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Economic impacts of electricity supply shortages in South Africa

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SA-TIED is a unique collaboration between local and international research institutes and the government of South Africa. Its primary goal is to improve the interface between research and policy by producing cutting-edge research for inclusive growth and economic transformation in the southern African region. It is hoped that the SA-TIED programme will lead to greater institutional and individual capacities, improve database management and data analysis, and provide research outputs that assist in the formulation of evidence-based economic policy.

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Economic impacts of electricity supply shortages in South Africa

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Abstract: This study examines the sectoral impacts of electricity supply shortages in South Africa, using the cost share information available from the 2015 social accounting matrix. A simulation conducted under each of two technological assumptions, Cobb-Douglas and Leontief, reveals that a productivity decline in the electricity, gas, steam, and hot water supply (EGSH) sector increases the price of the EGSH sector substantially, while it affects the other sectors marginally due to the small cost shares of the EGSH factor in these sectors. The total cost of supplying the baseline final demand increases by ZAR19 billion or 0.46% of the baseline gross value added (GVA) when EGSH productivity declines by 10%. This cost impact expands to ZAR150 billion or 3.57% of GVA when EGSH productivity is halved. Large shares of these cost increments are incurred by the EGSH and manufacturing sectors, owning to the direct physical impact of productivity decline for the former and a large share of its sectoral GVA in the aggregate economy for the latter. The simulation also indicates that the equilibrium wage should increase by a greater extent for workers with a lower education than for those with a higher education if the baseline final demands are to be met at the higher EGSH output price after the sector's productivity decline.

Key words: electricity supply shortage, equilibrium price model, South Africa

JEL classification: D57, D58, Q43

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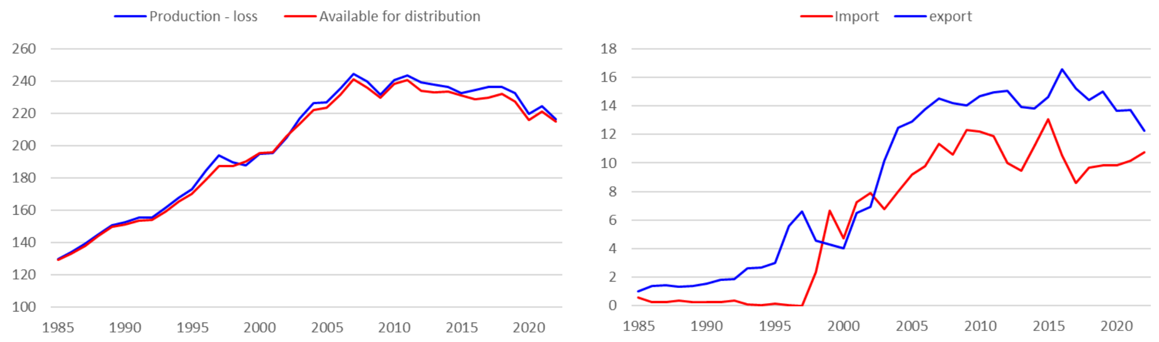
1 Introduction

South Africa has been experiencing severe electricity shortages in the past two and a half decades. According to Mabugu and Inglesi-Lotz (2022), Eskom, the state-owned electricity generator and retail service provider, has been suffering from several governance issues, which have prevented it from making sufficient investment to provide proper maintenance of the existing generation facilities and to expand capacity to meet increasing electricity demand. The problem was exacerbated in 2007, when Eskom was unable to supply sufficient electricity and curtailed its supply to a part of its end users. The demand–supply imbalance eased for several years, but it worsened again after 2014. The average energy availability factor (EAF) fell below 80% and declined further to reach its lowest value of 58.1% in 2022 (Pierce and Le Roux 2023). The magnitude of load shedding increased gradually from 203 GWh in 2014 to 2,521 GWh in 2021, then jumped to 11,529 GWh in 2022. Together with the 8,301 GWh of electricity unserved under the demand-side response programme, the total electricity unserved in 2022 amounted to 8.5% of potential demand.

The importance of electricity—or more broadly energy—for economic growth has been documented widely in the literature (for example, Apergis and Payne 2011; Joyeux and Ripple 2011; and references therein). Insufficient energy supply undoubtedly has substantial impacts on a wide range of economic activities. South Africa is not an exception. As shown in Figure 1, electricity consumption and generation in South Africa both grew on average at 2.95% per annum between 1994 and 2007. During the same period, real GDP increased by 3.5% per annum (Figure 2). Both electricity consumption and GDP growth declined after the Global Financial Crisis, averaging -0.8% and +1.7% per annum, respectively, before the COVID-19 pandemic.

Disruptions of electricity supply can have particularly severe impacts on economic activities because electricity demand is very price-inelastic, at least in the short run, and the lack of economical ways to store electricity prevents demand and/or supply disruptions being smoothed over time. Furthermore, these impacts are likely to vary across industries. Specifically, industries with high electricity intensities are expected to suffer greater adverse impacts from supply disruptions than those with low electricity intensities. Figure 2 illustrates this for South Africa at the macroeconomic level, where the gross value added (GVA) stagnates for the secondary sector during the period of negative electricity consumption growth, while it increases for the tertiary sector, albeit at slightly slower rate. Clear understanding of these variational impacts of electricity supply shortage is crucial both for minimizing its adverse impacts through optimally allocating the scarce electricity resources in the short run and for identifying the optimal investment level for the expansion of generation capacity in the long run. This study aims to examine these variational impacts of electricity supply shortages in South Africa.

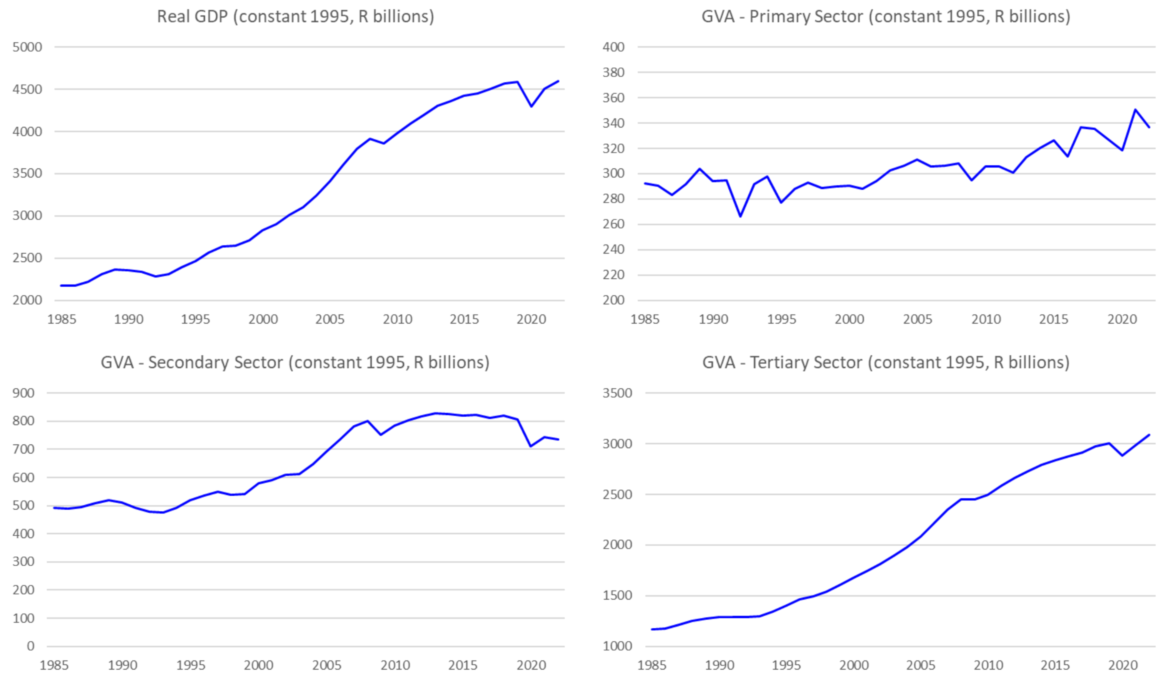
Figure 1: Time series plots of annual electricity production, consumption, import, and export



(a) Electricity generation and distribution (1,000 GWh) (b) Electricity import and export (1,000 GWh)

Source: author’s calculations based on data from Statistics South Africa.

Figure 2: Time series of GDP and GVA of selected sectors



Source: author’s calculations based on data from World Bank World Development Indicators, and South Africa Reserve Bank.

An approach commonly used in previous studies to estimate the value of unserved electricity is to calculate GVA per unit of electricity used in each sector of the economy. This approach is subject to three major drawbacks. First, it assumes that all sectors in the economy operate Leontief production technology, which imposes zero factor substitutability. Second, it does not account for the secondary effects that are incurred by industries using in their production the outputs produced by the sectors that are subject to the direct impacts of electricity supply shortage. Finally, the approach measures the economic value of unserved electricity, which tends to happen only when the supply shortage reaches an extreme level. However, the supply shortage likely constrains the economic activities of industries and other electricity users even before it reaches an extreme level, for example by mitigating demand from pre-agreed user groups through demand-side response programmes or by discouraging demand from broader user groups through tariff rate hikes.

