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Mining-related national systems of innovation in southern Africa

National trajectories and regional integration

Judith Fessehaie, Zavareh Rustomjee, and Lauralyn Kaziboni*

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Abstract: This paper explores the linkages between the national systems of innovation of Botswana, South Africa, Zambia, and Zimbabwe and their respective mineral extraction and mineral processing value chains, including input industries.

Our analysis reveals four individual national systems of innovation, with different outcomes in terms of engineering skills development, technical vocational education and training, research and development, innovation capabilities, and competitiveness of the domestic engineering consultancy services. These national systems of innovation are tentatively interconnected as an embryonic regional system of innovation, including institutional relationships, cross-border investment flows, flows of mining-related goods and services, and intra-Southern African Development Community flows of students, lecturers, technicians, and engineers. Notwithstanding important dynamics related to skills development and competence building happening across borders, more collaborative and synergistic initiatives between government, industry, and teaching and research institutions are required to shape a more balanced and coherent regional systems of innovation.

Keywords: national system of innovation, linkage development, human capital and industrialization, southern Africa, resource-based industrialization, Southern African Development Community
JEL classification: L5, L6, O1, O25, O38, Q32

* All authors Centre for Competition, Regulation and Economic Development, University of Johannesburg, South Africa. Corresponding author: jfessehaie@uj.ac.za.

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Information and requests: publications@wider.unu.edu

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Katajanokanlaituri 6 B, 00160 Helsinki, Finland

1 Introduction

The mining sector in the southern African region underlies substantial intra-regional flows of specialized equipment, engineering services, skills, and knowledge. South Africa, which historically had the most technologically sophisticated mining inputs cluster, has developed very strong linkages to the Southern African Development Community (SADC)[1] region. South Africa's prominent role in the region has several dimensions: it is a major source of investment, exports, and skills; attracts skilled labour and students; and has the most developed knowledge economy (Kraemer-Mbula and Muchie 2010). Moreover, South Africa is a mining supply 'hub' for the region, in terms of capital equipment and services (Fessehaie 2015). This appears to be more the result of corporate strategies rather than purposive inter-governmental cooperation. From a policy perspective, Fessehaie (2015) argues that policy developments in individual countries fail to recognize and leverage these regional linkages.

This research aims to explore the extent of technological upgrading and knowledge intensification around the mineral sectors, and in particular the role of South Africa in supporting these processes. These processes are analysed within the national system of innovation (NSI) literature, which emphasizes the systemic and dynamic components of domestic innovation ecosystems. South Africa and Botswana, in different ways, have built or are trying to build technological competencies around mining. In Zambia and Zimbabwe, such upgrading trajectories seem to be weak, and have particularly been eroded by a decline in public investment in the 1990s in Zambia, and the 2000s economic crisis in Zimbabwe. Yet, looking at these NSIs in isolation risks missing important dynamics related to skills development and competence building happening across borders. The latter present challenges for technological efforts taking place within countries, but also opportunities to tap into. These issues are explored in this paper through desktop research, interview data,[2] and the insights gained from fieldwork in Botswana, South Africa, Zambia, and Zimbabwe.

Section 2 provides a background on policy frameworks related to mining within the selected countries. Section 3 reviews the literature on NSI and resource-based economic growth. This will enable us to contextualize country trajectories in terms of building mining-related NSIs. Sections 4 to 6 discuss the main elements of NSI-building in Botswana, Zambia, and Zimbabwe, namely engineering and technical skills development, research and development (R&D) and innovation investment, and engineering consultancy services. Each section analyses the regional dynamics underpinning these elements. Section 7 concludes and poses key questions on the southern African regional system of innovation.

2 Background

Mining plays a fundamental role in the economic trajectories of Botswana, South Africa, Zambia, and Zimbabwe. The contribution of mining to GDP was substantial across the selected countries: 33 per cent of GDP in Botswana (2014), 16.2 per cent in South Africa (2014), 25.7 per cent in Zambia (2013), and 17.5 per cent (2014) in Zimbabwe.[3] In Botswana, the relative

[1] See Appendix 2 for full list of acronyms and abbreviations.

[2] For a list of interview respondents, see Appendix 1.

[3] Data drawn from the World Bank (WB) Indicators (World Bank 2016) and may not correspond exactly to national GDP statistics as the WB makes some adjustments for cross-country consistency (http://wdi.worldbank.org/table/4.2).

contribution of mining to GDP has decline since 1990 and will continue to do so as diamond deposits are depleted. Conversely, in South Africa, Zambia, and Zimbabwe, the contribution of mining has increased since the 2000s. In Zambia, this is due to an investment boom in the Copperbelt and so called 'New Copperbelt' (North West Province). In Zimbabwe, the rising importance of mining is a reflection of the decline of agriculture and manufacturing in GDP and exports (World Bank 2014). The mining sector itself has become less diversified. It used to be dominated by gold and small-scale production of more than 40 minerals, but is now led by large-scale platinum production and to a less extent diamonds.

The four economies have been characterized also by growing importance of services and declining contribution of manufacturing. Employment has shifted to low productivity service sectors (government and community services and wholesale and retail), whilst high productivity sectors such as finance, business services, and telecom, which are high skills intensive, are not absorbing large shares of the labour force. Indeed, the highest value added services related to mining and manufacturing (engineering, logistics, etc.) have seen relatively low levels of localization in Botswana, Zambia, and Zimbabwe. At the same time, the manufacturing sector continues to underperform. In Zambia and Zimbabwe, the manufacturing sector contribution to GDP has declined compared to 1990 and 2000 levels. In Zambia, it declined from 36.1 per cent in 1990, to 10.7 per cent in 2000, to 8.2 per cent in 2013. In Zimbabwe, it declined from 22.8 per cent in 1990, to 15.6 per cent in 2000, to 11.9 per cent in 2014. In Botswana, its contribution remains low and stagnant, at 5.7 per cent, increasing its contribution to GDP by 1 per cent between 1990 and 2000, and by 0.1 per cent between 2000 and 2014.

These dynamics highlight how important it is to promote formal manufacturing activities to create employment and value added. For this reason, all the countries analysed are engaging with linkage development strategies aimed at building upstream and downstream industries to mining.

2.1 Botswana

Botswana's considerable resource rents have historically been managed effectively by investing in human resources and infrastructure. This was possible also because of its strategic relationship with De Beers with a 50–50 per cent government–De Beers joint venture (JV) called Debswana. The JV is the largest corporate entity in Botswana and the largest procurer of goods and services after government. Given that diamond production is expected to decline by 2025–27, Botswana's main policy objective in the past two decades has been economic diversification, although progress in this direction has not met expectations (GB 2008: 7). Although the country's ranking in international business assessments has improved, this has not translated into an inflow of investment, the economy has not diversified, and formal employment growth stems from the public sector only (GB 2013, 2015).

Economic diversification policies and strategies have been articulated at different levels. The National Development Plan 9 (2003–09) and National Development Plan 10 (2009–16) established six hubs, namely Diamond, Health, Education, Agriculture, Innovation, and Transport (GB 2008). The Economic Diversification Drive 2011–16 (GB 2011) identifies strategies for market and sector diversification. In the short term, the strategy relies on public procurement, but the longer-term goal is to promote internationally competitive enterprises from primary to tertiary sectors such as finance and hospitality. Mineral beneficiation is included in the strategy and is indeed, where significant progress has been made. On the contrary, diversification into manufacturing is hampered by the fact that Botswana is a small market comprised of approximately two million people. The closest market is Johannesburg, which is already saturated and difficult to penetrate. Zambia and Zimbabwe are potential markets but most domestic firms are reluctant to enter these markets due to high entry costs. Debswana's procurement is significant, but tenders are too large for local micro, small, and medium enterprises (MSMEs). Launched in 2014, the Chamber of Mines' Business Development Forum is an initiative by the mining industry to create efficiency and cost savings for the mining companies, and support enterprise development and economic diversification. The initiative aims to coordinate purchasing power between the mines to support local suppliers and attract foreign direct investment (FDI) from Original Equipment Manufacturers (OEMs) (Botswana Chamber of Mines 2014).

In 2005, leveraging its 50 per cent partnership with De Beers at the time of licence renewal, the government realized an opportunity to adopt a diamond beneficiation policy (Mbayi 2011). The diamond beneficiation policy has been remarkable in supporting Botswana's ambition to move up the global value chain in sorting and valuing, marketing, and polishing and cutting. A key strategic aspect of the policy is that it was designed around De Beers, which exerts significant market power on domestic and global production, as well as global marketing and distribution channels.

Diamond sorting and valuing for De Beers global production has relocated from London to Gaborone. To capture a larger share of diamond marketing, government owns Okavango Diamond Company, a distribution company that receives an allocation of 15 per cent of national output. A large group of representatives of De Beers' sight holders—more than 80 of the world's leading diamantaires—travel to Gaborone up to 10 times a year, creating additional demand for local goods and services (De Beers 2014).

The policy also required that at least US$500 million per annum of De Beers Botswana's diamond output be reserved for local beneficiation, later raised to US$800 million a year. The policy was well articulated, with clear targets, a combination of export restrictions, penalties and fiscal incentives, private and public investment in public goods and skills, and effective implementation mechanisms. Diamond cutting and polishing firms are granted licences to operate in Botswana and access reserved diamonds subject to strict local training requirements. According to industry sources, having access to Botswana diamonds is critical, especially given the large size and high quality of the stones. Even if local processing is 15 per cent more expensive than the international benchmark, local beneficiation remained a good investment. Employment increased from 2,200 workers in 2008 to 3,750 in 2013. In 2015, however, Botswana's beneficiation strategy was in a serious crisis. The predicament was due to the misalignment of supply and demand at different stages of the value chain, with rising prices for rough stones, collapsing demand, and shrinking margins for cutting and polishing firms. In 2015, diamond cutters MotiGanz, Leo Schachter, and Teemane Manufacturing Company closed their plants in Botswana resulting in 500 job losses (Grynberg 2015).

As firms shut down and retrenched workers, the state has not been in a position to intervene. Its ownership stake upstream allowed it to extract higher rents from rough diamond sales such that restricting rough diamond supply would have been counterproductive. There are also structural factors over which Botswana has little leverage, such as De Beers' decreased market power in global output, increased financialization of the industry, and developments in the Chinese market. As such, its beneficiation project is under severe pressure. The recent downturn in rough diamond market however could change both Botswana and De Beers' response to the crisis. Declining prices for rough diamonds since the end of 2015 may cause major problems for the government because that will affect upstream revenues. In the long term, De Beers (2014) estimates that demand growth will increase in real terms for the next ten years and will outstrip production, due to lack of major new discoveries and declining output at existing mines.

2.2 Zambia

Zambia's linkages development strategy, as far as copper beneficiation is concerned, has relied heavily on FDI. Since 2007, Chinese investors are building an industrial park in Chambishi (Copperbelt Province) taking advantage of Zambia's incentives for Multi-Facility Economic Zones and Industrial Parks. One aspect of this strategy that has not received sufficient support has been the employment and skills development strategy to maximize the benefits of industrial parks. Policy developments around upstream linkage development on the other hand have been more complex and involved a multitude of institutional and private sector actors. Zambia's manufacturing capabilities in the mining supply chain were largely eroded during the 1990s, with the privatization of mining assets and the introduction of trade and investment liberalization measures (Fessehaie 2012). The private mining companies moved away from local procurement policies and largely relied on direct imports and sourcing from a large network of local agents and subsidiaries. The International Council on Mining and Metals (2014) estimated out of a total industry procurement of goods of approximately US$1.75 billion annually, only 5 per cent (or US$87 million) constitutes locally manufactured goods. The critical challenges for the inputs cluster include (1) operation of outdated equipment, (2) poor technological capabilities, (3) weak quality assurance mechanisms, and (4) high-cost of finance, inputs, and business operating environment (Fessehaie 2012; Kasanga 2012). Lack of skills at technical and tertiary levels has also worsened firms' competitiveness.

Notwithstanding high level political statements on the government's intention to support local suppliers, upstream linkages development is not clearly identified in Zambia's industrial policy framework, the 2008 Commercial, Trade and Industrial Policy, and the 2012 Strategy for the engineering manufacturing sector. The 2012 Strategy Paper on Industrialisation and Job Creation aims to operationalize Section 13 of the Mines and Minerals Development Act to support local manufacturing and procurement in the mining sector. However, this is clustered with a very large number of other priorities. Interviews with key stakeholders highlight three aspects of industrial policy making that are constraining the development of a coherent strategy for upstream linkage development. These are: (1) lack of clear policy objectives; (2) lack of coherence between various policy instruments and organizations; and (3) poor implementation capability.

Weak policy initiatives have led the private sector to take a leading role on the issue of local content. Zambia Association of Manufacturer (ZAM), the industry body, is currently driving the local content agenda with little support from government. The Zambia Mining Local Content Initiative is a product of a Memorandum of Understanding (MoU) between ZAM and the Chamber of Mines. The main activities of the Local Content Initiative revolve around addressing information gaps, through an online Business-to-Business platform, and conducting a capacity assessment of potential suppliers that will be assisted by targeted business development services.

2.3 Zimbabwe

Historically, Zimbabwe's mining sector was characterized by well-developed upstream and downstream industries (Jourdan et al. 2012). With the economic crisis in the early 2000s, capacity utilization in the manufacturing sector declined from approximately 80 per cent in 2000 to 10 per cent in 2008 and 26 per cent in 2015 (GZ 2011; MEPIP 2011: 19, 123; Field Interviews 2015). In particular, medium to high technology exports have stagnated. The large-scale loss of indigenous skills has negatively affected the mining industry, supplier firms as well as teaching and technology institutions. The Zimbabwe Chamber of Mines estimates that more than half of the industry's skilled personnel emigrated from the country since 2007 (Hawkins 2009).

