3	(68, 73)
31	374-6	(72, 74)
32	381-387	(75, 76, 77)
33	41	81
34	42	82
35	5	(83, 84)
36	61-63	85
37	64	86
38	71-74	87
39	75	88
40	81	89
41	82	89
42	83	89
43	84	90
44	85	(91, 94)
45	87	91
46	86_88	91
47	91_94	(92, 94)
48	92	93
49	93	93
50	95_96_99	94

Table 2: Concordance table SIC-Eora South-Africa.

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What is AFD ?
Agence Française de Développement (AFD) Group implements France's policy on development and international solidarity. Comprised of AFD, which finances the public sector and NGOs; Proparco, which finances the private sector; and soon, Expertise France for technical cooperation, the Group finances, supports and accelerates transitions towards a more resilient and sustainable world.
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