To address these limitations, this study employs an approach proposed by Kim et al. (2017) and constructs a general equilibrium price model using the cost share information available from the

Input–Output (IO) table of South Africa. The model is then used to simulate the effects of constrained electricity supply, in the form of a productivity decline of the electricity sector, on the equilibrium prices of sectoral outputs, the cost of maintaining the baseline final consumption demands, and its distribution across industry sectors. The simulation is conducted under the assumption that all industries operate Cobb-Douglas technology and the results are compared with a conventional case where all industries are assumed to operate Leontief technology.

The rest of the paper is organized as follows. Section 2 reviews previous studies examining the sectoral impacts of electricity supply shortages using data from the IO table. Section 3 presents an approach used to construct a generalized equilibrium price model and to simulate the sectoral impacts of electricity supply shortages. Section 4 describes the data and Section 5 presents the results from the simulation analyses for the sectoral impacts of constrained electricity supply. Section 6 concludes with a synopsis of the results and discusses their policy implications.

2 Previous studies on the sectoral impacts of electricity supply shortage

The economic impacts of electricity supply disruptions have been examined widely in the literature. While various approaches have been used in previous studies, those examining the sectoral impacts of supply shortages using Input–Output (IO) table data are of particular relevance to the current study.[1] An IO table summarizes transactions of goods and services produced and consumed across industry sectors, consumers, and other institutions in an economy. Specifically, it lists how output produced by each industry sector is used by other sectors as production inputs and consumed by households, government, and other institutions as final consumption goods. It also shows how output in each industry is produced from factor inputs from other industries as well as primary production factors, namely labour and capital. The sum of the payments to these primary production factors is termed gross value added (GVA), which represents the contribution of the sector to the economy.

A simple approach to quantifying the economic value of electricity supply disruption is to calculate the GVA produced per unit of electricity used in each sector of the economy. This approach has been used widely in previous studies, including Castro et al. (2016) for Portugal, de Nooji et al. (2007) for Netherlands, Growitsch et al. (2013) for Germany, Leahy and Tol (2011) for Ireland, Linares and Rey (2013) for Spain, and Zachariadis and Poullikkas (2012) for Cyprus. The estimated values, termed value of lost load (VoLL), vary widely due to the differences in the structures of the economies studied. While VoLL also varies across sectors within an economy, previous studies typically report high VoLL for services and household sectors and low VoLL for construction and manufacturing sectors. This is not surprising given that VoLL is simply the ratio of sectoral GVA to the amount of electricity used in the sector and hence it inversely relates to the intensity of electricity used in production process. This property relates to the underlying assumption that each sector operates Leontief technology, which allows no substitutability between production factors.

Another shortcoming of VoLL is that it captures only the direct impact of electricity supply disruption on each sector and does not account for the secondary impacts incurred by sectors

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[1] Other approaches commonly used in examining the economic impacts of electricity supply disruptions include econometrically examining the dynamic relationship between electricity consumption and economic growth, typically through applying vector autoregression-type models to macro-level aggregated data (for example, Apergis and Payne 2011) and the microeconomic analysis of firm-level data (for example, the analyses of World Bank Enterprise Survey (WBES) data by Cole et al. 2018 and Oseni and Pollitt 2015).

utilizing the output produced by the directly affected sector as their production factor. To accommodate these secondary impacts, Chen and Vella (1994) proposed an alternative approach in which aggregate GVA across all sectors of the economy is expressed as a function of the output from the electricity sector, and the optimal allocation of the limited electricity resource is found that maximizes this aggregate GVA. According to this approach, the electricity supply should be curtailed for the sector with the smallest multiplier in the aggregate GVA function. The model typically suggests that the final consumption of electricity by the end users should be curtailed first due to its zero secondary effect. Ju et al. (2016) applied the same approach to quantify the electricity shortage cost in Korea.

For South Africa, Minnaar et al. (2017) calculated both the direct and total costs of unserved electricity using the 2013 IO table. Their estimates of direct cost, as a ratio of sectoral GVA to the amount of electricity used by the respective sector, vary widely across industries, ranging from ZAR5.79 per KWh for manufacturing to ZAR196.47 per KWh for construction. The results are generally consistent with the other studies applying the same approach, which inherently yields a low (high) cost estimate for a sector with high (low) electricity intensity. For the total cost of unserved electricity, Minnaar et al. (2017) used the technical coefficients derived from the IO table to reflect the secondary impacts. The estimated total costs are substantially greater than the direct cost, ranging from ZAR27.60 per KWh for electricity and water supply sector to ZAR376.83 per KWh for the construction sector.

These total cost estimates are more meaningful than those of direct costs as they reflect the secondary impacts of the unserved electricity. Nonetheless, they are subject to two key shortcomings. First, the estimates still assume Leontief production technology and thus allow no factor substitutability in production. Thus, output in each sector is produced in a fixed proportion to electricity use. Second, neither approach incorporates the potential indirect impacts associated with likely price changes. The standard microeconomic model suggests that the optimal output and factor demands of a profit-maximizing firm depend on the prices of output and production factors. Electricity prices, in particular retail tariffs, are often heavily regulated in the short run, yet they are periodically reviewed in the medium to long run. Thus, even though these price effects might be ignored for evaluating the economic impacts of short-term supply disruption, the practice might result in a significant bias when estimating the economic impacts of medium- to long-term supply disruptions, such as planned outages caused by insufficient generation capacity. The following sections consider an approach that addresses these limitations.

3 Method

An IO table records the transactions across various sectors within the economy. It presents how each sector of the economy produces its outputs using primary factors (namely, labour and capital) as well as the outputs produced by other sectors of the economy. It also describes how output produced by each sector is used as intermediate inputs to other sectors or consumed as final consumption goods. For an economy comprised of k sectors, these transactions are typically expressed as:

$$y_j = \sum_{i=1}^{k} x_{ij} + v_j$$

$$y_i = \sum_{j=1}^{k} x_{ij} + f_i + e_i - m_i$$

where y_j is the value of the output produced by sector *j*, x_{ij} is the value of output produced by sector i that is used as an intermediate input in sector *j*, v_j is sector j's payment to the primary production factor or GVA, and f_i, e_i, and m_i represent, respectively, the final demand, export, and import of sector i's output.

As reviewed in Section 2, an approach common in the literature is to calculate the direct cost of electricity supply disruption as a ratio of sectoral GVA to the amount of electricity used by the sector; i.e. $VoLL_j = v_j q_{E,j}^{-1}$, where $q_{E,j}$ is the amount of electricity used in sector *j*. This approach, however, relies on a critical assumption that output in each sector is produced in fixed proportions of electricity and other factor inputs, and hence cannot accommodate potential substitution effects in response to the likely price impacts of a constrained electricity supply. To address this limitation, I follow the approach proposed by Kim et al. (2017) and formulate a general equilibrium price model to examine the economy-wide impacts of a constrained electricity supply under two different technological assumptions, Cobb-Douglas and Leontief technology.[2]

3.1 General equilibrium price model with two production technologies

First, a multifactor Cobb-Douglas production function is specified as, for each economic sector *j* (*j* = 1, …, *k*),

$$q_j = z_j \prod_{i=0}^{k} q_{ij}^{\alpha_{ij}} \tag{1}$$

where q_j is the output produced in sector *j*, and q_{ij} represents the intermediate input that is supplied by sector *i*, and used for production in sector *j*, with q_{0j} being the primary factors (labour and capital) used in sector *j*. z_j and α_{ij} are the parameters determining the productivity and factor substitutability in sector *j*, respectively.

The cost function derived from the multifactor Cobb-Douglas production technology (1) is:

$$TC_j = \left(\frac{\bar{q}_j}{z_j} \prod_{i=0}^{k} \left(\frac{w_i}{\alpha_{ij}}\right)^{\alpha_{ij}}\right)^{\frac{1}{\lambda_j}} \lambda_j$$

where $\lambda_j = \sum_{i=0}^{k} \alpha_{ij}$, w_i is the price of factor *i*, and $\bar{q}_j$ is the a priori determined output level for sector *j*.