Since 2010, FDI inflows into mining have resumed from a low level, coupled with significant imports of capital equipment. The mining sector is currently the main driver of economic recovery in Zimbabwe, and the World Bank (2014) argues that the growth prospect for manufacturing rests mainly in domestic demand, in particular linked to the resource sector. Manufacturing is still highly diversified compared to other African countries, but firms have downsized considerably and import penetration in the supply chains is high (World Bank 2014). Davies et al. (2012) argue that supply-side constraints are now more critical than demand side ones: firms operate obsolete machinery, struggle to access finance, and operate in a high cost and volatile environment due to regular power outages, imported inputs, and unreliable supply-chains.

In the high-level power struggle over mining rights and revenues, local content issues have been relatively marginalized. The crisis had a two-fold impact on the local supply chain. Some firms moved away from manufacturing to distribution while other international OEMs sold their subsidiaries to local investors. The overall decline has been staggering with more than 50 per cent of foundries having closed down out of more than 20 foundries in operation a decade ago (ZEPARU 2014). In metal fabrication, 25 per cent of firms identified by the same study had closed down while 40 per cent in heavy machinery had also shutdown. When mining production recovered, local suppliers were unable to meet local demand or reinvest to resuscitate the industry and catch up with pre-crisis capabilities.

Zimbabwe's policy framework is largely focused on mineral beneficiation, which is included as a priority in the Mid-Term Plan 2011–15 and more recently in Zimbabwe Agenda for Sustainable Socio-Economic Transformation (Zim Asset) 2013–18, the latest blue print for economic development.[4] According to interviews with the Ministry of Economic Planning and Investment Promotion, concerns over tax avoidance are leading policy makers to look at beneficiation as a mechanism to introduce transparency in the sector. Currently, there is very limited local beneficiation and value addition of minerals, resulting in about 90 per cent of the minerals being exported raw or semi-processed (ZEPARU 2014). To promote beneficiation, government has reduced royalties applicable to mineral output destined to domestic downstream industries.[5] This policy however had to be tempered by considerations of existing production capabilities.

Together with beneficiation, indigenization has been another key policy objective that is influencing the design of policies in the mineral and industrial sector.[6] Currently, there is no interest in linking the indigenization agenda to increasing mining local content, even if several stakeholders interviewed for this research indicated that there would be concrete opportunities in this area. During the last part of 2015, under pressure from the Confederation of Zimbabwe Industries (CZI), local content had begun to feature on the political agenda.

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[4] This intervention however is not included in the Value Addition and Beneficiation Cluster Matrix, Zim Asset, pp. 103–13 (GZ 2013).

[5] Mines and Minerals Act of 2005 [Chapter 21: 05] Section 247 provides the Minister with the power to grant royalty rebates to investors in mineral beneficiation.

[6] The indigenization policy and legal framework is composed of the following: the 2004 Revised Policy Framework for the Indigenization of the Economy; and the Indigenization and Economic Empowerment Act (Chapter 14: 33), 2008. The Indigenization and Economic Empowerment (General) Regulations in 2010 through SI 21, amended in 2011 provide that all businesses with a net asset value equal to or above US$500,000 should formulate plans that will lead to 51 per cent of the shares in the firm being transferred to 'indigenous' Zimbabwean shareholders within five years.

Zimbabwe's Industrial Development Policy 2012–2016, aimed at the recovery of the manufacturing sector (steel production in particular), has seen low levels of implementation mainly due to lack of resources and low levels of domestic and foreign investment (GZ 2012).[7] The mineral sector is regulated by the 2005 Mines and Minerals Act, which does not include very strong provisions on local content.[8] A Minerals Policy has thus been in draft process for many years, inclusive of a number of interventions related to stimulation of backward, forward, spatial, and fiscal linkages, improved transparency, and the introduction of progressive taxation.[9] Interviews with key respondents highlight that the failure to conclude the design of this policy has hindered the development of strategies related to skills development, FDI, and local content.

2.4 South Africa

South Africa has a longer history of mining around which the overall national economy has evolved. While mining still plays an important part in the economy, particularly in its contribution to exports, a significantly greater degree of diversification out of mining has occurred in comparison to Botswana, Zambia, and Zimbabwe. The diversification has taken a particularly capital- and energy-intensive form with the emergence of a core set of mining and mineral-processing sectors (falling within the manufacturing sector) that have dominated the economy for many decades (Fine and Rustomjee 1996). South Africa's capital goods sector has developed around this minerals-energy-complex core and the sector is playing a major role in supplying the regional mining industry with mining machinery, mining inputs, and associated engineering services. Conversely, the South African mineral industry is also reliant on imported technical and engineering skills from the region.

The South African mining inputs cluster, mainly located in Gauteng, is a well-established regional supply hub for southern Africa (Fessehaie 2015). South Africa's mining inputs cluster, through global and domestic OEMs, is supplying capital equipment and engineering services to mining houses across the region. Often, these are supplied through relationships with Engineering, Procurement, Construction, and Management (EPCM) firms. These are contracted by the mining companies across the region for greenfield and brownfield projects, and tend to tap into their suppliers in South Africa to carry on these projects. South Africa's presence in established markets is remarkable: the share of capital equipment imports sourced by South Africa amounted to 73 per cent in Botswana, 37 per cent in Zambia, and 57 per cent in Zimbabwe (average 2012–2014).

Whilst previous research has analysed South Africa's mining inputs cluster (Walker and Minnitt 2006; Lydall 2009) and there is considerable policy and academic research on South Africa's NSI, very little is known about developments in the rest of the region on mining-related NSIs and in relation to South Africa. The manner in which South Africa's NSI has generally interacted with the region is detailed in Sections 4–6, revealing the extent to which South Africa's capabilities outweigh those of neighbouring countries, but also identifying the interfaces and interactions

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[7] Objectives are: contribution of manufacturing to GDP to 30 per cent by 2015, 50 per cent of total exports by 2015, and capacity utilization to 80 per cent by 2016.

[8] The Act states that an applicant for a special mining lease should submit a plan, which includes information on the extent to which local procurement of goods and services—Bullet point xii) of paragraph e) of sub-section 3 of section 158.

[9] Other mining-related policy measures include a draft mining exploration bill, re-building the national geological survey units to ensure government has leverage in negotiating mining rights, and support for small-scale mining sector.

between the respective NSIs and the potential for greater synergies should conscious alignment of respective national policies be achieved.

3 Natural resources, technological upgrading, and national systems of innovation

3.1 National systems of innovation

The contribution of technology to economic growth is well-established in the economic literature (Romer 1986; Grossman and Helpman 1991). Since the 1980s, research rooted in evolutionary economics started looking at the dynamics and determinants of technology development as a research area of its own, moving away from neo-classical models in which access to technology was taken for granted (Pack and Westphal 1986; Lall and Teubal 1998). In these neo-classical models, homogenous firms search and adopt technologies without effort and cost, operate in an environment where linkages and spillovers are insignificant, and decisions are based on the optimal allocation of capital and labour (Nelson and Winter 1977; Pack and Westphal 1986; Lall 2000). Until the 1980s, the prevailing view was that innovation followed a linear model, where inputs in science and R&D, translated into inventions and radical innovations. These models, it has been argued, have been inadequate in understating the pace, direction, and determinants of technological change.

The NSI approach, and related literature on technological capabilities, focuses on the micro-economic foundations of firm-level technological upgrading, adopting more realistic assumptions. Firms operate in imperfect markets and with imperfect information over which technologies are available (Nelson and Winter 1977; Pack and Westphal 1986; Lall 2000). Because technologies are not perfectly codified and transferable, and have a tacit component, firms have to invest time and effort to adopt them, and face risks and unpredictability. Rather than capital/labour allocation, firms maximize organizational and managerial routines.

The NSI literature, in particular researchers from Aarborg University (Freeman 1995; Lundvall and Lema 2014) broadened the analysis of technological upgrading to include multiple actors and activities. Building on the seminal work by Freeman (1987) on firm activities, and on Nelson and Winter's (1977) emphasis on the role of institutions, innovation is seen as the result of a variety of intra-firm and inter-firm activities, in particular 'feedback loops from the market and from production into the R&D system' (Freeman 1995: 10).

The NSI framework is 'constituted by elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge' (Lundvall 2010: 2). Innovation can take different forms: new products, techniques, forms of organization, and markets (Lundvall 2010). Moreover, because the distinction between inventions, innovation, and diffusion is blurred, technological upgrading is conceptualized as a process (Hobday 2000; Lundvall 2010). Lastly, the innovation process is seen as socially-embedded and as the result of interactive learning (Lundvall et al. 2002). For these reasons, NSI research has placed considerable emphasis on historical contexts and the role of institutions (Lundvall 2010). Learning is seen as 'collective, cumulative and path-dependent' (Lall and Teubal 1998: 1372).

The institutions and relationships explored in NSI literature include the following ones:

- Internal organization of the firm
- Inter-firm relationships
- Role of public sector

- Financial sector
- R&D organization
- Training (Lundvall 2010)

Differences in these elements and in the relationships between them are seen as defining specific NSIs. Technological learning is industry-specific (Lall 2000). In some industries, technologies can be more embodied than in others, technologies differ in the costs, risks, and duration of learning; skills and knowledge required by firms; transferability to other activities; and the breadth of linkages with outside actors (suppliers, research institutes, etc.). Moreover, externalities are industry-specific, and some technologies and industrial clusters yield more dynamic growth and spillovers than others (Lall and Teubal 1998).

Early NSI research focused on mature industrial economies and was concerned with differentials in their technological performance (Lundvall 2010: 3). Subsequent research however became increasingly concerned with the Newly Industrialized Countries (NIEs), in particular the four Asian Tigers. Arguing that the NIEs' catch up could not be explained only by high investment rates in physical and human capital, this research turned to other explanations linked to entrepreneurship, learning, and innovation (Pack and Westphal 1986; Kim and Nelson 2000).

Research on developing countries broadened the NSI framework in different ways: incorporating education, training, and technological adaptation, and looking at the role of industrial and FDI strategies. Training and education did not receive extensive attention in NSI research on mature economies (Lundvall and Lema 2014). Research on Asia and Latin America however has incorporated education as a critical foundation of the NSI (Lall 2000; Viotti 2002). In particular, engineering, technical, and vocational education are critical to support technology absorption and adaptation, which are the first steps for developing countries' climbing up the technological ladder.

The NSI literature on developing countries argued that what constitutes technological upgrading should no longer be limited to inventions and radical innovations, but extend to 'inferior' technological efforts that played an important role in East Asia: reverse engineering, duplicative imitations (counterfeit and knockoffs), and creative imitations (Kim and Nelson 2000). What is critical for technological upgrading is 'learning', defined as 'the absorption of already-existing techniques that is, the absorption of innovations produced elsewhere, and the generation of improvements in the vicinity of acquired techniques' (Viotti 2000: 658).

Firms in developing countries struggle to acquire even basic technologies and capabilities (Lall and Teubal 1998). National technological upgrading is shaped heavily by the functioning of markets for skilled labour, finance, and knowledge on the one hand, and incentives and factor markets in terms of macro-economic stability, trade interventions, subsidies, domestic competition, and domestic demand, on the other (Lall 2002). Selective industrial policies, which have targeted specific sectors and subsidized learning, have played a critical role in supporting technological learning (Pack and Westphal 1986; Lall 2000).

In particular, researchers have been concerned that FDI does not automatically contribute to the development of local innovation capabilities in host countries (Lall 2000; Viotti 2002). Multinational Enterprises' (MNEs) technological investments were usually limited to local design modification to meet domestic conditions and regulations (Freeman 1995).[10] Hobday (2000) highlighted that the success of South Korea and Taiwan in promoting indigenous innovation capabilities can be ascribed to their strategic approach to FDI, which supported significant knowledge transfer to domestic firms. Whist MNEs are increasingly internationalizing their R&D operations (UNECA 2010); most developing countries are excluded from these types of FDI.

3.2 Technological learning and natural resources

The historical experience of resource-rich countries shows that natural resource sectors have catalysed important processes of productivity growth, technological innovation, and forward and backward linkages. Good institutions and investment in human capital and knowledge were critical for such processes (Rostow 1956; de Ferranti et al. 2002). The positive externalities of *learning by doing* found in manufacturing are also found in productive activities linked to natural resources' sectors (Davies 1995; Stijns 2005). Bartos (2007) argues that technological breakthroughs and productivity gains in the United States (US) mining industry have been comparable to other manufacturing sectors, with the exception of high-tech sectors. Natural resources exploitation, which requires specific knowledge and problem-solving, has given rise to localized and deep forms of technological intensification processes (Lorentzen 2008). These differing dimensions of NSIs shall be reviewed across Scandinavian countries, Australia, the US, and Africa.

Reviewing the experience of resource-rich Nordic countries, Blomström and Kokko (2007) argue that, from the 1850s onwards, Sweden witnessed an export boom of cereals and sawn wood and, later, pulp, paper, and iron ore. In the early stages, access to foreign knowledge and capital was important, but technology transfer was made possible by previous investments in dynamic domestic knowledge clusters. These allowed Sweden to move from technology absorption and adaptation, to technological innovation and progressively higher value-added activities. A network of private sector-led research institutes, universities, and companies, characterized by high density of linkages in the form of joint research programmes and collaborations, was instrumental in creating and disseminating new knowledge of both a commercial and an academic nature. Public investment in skills development dated back to the early 19th century, and became increasingly specialized and oriented to meet the needs of the industry, which contributed financially to such investment. A similar trajectory characterized Finland and underlined Nokia's successful move from pulp and paper milling into cellular technology. By upgrading materials, products, and processes, Scandinavian resource-based industries remained competitive against low-cost producers. Moreover, a number of industries related to resource extraction developed in parallel: specialized machinery, engineering products, transport services, and equipment (de Ferranti et al. 2002; Blomström and Kokko 2007; Bitard et al. 2008). Scandinavian industries producing aircrafts, luxury cars, and designer furniture were initially developed as upstream industries to natural resource sectors.

Similarly, US emergence as an industrial power at the turn of the 20th century was propelled by resource abundance (Wright 1990). Between 1879 and 1940, American manufactured exports were highly resource-intensive in petroleum products, meat and poultry packing, primary copper products, and steel works. At the same time, the US was a leading producer of copper,

[10] Indeed, it was argued that MNEs could actually undercut the development of local technological capabilities, because the subsidiary's access to parent companies for 'just in time' technological solutions made it unnecessary to develop local technological capabilities, and also inhibit efforts by local, smaller competitors that could not compete with MNEs (Viotti 2002).

petroleum, iron ore, zinc, phosphate, molybdenum, lead, tungsten, and many other minerals. Such leadership in mineral extraction did not simply derive from geological endowments, but was endogenously determined (David and Wright 1997). From the mid-1800s, public and private investment in geological exploration and mining education boomed, coupled with significant technological innovations in mineral extraction, refining, utilization, and transportation. In copper mining, for example, technological advances in drilling and blasting in the 1870s and 1880s were followed a decade later by two major metallurgic innovations for copper refining, which allowed the US to overtake Chile as a world leading copper producer (Wright and Czelusta 2004, 2007; Maloney 2007).

In recent times, Australia's booming mineral sector and Norway's oil sector supported sustained economic growth and technological progress both within the sector and in related industries: metal and steel products, industrial equipment, chemicals, and mining software (David and Wright 1997; Wright and Czelusta 2007; Grønning et al. 2008). Reviewing case studies in Latin America and Africa, Lorentzen (2008) found important knowledge-intensification efforts around natural resources, which were founded on previously accumulated knowledge. Some resulted in successful technological innovation and lateral migration. Examples include the sugar-based biodegradable plastic production in Brazil, grain-sorting machineries in Costa Rica, and hydro-hydraulic technologies in South Africa. In other cases, technological intensification efforts failed to find commercial application, but nevertheless formed an important learning process for the institutions involved.

In Africa, we find different experiences of technological upgrading and linkage development across countries (Morris et al. 2012). Whilst most countries failed to develop processing or supply industries, and have under-developed human capital and governance, there are few countries in which these have been growing and improving, with deeper knowledge intensification processes taking place. South Africa is undoubtedly the most successful country in this respect, endowed with a well-developed mining inputs cluster and, to a lesser extent, some beneficiation industries.

In sum, the historical experience of resource-rich countries suggests that 'the broad lesson is that the inherent character of resources does not matter for resource-based development, but rather, the nature of the learning process through which economic potential is achieved' (Wright and Czelusta 2007: 184–5). Learning and innovation determine the creation, distribution, and use of new resources (Andersen 2012). The NSI literature, especially research on developing countries, suggests that technological learning requires coherent and dynamic NSIs, with emphasis on engineering, technical, and vocation skills; strategic industrial and FDI policies; and linkages between universities, research centres, and industry.

4 Engineering and technical skills

4.1 Tertiary education in the region

Education levels, in particular enrolment in scientific and engineering subjects, are used as a measure of human capital investment for the NSI (Lall 2000; Viotti 2002). School enrolment rates indicate that sub-Saharan Africa (SSA) is lagging behind other developing regions not only for university and secondary enrolment, but also for primary enrolment (Table 1). Even basic courses and on-the-job training require workers to have good basic literacy and numeracy skills, i.e. good elementary schooling (Pack 1993). Poor primary school enrolments imply that firms would struggle to introduce even basic improvement in production process and organizational structures.

Table 1: Primary, secondary, and tertiary enrolment rates in SSA and selected countries (per cent, latest available year)

	Enrolment rates		
	Primary (adjusted net)	Secondary (net)	Tertiary (gross)
SSA	78.6 (2013)	33.7 (2013)	8.6 (2013)
Botswana	90.9 (2012)	60.8 (2008)	24.8 (2013)
South Africa	94.6 (2005)	65.6 (2005)	19.7 (2012)
Zambia	93.1 (2013)	-	-
Zimbabwe	94.3 (2012)	35.4 (2003)	5.8 (2013)
East Asia & Pacific (developing only)	96 (2013)	77 (2013)	30 (2013)
Latin America & Caribbean	93.5 (2013)	75.7 (2013)	43.9 (2013)
South Korea	97.8 (2014)	97.4 (2014)	96.6 (2013)

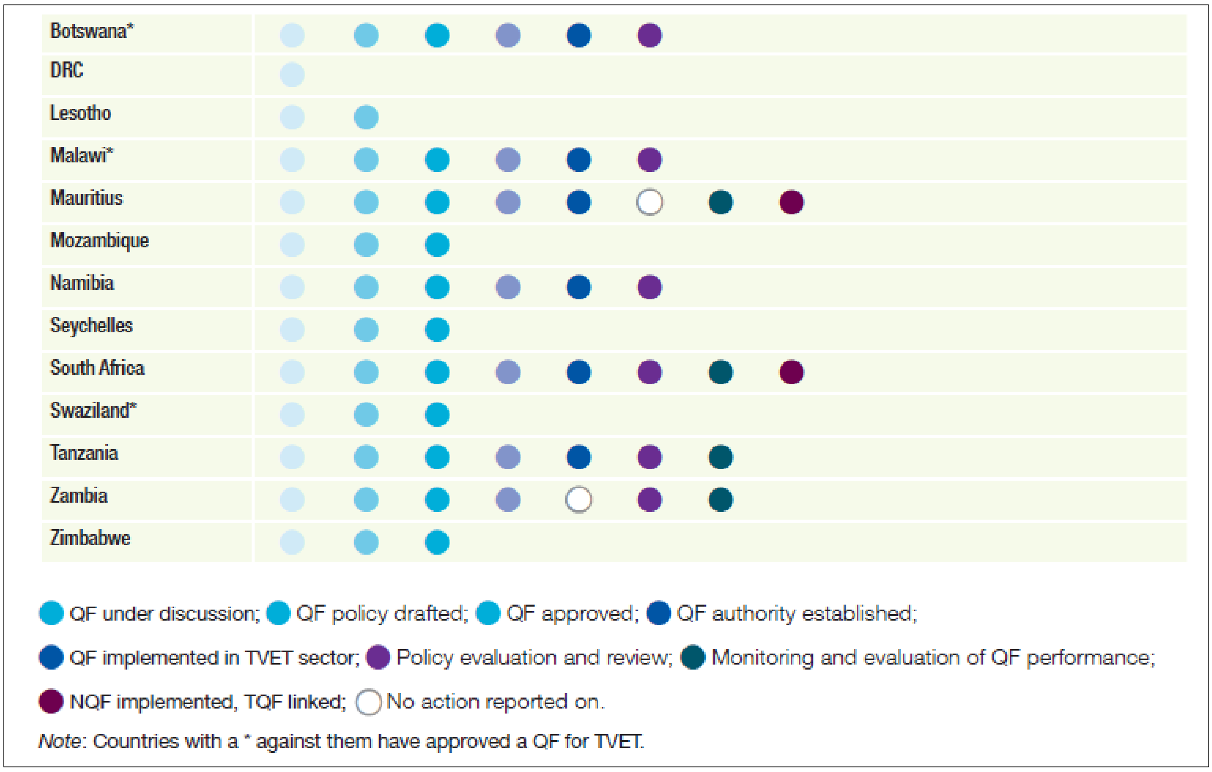
Note: Latest available data.

Source: World Bank (2016).

South Africa, Botswana, Zambia, and Zimbabwe have enrolment rates higher than the continental average at all levels of education. Compared to other developing countries listed in Table 1, however, the four countries underperform at all levels with the exception of primary enrolment rates. Botswana (61 per cent) and South Africa (65 per cent) secondary enrolment rates are 10 to 15 percentage points below East Asia and Latin America. Their tertiary enrolment rates are 5–10 percentage points below East Asia and more than 20 percentage points below Latin America. Compared to Korea, these differences are even more staggering. Zimbabwe enrolment rates have declined dramatically, at both secondary (35.4 per cent) and tertiary levels (5.8 per cent). Moreover, data is not sufficiently disaggregated by areas of study, but in SSA, social sciences and humanities have traditionally been privileged, at the expense of scientific, technical, and engineering subjects (Lundvall and Lema 2014).

National Qualification Frameworks (NQF) pursues important education policy objectives such as quality assurance and coherence across the various public and private components of the system. Industrial policy objectives of an NQF include ensuring that the education and training system is dynamic and coherent enough to respond to changing industrial and economic production requirements and to facilitate the transfer of skills across firms and sectors. SADC countries are at relatively different levels of development (Figure 1). South Africa has the most developed NQF, with systems being implemented, reviewed, and monitored. Botswana and Zambia have technical vocational education and training (TVET) qualification frameworks in place and are in process of establishing NQFs. Zimbabwe is at the earliest stages of NQF development. Although proposals to implement an NQF have been discussed in parliament, the Zimbabwe Examinations Qualifications Authority Act has not been finalized. Our fieldwork however suggests that the NQF processes in the countries surveyed have advanced since the 2013 UNESCO survey referred to in Figure 1.

Figure 1: Progress in qualification framework implementation in the SADC region



Source: UNESCO (2013: 43).

4.2 Trajectory of mining and state role in skills development

All of the countries investigated have conscious public policy objectives of skills development through the primary, secondary, and tertiary segments of the respective education systems. As outlined above, Botswana and South Africa have the highest proportion of secondary education graduates who enter university. Such aggregated statistics however do mask a range of common problems within that part of the NSI relating to tertiary institutions and public and private sector employers across all countries surveyed.

Across Botswana, Zambia, and Zimbabwe, the mineral sector has played a very important role in human capital development, in particular in relation to engineering and technical skills. In Botswana, investment in skills development has been sustained through proactive government education policies with strong resonance from the productive sector (Debswana). The 1990s and 2000s witnessed considerable public investment in the engineering segment of the tertiary education system. The number of graduating engineers increased during this period and was rapidly absorbed by the mineral extraction industry. However, the 2008 economic crisis slowed down this pipeline: government sponsorships are shrinking, and whilst there is high demand and students entering the programmes have high marks, weak performance at graduate level indicates increasing gaps in math and science education at secondary level.

In Zambia and Zimbabwe, the role of the mineral sector and government in supporting skills development around the mining complex declined much earlier and more dramatically than in Botswana. Between the 1970s and 1990s, the mining industry contributed greatly to skills development in Zambia. Through state owned enterprise (SOE) Zambia Consolidated Copper Mines (ZCCM), a large number of Zambians were trained directly and indirectly by the mining industry as part of the state 'Zambianization' policy. Training took place within the mining company, through peripheral training institutions, and within the manufacturing complex linked to mining. This manufacturing complex included private firms and SOEs. Mining companies during this period committed considerable internal resources towards skill development and skill transfers given the large scale and continuity of mining activities, as well as sponsoring graduate and post-graduate students. A stint on the Copperbelt during the ZCCM era was an essential experience for a mining engineer's career progression, regarded as a site of best global mining practice. Up until the mines' privatization in the mid-1990s, no skills gap was experienced in the Zambian mining industry. Following the Structural Adjustment Programme, the training capability of the state and the mining sector has eroded and today, the total output of technically qualified people is low. Several respondents agreed that Zambia is not able to supply the skills required by growth in the mining sector, especially as far as technical skills are concerned.

Since the end of the 1990s, Zambia's education policy has been predominantly focused on basic education. In addition to the focus on basic education, international aid programmes tend to prioritize basic education as well. The decline in financing of the secondary and upper secondary sector has contributed to a decline in Science, Technology, Engineering, and Math (STEM) education. Structural challenges in terms of basic STEM knowledge trickle down to the competency of graduate students, which also has an implication on state funding since few students obtain the minimum results to pass and are awarded a scholarship for engineering and science. The success rate of the enrolled students and quality of education is then undermined by the lack of staff in universities as departments struggle to fill these knowledge gaps adequately.

The industry-based skills development system rapidly fragmented following the exit of the mining engineers out of Zambia and the mining sector. The newly privatized mining companies from Australia, Canada, India, and China, few of which had previously operated in Zambia or in southern Africa, largely relied on imported skills as a result. Moreover, the fragmented ownership of the mining sector (compared to dominant ZCCM) undermined the previous relationships with education and training institutions. Subsequently skills development in the sector declined while other service sectors grew.

In the 1960s and 1970s, Zimbabwe emerged as one of the most industrialized economies in southern Africa. Post-independence education and other policies resulted in a robust NSI that was not only centred around mineral extraction and manufacturing, but around other industries. The number of universities and colleges increased significantly from three in 1980 to more than 18 in 2013 (Afonja et al. 2005). Overall, Zimbabwe has 40 universities, polytechnics, and vocational schools. Out of 13 universities in Zimbabwe, five support technical education, which directly feed into the engineering and metals sector, namely University of Zimbabwe (UZ), National University of Science and Technology (NUST), Harare Institute of Technology (HIT), Chinhoyi University of Technology (CUT), and Bindura University of Science Education (BUSE).[11]

In the 1980s, Zimbabwe opened a Department of Mining Engineering and a Department of Metallurgical Engineering at UZ. The University also has a long-standing Department of Geology, a geophysics section under the Physics Department, and an Institute of Mining Research. At a technical level, a School of Mines in Bulawayo for the training of mining and

[11] The universities offer four-to-five year Bachelor of Technology (BTech) or Bachelor of Engineering (BSc Eng Honours) degrees in fields such as mechanical and production engineering, industrial engineering, water engineering, chemical engineering, electrical engineering, energy, and fuels amongst others (ZEPARU 2014). Other degree programmes uniquely offered by UZ include civil engineering, electrical, mining, and metallurgical engineering as well as geo-informatics and surveying.

mineral processing technicians exists (Jourdan et al. 2012). All the universities aligned to the engineering and metals industry are state funded and no private university offers programmes directly supporting the sector. Meanwhile, mining companies spent significant efforts to increase the share of African staff, especially via in-house training. According to Afonja et al. (2005), the educational policy of Zimbabwe used to promote technical education as well as the integration of theory and practice from primary to higher education.