The cost share of input i is:

$$a_{ij} = \frac{w_i q_{ij}}{TC_j} = \frac{\alpha_{ij}}{\lambda_j}$$

which simplifies to $a_{ij} = \alpha_{ij}$ if $\lambda_j = 1$, i.e. if sector j operates the constant returns to scale technology. Under the same assumption, the unit cost simplifies to

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[2] In addition to these two production technologies, Kim et al. (2017) considered the case where all sectors in the economy operate Constant Elasticity of Substitution (CES) technology in their analysis of the general equilibrium impacts of sectoral productivity change in Korea and Japan. The current analysis does not consider CES because estimating the CES parameters requires price data corresponding to the industry classification of the IO table, which are not available for South Africa.

$$C_j = z_j^{-1} \prod_{i=0}^{k} \left(\frac{w_i}{\alpha_{ij}}\right)^{\alpha_{ij}} \tag{2}$$

or in a log form,

$$\ln C_j = -\ln \tilde{z}_j + \sum_{i=0}^{k} \alpha_{ij} \ln w_i$$

where $\tilde{z}_j = z_j \prod_{i=0}^{k} \alpha_{ij}^{\alpha_{ij}}$.

If the sector operates competitively and makes zero profit, the unit production cost is equal to the output price. Thus, setting $C_j = w_j$,

$$\ln w_j = -\ln \tilde{z}_j + \alpha_{0j} \ln w_0 + \sum_{i=1}^{k} \alpha_{ij} \ln w_i \tag{3}$$

where the primary factor is separated from the rest of factor inputs.

Equation (3) for $j = 1, \ldots, k$ forms a system of k equations that define the equilibrium prices of k sectoral outputs (w_i for $i = 1, \ldots, k$) as functions of the substitution and productivity parameters (α_{ij} and z_j) as well as the price of the primary factor w_0. It can be expressed in a short form:

$$\ln \mathbf{W} = -\ln \tilde{\mathbf{z}} + \ln w_0 \, \mathbf{a}_0 + \mathbf{A}' \ln \mathbf{W} \tag{4}$$

where $\mathbf{W}$ is a column vector of k output prices, $\tilde{\mathbf{z}} = \left(z_1 \prod_{i=0}^{k} \alpha_{1i}^{\alpha_{1i}}, \ldots, z_k \prod_{i=0}^{k} \alpha_{ki}^{\alpha_{ki}}\right)'$, $\mathbf{A}$ is the technical coefficient matrix with its element $\alpha_{ij} = x_{ij} y_j^{-1}$ obtained from the cost share information from an IO matrix, and $\mathbf{a}_0 = (a_{01}, \ldots, a_{0k})' = (\alpha_{01}, \ldots, \alpha_{0k})'$ is a column vector of substitution parameters of the primary factor with $\alpha_{0j} = x_{0j} y_j^{-1}$ for $j = 1, \ldots, k$.

Setting the price of the primary factor as a numeraire and solving Equation (4) for $\mathbf{W}$ yields

$$\mathbf{W} = \exp\{-(\mathrm{I} - \mathbf{A}')^{-1} \ln \tilde{\mathbf{z}}\} \tag{5}$$

Equation (5) defines the equilibrium prices (relative to the numeraire) of k sector outputs as a function of productivity ($\mathbf{z}$) and substitution parameters ($\mathbf{A}$). It can be used to simulate how the equilibrium prices of k outputs alter in response to a change in the production parameters.

The associated welfare effect can be measured in terms of the change in the total cost required to meet the initial levels of final demands for all k sectors. This can be obtained as:

$$\Delta SW = \mathbf{D}(\mathbf{W}_1 - \mathbf{W}_0) \tag{6}$$

where $\mathbf{D} = (d_1, \ldots, d_k)$ is a k-dimensional vector of final demand, and $\mathbf{W}_0$ and $\mathbf{W}_1$ are k-dimensional vectors of output prices before and after the productivity change, respectively. The total welfare change, ΔSW, is equal to the sum of changes in the value added created by k sectors, which is distributed across k sectors as:

$$\mathbf{V} = \mathbf{a}_0{}'(\mathrm{I} - \mathbf{A})^{-1} \langle \mathbf{W} \odot \mathbf{D} \rangle \tag{7}$$

where $\odot$ is the Hadamard product and $\langle \; \rangle$ converts a vector into a diagonal matrix.

Second, the standard Leontief technology with $k + 1$ production factors can be specified as:

$$q_j = z_j \min\left(a_{0j}q_{0j}, \ldots, a_{kj}q_{kj}\right) \tag{1a}$$

where q_j and q_{ij} are as defined before, and z_j and $a_{ij}$are parameters determining the total productivity and the shares of factor requirement, respectively.[3] Since the production technology (1a) exhibits the constant returns to scale, z_j in (1a) is directly comparable to the one in the Cobb-Douglas case assuming the constant returns to scale.

Under the Leontief case, the production cost is minimized when $\bar{q}_j = z_j a_{ij} q_{ij}$ for $i = 0, \ldots, k$ where $\bar{q}_j$ is the a priori determined output level. The conditional factor demand, cost function, and per unit cost are thus

$$q_{ij}^* = \bar{q}_j (z_j a_{ij})^{-1}$$

$$TC_j(\bar{q}_j) = \sum_{i=0}^{k} p_i q_{ij}^* = \frac{\bar{q}_j}{z_j} \sum_{i=0}^{k} \frac{w_i}{a_{ij}}$$

$$C_j = \frac{TC_j(\bar{q}_j)}{\bar{q}_j} = \frac{1}{z_j} \sum_{i=0}^{k} \frac{w_i}{a_{ij}}$$

where w_i is the price of factor i.

As before, if each industry operates competitively, $C_j = w_j$. Thus, along the equilibrium,

$$w_j = \frac{1}{z_j} \sum_{i=0}^{k} \frac{w_i}{a_{ij}} \tag{3a}$$

for $j = 1, \ldots, k$. The system of k equations (3a) can be expressed in a short form,

$$\mathbf{z} \odot \mathbf{W} = w_0 \mathbf{a}_0 + \mathbf{AW} \tag{4a}$$

where $\mathbf{a}_0$ and $\mathbf{A}$ are k-dimensional column vector and square matrix with their elements, a_{0i}^{-1} and a_{ji}^{-1}, respectively. Solving (4a) for $\mathbf{W}$ yields

$$\mathbf{W} = w_0 (\langle \mathbf{z} \rangle - \mathbf{A})^{-1} \mathbf{a}_0 \tag{5a}$$

As in the Cobb-Douglas case, the effects of reduced productivity of the electricity sector on the equilibrium prices of k sectoral outputs are derived from (5a), while setting the primary production factor as a numeraire ($w_0 = 1$). The impact on the social cost and its distribution across k sectors are obtained as

$$\mathit{\Delta SW} = \mathbf{D}(\mathbf{W}_1 - \mathbf{W}_0) \tag{6a}$$

$$\mathbf{V} = \mathbf{a}_0 (\langle \mathbf{z} \rangle - \mathbf{A})^{-1} \langle \mathbf{D} \rangle \tag{7a}$$

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[3] The productivity coefficient z_j is not identifiable in (1a). It is introduced for simulation analysis where its value is set to unity for all $j = 1, \ldots, 13$ in the initial condition.

where $\mathbf{W}_0$ and $\mathbf{W}_1$ are vectors of output prices before and after the productivity change, and $\mathbf{D}$ is the k-dimensional vector of final demand.

3.2 Simulating the constrained electricity supply

As discussed in Section 1, one of the major causes of recent electricity supply shortages in South Africa is insufficient investment for the maintenance of existing generation facilities and the installation of the additional generation capacity required to meet increasing demand. The supply shortage has reached extreme levels recently, resulting in load shedding of increased magnitudes and frequencies. While previous studies have attempted to quantify the economic value of the unserved electricity, the reduced electricity supply has likely been constraining economic activities of industries and other electricity users even before the supply is curtailed for certain consumers, for example by forcing specific users to reduce their consumption through demand-side response programmes or by encouraging broader groups of users to reduce consumption through tariff hikes. These adjustments are often incomplete and non-instantaneous due to very inelastic electricity demand and the stickiness of electricity tariffs, which are heavily regulated and revised only periodically. Undoubtedly, they will follow very complex dynamics and hence are difficult to model in practice.

As an alternative, the analysis in the subsequent section simulates the sectoral impacts of the constrained electricity supply in a form of reduced productivity of the electricity sector (z_E) and examines how it affects the equilibrium prices and value added generated across economic sectors in South Africa. More specifically, the analysis follows Kim et al. (2017) and sets the output price (w) to unity for all k sectors in the initial state so that the value in each account is interpreted as a physical quantity. The productivity parameters $\tilde{z}_j$ and z_j are also set to unity for all k sectors in the initial state. Since the sectoral output is linear in z, a reduction in z translates into the same fractional decline in the sectoral output, while the levels of factor inputs are not altered. Effects of the reduced parameter z in the electricity sector on sectoral output prices ($\mathbf{W}$), aggregate social costs (ΔSW), and distribution across production sectors ($\mathbf{V}$) are then calculated according to equations (5)–(7). The simulated price and welfare impacts are obtained under each of the two cases with different technology assumptions. Unlike the Cobb-Douglas case, the Leontief technology imposes zero factor substitutability in production; thus it is expected to imply greater price and welfare impacts of a constrained electricity supply than the Cobb-Douglas case. The results from the two scenarios complement each other by providing upper and lower bounds of the predicted impacts of the electricity supply disruption, under which factor substitutability in response to supply disruption is allowed to the minimum or maximum level, respectively.