In Zimbabwe, the economic decline since 2000 has led to fraying of the education system. This is acutely reflected in the exodus of skilled Zimbabweans, mainly to South Africa but also to other countries of the region as registered engineers declined from more than 3,000 in 2001 to 600 in 2012 (Nkala 2012). The massive loss of indigenous skills has adversely affected the mining industry and teaching and technology institutions. The Zimbabwe Chamber of Mines estimates that in early 2008, there were 1,116 vacancies for professional and technical staff (Hawkins 2009).

4.3 Engineering skills

As a result of the trend towards mechanization, mining operations increasingly require mechanical and electrical engineers. However, countries in the region have traditionally focused on mining engineering. This concentration has borne multifaceted challenges with regards to engineering skills. For example, South Africa has an excess of mining engineering skills, only partly absorbed by consultancy firms and mining houses. The University of the Witwatersrand (Wits) and University of Pretoria (UP) graduated more mining engineers than the industry can absorb. According to the Southern African Institute of Mining and Metallurgy (SAIMM), 20 per cent of 2014 graduates are unemployed and less than 5 per cent of 2015 graduates (800) have guaranteed jobs. Universities are providing internships so that graduates can prolong their stay at the universities for another year by supporting the institutions and/or enrolling for other qualifications exacerbating the oversupply of skills. Conversely, the South African Chamber of Commerce reports shortages of mechanical and electrical engineers as they have more opportunities and prefer living in cities rather than mining towns. The quality and output of graduates from regional universities is sub-standard and an additional constraint on skills evidenced by regional statistics. The quality and output of students along with conditions of learning and institutional capability (or capacity) will be discussed in more detail, looking across the country experiences, to understand its impact on the regional (or national) system of innovation.

4.3.1 Engineering graduates' turnover

There is a significant difference among the three countries regarding the engineering disciplines and the number of graduates. Botswana's turnover has been influenced by the small population and the limited mining companies in the economy. Conversely, Zambia's turnover does not match the needs of a large mining sector and its potential supply chain, while Zimbabwe has experienced significant brain drain following the demise of the economy in the mid-2000s.

On average, the University of Botswana (UB) produces approximately 100–120 graduates per year, with around 15–20 master's and other post-graduate qualifications (Table 2). The mining engineering programme, recently instituted, targets 15 undergraduate students per year (mining and mineral processing) with the first set of students graduating in 2016. The programme was designed in two parts: three years at UB with an additional two years at Missouri University of Technology. However, in support of localization, the two-year study in Missouri has been cancelled, and the whole programme is being undertaken in Botswana.

Table 2: Mining and engineering graduates and post-graduates—Botswana (2015)

	Graduates per annum	Masters per annum	PhD per annum	Staff and (vacancies)
University of Botswana	100–120, Civil/Mining 40 Mechanical/Industrial 60 Electrical 30	15–20	15–20	Approximately 65 per cent of posts are filled.

Source: Field interviews.

The UZ Department of Metallurgy, which was incorporated with the Department of Mining in 2011, currently has 30 graduates. In 2006, the department was non-functional due to skills flight and poorly furnished laboratories as operating the two departments separately had become expensive. Due to inability to sustain detached entities, the mining and metallurgical departments were subsequently merged, and in 2011, benefactors funded the re-opening of the Department of Metallurgy.

The combined output from the schools of mines and engineering from the University of Zambia (UNZA) and the Copperbelt University (CBU) is approximately 400 graduates, higher than Botswana and Zimbabwe (Table 3). However, the proportion of master's students is very low, with the exception of the CBU School of Mines and Mineral Sciences (approx. 40–50 per year). The number of students from CBU needs to be viewed with caution. According to interviews, the university management is churning out high numbers in order to reduce costs, which subsequently may affect the quality of graduates and distort the actual number of graduates.

Table 3: Mining and engineering graduates and post-graduates—Zambia (2015)

	Graduates per annum	Masters per annum	PhD enrolled	Staff and (vacancies)
School of Mines, University of Zambia	50	7–12	A few	Geology Dept. 6 (6) Mining Engineering 6 (6) Metallurgy 11(1)
School of Engineering, University of Zambia	70 Civil/ Environmental 20 Mechanical 20 Electrical 20 Agricultural 5 Geomatics 5	-	-	Departments: Agricultural 11 (5) Civil& Environmental 11 (5) Electrical & Electronic 11 (5) Geomatic 11 (5) Mechanical 11 (5)
School of Engineering, Copperbelt University	Approx. 300–400 students at graduate and diploma level	5	-	-
School of Mines and Mineral Sciences, Copperbelt University	150 graduates 150 diploma	30–40	-	-

Source: Field interviews.

As mentioned earlier, the growth of mining investment using opencast and mechanized mining technologies in the new Copperbelt region of Zambia since 2000 has increased demand for mechanical and electrical engineers. Whilst the Schools of Mines were the traditional source of skills for the industry, the Schools of Engineering have become increasingly important. Yet, these schools are equally under-resourced.

4.3.2 Conditions of learning

Despite the growing demand of mechanical and electrical engineering skills, university departments across the region are fraught with challenges including inability to retain staff, with some exceptions. Mining companies in Botswana have been instrumental in retaining academic staff in the engineering departments through salary supplementation and access to consulting work. The mining industry is involved in additional ways: revision of the curriculum, and student attachments, especially sandwich programmes for diplomas (i.e. students spend time at school and attached to firms). In addition to the relationship with the mining industry, the Faculty of Engineering and Technology signed a MoU with the Chamber of Mines that provides work placement for students during their practical training.

Lack of infrastructure is a key impediment to UNZA's teaching and research activities. Non-existent laboratories force lecturers to teach with no equipment and without being able to undertake practical demonstrations. According to the Association of Consulting Engineers of Zambia (ACEZ), the quality of UNZA graduates is of a high standard, but lack of practical experience is a major hindrance to producing well-rounded engineers. Another challenge is the weak apprenticeship programme. Despite the absence of a formal programme, practical training is a requirement. Certification is not issued unless the student has had 14 weeks minimum of industrial experience, but placing students is difficult.

The mines overall have not been willing to invest in local skills development due to the economic downturn. Although mining houses complain about the quality of graduates, their assistance in addressing this issue has not been consistent, but rather in the form of ad-hoc project-based support, such as an e-library or the donation of vehicles and equipment to the School of Mines (UNZA n.d.). More recently, the Canadian mining company, First Quantum Minerals (FQM), entered into a MoU with the Ministry of Mines and has also secured a consultant for the development of the business plan of the School of Mines. The African Development Bank is also assisting through a project that started in 2014.

In Zimbabwe, the School of Mines receives no assistance from the mining companies, except for short periods of attachment of students at their operations. Around two-thirds of students are attached to the mines but the duration is inadequate to acquire the necessary training. There are instances where students do not have work placements at all.

Moreover, mining firms ceased sponsoring engineering graduates at the UZ. Prior to 2000, mining companies used to sponsor five engineering graduates at UZ and Wits, which has since ended and currently, all the students are self-sponsoring. Once students complete their studies, they have to secure work opportunities as opposed to previously, when attachment opportunities were readily available. To address this, a programme was initiated in 2011 for placement of lecturers and students through MoUs between four Zimbabwean Universities and the Royal Academy of Engineering in the UK, and six universities in Mozambique, Namibia, and Botswana.

4.3.3 Institutional capability (capacity)

Access to trained appropriately staff has also been a significant impediment for universities in the region as they battle to fill vacant posts due to more attractive working conditions outside the home country, among other factors.

Frozen budget constraints limit UNZA's capability to retain experienced teaching and academic staff. Half of the teaching positions in two out of three departments at the School of Mines, and one third of the teaching positions at the School of Engineering are not filled. Out of 300 lecturers at CBU Schools of Mines/Engineering/Natural Resources/Built Environment, only 50 have PhDs. Lack of funding to upgrade the qualifications of the existing teaching body aggravates the quality of education as vacancies are filled by underqualified staff. Furthermore, engineering schools are not treated differently from competing national interests and as a result, have to compete for resources with other national priorities (agriculture, etc.). The problem is particularly acute because engineering and science lecturers can easily secure employment in the private sector rendering the schools' salary packages unattractive.

According to Jourdan et al. (2012: 92, Box 4), 'Vacancies for academics at the University of Zimbabwe have reached such a stage that courses in mining, metallurgical and electrical engineering as well as in geology and survey are at risk' (Viewing 2007 in Hawkins 2009). 'The vacancy rate in the Faculty of Engineering in mid-2007 was 66 percent while in the Geology and Chemistry departments of the Faculty of Science the vacancy rate was 62 percent' (Jourdan et al. 2012: 92, Box 4). In geology, only three academics were in a post out of an establishment of 16, while the departments of mining engineering, metallurgy, and survey had a total of five people in post against 35. Interviews in 2015 suggest that the situation has further deteriorated since the 2007 study. In 2015, of the 10-member staff complement at the Department of Engineering, there were six vacancies. Departments that had 15 lecturers each after 2000 were downsized to three-to-four permanent staff. The Mining Department does not have a full-time dedicated qualified lecturer and has resorted to sending students for postgraduate studies to UNZA, which also has its own set of challenges. Students are also sent for post-graduate studies to South Africa, China, and the European Union (EU). Shortages of academic staff affect the mining engineering, metallurgical engineering, electrical engineering, geology, surveying, and chemistry departments at UZ as well as the Bulawayo School of Mines. Moreover, the Institute of Mining Research (IMR) in Zimbabwe and the Government Metallurgical Laboratory are also severely affected, as these institutions are their main source of research capabilities.

Botswana has the lowest vacancy rate. Even though 65 per cent of posts at UB are filled, the qualifications of lecturers do not meet the required criteria: academic staff are required to have a PhD (some departments still only have 30 per cent of PhD holders among staff). Respondents highlight that there is high demand for competent staff with the appropriate training and interaction with the industry in the region. Previously, UB used to attracted lecturers from the region, due to the strong Botswana Pula and fringe benefits, however, this is not the case anymore and key staff are migrating to the private sector and other universities in the region, mainly South Africa, for better conditions.

4.3.4 Plans following skills acquisition

Most Zambian mining school graduates and post-graduates find employment in Zambia within the mining industry or in government although others struggle to find employment. The mines used to employ large numbers of graduates however since the 2008–09 slow down, demand for graduates declined. Even though there is a dispensation to offer employment to female graduates first, female graduates still struggle to find employment.

The 2006 Zimbabwe National Human Resources Survey concluded that as many as 70 per cent of 1,519 graduates surveyed wished to emigrate—76 per cent for graduates and 86 per cent for postgraduates (Viewing 2007 in Hawkins 2009). UZ itself estimated that, of 2,800 students who graduate each year, only about 700 prefer to stay in Zimbabwe. Students sent for postgraduate studies to foreign institutions rarely return. Even though these are overall graduate statistics, not isolating engineering, it shows that there is a strong desire to emigrate upon completion of studies. One astonishing example is from the National University of Science and Technology

(NUST). NUST has an exchange programme that allows students to study abroad, and upon completion of their studies, the students can work in Zimbabwe for a certain time frame, otherwise the students can settle the student loans and work anywhere. In 2000, NUST sent 40 postgraduate students for master's and PhD programmes to the United Kingdom (UK) and only two returned to the country following completion of studies, while the rest opted to settle their student loans. One of the two only came to Zimbabwe to pay his student loan in cash before returning to the UK. Indeed the brain drain of R&D and innovation institution discussed later in this paper confirms that most engineering, scientific, and technical skills have been lost, mostly to the benefit of South Africa. According to the Engineering Council of Zimbabwe (ECZ), because the mining industry is shrinking, engineers tend to work in other non-related fields rendering their skills obsolete.

Botswana does not have a significant manufacturing sector, which disadvantages mechanical engineering students. Civil engineering students do not encounter this problem due to higher levels of national construction activity. The demands for non-civil engineering discipline graduates are low and graduates not only have challenges securing work placement during studies, but this is translated to difficulty in finding employment post-studies. Graduates then resort to limited opportunities in government, parastatals (utilities), engineering consulting, contracting firms, and the mining sector.

The Engineering Council of South Africa (ECSA) conducted a survey to audit the skills in the South African engineering industry. The survey was responded to by 10,000 respondents (8 per cent of the profession), which included engineers, technicians, and technologists. The survey indicated that almost 90 per cent of the respondents are employed within the industry: consulting/professional service provider, parastatal/utility, process plant, contracting, and mining houses. The available opportunities and better working environment deem it conducive for students and lecturers from other countries to relocate to South Africa, which has particularly impacted Zimbabwe and Zambia adversely, and less so Botswana. The foreigners that responded to the survey cited better job opportunities, personal reasons, education and training, and the economy as the main reasons for relocating to South Africa. Despite the emigration by SADC citizens into South Africa, 11 per cent of South African engineers have left the country due to better job opportunities, crime, and remuneration (60 per cent of these left between 2008 and 2013 and 13.7 per cent do not have plans to return).

4.3.5 Poor human capital planning

The status of skills across South Africa, Botswana, Zambia, and Zimbabwe is skewed. Botswana seems the least affected due to the low demand from mining companies in the country, however there is an oversupply of mining skills. Zambia has a high output of graduates, though the quality of the students is questionable leading academic and research staff to South Africa for greener pastures. Zimbabwe's academic and research staff underwent an exodus to international countries, mainly South Africa, following the economic downturn. South Africa seems to have benefitted from the movement of skills across borders. Nonetheless, individual countries are failing to churn out students appropriately trained in engineering with the requisite technical skills.

Recent years have witnessed an increased role by private providers of tertiary education and training skills across the region. These institutions are driven more by short-term profit motives and tend to offer courses of study for skills that are not necessarily in short supply. Partly as a result, Botswana in 2015 had a surplus of IT graduates and diplomas, estimated at around 10,000. This situation arose from a confluence of factors, including the practice of accepting government-to-government ICT-specific training offers, for example to Malaysia. It is also a result of a lack of planning. For these reasons, Botswana is trying to absorb ICT graduates into its NSI development efforts. In Zambia, an increasing number of students have studied at private institutions for business-related courses, with diminishing interest in engineering and technical subjects. The underlying reasons for this trend are multifaceted and include the growing importance of service sectors and poor human capital planning capabilities from governments in the region.

Poor human capital planning has been highlighted in both Botswana and Zimbabwe. In Botswana, the newly established Human Resource Development Council has been mandated with planning the skills requirement to support Botswana innovation goals. In Zimbabwe, the National Manpower Advisory Council of Zimbabwe (NAMACO 2012) has a similar mandate. According to the Zimbabwe Institution of Engineers (ZIE), there has not been an updated assessment of skill requirements for the mining industry since the IS152 paper of 1990 and a United Nations' study in 1996. This is despite the heavy industrial policy emphasis being placed today on the beneficiation of Platinum Group Metals (PGM), which will require a comprehensive skill set.

4.4 Misalignments in TVET systems

Gaps in technical skills are pervasive across the three countries and affect the mining and manufacturing sectors. Some challenges are related to the TVET system set up by the state. For example, the implementation of a coherent TVET qualifications framework in Botswana has been impeded by lack of clarity between the roles of different agencies that have responsibility for TVET qualifications (UNESCO 2013). Trade tests and craft qualifications are the responsibility of the Labour and Education Departments. The TVET agency (previously known as the Botswana Training Authority, BOTA) focuses on developing new unit standards-based occupational qualifications, accrediting their delivery, and qualifications offered by private and employer-based providers. The government of Botswana has recently addressed this gap by converting BOTA into the Botswana Qualifications Authority.[12]

In other cases, the role of the private sector has been critical. In Zimbabwe, this has proved so with a positive outcome. Despite the seemingly unravelling of the Zimbabwe NSI, its technical and vocational training institutions in Harare, Bulawayo, and Gweru are still producing high calibre mining and metallurgy skills. The TVET segment of Zimbabwe's NSI seems to have been more resilient to economic decline than the engineering segment. The Zimbabwe School of Mines in Bulawayo, established in 1926, provides technical and artisanal training to National Diploma and Higher National Diploma level Mine Geology, Mine Survey, Mining Mineral Processing and Extractive Metallurgy, and Metallurgical Assaying.[13] The School of Mines Bulawayo has marketed itself well to get part-time senior professorial staff. In 2000, the degree programme was adapted into modules to circumvent the short supply of lecturers. The lecturing is therefore conducted in 4–6 week timeframes to allow the lecturers to fulfil their work obligations. The School caters to students from all over the region including Namibia, South Africa, and the Democratic Republic of the Congo (DRC). The School resisted incorporation into the local University and operates as a separate entity. According to 2015 interviews, it is

[12] For information on the new Botswana Qualifications Authority, see http://www.bota.org.bw/?q=node/195 (accessed 17 May 2016).

[13] For information on the School of Mines, see http://www.zsm.ac.zw/zsmsite/about-zsm/historical-perspectives (accessed 17 May 2016).

actively supported by the Chamber of Mines and by the mining industry through provision of training for students from across the SADC region.

In Botswana, skills development by the private sector has been a critical component of the success of the beneficiation strategy. Diamond cutting and polishing is skills intensive, and skills can only be transferred with significant on-the-job and in-house training. A company reports that out of 15 trainees only three-to-five people can be employed after four years of training.

Zambia's case starkly illustrates a combination of misalignments in investment in skills development within the public sector (with technical skills being largely marginalized), and between public and private sector.

4.5 Zambia's TVET experience

4.5.1 State investment in skills development

While there is a gap in Zambia's graduate engineering skills, the shortage of technical and artisan skills is more severe, estimated at 11,000 in 2015. For some time, there has not been a coherent skills development policy in Zambia. Zambia's Technical Education, Vocational and Entrepreneurship Training Authority (TEVETA) was established in 2000 and designed to address the shortage of technical and artisanal skills. TEVETA falls under the Ministry of Education, Science, Vocational Training, and Early Education, which is the largest within Zambia's government. Within the large mandate of the ministry, TVET has been increasingly marginalized. Increasing recognition of the importance of technical/vocational skills has not been matched by funding, evidenced by resources being cut by 5 per cent in the 2015 annual budget.

TEVETA priority areas are identified by the Sixth National Development Plan (Ministry of Finance 2015), which refers to agriculture, manufacturing, mining, construction, and hospitality. TEVETA now has an even larger mandate, which includes technical and vocational training in secondary schools. Vocational courses (metal fabrication, bricklaying, carpentry, agriculture, music, art and design, home management, and economics) have been recently introduced at Grade 9, so as to provide those students who do not matriculate from school with alternative career paths.[14] Moreover, Ministries like Agriculture and Community Development have to promote training and implementation through TEVETA because curriculum development and certification are centralized functions within TEVETA; however, this stretches the already limited resources.[15]

Relationship with the private sector are structured around the Sectoral Advisory Groups, a public–private sector platform aimed at supporting industrial policy implementation, inter-ministerial coordination, and rallying the private sector into addressing some of the key challenges for economic development. However, engagement by industry is poor. TEVETA participates as the lead agency for curriculum and competencies development in the Sectoral Advisory Groups for construction, manufacturing, tourism, and services. With the exception of

[14] In 2015, the first batch of students trained in electrical, carpentry, metal fabrication, and brick laying were assessed, and results are still to be released, though there is a general consensus that it was successful. Courses in agriculture, computers, art design, and home management will be offered in 2016, which will further stretch the budget.

[15] TEVETA is also working in sectors other than mining, for example they are also doing assessments for skills employed in the informal sector.

construction and tourism companies, industry has not been interested in contributing resources for skills development. The construction and hospitality sectors are the most advanced in adopting a sector-based collective training initiative. The construction sector initiative has developed fast after the first consultative meeting—firms in 2015 finalized a levy contribution system to be invested in skills relevant for their sector.

4.5.2 Firm-level investment in skills development

In the 2000s, when the private mining companies entered Zambia's mining sector and benefitted from the commodity price boom, skills development was not viewed as a priority. As a result, international firms either recruited mining skills from their home countries or from South Africa. The linkages that previously existed between local engineering firms and ZCCM fragmented resulting in the loss of specialized skills. However, as operations expanded and greenfield and brownfield projects took off, the sector began to experience domestic skill shortages. The new mining companies set up their own training programmes in separate training centres to meet their own individual requirements. Over time, this has evolved into approximately 15 different company-specific training programmes.[16]

Firm-level initiatives are at different stages and adopt different philosophies depending on the scale of their respective operations. According to the International Council on Mining and Metals (2014), the mining companies are investing in a combination of in-house and outsourced training.[17]

Companies adopt different approaches to in-house training and skills development: some focus on technical and safety training, others on technical and managerial training. Although individual companies tend to start training employees immediately after employment and keep good learning record systems, workers receive no certification so their skills are neither accredited nor portable when, for example, they move to another mine. Consequently, they re-enter the labour market as unskilled labour at entry-level conditions.

In terms of outsourced training, Lumwana's training centre in Solwezi is a modern facility and was built in collaboration with TEVETA. Lumwana took a section of Solwezi's existing school, and established a workshop and training programmes on metal fabrication, electrical, and heavy equipment operations. In-house, at the mine site, the company has mineral processing training and is working with TEVETA to localize the programme. Chinese-owned Chambishi built a training school, set up training programmes, and started working together with TEVETA from inception. KCM technical training is provided through courses at Kitwe Trade School. FQM has a learning scheme in equipment repair and training programmes for mineral processing workers at technician level. The training programmes are in partnership with Nortech and, because of this, they have a stronger partnership with TEVETA via Nortech. Mopani built a training school 2–3 years ago and is now the biggest training centre in the area. All these programmes however need to be centralized and framed within Zambia's TVET system.

[16] Industry also report to invest actively in the skills of those they employ as contractors, thus making a further contribution to human capital development in Zambia (ICCM 2014). This however could not be independently verified.

[17] 'Data provided by three mining companies indicates that together they spent around US$5 million on outsourced training in 2012. The spending on training in recent years, in absolute terms and as a share of total labour costs, has increased' (ICMM 2014: 64).

Zambia's experience contrasts with South Africa's. South Africa's mining houses have their own individual training centres, which have been established over a long time near the mines. The training centres are well equipped and are dedicated to trade and artisans. The mining houses' certifications are accredited, which allows workers to move to other mining companies should they want to. Over the years, the mining houses have trained above the needs level, to make sure they have sufficient numbers, so there is no scarcity. Whilst the system is private, they interface with the public sector because for a trainee to become an artisan, they need to go to TVET colleges. The TVET colleges however are not matching the investment by private firms as the artisans and technicians are of sub-standard quality evidenced by a pass rate of 4–11 per cent.

Each mining house undertakes its own in-house and external training with the exception of the coal sector, where the mines have cooperated and set up a shared training facility, the Colliery Training College. The college trains workers on how to mine, operate plant and equipment, and artisanal skills. The Chamber of Mines is involved since the college had no pre-existing training facility. The training is located in one area so movement to and from the training centres is limited. Overall, there is no shortage of technical skills. During the PMGs price boom, there was a slight skills shortage, but it was artificial and short-lived. There is no shortage of semi-skilled (operators and miners with a blasting certificate) and OEMs are involved in training of operators on specific machineries.

In Zambia, a structured collaborative process is currently underway between TEVETA, the Chamber of Mines, and individual mining firms to integrate company-specific qualifications within an NQF. The programme seeks to recognize retrospectively prior company-specific training within the NQF. The initial focus of activity is on entry-level skills (heavy equipment operators, crane operators, excavator operators, smelter process controllers, locomotive operators, etc.). In addition, TEVETA is putting recognition of prior learning framework in place to assess skills already acquired by workers that can be recognized towards an official qualification. The guidelines have been prepared, and the next stage is to implement them using the respective mine's assessment records.

There is no training or skills development obligation on the mining companies under current Zambian legislation. The Zambian Government has been discussing a mandatory skills levy, since TEVETA was established in 2000, before the commodity supercycle boom that drove the expansion of Zambia's copper mining sector. The National Economic Advisory Council—linked to the presidential office—in late 2014/early 2015 made a proposal that one per cent turnover be collected by any firm to fund skills development. This has received strong industry opposition, partly because of scepticism about the ability of government to collect and spend the levies appropriately. Another concern by private firms in specific sectors is the belief that a levy would be used to support the creation of skills that are not specific to their respective sectors. It is notable that domestic Zambian manufacturers, as represented by ZAM, also opposed the skills levy. ZAM and Zambia Federation of Employers opposed it on the grounds that skills development challenges are not limited to availability of financial resources.

This policy debate, the need to address local skills shortages, and stricter immigration rules have resulted in the setting up of the Zambia Mining Skills and Education Trust (ZAMSET) the end of 2014. All the major mining companies (except Chinese-owned Chambishi) have joined the initiative, under the Chamber of Mines. ZAMSET was expected to become operational by the end of 2015, with strategies in place and more importantly financing. TEVETA was not opposed to the ZAMSET-type approach. Should the mines focus on mine-specific skills, this would allow TEVETA to focus on the skills cutting across other sectors.

This approach follows closely the one adopted by South Africa, where mining houses make voluntary contributions to the Mining Education Trust Fund, based on a contribution for each graduate employed. The Fund provides scholarships and supports mining-related degrees: mining, chemicals/metallurgy, geology, in particular supplementing lecturers' salaries. This ensures that the Universities can retain good lecturers by offering market competitive salaries. Otherwise, they would go into private sector, or relocate to Canada or Australian universities. It is not clear however whether ZAMSET has the same level of ambition and commitment.

4.6 The regional dimension

The emergence of NQFs within individual countries will facilitate the movement of engineering and technical skills across the region. Interviews with SADC confirm that information exchange between national institutions is increasing—for example between South Africa Qualification Authority and Zambia Qualification Authority—and has led to regional recognition of qualifications. In the absence of a Regional Qualification Framework (RQF), each country assesses applications for recognition on an individual basis, which is time consuming even if there is good cooperation between individual NQF authorities. In some cases, bridging courses may be required.

The SADC Education Desk works on the basis of the Revised Arusha convention linked to the Washington Accord. In 2000, SADC established a Protocol to establish a Regional Qualification Framework. As of November 2015, the first stage had been implemented, namely the development of one framework for all skills. This is a long process because member states first need to build their respective NQFs and establish their own NQAs, which as discussed in Section 4.1, are still under development. The process is also time consuming, for example, countries struggled to reach an agreement on the matric or A Level framework, and eventually resorted to UNESCO international standards. The underlying principle of the RQF is not standardization, but rather recognition and development of minimum standards. Of the countries surveyed, only South Africa has a well-established NQF, with Botswana and Zambia having recently started.[18] South Africa has been sharing experiences and benchmarking, which is also happening across the region with for example Zambia assisting Botswana.

A striking feature of the SADC education systems analysed is the extent to which national tertiary institutions are unable to accommodate their national student complement (Table 4). A very large proportion of students from Botswana (71 per cent), Zimbabwe (29.9 per cent), and Zambia (14.7 per cent) study outside their home country. Even though Zimbabwe has a low proportion in relative terms, in absolute terms, Zimbabwe has by far the largest stock of students abroad (16,700) in SADC, given the decline of the domestic education system. Botswana has the second largest stock (9,500) in absolute terms, while Zambia has a relatively low stock both in absolute numbers and as mobility rate.