For both the Cobb-Douglas and Leontief cases, the equilibrium price equations derived in (5) and (5a) assume that the price of each sectoral output is homogeneous in both the input and output markets. The model also presumes no transaction cost so that industries and other agents in the economy can adjust their production and consumption plans efficiently in response to correct price signalling of the resource scarcity. These assumptions are rather unrealistic, particularly for electricity, of which prices tend to vary across sectors and tariffs are often heavily regulated and revised only periodically. Besides, factor substitutions through price signals are likely to be slower and less complete in a real-world than in a simulation setting. Simulation results presented in subsequent sections represent the outcome that could be achieved in an ideal world, which should be used to draw a lower or upper boundary of a real-world outcome in a long run.

4 Data

The structural analysis described in Section 3 is implemented using the 2015 South African social accounting matrix (SAM) constructed by van Seventer et al. (2019). Like an IO table, a SAM records the transactions between any two accounts within the economy, yet it provides more detailed transaction information than an IO table. Specifically, the 2015 South African SAM comprises seven sections, namely, (i) Activity/Industry (62), (ii) Commodity (105), (iii) Factor (5), (iv) Institution (16), (v) Tax (4), (vi) Savings/Inventory (2), and (vii) Rest of the World (1), with the numbers in parentheses representing the number of sub-accounts within each section. By separating the Commodity section from the Activity/Industry section, the 2015 South African SAM records the intermediate consumptions and output of each industry in terms of commodities. It also separates the Factor from the Institution section and further disaggregates them into five subgroups (capital and four groups of labour classified by education level) and 16 subgroups (enterprise, government, and 14 household groups classified according to income level), respectively. This allows the SAM to provide detailed information about the payments from industries to each of five categories of primary factors and how these payments are distributed across subaccounts within the institution section.

To apply the equilibrium analysis presented in Section 3, three major transforms are applied to the 2015 South African SAM. First, following the procedure described in GAIN (2017), I converted all the transactions under the Commodity section into transactions under the Activity/Industry section. Specifically, the transactions (payments) from Activity/Industry to Commodity representing the intermediate consumptions of commodities used in production processes by each activity/industry are converted into transactions from Activity/Industry to Activity/Industry so that they represent the intermediate consumption of output produced by a particular industry that is consumed in the production process of another industry. This transform is performed under the assumption that the commodity consumed in the production process is homogeneous no matter which activity/industry it is sourced from. Other transactions recorded under the Commodity section are similarly transformed into outputs from (or payments by) the Activity/Industry section.

Second, the transactions listed under the Institution section are converted into the Factor section. Key entries transformed are the transactions from Institution to Commodity representing the final demand by each of the 16 institutional groups (14 household groups, enterprise, and government) for the commodities produced by industries. They are first transformed to Institution-to-Activity/Industry and then to Factor-to-Activity/Industry so that they represent the final demand for the output produced by each industry sector that is purchased by payments received in compensation for the supply of each type of primary production factor. Transactions from Institution to Institution representing inter-institutional transfers across enterprise, government, and the 14 household groups are converted accordingly into Factor-to-Factor transactions.

For the third major transform, 62 subaccounts within the Activity/Industry section are aggregated into 13 categories, as shown in Table 1, to make the simulation analysis tractable.

Table 1: Sector aggregation

62 activity accounts in the original 2015 SA SAM	13 aggregated sectors	62 activity accounts in the original 2015 SA SAM	13 aggregated sectors
Agriculture	1 Agriculture	Construction	4 Construction
Forestry		Wholesale trade, commission trade	5 Trade + logistics
Fishing			
Mining of coal and lignite	2 Mining	Retail trade	
Mining of gold and uranium ore		Sale, maintenance, repair of motor vehicles	
Mining of metal ores			
Other mining and quarrying		Hotels and restaurants	
Food	3 Manufacturing	Land transport, transport via pipelines	
Beverages and tobacco			
Spinning, weaving, and finishing of textiles		Water transport	
		Air transport	
Knitted and crocheted fabrics, wearing apparel, fur articles		Auxiliary transport	
Tanning and dressing of leather		Renting of machinery and equipment	
Footwear			
Sawmilling, planing of wood, cork, straw		Post and telecommunication	6 Communication / IT
Paper		Computer and related activities	
Publishing, printing, recorded media		Financial intermediation	7 Financial
Coke ovens, petroleum refineries		Insurance and pension funding	
Nuclear fuel, basic chemicals		Activities to financial intermediation	
Other chemical products, man-made fibres		Real estate activities	
Rubber		Research and experimental development	8 Education + Research
Plastics			
Glass		Education	
Non-metallic minerals		Collection, purification and distribution of water	9 Water / Sewerage
Basic iron and steel, casting of metals		Sewerage and refuse disposal	
Basic precious and non-ferrous metals		Health and social work	10 Health
		Government	11 Govt service
Fabricated metal products			
Machinery and equipment		Activities of membership organisations	12 Other services
Electrical machinery and apparatus		Recreational, cultural and sporting activities	
Radio, television, communication equipment and apparatus		Other activities	
Medical, precision, and optical instruments, watches and clocks		Non-observed, informal, non-profit, households,	
Motor vehicles, trailers, parts		Other business activities	
Other transport equipment		Electricity, gas, steam and hot water supply (EGSH)	13 EGSH
Furniture			
Manufacturing n.e.c., recycling			

Source: author’s construction based on 2015 SA SAM by Pierce and Le Roux (2023).

One of the major advantages of using the SAM is that it disaggregates the primary production factor into five subaccounts, comprising a capital and four labour accounts that are classified according to workers' education level: (i) labour with primary education (grades 1–7), (ii) middle school (grades 8–11), (iii) secondary school (grade 12), and (iv) tertiary education. This disaggregation allows us to examine how the constrained electricity supply affects variously the four labour groups. Specifically, I treat the four labour accounts as if they were part of the Activity/Industry section, while leaving the capital account as a single primary production factor, so that each labour category consumes outputs produced by other activities/industries and converts them into labour that is supplied to the production activities of the other sectors. This treatment allows us to simulate how a productivity change in the electricity sector affects the prices of outputs from 13 industry sectors as well as those of the four labour sectors (i.e. wages), relative to the price of capital as a numeraire. Since the four labour accounts are treated as internal to the system, the simulated impacts reflect the secondary effects through the spending of increased or decreased wages on the consumption of industry outputs. The results of this analysis will be compared with those obtained from a conventional model that aggregates capital and four categories of labour into a single primary production factor.

5 Results

This section presents the results from simulating the economic impacts of productivity changes in the electricity sector based on the 2015 South African SAM. It starts with the model using the aggregate primary production factor and compares the results under the two different technological assumptions: Leontief and Cobb-Douglas technology (Section 5.1). It then reports the results from the model disaggregating the primary production factors into capital and four categories of labour accounts (Section 5.2).

5.1 Model with aggregate primary production sector with Leontief technology

Table 2 shows how the equilibrium prices of outputs from the 13 sectors respond to a change in the productivity of the electricity, gas, steam, and hot water supply (EGSH) sector, ranging from a 50% decline from the base case (z_{EGSH}= 0.5) to a 50% increase (z_{EGSH}= 1.5).[4] The calculation of these prices is based on the model with the capital and four groups of labour aggregated into a single primary production factor, using equations (5a) and (5), respectively, for the Leontief and Cobb-Douglas cases.

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[4] The simulation is implemented for the productivity of the EGSH sector, since the sector is the most disaggregated sector that produces 'Electricity distribution' in the 2015 South African SAM. It is also the sole supplier of the 'Electricity distribution', which accounts for a dominant share (82.2%) of the sector's total output (ZAR177.695 billion). Of the four other commodities produced by the EGSH sector, 'Electricity and gas' accounts for 17.6% of the sector's total output, the remaining three commodities jointly accounting for 0.2% of the sector's output.