[18] Most countries have developed qualification frameworks at sub-sector level, making integration more difficult.

Table 4: Intra-SADC student flow

Country	Students from a given country studying abroad			Top five destinations for outbound mobile students	Number of students from abroad studying in given country
	Total	Outbound mobility rate (%)	Gross outbound enrolment ratio		
Angola	5942	45.9	0.4	Portugal (3,367), South Africa (839), USA (442), Namibia (354), France (205)	50
Botswana	9471	71.6	4.5	South Africa (7,012), Australia (792), UK (700), USA (488), Malaysia (152)	n/a
DRC	3956	6.6	0.1	Belgium (1,271), France (816), South Africa (378), USA (340), Burundi (276)	n/a
Lesotho	4537	74.3	2.0	South Africa (4,366), UK (42), USA (39), Australia (15)	116
Madagascar	3995	9.5	0.2	France (3,487), USA (109),Germany (100), Switzerland (80), Canada (41)	1219
Malawi	1438	28.3	0.1	South Africa (417), UK (404), USA (399), Australia (77), Canada (22)	n/a
Mauritius	7224	40.6	7.0	France (1,893), South Africa (1,732), UK (1 646), Australia (860), India (366)	75
Mozambique	2366	10.6	0.1	Portugal (1,066), South Africa (815), USA (93), UK (71), Australia (67)	n/a
Namibia	6847	58.1	3.5	South Africa (6,530), USA (95), UK (74), Australia (24), Germany (16)	1026
South Africa	5619	0.8	0.1	USA (1,971), UK (1408), Australia (643), Cuba (340), Germany (196)	49979
Swaziland	2106	31.9	1.7	South Africa (1,882), USA (86), UK (67), Lesotho (17), Australia (13)	127
Tanzania	3907	9.1	0.1	USA (1,471), UK (1,053), South Africa (283), Australia (119), Germany (115)	275
Zambia	3610	14.7	0.3	South Africa (1,363), USA (859), UK (541), Australia (317), Namibia (228)	n/a
Zimbabwe	16669	29.9	1.1	South Africa (10,586), UK(2,741), USA (1,999), Australia (892), Namibia (71)	n/a

Source: CREST (2011).

These figures are not disaggregated by schooling level or disciplines. Enrolment data from Schools of Engineering at University of Cape Town (UCT) and Stellenbosch University shed some light on trends by country (Table 5). Zimbabwean students seem more likely to move abroad for undergraduate degrees. Students from Zambia undertake graduate and even more postgraduate courses abroad. For example, UNZA Engineering School report that there are three Zambian PhD students at Wits and University of Pretoria, plus staff members studying in South Africa. Botswana's students moved for undergraduate studies, with small numbers of postgraduate students.

Table 5: Enrolment of regional students at Stellenbosch University and UCT

	Stellenbosch University			**UCT**		
	2013	2014	2015	2013	2014	2015
Undergraduate						
Botswana	0	1	1	20	17	11
Zambia	1	1	1	17	14	14
Zimbabwe	42	48	43	145	145	122
Others Africa	112	109	109	254	252	244
Postgraduate						
Botswana	2	4	3	5	3	4
Zambia	13	21	24	13	17	18
Zimbabwe	24	24	30	57	55	67
Others Africa	97	108	94	149	155	185

Source: Fieldwork.

South Africa was the largest destination country for the three countries selected, and hosted almost 50,000 foreign students (Table 5). This points to a largely regionally integrated education system. Even though the development of the RQF lags behind, it is difficult to obtain recognition for courses obtained in home countries. The particular dynamics of the education system within the region has led to students moving across to South Africa and attaining South African qualifications. For example, notwithstanding the fact that Botswana has education statistics comparable to South Africa, if not superior in terms of tertiary education enrolment, South Africa's tertiary education system has, over decades, developed centres of excellence in engineering, in particular at Wits and UP. As discussed in the next sections, many Zambian and Zimbabwean graduates tend to remain in South Africa's university systems or engineering consultancy sector after completing their studies. According to Stellenbosch University and UCT, up to 50 per cent and 70 per cent respectively of their Zimbabwean students do not return to their home country after completing their studies. Out of Botswana's students studying in South Africa, on the other hand, more than 90 per cent returns home.

At UB, individual departments and faculties have MoAs with other universities including Stellenbosch University and UCT. Zambia's CBU has no cooperation agreement. So far, relationships with South Africa universities have been mainly built through connections between supervisors in South Africa and postgraduate students returning to CBU. UNZA's School of Mines promotes regional cooperation and its strategic plan encourages synergies with institutions anywhere in the world. At the moment, there is a MoU with UCT/Stellenbosch University. UNZA School of Mines has four PhD students at Stellenbosch (chemical/environment engineering), whilst the School of Engineering has two students at Stellenbosch University. There was a previous agreement with UJ's Geoscience department but this was not renewed. The School is looking at establishing a relationship with the University of Venda, building on the current informal relationship whereby UNZA provides external examination and quality assurance. There are also exchanges not related to South Africa: UNZA School of Mines report there are academic exchanges in place with the region, and it is currently hosting several post-graduate students from Zimbabwe and eight post-graduate students who are staff members at UZ.

5 R&D and innovation

R&D investment is a particularly important indicator for understanding the NSI of mature economies and advanced industrializing countries. Proxies include national expenditures on R&D, financing of industry's R&D, and number of scientists and engineers employed in R&D. The industry share of R&D funding is a critical indicator of NSI dynamism, and large industry spending has been found to contribute to technological innovation and economic growth (see Freeman 1995 for Japan; Viotti 2002 for South Korea).

R&D investment in SSA is low by international standards. R&D expenditures as a share of GDP in 2007 stood at 0.58 per cent, which is less than any other developing region (Table 6). Botswana and Zambia's R&D investment are below SSA average, both in terms of expenditure and relative number of R&D researchers. Other figures for Botswana however suggest that in terms of full-time researcher per million, the country is SADC's second largest investor (139) after Mauritius (150) and before South Africa (135) (CREST 2011).

South Africa is a relatively large investor, with 0.76 per cent of GDP spent on R&D and 363 R&D researchers per million people. By international standards, South Africa is below the BRICS and South Korea, but not too far from India, and with a significantly higher number of researchers/million (although in absolute terms, India has a very large stock of researchers)

(Department of Science and Technology 2013). South Africa's R&D expenditures nevertheless have been declining in both absolute and percentage terms since the second half of 2000s (Figure 2). The decline is also reflected by the decline in the number of researchers employed by industries' R&D departments from 6,172 in 2008 to 4,556 in 2013. Conversely, the number of researchers in universities increased from 9,953 in 2008 to 13,744 in 2013. One-third of researchers at PhD and post-doctoral level were non-South Africans.

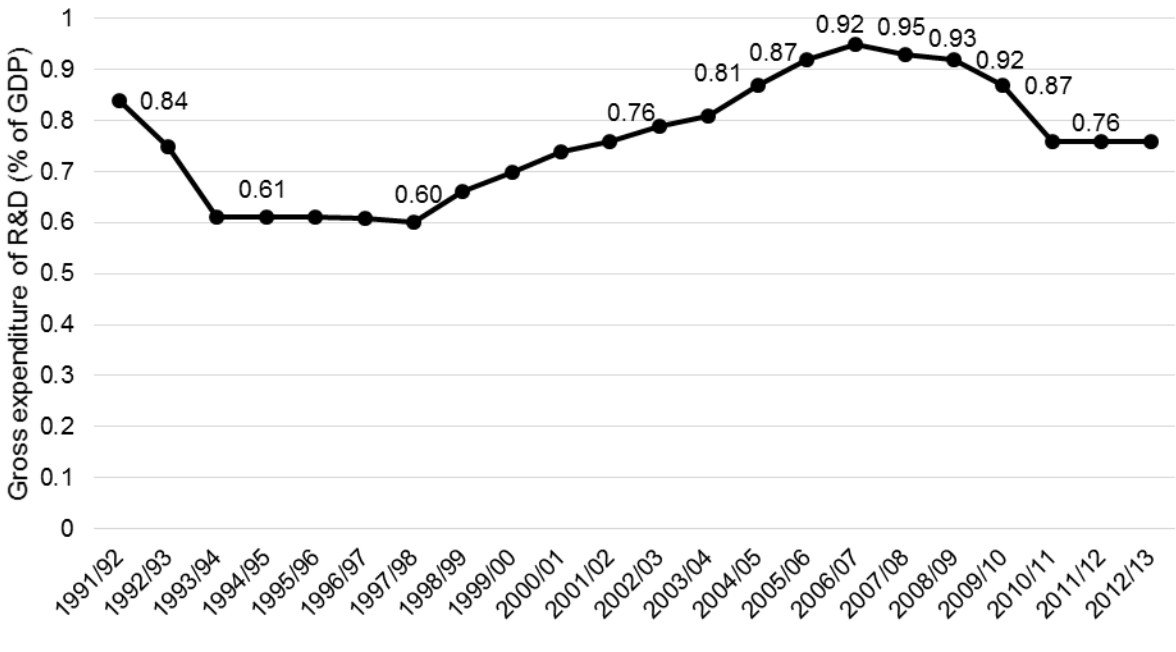
Table 6: R&D investment in SSA and selected countries

	R&D	
	R&D expenditure (% of GDP)	Researchers in R&D (per million people)
SSA	0.58 (2007)	-
Botswana	0.53 (2005)	-
South Africa	0.76 (2010)	363.8 (2010)
Zambia	0.34 (2008)	43.0 (2008)
Zimbabwe	-	95.1 (2012)
East Asia & Pacific (developing countries)	2.00 (2011)	1,020 (2012)
Latin America & Caribbean	0.84 (2011)	538.1 (2010)
Brazil	1.00 (2011)	710 (2010)
India	0.81 (2011)	159.9 (2010)
South Korea	4.04 (2011)	5,928.3 (2011)

Note: Latest available data.

Source: World Bank (2016).

Figure 2: South Africa gross expenditure on R&D (1991–2013, % GDP)



Source: Department of Science and Technology, South Africa (2013).

African governments are the main source of R&D funding, accounting for more than 60 per cent of total R&D expenditures (UNECA 2014). More than 70 per cent of R&D activities are performed in government laboratories, public R&D institutions, and universities. This is confirmed for SADC, where the majority of countries and most of the universities (with the exception of South Africa) relies for more than 70 per cent of their total research funding on international funding organizations; the comparative figure for South Africa was 6 per cent (CREST 2011). Industry R&D is very low, with weak firm R&D capabilities and industry-research institutions collaborations (World Bank 2011).

Unlike the rest of the region, in South Africa, industry, mostly national firms, is the largest source of R&D funding, 44.3 per cent of total expenditures in 2012–13, amounting to ZAR10.5 billion (Department of Science and Technology 2013). Manufacturing (machinery and equipment) and mining were the second and third most important sectors for industry R&D. Industry funded mainly its own research, with small shares directed to universities (6 per cent) and science councils (1 per cent). This is consistent with the view that industry-research links are insufficient (World Bank 2011).

As expected, the performance of Africa's NSI in terms of IPRs has been weak. Africa accounted for about 0.8 per cent of the world total of about 2.35 million patent applications in 2012 (UNECA 2014). Patent registration data show very low activity within Botswana, Zambia, and Zimbabwe (Table 7). There are however missing data for several countries and years. During the ten-year period 2004–13, Botswana registered 32 patents, Zambia 286, and South Africa 72,758.[19] In South Africa, two worrying trends were noticeable: patent registrations trend has been stagnant, compared to high growth in Asian countries, and the ratio of resident to non-resident patents equalled 0.1 in 2013, due to declining numbers of resident patents—from 1,003 in 2005 to 638 in 2013. This ratio was low by international standards: for example, it was 0.33 in India and 3.56 in South Korea.

Table 7: Patent and trademark registrations, selected countries (cumulative 2004–13)

	Botswana		Zimbabwe		Zambia		South Africa	
	non-resident	resident	non-resident	resident	non-resident	resident	non-resident	resident
Patents	18	14	0	0	194	92	64,613	8,145

Source: World Bank (2016).

The number of African articles on science, engineering, or technology published in peer-reviewed journals has grown faster than the world average, although from a low basis (1.8 per cent of the global total of science, engineering, and technology articles in peer-reviewed journals, with 2.4 per cent of the world's researchers) (UNECA 2010). Botswana, Zambia, and Zimbabwe produced insignificant numbers of publications (Table 8). South Africa was a regional leader, but its publication record was still low by international standards. However, South Africa and Botswana also reflect the greatest growth in ISI-output between 1995 and 2007.[20] Overall, with the exception of South Africa, mining is not a dominant subject of publications, and scientific output in the SADC region is focused largely on medical research on infectious and tropical diseases.

[19] From 1995–2007, South Africa received 188 applications from 12 African countries. In Zambia and Malawi, their resident applications to South African patent office was higher than the ones received by their own offices (UNECA 2010).

[20] Institute of Scientific Information (ISI) The Thomson ISI® is the leading database with more than 6,000 mainstream journals in the Science Citation Index.

Table 8: Scientific and technical journal articles, selected countries (2002–11)

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Botswana	60	67	64	48	67	62	58	45	33	50
South Africa	2,328	2,205	2,320	2,395	2,643	2,808	2,916	2,864	2,972	3,125
Zambia	29	22	26	31	40	36	42	35	43	60
Zimbabwe	97	87	64	62	64	80	66	56	70	63
SSA	4,050	3,947	4,097	4,183	4,616	4,952	5,074	5,080	5,248	5,422

Source: World Bank (2016).

Analysis by CREST (2011) reveals that, for SADC countries as a whole, there has been a general de-institutionalization of science reflected by poor research output, deteriorating state of research infrastructure, declining research funding coupled with rapidly increased student enrolments. The critical impediments to deepening respective NSIs have been identified in terms of: low government expenditures on R&D; weak institutional infrastructure for coordinating and facilitating research; and working with universities (CREST 2011).