Table 2: Simulated price impacts of productivity changes in the EGSH sector—model with exogenous labour sector

(a) Leontief technology

	Productivity of EGSH sector										
	0.5	**0.6**	**0.7**	**0.8**	**0.9**	**1**	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
(s1.i) Agriculture	1.035	1.023	1.014	1.008	1.004	1.000	0.997	0.995	0.993	0.991	0.989
(s1.ii) Mining	1.057	1.037	1.024	1.014	1.006	1.000	0.995	0.991	0.988	0.985	0.983
(s2.i) Manufacturing	1.044	1.029	1.018	1.010	1.005	1.000	0.996	0.993	0.991	0.989	0.987
(s2.ii) Construction	1.025	1.016	1.010	1.006	1.003	1.000	0.998	0.996	0.995	0.994	0.992
(s3.i) Trade + logistics	1.019	1.013	1.008	1.005	1.002	1.000	0.998	0.997	0.996	0.995	0.994
(s3.ii) Information	1.020	1.013	1.008	1.005	1.002	1.000	0.998	0.997	0.996	0.995	0.994
(s3.iii) Financial	1.020	1.013	1.008	1.005	1.002	1.000	0.998	0.997	0.996	0.995	0.994
(s3.iv) Education/ Research	1.026	1.017	1.011	1.006	1.003	1.000	0.998	0.996	0.995	0.993	0.992
(s3.v) Water/Sewerage	1.017	1.011	1.007	1.004	1.002	1.000	0.999	0.997	0.996	0.996	0.995
(s3.vi) Health	1.024	1.016	1.010	1.006	1.003	1.000	0.998	0.996	0.995	0.994	0.993
(s3.vii) Government	1.009	1.006	1.004	1.002	1.001	1.000	0.999	0.999	0.998	0.998	0.997
(s3.viii) Other services	1.022	1.014	1.009	1.005	1.002	1.000	0.998	0.997	0.995	0.994	0.993
(s3.ix) EGSH	2.159	1.752	1.475	1.273	1.120	1.000	0.903	0.823	0.756	0.700	0.651

(b) Cobb-Douglas technology

	Productivity of EGSH sector										
	0.5	**0.6**	**0.7**	**0.8**	**0.9**	**1**	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
(s1.i) Agriculture	1.023	1.017	1.012	1.007	1.003	1.000	0.997	0.994	0.991	0.989	0.987
(s1.ii) Mining	1.038	1.028	1.019	1.012	1.006	1.000	0.995	0.990	0.986	0.982	0.979
(s2.i) Manufacturing	1.029	1.021	1.015	1.009	1.004	1.000	0.996	0.993	0.989	0.986	0.984
(s2.ii) Construction	1.016	1.012	1.008	1.005	1.002	1.000	0.998	0.996	0.994	0.992	0.991
(s3.i) Trade + logistics	1.013	1.009	1.006	1.004	1.002	1.000	0.998	0.997	0.995	0.994	0.993
(s3.ii) Information	1.013	1.010	1.007	1.004	1.002	1.000	0.998	0.997	0.995	0.994	0.992
(s3.iii) Financial	1.013	1.009	1.007	1.004	1.002	1.000	0.998	0.997	0.995	0.994	0.993
(s3.iv) Education/ Research	1.017	1.012	1.009	1.005	1.003	1.000	0.998	0.996	0.994	0.992	0.990
(s3.v) Water/Sewerage	1.011	1.008	1.006	1.004	1.002	1.000	0.998	0.997	0.996	0.995	0.994
(s3.vi) Health	1.016	1.012	1.008	1.005	1.002	1.000	0.998	0.996	0.994	0.992	0.991
(s3.vii) Government	1.006	1.004	1.003	1.002	1.001	1.000	0.999	0.998	0.998	0.997	0.997
(s3.viii) Other services	1.014	1.010	1.007	1.005	1.002	1.000	0.998	0.996	0.995	0.993	0.992
(s3.ix) EGSH	2.104	1.730	1.466	1.271	1.120	1.000	0.903	0.822	0.755	0.697	0.647

Note: the table reports how the equilibrium prices (w_i) of outputs from the 13 sectors of the South African economy, relative to the price of the primary production factor, alter in response to productivity changes in the EGSH sector, ranging from Z_{EGSH} = 0.5 (50% decline from the base case) to Z_{EGSH} = 1.5 (50% increase). These prices are calculated according to Equations (5a) and (5) under the assumption that all 13 sectors operate (a) Leontief and (b) Cobb-Douglas technology, respectively.

Source: author's calculations based on 2015 South African SAM by van Seventer et al. (2019).

In panel (a) of Table 2, the model assuming Leontief technology indicates that, of the 13 sectors considered, the price of the EGSH sector is most sensitive to changes in EGSH productivity. For example, when EGSH productivity declines by 10% from the base case (z_{EGSH}= 0.9), the EGSH price relative to the price of the primary factor increases by 12%. It increases further to 2.159 times the numeraire when EGSH productivity is halved (z_{EGSH} = 0.5). This large price impact on the EGSH sector is attributable to the direct negative impact of EGSH productivity decline on the sector's physical output. The reduced output of the EGSH sector raises the value of EGSH output for final consumption and for intermediate consumptions by the other industries. The increased price of the EGSH output is thus reflected in the production costs of all 13 sectors, raising the output prices of all sectors in the economy. Nonetheless, this secondary price impact is rather moderate due to the small cost shares of the EGSH factor in the productions of all 13 sectors (Table 3). Among them, the mining and manufacturing sectors experience relatively large price changes—respectively, 5.7% and 4.4% above the numeraire—when EGSH productivity is halved, due to the relatively large cost shares of the EGSH factor in their production.

Table 3: Technical coefficients with disaggregated primary factors

	Production in																	
	Agriculture	**Mining**	**Manufacturing**	**Construction**	**Trade + logistics**	**Information**	**Financial**	**Education/Research**	**Water/Sewerage**	**Health**	**Government**	**Other**	**EGSH**	**Labour (grade 1–7)**	**Labour (grade 8–11)**	**Labour (grade 12)**	**Labour (grade 12+)**	**Capital**
(s1.i) Agriculture	0.023	0.000	0.050	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.004	0.000	0.078	0.056	0.030	0.014	0.004
(s1.ii) Mining	0.024	0.018	0.095	0.035	0.001	0.001	0.000	0.006	0.016	0.010	0.003	0.007	0.135	0.002	0.002	0.001	0.000	0.000
(s2.i) Manufacturing	0.232	0.134	0.278	0.317	0.075	0.161	0.032	0.088	0.044	0.141	0.064	0.112	0.076	0.318	0.283	0.220	0.153	0.033
(s2.ii) Construction	0.001	0.004	0.006	0.035	0.016	0.049	0.006	0.033	0.030	0.024	0.007	0.017	0.001	0.003	0.004	0.004	0.003	0.001
(s3.i) Trade + logistics	0.201	0.180	0.169	0.193	0.418	0.111	0.031	0.081	0.039	0.088	0.049	0.097	0.074	0.263	0.244	0.195	0.135	0.029
(s3.ii) Information	0.001	0.006	0.011	0.022	0.018	0.102	0.014	0.047	0.005	0.050	0.038	0.037	0.004	0.023	0.024	0.023	0.018	0.003
(s3.iii) Financial	0.051	0.042	0.015	0.023	0.041	0.039	0.265	0.029	0.016	0.052	0.019	0.072	0.014	0.080	0.096	0.117	0.129	0.020
(s3.iv) Educ/Research	0.000	0.001	0.002	0.001	0.002	0.003	0.006	0.005	0.004	0.002	0.000	0.007	0.001	0.012	0.015	0.018	0.018	0.003
(s3.v) Water/Sew'age	0.004	0.014	0.002	0.000	0.002	0.001	0.002	0.002	0.340	0.002	0.001	0.002	0.000	0.006	0.007	0.007	0.006	0.001
(s3.vi) Health	0.026	0.000	0.000	0.001	0.001	0.009	0.013	0.043	0.001	0.004	0.015	0.022	0.000	0.043	0.042	0.039	0.034	0.006
(s3.vii) Government	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.052	0.077	0.000	0.000	0.005	0.006	0.008	0.009	0.192
(s3.viii) Other services	0.028	0.033	0.044	0.063	0.091	0.143	0.053	0.150	0.018	0.099	0.037	0.056	0.019	0.060	0.065	0.072	0.076	0.012
(s3.ix) EGSH	0.014	0.039	0.017	0.002	0.004	0.003	0.009	0.011	0.005	0.009	0.002	0.009	0.057	0.032	0.031	0.026	0.018	0.004
Labour (grade 1–7)	0.029	0.019	0.006	0.014	0.007	0.001	0.001	0.002	0.012	0.004	0.012	0.040	0.003	0	0	0	0	0
Labour (grade 8–11)	0.024	0.030	0.018	0.022	0.016	0.004	0.002	0.008	0.014	0.009	0.025	0.052	0.003	0	0	0	0	0
Labour (grade 12)	0.026	0.070	0.039	0.040	0.038	0.023	0.045	0.014	0.028	0.026	0.139	0.055	0.018	0	0	0	0	0
Labour (grade 12+)	0.042	0.129	0.080	0.064	0.065	0.117	0.147	0.177	0.070	0.153	0.400	0.088	0.144	0	0	0	0	0
Capital	0.255	0.274	0.079	0.155	0.157	0.163	0.317	0.274	0.324	0.172	0.080	0.269	0.420	0.046	0.076	0.143	0.222	0.313

Note: values reported in the table, $\alpha_{ij} = x_{ij}/y_j$, are the ratio of the payment from the column *j* sector to the row *i* sector (x_{ij}) to the value of total output produced by the column *j* sector (y_j). For the first 13 columns representing industry sectors (*j* = 1, ..., 13), they represent the technical coefficients, i.e. the cost share of the production factor from industry *i* (*i* = 1, …, 13) or the primary production factor *i* (*i* = 14, …, 18) in industry *j*'s production. For the last five columns (*j* = 14, …, 18), these coefficients represent the expenditure shares, i.e. how the compensation received by primary factor *j* is used for the consumption of the output from industry *i* (*i* = 1, …, 13) and for capital investment (*i* = 18).