All the countries surveyed have or are building central institutions to coordinate and facilitate science funding and research funding as indicated in Table 9.

Table 9: The state of national and institutional funding agencies

Country	National Funding Agency	Central coordinating office for research funding at main universities
Botswana	Yes [Botswana Research Science and Technology Funding Agency] (BRSTFA)	University of Botswana Research Department
South Africa	Yes (National Research Foundation)	Yes (The majority of South African universities have a central Research Office that manages external flows of research funding)
Zambia	Yes [National Science and Technology Council (NSTC) - Science and Technology Development Fund]	Directorate of Research and Post- Graduate Studies (UZ)
Zimbabwe	Yes [Scientific Industrial Research and Development Centre (SIRDC)]	No information

Source: CREST (2011).

The research findings confirm that the main common impediments to R&D, innovation and the evolution of a robust NSI include:

- R&D and intellectual property (IP) funding
- R&D and IP commercialization
- Skills
- Industry relationships with NSI education and research institutions

Across Botswana, Zambia, and Zimbabwe, we note that policies to develop a NSI have recognized an important role for the state. However, this has often marginalized the opportunity to promote firms' own innovation capabilities; for example, Zambia's government does not offer incentives or support at the firm level for technology upgrading. To finance new equipment, firms have to resort to the banking system, which however, does not cater to their needs and charges commercial interest rates.[21] Incentives or support mechanisms for firms to upgrade

[21] MCTI used to have a SMEs board, which at least provided technical services, but this was collapsed under the ZDA and its functions have been limited.

skills, access consultancy services, improve operations, and access information on inputs suppliers or technologies are not available.

Botswana and Zimbabwe present two contrasting experiences, whilst the former is laying the foundations for an ambitious NSI, the latter has seen the rapid deterioration of its NSI, which used to be SADC's second more established one after South Africa before the economic crisis.

5.1 Botswana's ambitious NSI and innovation policy

Botswana has been systematically building and extending an NSI institutional capability since 1998, when it adopted a Science and Technology Policy. A Department of Research, Science & Technology was created in 2004, followed by the Botswana National Research, Science and Technology Plan in 2005 (CSIR 2005), the creation of the Botswana Innovation Hub (BIH) in 2007, and the proposed Botswana, Research Science and Technology Funding Agency (BRSTFA).

Prior to this, funding was directed more towards primary research and development (rather than commercialization) and was carried out by dedicated state-funded research institutions, such as the Botswana Technology Centre (BOTEC),[22] the Rural Industries Promotion Company Botswana (RIPCO), and others. While these institutions produced important first generation research, they were not geared towards commercializing the output, with no technology transfer capacity and weak interfaces with private sector interests.

The establishment of the BIH and the 2008 Botswana Excellence Strategy represent the government's intention to move Botswana towards a knowledge economy. Innovation has been hampered by a number of factors. A small domestic market and narrow resource base discouraged investment in manufacturing. For this reason, Botswana's current focus is on upgrading technological capabilities for niche industries. Interviews highlighted that the main gaps in the development of a dynamic NSI consist of insufficient R&D funding, poor commercialization, and weak management skills of start-up firms. Private firms spend little on innovation and public R&D efforts have been limited with most university staff being more committed to teaching (90 per cent of their time) than research. Moreover, research output has often been a lost opportunity because researchers have not been supported in patenting and there was no interest from the private sector in taking over and developing. R&D and skills development have also not been aligned to industry needs. Two organizations have been designed to address these constraints: Botswana Institute of Technology, Research and Innovation (BITRI) and BIH.

5.1.1 Botswana Institute of Technology, Research and Innovation

In 2012, primary research capacity was consolidated under BITRI (2012), largely through the incorporation of BOTEC and RIPCO. BITRI has two thematic focus areas (BITRI 2014):

- Technologies (Electronics, Energy, ICT)
- Natural Resources and Materials (Environment and Climate Change, Materials, Water)

[22] See Climate Action Network for a description of Botec, http://www.climatenetwork.org/profile/member/botswana-technology-centre-botec (accessed 17 May 2016).

During the subsequent three years, the policy framework had been finalized with the construction of offices and laboratories, and by 2015, BITRI had equipped almost all laboratories. BITRI's task is to identify, absorb, and innovate technologies. Hence, there are significant efforts to acquire intellectual property, adapt foreign technologies to domestic conditions, and pursue incremental innovation. In this spirit, BITRI has concluded an agreement with Singapore Solar Energy Research Institute (SERIS) to develop new applications for their existing products. BITRI is funded by government and parastatals commissioning services from their labs and research centres. So far, cooperation with the mining sector has been minimal with management forecasting a change.

The institute has three sites and several centres devoted to ICT, chemistry, engineering, and industrial workshops (CNC equipment and metalworking). At full capacity, BITRI has a staff complement of 250 personnel. However, in 2015, it had 97 staff and 60 interns. Personnel include expatriates for strategic positions, with large numbers of juniors trained to take senior roles in future. The previous institutions had five PhDs, while BITRI already has 35.

BITRI is establishing two pilot plants for the coal to liquid and coal beneficiation research programme in line with resource-based industrialization. It is particularly interesting that the coal to liquid plant research is targeting chemicals and fertilizers rather than fuel (which is the main product of coal to fuel technology perfected by SASOL). Interviews with management indicated that future areas of research would target copper, gold, and soda ash. Gold in particular may be critical for the newly established research facility for nano-materials, which aims to be one of the best facilities in the world. Whilst BITRI aims to focus on long-term basic research, it is also undertaking short-term innovation work to deliver quick wins and garner support, such as helping brick makers optimize operations and develop patents on Kalagadi sand-based brick manufacturing.

A significant portion of BITRI's resources is currently allocated towards ICT with the objective of infusing entrepreneurship amongst the estimated 10,000 unemployed ICT graduates. In parallel with diversifying from an extractive resource base, BITRI sees potential in adding value to resources and plans to influence policymakers to invest further in material-based technological innovation. However, building such capacity is recognized as a long-term process.

5.1.2 Botswana Innovation Hub

BIH was established in 2008 and has a staff complement of 20. Its mandate is to attract FDI in innovation-driven economic activities, develop a science and technology park, support commercialization of innovation, and intellectual property protection of domestic innovators. In 2015, the priority areas have been consolidated under the following sectors:

- Information Communication Technology
- Biotechnology[23]
- Mining Technology
- Energy and Environment (Clean) Technology
- Knowledge Intensive Business Services supporting above sectors

[23] This policy objective is also supported by the state-owned National Food Technology Research Centre, which can be found at http://www.naftec.org/?page=research.BioChem.

The objective is for BIH to be the main implementing agency for the achievement of Botswana's science, technology, and innovation policy objectives.[24] BIH has transformed from being completely government owned to being 51 per cent parastatal in 2012, and aspires to become fully private in future. The model of transformation enables BIH to pursue a very dynamic and responsive business strategy securing more than 80 partnerships with academic, research institutes, and the private sector. The most noticeable partnership is with Microsoft, where it managed to establish a fully equipped laboratory and has supported software development start-ups.

The new BIH head office in Gaborone cost P 350 million with an additional BWP245 million allocated for primary road, sewerage, water, power, and telecommunication infrastructure at the 57 hectare innovation park located adjacent to the Diamond Hub Park near the Sir Seretse Khama International Airport, to be completed by 2016. International investors have been incentivized to locate to the park through lower taxes and labour laws dispensations that allow companies to import skills.[25] Despite the impressive NSI system that is evolving in Botswana, our analysis did not reveal any significant results in the form of emerging innovative private sector firms yet.

By 2015, the BIH had established seven private firms in incubation and ten virtual companies, mostly operating in the ICT field. One of the incubators is the mining entrepreneurship development programme, based in Selebi Phikwe, funded and supported by BCL, a large copper and nickel producer, and run under the Southern African Innovation Support Programme.[26] BIH provides incubation and development support for mining supply entrepreneurs with around 20 firms focused on:

- Hydro-geology
- Aero-spatial mapping (drones)
- Protective clothing/containers for mining samples manufacturing
- Pumps re-engineering
- Software development

The programme is part-funded by mining firm BCL, which set up the facilities and is carrying out the training and mentoring. BIH together with BCL and private companies are working on a project to utilize the slag from the BCL mine to produce nickel and iron powders. The current slag stockpile is estimated in excess of 40.5 million tonnes containing various amounts of iron, nickel, copper, and cobalt.

BIH plans to provide seed funding through their newly established Innovation Fund and will try to encourage angel funding. The BRSTFA funding mechanism did not ultimately emerge—only the Innovation Fund, which channelled resources to the BIH. In 2014, Botswana's NSI was enhanced by the creation of the National Technology Transfer Office, to assist local firms with IPR management and the protection and commercialization of their innovations (BIH 2016).

[24] Botswana's Vice President highlights the Botswana Innovation Hub's contribution to Botswana's Excellence Strategy, http://www.saisprogramme.com/botswanas-vice-president-highlights-the-botswana-innovation-hubs-contribution-to-botswanas-excellence-stratetgy/.

[25] A labour dispensation was published for a company manufacturing drilling rigs dependent on the investor's ability to meet skills transfer, exports, and turnover targets.

[26] The Southern Africa Innovation Support (SAIS) programme, funded by the Finnish Ministry of Foreign Affairs, is a four-year pilot project supporting collaboration between the innovation systems of African countries.

The office is located within the BIH and supported by the University of Botswana, and is part of the Southern Africa Innovation Support (SAIS) programme, a regional programme to support technology transfer organizations in Namibia, Botswana, and Zambia funded by the Finnish government.

It is worth noting that by creating two institutions of excellence, government has also externalized a lot of policy advice as these are better placed to influence policy design. The importance of BITRI and BIH is two-fold. Firstly, BITRI and BIH compensate for the lack of private funding going into research, development, and innovation. The lack of funding is compounded by the lack of incentives at the firm level for technology upgrading or innovation. Secondly, the management of BITRI noted that private and public funds could be attracted for incremental investment. Hence, government has to incur huge sunk costs of developing research capacity, to be able to attract specific research project financing. This is particularly true for areas where Botswana still has to build its reputation, and that are more technologically sophisticated such as nano-material technologies.

The challenge for Botswana (and other countries surveyed) is to align better skills and R&D programmes to the needs for entrepreneurial firms and to create more R&D relationships between industry and universities. Universities have not traditionally been focused on R&D. In an effort to expand post-graduate R&D, the Botswana International University of Science and Technology (BIUST) was established in 2012. Located around 270 km from Gaborone, the institution has completed its first enrolment and is more commercially oriented aiming to carry out research with BIH assisting with the commercialization. Moreover, Botswana's PhD intake has increased recently through a consortium of ten African universities sponsored by the EU, which promotes intra-African exchange students for PhDs.

5.2 The decline of Zimbabwe's NSI

Zimbabwe's NSI has been unravelling since the early 2000s, which is not only illustrated by the extent of brain drain discussed earlier, but also by the performance of national research and teaching institutes. The trajectories of the Institute of Mining Research (IMR) and Scientific and Industrial Research and Development Centre (SIRDC) are instructive.

5.2.1 Institute of Mining Research

The IMR was established in 1969 with a fourfold mandate: innovation (relevant for industry and government); responsive research (for government); sample analysis for the mining companies; and mining exploration (for government). Before the crisis, the IMR produced significant output in terms of technical reports and explorations, also successfully registering a patent for fertilizer production. The downward trend started in 2002, and in 2009, it accelerated. The loss of capacity can be assessed in many areas. In terms of labs for sample analysis, whilst the coal lab and chemical labs are functional, the crushing and pulverizing machines, carbonite and sulphur testing machines, and XRF are not working. In terms of research staff, there have not been new appointments since 2009 due to the requirement that applicants hold a PhD. Yet to attract this calibre of applicants, IMR should improve salary and work conditions, which at the moment is not feasible. Some posts could be filled by lower qualified staff but the PhD requirement has been institutionalized. This has resulted in only three out of 14 post-PhD position posts being filled, with no geologist, and only one of two chemists. Three out of five technician positions are filled, and there are no research assistants. In terms of funding, government only provides operational funding, which is insufficient—only one equipment piece is in working condition, there is only one vehicle for fieldwork, and there is no funding for consumables (chemicals).

5.2.2 Scientific and Industrial Research and Development Centre

The SIRDC was established in 1993 to undertake research for the mining sector, which also entails working hand-in-hand with the Ministry of Mines and the Chamber of Mines. In particular, SIRDC provides environmental impact assessments, optimization services, and waste management solutions for the mining companies. It also has a foundry for spares casting and lab testing services, which support manufacturing firms. There are 12 institutes, of which three are mining-related: geo-information and remote sensing, metallurgical research, and national metrology.

At full capacity, SIRDC employs 400 engineers, scientists, and artisans, however in 2015, only 150 were employed and mostly not at senior level. Brain drain has been severe, across all staff categories with staff mainly locating to South Africa due to better working and living conditions. During the first years of establishment, staff were funded to pursue training and post-graduate degrees overseas. However, the economic crisis convinced them to remain overseas or move to research institutes and universities in South Africa (Wits, Mintek, and CSIR). Often, staff would leave in teams, with scientists and engineers leaving first and other team members following. In some instances, scientists and engineers left with their databases and research output, then patenting the research in South Africa. There were also instances where SIDRC lost contracts because the mining company had a specific relationship with the researcher who left. The decline affects also physical facilities, which are caught in a 'catch 22' situation: personnel will not remain because laboratories are not up to standards, but laboratories do not remain up to standards because they are not utilized nor funded.