Source: author's calculations based on 2015 South African SAM by van Seventer et al. (2019).

Table 4 illustrates how EGSH productivity affects the cost required to meet the same levels of final demand less net exports as in the baseline. The calculations are based on the model with the aggregate primary production factor, using Equations (6a) and (6) for the Leontief and Cobb-Douglas cases, respectively. In the last row of panel (a) of Table 4, a 10% decline in EGSH productivity ($z_{EGSH} = 0.9$) increases the cost of meeting the baseline final demand by ZAR19.620 billion, which translates into merely 0.478% of the baseline total cost (ZAR4,103.6 billion). This small cost impact is attributable to the small cost shares of the EGSH factor in the South African economy, which average only 2% of total intermediate consumptions across the 13 industries. The total cost increases nonlinearly as EGSH productivity declines further, yet the cost impact stays at around 4.472% above the base level even when EGSH productivity is halved ($z_{EGSH} = 0.5$).

Table 4: Social cost impacts of EGSH productivity change—model with exogenous labour sector

(a) Leontief

	Productivity of EGSH sector										
	0.5	**0.6**	**0.7**	**0.8**	**0.9**	**1**	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
(s1.i) Agriculture	100.7	99.5	98.7	98.1	97.6	97.3	97.0	96.7	96.5	96.4	96.2
(s1.ii) Mining	18.7	18.4	18.1	17.9	17.8	17.7	17.6	17.5	17.5	17.4	17.4
(s2.i) Manufacturing	1011.1	996.2	986.0	978.6	973.0	968.6	965.0	962.1	959.6	957.6	955.8
(s2.ii) Construction	301.9	299.4	297.6	296.3	295.4	294.6	294.0	293.5	293.1	292.7	292.4
(s3.i) Trade + logistics	746.5	741.5	738.1	735.7	733.8	732.3	731.1	730.1	729.3	728.6	728.0
(s3.ii) Information	72.5	72.0	71.6	71.4	71.2	71.1	70.9	70.8	70.8	70.7	70.6
(s3.iii) Financial	447.7	444.7	442.6	441.1	440.0	439.1	438.4	437.8	437.3	436.8	436.5
(s3.iv) Educ/Research	77.5	76.9	76.4	76.1	75.8	75.6	75.4	75.3	75.2	75.1	75.0
(s3.v) Water/Sew'age	23.4	23.2	23.1	23.1	23.0	23.0	23.0	22.9	22.9	22.9	22.9
(s3.vi) Health	129.4	128.3	127.6	127.1	126.7	126.3	126.1	125.9	125.7	125.5	125.4
(s3.vii) Government	866.0	863.2	861.3	859.9	858.8	858.0	857.3	856.8	856.3	855.9	855.6
(s3.viii) Other services	329.5	327.0	325.3	324.1	323.1	322.4	321.8	321.3	320.9	320.6	320.3
(s3.ix) EGSH	167.8	136.2	114.6	99.0	87.1	77.7	70.2	64.0	58.8	54.4	50.6
Total	4,292.6	4,226.4	4,181.1	4,148.2	4,123.2	4,103.6	4,087.8	4,074.8	4,063.9	4,054.6	4,046.6

(b) Cobb-Douglas

	Productivity of EGSH sector										
	0.5	**0.6**	**0.7**	**0.8**	**0.9**	**1**	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
(s1.i) Agriculture	99.5	98.9	98.4	98.0	97.6	97.3	96.9	96.7	96.4	96.2	96.0
(s1.ii) Mining	18.4	18.2	18.0	17.9	17.8	17.7	17.6	17.5	17.5	17.4	17.3
(s2.i) Manufacturing	996.3	988.9	982.7	977.4	972.7	968.6	964.8	961.4	958.3	955.4	952.7
(s2.ii) Construction	299.3	298.1	297.0	296.1	295.3	294.6	294.0	293.4	292.8	292.3	291.9
(s3.i) Trade + logistics	741.5	739.1	737.0	735.2	733.7	732.3	731.1	729.9	728.9	727.9	727.0
(s3.ii) Information	72.0	71.7	71.5	71.4	71.2	71.1	70.9	70.8	70.7	70.6	70.5
(s3.iii) Financial	444.6	443.2	441.9	440.9	439.9	439.1	438.3	437.6	437.0	436.4	435.8
(s3.iv) Educ/Research	76.9	76.5	76.2	76.0	75.8	75.6	75.4	75.3	75.1	75.0	74.9
(s3.v) Water/Sew'age	23.2	23.2	23.1	23.1	23.0	23.0	22.9	22.9	22.9	22.9	22.8
(s3.vi) Health	128.3	127.8	127.3	127.0	126.6	126.3	126.1	125.8	125.6	125.4	125.2
(s3.vii) Government	863.1	861.8	860.6	859.6	858.8	858.0	857.3	856.6	856.1	855.5	855.0
(s3.viii) Other services	327.0	325.8	324.7	323.9	323.1	322.4	321.8	321.2	320.7	320.2	319.8
(s3.ix) EGSH	163.6	134.5	114.0	98.8	87.0	77.7	70.2	63.9	58.6	54.2	50.3
Total	4,253.6	4,207.6	4,172.7	4,145.2	4,122.6	4,103.6	4,087.3	4,073.1	4,060.6	4,049.3	4,039.2

Note: the table presents how the total cost (in the last row) required to meet the baseline final demand of the outputs from the 13 sectors alters with a change in EGSH productivity ranging from 0.5 (50% decline from the base case) to 1.5 (50% increase), and how this cost is distributed across 13 sectors (rows 1–13). They are calculated according to Equations (7a) and (7) under the Leontief and Cobb-Douglas cases, respectively.

Source: author's calculations based on 2015 South African SAM by van Seventer et al. (2019).

At the sectoral level, the EGSH sector incurs a significant cost increase from its own productivity decline, with a 10% (50%) reduction in z_{EGSH} raising the sector's cost by 12.0% (110.4%). This large cost increase is attributable primarily to the direct impact of the productivity decline, which linearly lowers the physical output of EGSH production, and secondarily to the price impacts that raise the costs of its factor inputs from all 13 sectors. The other 12 sectors experience a limited cost impact by z_{EGSH} decline, as they receive only the secondary price impacts, which are at most moderate due to the small cost shares of the EGSH factor in their production. Among these, the manufacturing sector incurs the largest cost increase, due to the sector's large share in the total final demand (roughly 24% in 2015). Consequently, the EGSH and manufacturing sectors incur the largest shares (47.6 and 22.5%, respectively) of the total cost increment from a 10% decline in z_{EGSH}.

Panel (b) of Table 2 presents the equilibrium price impacts of EGSH productivity changes simulated on the model assuming Cobb-Douglas technology. As expected, the Cobb-Douglas case—allowing factor substitutability—shows smaller price impacts than the Leontief case for any levels of EGSH productivity change and for all 13 industry sectors. Nonetheless, the difference in the implied price impacts between the two cases is small, simply because EGSH productivity has only marginal price impacts on the majority of sectors in both the Leontief and Cobb-Douglas cases. The difference is particularly small for small changes in z_{EGSH} and it grows with the magnitude of the z_{EGSH} change. For example, the difference in the output price of the EGSH sector between the Leontief and Cobb-Douglas cases is less than 0.001 when z_{EGSH} declines by 0.1, yet it increases to 0.054 when z_{EGSH} declines by 0.5. The same tendency is observed for the other sectors, with the price impacts always smaller in the Cobb-Douglas case than the Leontief case and the difference between the two cases increasing with the magnitude of z_{EGSH} change.

In panel (b) of Table 4, EGSH productivity's impacts on the cost of meeting the baseline final demands are smaller in the Cobb-Douglas case than in the Leontief case. Again, the result is as expected, given that Cobb-Douglas allows factor substitution while Leontief technology does not. As with the price impacts, the difference in the implied cost impacts between the two cases is small for a small change in z_{EGSH} and it widens as z_{EGSH} changes by greater magnitudes.

5.2 Model with disaggregated primary production factor

Tables 5 and 6 present the price and cost impacts of EGSH productivity changes simulated on the model disaggregating the primary production factor into five categories. The model treats capital as a numeraire while determining the equilibrium prices of the four labour categories (i.e. wages) endogenously.

Table 5: Simulated price impacts of EGSH productivity change—model with endogenous labour sector

(a) Leontief

	Productivity of EGSH sector										
	0.5	**0.6**	**0.7**	**0.8**	**0.9**	**1**	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
(s1.i) Agriculture	1.060	1.039	1.024	1.014	1.006	1.000	0.995	0.991	0.988	0.985	0.982
(s1.ii) Mining	1.086	1.056	1.035	1.020	1.009	1.000	0.993	0.987	0.982	0.978	0.975
(s2.i) Manufacturing	1.072	1.046	1.029	1.017	1.007	1.000	0.994	0.989	0.985	0.982	0.979
(s2.ii) Construction	1.053	1.034	1.021	1.012	1.005	1.000	0.996	0.992	0.989	0.987	0.984
(s3.i) Trade + logistics	1.045	1.029	1.018	1.010	1.005	1.000	0.996	0.993	0.991	0.989	0.987
(s3.ii) Information	1.045	1.029	1.018	1.011	1.005	1.000	0.996	0.993	0.991	0.989	0.987
(s3.iii) Financial	1.041	1.027	1.017	1.010	1.004	1.000	0.997	0.994	0.992	0.990	0.988
(s3.iv) Educ/Research	1.050	1.033	1.020	1.012	1.005	1.000	0.996	0.992	0.990	0.987	0.985
(s3.v) Water/Sew'age	1.037	1.024	1.015	1.008	1.004	1.000	0.997	0.995	0.992	0.991	0.989
(s3.vi) Health	1.050	1.033	1.020	1.012	1.005	1.000	0.996	0.992	0.990	0.987	0.985
(s3.vii) Government	1.053	1.034	1.022	1.012	1.005	1.000	0.996	0.992	0.989	0.987	0.984
(s3.viii) Other services	1.050	1.032	1.020	1.012	1.005	1.000	0.996	0.993	0.990	0.987	0.985
(s3.ix) EGSH	2.200	1.774	1.486	1.279	1.122	1.000	0.902	0.821	0.753	0.696	0.647
Labour (grade 1–7)	1.089	1.057	1.036	1.021	1.009	1.000	0.993	0.987	0.982	0.977	0.974
Labour (grade 8–11)	1.084	1.054	1.034	1.019	1.009	1.000	0.993	0.988	0.983	0.979	0.975
Labour (grade 12)	1.070	1.045	1.029	1.016	1.007	1.000	0.994	0.989	0.986	0.982	0.979
Labour (grade 12+)	1.053	1.034	1.022	1.012	1.005	1.000	0.996	0.992	0.989	0.987	0.984

(b) Cobb-Douglas

	Productivity of EGSH sector										
	0.5	**0.6**	**0.7**	**0.8**	**0.9**	**1**	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
(s1.i) Agriculture	1.039	1.028	1.020	1.012	1.006	1.000	0.995	0.990	0.986	0.982	0.978
(s1.ii) Mining	1.056	1.041	1.028	1.018	1.008	1.000	0.993	0.986	0.980	0.974	0.969
(s2.i) Manufacturing	1.046	1.034	1.024	1.015	1.007	1.000	0.994	0.988	0.983	0.978	0.974
(s2.ii) Construction	1.034	1.025	1.017	1.011	1.005	1.000	0.995	0.991	0.987	0.984	0.981
(s3.i) Trade + logistics	1.029	1.021	1.015	1.009	1.004	1.000	0.996	0.993	0.989	0.986	0.984
(s3.ii) Information	1.029	1.021	1.015	1.009	1.004	1.000	0.996	0.993	0.989	0.986	0.983
(s3.iii) Financial	1.026	1.019	1.013	1.008	1.004	1.000	0.996	0.993	0.990	0.987	0.985
(s3.iv) Educa/Research	1.032	1.024	1.016	1.010	1.005	1.000	0.996	0.992	0.988	0.985	0.982
(s3.v) Water/Sew'age	1.023	1.017	1.012	1.007	1.004	1.000	0.997	0.994	0.991	0.989	0.987
(s3.vi) Health	1.032	1.024	1.016	1.010	1.005	1.000	0.996	0.992	0.988	0.985	0.982
(s3.vii) Government	1.034	1.025	1.017	1.011	1.005	1.000	0.995	0.991	0.987	0.984	0.981
(s3.viii) Other services	1.032	1.023	1.016	1.010	1.005	1.000	0.996	0.992	0.988	0.985	0.982
(s3.ix) EGSH	2.130	1.746	1.476	1.276	1.122	1.000	0.901	0.820	0.751	0.693	0.643
Labour (grade 1–7)	1.058	1.042	1.029	1.018	1.009	1.000	0.992	0.985	0.979	0.973	0.968
Labour (grade 8–11)	1.054	1.040	1.028	1.017	1.008	1.000	0.993	0.986	0.980	0.975	0.970
Labour (grade 12)	1.045	1.033	1.023	1.014	1.007	1.000	0.994	0.988	0.983	0.979	0.974
Labour (grade 12+)	1.034	1.025	1.017	1.011	1.005	1.000	0.995	0.991	0.987	0.984	0.981

Note: the table reports how the equilibrium prices (w_i) of outputs from the 13 sectors and wages of four labour groups, relative to the price of capital, alter in response to the productivity change of the EGSH sector, ranging from Z_{EGSH} = 0.5 (50% decline from the base case) to Z_{EGSH} = 1.5 (50% increase). These prices are calculated according to Equations (5a) and (5) under the assumption that all 13 sectors operate Leontief and Cobb-Douglas technology, respectively.

Source: author's calculations based on 2015 South African SAM by van Seventer et al. (2019).

Table 6: Social cost impacts of EGSH productivity change—model with endogenous labour sector

(a) Leontief

	Productivity of EGSH sector										
	0.5	**0.6**	**0.7**	**0.8**	**0.9**	**1**	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
(s1.i) Agriculture	23.0	22.5	22.2	22.0	21.8	21.7	21.6	21.5	21.4	21.3	21.3
(s1.ii) Mining	17.1	16.6	16.3	16.1	15.9	15.7	15.6	15.5	15.5	15.4	15.3
(s2.i) Manufacturing	466.6	455.5	448.0	442.6	438.5	435.4	432.8	430.7	428.9	427.4	426.2
(s2.ii) Construction	300.9	295.5	291.9	289.3	287.3	285.8	284.5	283.5	282.7	281.9	281.3
(s3.i) Trade + logistics	278.4	274.2	271.3	269.2	267.7	266.5	265.5	264.7	264.0	263.4	262.9
(s3.ii) Information	16.6	16.4	16.2	16.1	16.0	15.9	15.8	15.8	15.7	15.7	15.7
(s3.iii) Financial	124.2	122.5	121.3	120.4	119.8	119.3	118.9	118.6	118.3	118.0	117.8
(s3.iv) Educ/Research	30.8	30.3	30.0	29.7	29.5	29.4	29.2	29.1	29.1	29.0	28.9
(s3.v) Water/Sew'age	6.6	6.5	6.4	6.4	6.4	6.3	6.3	6.3	6.3	6.3	6.3
(s3.vi) Health	28.4	27.9	27.6	27.4	27.2	27.0	26.9	26.8	26.8	26.7	26.6
(s3.vii) Government	880.2	864.4	853.8	846.1	840.3	835.7	832.1	829.1	826.6	824.5	822.7
(s3.viii) Other services	133.6	131.3	129.8	128.7	127.9	127.2	126.7	126.3	125.9	125.6	125.4
(s3.ix) EGSH	36.7	29.6	24.8	21.3	18.7	16.7	15.0	13.7	12.6	11.6	10.8
Labour (grade 1–7)	114.9	111.5	109.3	107.7	106.4	105.5	104.7	104.1	103.5	103.1	102.7
Labour (grade 8–11)	140.2	136.4	133.8	131.9	130.5	129.4	128.5	127.8	127.2	126.7	126.2
Labour (grade 12)	211.7	206.8	203.4	201.0	199.2	197.8	196.6	195.7	194.9	194.2	193.7
Labour (grade 12+)	369.3	362.7	358.2	355.0	352.5	350.6	349.1	347.9	346.8	345.9	345.2
Total	3,179.1	3,110.6	3,064.2	3,030.8	3,005.6	2,985.8	2,970.0	2,957.0	2,946.1	2,936.9	2,929.0

(b) Cobb-Douglas

	Productivity of EGSH sector										
	0.5	**0.6**	**0.7**	**0.8**	**0.9**	**1**	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
(s1.i) Agriculture	22.5	22.3	22.1	21.9	21.8	21.7	21.6	21.5	21.4	21.3	21.2
(s1.ii) Mining	16.6	16.4	16.2	16.0	15.9	15.7	15.6	15.5	15.4	15.3	15.2
(s2.i) Manufacturing	455.5	450.1	445.6	441.7	438.4	435.4	432.7	430.2	428.0	425.9	424.0
(s2.ii) Construction	295.5	292.9	290.7	288.8	287.2	285.8	284.5	283.3	282.2	281.2	280.2
(s3.i) Trade + logistics	274.1	272.1	270.4	268.9	267.6	266.5	265.4	264.5	263.6	262.8	262.1
(s3.ii) Information	16.4	16.2	16.1	16.0	16.0	15.9	15.8	15.8	15.7	15.7	15.6
(s3.iii) Financial	122.4	121.6	120.9	120.3	119.8	119.3	118.9	118.5	118.1	117.8	117.5
(s3.iv) Educ/Research	30.3	30.1	29.9	29.7	29.5	29.4	29.2	29.1	29.0	28.9	28.8
(s3.v) Water/Sew'age	6.5	6.4	6.4	6.4	6.4	6.3	6.3	6.3	6.3	6.3	6.3
(s3.vi) Health	27.9	27.7	27.5	27.3	27.2	27.0	26.9	26.8	26.7	26.6	26.5
(s3.vii) Government	864.2	856.6	850.3	844.8	840.0	835.7	831.9	828.4	825.2	822.3	819.5
(s3.viii) Other services	131.3	130.2	129.3	128.5	127.8	127.2	126.7	126.2	125.7	125.3	124.9
(s3.ix) EGSH	35.5	29.1	24.6	21.3	18.7	16.7	15.0	13.7	12.5	11.5	10.7
Labour (grade 1–7)	111.6	109.9	108.6	107.4	106.4	105.5	104.7	103.9	103.3	102.6	102.1
Labour (grade 8–11)	136.4	134.5	133.0	131.6	130.4	129.4	128.5	127.6	126.8	126.1	125.5
Labour (grade 12)	206.7	204.3	202.3	200.6	199.1	197.8	196.6	195.5	194.5	193.6	192.7
Labour (grade 12+)	362.6	359.4	356.7	354.4	352.4	350.6	349.0	347.6	346.2	345.0	343.8
Total	3,116.0	3,079.9	3,050.5	3,025.8	3,004.5	2,985.8	2,969.2	2,954.3	2,940.7	2,928.2	2,916.7

Note: the table presents how the total cost (in the last row) required to meet the base line final demand of the outputs from the 13 sectors alters with a change in EGSH productivity ranging from 0.5 (50% decline from the base case) to 1.5 (50% increase), and how this cost is distributed across 13 sectors as well as the four labour groups (rows 1–17). The cost is calculated according to Equations (7a) and (7) in the Leontief and Cobb-Douglas cases, respectively.

Source: author's calculations based on 2015 South African SAM by van Seventer et al. (2019).

Two observations are worth noting on Tables 5 and 6. First, the equilibrium prices of the four labour categories all increase monotonically with a decline in EGSH productivity. That is, the wages of all four labour groups become increasingly expensive relative to the capital as z_{EGSH} declines. Furthermore, comparing the four labour groups, wages increase most for labour with primary education and less for labour with higher education.

These results appear to be driven by the price effects from the expenditure side rather than the revenue side of the primary factor accounts. In Equation (3), the output price from each sector ($\ln w_j$) is equalized to the per-unit production cost (the right-hand side of Equation (3)) along the equilibrium. The first term of this per-unit production cost ($-\ln z_j$) represents the direct impact of the productivity change in sector j on the sector's own output price ($\ln w_j$). This effect is negative as the productivity increase ($z_j > 1$ or $\ln z_j > 0$) lowers the per-unit production cost of sector *j*. It also lowers the production costs of the other sectors in the economy that utilize sector *j* output in their production. This creates the secondary impact on the sector *j* output price through the substitution parameters (α_{ij}), which is captured by the second term on the right-hand side of Equation (3). For the model internalizing the four labour accounts, the substitution parameter (α_{ik}) for labour account k represents the expenditure share, i.e. the share of the expenditure by labour group k that is spent for the consumption of output produced by sector *i*.

As Table 3 shows, the expenditure share of the EGSH consumption is the highest for labour with the lowest education (3.2%) and it decreases monotonically as the education level increases. Thus, with the price hike of EGSH output resulting from the EGSH productivity decline, the equilibrium wage needs to increase for all four labour groups, but by the largest magnitude for the labour group with the lowest education, so that they can maintain the same levels of expenditure share as in the baseline. This result is peculiar to the equilibrium nature of the simulation model; the decline in EGSH productivity raises the EGSH output price, which needs to be associated with an increase in the prices of its consumers—either the industries using EGSH output as a production factor or the end users consuming EGSH output as a final product. The first observation that the equilibrium wage increases for all four labour groups relative to the numeraire results from the same mechanism via the greater expenditure share on EGSH consumption for all four labour groups than for the capital account.

The second observation is that the model with disaggregated primary factors implies greater price impacts of reduced EGSH productivity on all 13 industry sectors than the model with the aggregated primary factor. This result is attributable to the difference in the numeraire between the two models; the model with the disaggregated primary factors sets the capital as the numeraire, whereas the model with the aggregated primary factor sets the aggregated primary factor as the numeraire. Since the EGSH productivity decline raises the wages of all four labour groups relative to the capital, the numeraire would be lower in the model with the disaggregated primary factors than the one with the aggregated primary factor.

Aside from the above observations, the price and cost impacts of the EGSH productivity change reported in Tables 5 and 6 are similar to those obtained for the model with the aggregated primary factor. That is, the EGSH sector receives the largest price and cost impacts from the EGSH productivity change, due to the direct negative impact on its physical output. The price and cost impacts on the other 12 sectors are marginal due to the small cost share of the EGSH factor in their production. Furthermore, for all 13 sectors and for any levels of the EGSH productivity change, the model assuming Cobb-Douglas production technology implies the smaller price and cost impacts than the model assuming Leontief technology due to factor substitutability.

6 Conclusion

This study examined the sectoral impacts of electricity supply shortages in South Africa by constructing a general equilibrium price model based on the cost share information available from the 2015 SAM. Unlike previous studies, the analysis allowed factor substitutability by assuming that every sector operates multifactor Cobb-Douglas production technology, and compared the results from the conventional Leontief model. The simulation is conducted in the form of a productivity decline in the EGSH sector, to account for adverse impacts of a constrained electricity supply before it reaches an extreme level where electricity supply is curtailed for certain users (i.e. load shedding). The model assumes uniform and competitive pricing of each sectoral output. It also implicitly assumes that production and consumption activities respond instantaneously to any exogenous shocks. While these assumptions deviate from the reality to various extents, the presented simulation results are still useful as a reference-case estimate of the impacts that could be attainable were the scarce electricity resource allocated efficiently through the correct price signalling with no transaction cost.

The analysis reveals that a decline in EGSH sector productivity increases the price of EGSH sector output substantially, due to its direct negative impact on the physical output. Prices are also increased for the other sectors but only marginally, due to the small cost shares of the EGSH factor in the production of these sectors. A reduced productivity of the EGSH sector raises the cost of meeting the baseline final demands, a 10% decline in EGSH sector productivity raising the cost of meeting current final demands by ZAR18.982 billion under the assumed Cobb-Douglas technology or ZAR19.620 billion in the Leontief case. These increases correspond to the small shares of the baseline cost, 0.46% and 0.48%, respectively, for the Cobb-Douglas and Leontief cases, due to small shares of the EGSH factor across all industries. The largest shares of this cost increment are incurred by the EGSH and manufacturing sectors, owning to a direct physical impact for the former and a large share of sectoral GVA in total GDP for the latter. The analysis also indicates that wages should increase by a greater extent for the labour group with the lowest education than for those with higher education, if the baseline final demand for EGSH output is maintained at the higher EGSH price resulting from the EGSH productivity decline.

Some policy implications follow from these results. First, to address the fundamental cause of the current supply shortage, a sufficient level of investment needs to be made for adequate maintenance of the existing generation facilities and expansion of supply capacity. It is desirable that a further analysis is conducted to jointly assess the optimal mixture of generation asset types in consideration of the global movement towards clean and renewable energy. Second, the general equilibrium analysis allowing factor substitution and instantaneous reallocation of scarce resources implies smaller cost impacts of the constrained electricity supply than the model not allowing factor substitution. This result highlights the importance of designing market mechanisms that promote the efficient allocation of scarce electricity resources and hence moderate the adverse impacts of a constrained electricity supply. Economists instinctively believe that proper, market-based pricing will help achieve efficient resource allocation. This is often difficult in practice for electricity because its true economic value fluctuates immensely at a very high frequency, yet the majority of end users do not observe these true economic signals while paying fixed retail rates, which are revised only periodically. Non-uniform or discriminatory pricing might be supported when some secondary objective such as equal distribution applies. Yet, its benefits relative to the associated cost of efficiency loss should be monitored carefully and continuously as the electricity demand–supply balance changes over time.

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