Government funding has been shrinking, and now only covers salaries, not operations, with the exception of a recent purchase of lab equipment for crosscutting analysis, which in 2015 would cover only 30 per cent of their operational expenditures. As such the institute sources grants from international donors or domestic customers. The decline of the domestic manufacturing sector has also had a negative impact on the institute as it deprived it of current and potential customers and partnerships in technology development.

A firm survey conducted in 2014 confirms the weakness of the NSI (ZEPARU 2014). Firms reported very low levels of collaboration between the industry and national R&D institutions, and these being largely irrelevant in their upgrading efforts.[27]

As a result, the mining sector mainly taps into the South African NSI and engineering services sector for research, consultancies, and various services. Respondents highlight that there is no interest from the mining companies in cooperating with local research institutes, even if government encourages the mining sector to use local service providers.

5.3 The regional dimension

An analysis of mining-related NSI in southern Africa has to focus on the role of South Africa for a couple of reasons. Firstly, South Africa has the highest R&D capabilities in the region. For example, according to royalties, licencing fees, and using payments as proxy for technology transfer and capabilities, South Africa accounted for 92 per cent of Africa's total payments for

[27] For foundry and metal fabrication, more than 90 per cent of the respondents stated that there was slight or none such collaborations respectively (ZEPARU 2014). Fifty per cent of foundries and machinery manufacturers and 65 per cent of metal fabricators stated that local research and development institutions were irrelevant (ZEPARU 2014).

2013 (World Bank 2016).[28] Secondly, South Africa operates at the global technological frontier for mining related technologies. Kaplan (2012) examined the quality of South Africa's innovation efforts in the mining sector and found that mining-related innovation is relatively more important than other sectoral innovation within South Africa: it produces more patents than other sectors such as biotechnology and fuel technology and is more valuable at international level; and South Africa is globally competitive (its mining-related patents are more valuable than competitor countries).

There are three key centres for public mining-related research in South Africa: CSIR, Mintek, and the universities. CSIR inherited the mandate and facilities of the Chamber of Mines Research Organisation (COMRO), which used to channel large-scale R&D funds from industry into pure R&D. Following its demise in the early 1990s, R&D capabilities in mining research collapsed. CSIR has an annual budget of ZAR750 million per year, and mining research continues to be marginalized.

A regional research alliance has been in place between South Africa's CSIR, Botswana's BITRI, and Zimbabwe's SIRDC with the aim of sharing knowledge, information, and exchange personnel. Priority areas were identified in mining, pollution, water, and food security in mining communities. Interview findings suggest that the initiative has not been successful, for reasons including lack of resources available to undertake projects and weak leadership in driving this partnership forward from the CSIR. This alliance has deteriorated due to lack of funding.

Mintek traditionally has strong R&D capabilities related to mineral processing. Mintek balances long-term, break-through research (where the payback in terms of implementable technology may be 10–20 years) with short-term, incremental research suitable for rapid implementation. Its services include test work to develop technologies applied to new projects and optimization of existing operations; contract research; transferring innovative technology to industry; design and fabrication of specialized plant and equipment for the minerals industry; production and supply of specialized mineral and metal products; and provision of specialized consultancy, training, and advisory services to the minerals industry. Forty per cent of commercial revenue is from research undertaken outside of South Africa. Mintek's focus is more domestic than the region, although its capabilities in the development and optimization of mineral processing systems to cater to different minerals can be extended to any mining operation, as is evident in its global activities outside of SADC. The potential for regional R&D and innovation work is illustrated by a number of regional projects reported for 2015: grinding media quality control projects in Botswana, and assistance to a number of regional base metal producers to optimize their plant throughput. An obvious limitation is that Mintek does not work on open cast, which is prevalent in Africa—its focus area is not aligned to regional needs. However, significant research and technical staff at Mintek and CSIR originate from the region, which implies that there may be scope to tap into open cast mining services.

The South African Minerals to Metals Research Institute (SAMMRI) is a leading research collaboration between South African universities and industry (12 OEMs and mining houses) focused on incremental innovation. There is also a lot of knowledge transfer taking place, with industry members mentoring principal investigators and researchers. SAMMRI is very competitive; hence some of these OEMs have a genuine interest in its activities. SAMMRI has a competitive advantage on some innovation, but it needs to make sure that application is successful. A significant number of researchers originate from DRC, Zimbabwe, and Ghana.

[28] Payments rather than receipts are a more accurate proxy for technology transfer and capabilities, because the latter include mining licences and royalties (UNECA 2010).

However there is no regional cooperation programme in place, except for personal networks through the investigators themselves.

The Wits Centre for Mechanised Mining Systems was set up by mining houses, consultants, and OEMs for graduate training in mechanization. The centre offers single courses, which can be compiled into a master's degree. Currently, the research centre has four graduates, a lecturer, a lab manager (who carries out bulk materials testing that they run under licence from Australia), and a research engineer. There are also 13 master's and PhD students. The Centre's network with the industry allows it the ability to put together a team to carry out a project quickly. The challenge the Centre faces is enrolling apt South African students due to the weak education system. The current student composition is mainly from Zimbabwe and Zambia, and rarely non-English speaking countries such as Mozambique and Angola. The majority of post-graduates are foreigners however due to the Black Economic Empowerment (BEE) and immigration laws, securing employment is challenging. There are a proportion of students who are potentially interested in returning to their home countries. Demand for their skills will grow across the region as underground mines become increasingly mechanized.

At the same time, Botswana NSI is developing its own regional linkages. BITRI has a MoU with the Namibian National Commission for Science and Technology. In parallel, a similar programme to the mining entrepreneurship development programme, based in Selebi Phikwe is underway in Zambia, run by the Motivational Centre for Africa Transformation, the Lumwana Mining Company, and Lumwana Community Business Association and facilitated by business incubation experts. The programme is managed through the BIH but funded by the government of Finland, through the SAIS programme. The funder's approach strengthens the BIH's institutional base as part of Botswana's NSI. The Zambian project focuses more on agro-business suppliers rather than the more diverse light industry and service suppliers in Botswana.

At SADC level, progress has been slow. Science and technology (S&T) is a relatively new policy area for SADC, with a regional protocol signed only in 2008 and ratified by only four countries, Botswana, Mauritius, Mozambique, and South Africa. Of the many S&T objectives contained in the Revised SADC Regional Indicative Strategic Development Plan (RISDP), the priorities include a framework on innovation and technological transfer, IPR, and Centres of Excellence.[29] Whilst South Africa is taking a leadership position in this area, for example seconding to SADC an official from its Department of Science and Technology, this S&T programme still has to secure funding. The NSI is impacted by, amongst others, industrial policy. A regional SADC industrial policy is evolving as is a specific programme on mining that includes an action plan for the implementation of SADC mining legislative regulatory framework, a study in mining sector skills development across SADC, and a minerals beneficiation study.[30]

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[29] The Regional Indicative Strategic Development Plan (RISDP) is a comprehensive development and implementation framework guiding the Regional Integration agenda of the SADC over a period of 15 years (2005–20).

[30] Other important initiatives include the Pan-African Minerals University of Science and Technology, which focuses on energy, water, and environment. It is an African Union initiative and it will be based in Zimbabwe in partnership with SIDRC.

6 Engineering consultancy services

The depth and breadth of a country's indigenous consulting engineering sector is a valuable indicator of the strength of the respective country's NSI.

Consulting engineering services straddle a wide range of knowledge-intensive activities including the design of products, processes (new and process modification), project design, project management, contract administration, and other engineering management services. Consulting engineering services are not confined to the mining industry, but cover a wide range of economic activities. The most common of these relate to essential infrastructure sectors such as civil, electrical, and water engineering.

Consulting engineering service companies are present in all countries surveyed. These capabilities have evolved around the mining and utility sectors of the respective countries. Domestic firms consist of national citizens as well as foreign engineers. In general, we have observed that the engineering service requirements of domestic (largely state-owned) utility sectors for civil, public works, electricity, and water sectors have tended to be serviced by indigenous engineering service firms, some of whom have expanded to support the mining sector.

Research findings point out that whilst there is significant competition amongst construction firms operating in the region's large infrastructure projects, especially from domestic, South African, and Chinese firms, in mining-related projects, South African engineering consultancy firms have a strong regional presence and face less competition. This is probably due to strong inter-firm linkages that characterize South African regional exports: when South African EPCM firms move into the region, they tend to bring with them specialized engineering consulting firms and OEMs (Walker and Minnitt 2006; Rustomjee 2007; Kuriakose et al. 2011).[31]

6.1 Domestic engineering consultancy sectors

South Africa's consulting engineering capabilities are significant. The industry is organized and represented by Consulting Engineers South Africa (CESA), which has 540 member firms employing more than 24,300 staff, with a total fee income in excess of ZAR25 billion per annum (CESA 2014a). To accede to CESA, potential members have to achieve a certain standard of service (CESA 2014b). CESA membership therefore provides a degree of quality assurance to entities that contract with CESA members.

Most South African consulting engineering work is carried out within South Africa on public sector infrastructure projects as well as on projects across the mining and manufacturing sectors. Consulting engineering work is often associated with the supply of machinery and equipment used in specific projects, which require design and engineering for specific customer requirements and location conditions.

Consulting engineering activities are interwoven with machinery and engineering service inputs into the SADC mineral sector; South Africa's capital goods sector has developed strong export capabilities, particularly in the SADC region. It is estimated that some 10 per cent of total annual South African engineering consulting sector income comes from exports of services, usually

[31] According to a 2007 study on engineering services trade, industry data shows that exports, mostly to SADC, accounted for less than 10 per cent of total income in the engineering consulting sector (Rustomjee 2007) However the report finds that exports of construction services were not accurately captured because they were often recorded as part of equipment exports, or turnkey projects under a separate coding, or not recorded because transaction took place at intra-firm level.

associated with infrastructure and mineral sector projects. However, this figure may be inaccurate because the service may have been recorded as part of equipment exports, or turnkey projects under a separate coding, or not recorded because transaction took place at intra-firm level (Rustomjee 2007).

In recent years, some South African capital goods firms have organized themselves around export council structures with strong support from industrial policy. Central to this is the South African Capital Equipment Export Council (SACEEC 2016) and the Built Environment Professions Export Council (BEPEC 2013), which was formed in 2001 by CESA but now includes the South African Institute of Architects (SAIA), the Association of South African Quantity Surveyors (ASAQS), and the Association of Construction Project Managers (ACPM). BEPEC aims to assist South African Companies operating in the Built Environment to export their Professional & Engineering Services abroad. BEPEC, for example assists members to participate in global infrastructure project tenders put out by, for example, the World Bank.

South African mining capital equipment OEMs have significant levels of cooperation with the mining companies, especially smaller OEMs with limited capacity in terms of prototypes development and testing (Walker and Minnitt 2006; Kuriakose et al. 2011). This collaboration has been driven also by regulations on environmental and safety legislation, which are stringent by developing countries' standards and is also true for the engineering services industry.

Due to Botswana's proximity to South Africa and due to its relatively small population, mining and metallurgical skills in this country have been traditionally supplied from South Africa. Botswana engineering sector relies on government for business, but in recent years this has been difficult. Local firms range from one-person companies, to some, very large international ones, mostly from South Africa. Mining companies tend to give work to South African companies, with whom they have done business before, with limited opportunities to local firms. The local content requirements under the citizen empowerment policy, is not really monitored and enforced in this sector, and engineering companies can decide if and how to implement provisions, with no penalty.

In Zimbabwe, there are more than 30 engineering consultancy firms (ZEPARU 2014). They are organized under the Zimbabwe Association of Consulting Engineers (ZACE 2016). Most of the registered companies are involved in civil, structural, mechanical, and electrical consultancy. Engineering consulting firms are involved in the design and construction of facilities such as mines, buildings, and road structures with the use of unique high tech components. Typical areas of expertise are electrical engineering, heat, ventilation and air-conditioning (HVAC), maintenance management systems, enterprise resource management and environmental management, and services for statutory inspections as well as plant maintenance contractors. Due to the requirement of significant expertise in the design and integration of components, such technical integrators were often foreign project management companies (ZEPARU 2014). South African firms are increasingly entering the market by partnering with local firms, with better knowledge of the domestic business environment. South African firms sub-contract to Zimbabwean firms at low rates, whilst retaining most of the profits. When South African and Zimbabwean firms bid together for tenders, the South African firms tend to crowd out the Zimbabwean firms and keep all the business and profits. An example of this was the pre-feasibility study of a platinum mine.

According to key informants brain drain was the major reason behind limited local expertise. Ironically, the foreign expertise, included experienced Zimbabwean engineers and scientists mainly based in South Africa, having been lured by better working conditions during the economic crisis. Many Zimbabwean engineers have also been working in Zambia.

There are several small-scale engineering consultancy firms in existence due to the relatively high number of technical graduates in Zimbabwe (ZEPARU 2014). However, most of them are not formally registered and lack the experience to handle big projects. According to the law, foreign engineering firms are supposed to partner with domestic firms, but interviews highlight this has not been monitored and enforced.

The Engineering Council of Zimbabwe (ECZ) established in 2009 is responsible for regulating the engineering profession and accrediting engineers and technicians in Zimbabwe. In 2012 it embarked on a drive to register the large number of Chinese, Korean, Indian, and other nationals who were working on the various infrastructure, mining, and telecommunication projects in Zimbabwe, creating a legal and inspectorate department to do this. These efforts seem not to have been successful. The ECZ advises that foreign firms and engineers do not adhere to regulations requiring that they have Zimbabwean understudies. The ECZ is apparently underfunded and, consequently, has been unable to carry out its regulatory and inspection functions.

In Zambia, privatization impacted adversely on the Zambian consulting engineering sector, because mining companies relied on foreign engineering firms. Most domestic firms are relegated to the lowest value added of the engineering value chain: small and medium scale civil works. Currently, Zambia's domestic engineering firms have capabilities in civil engineering (township development, road network development) and to a lesser extent mechanical engineering. There is some capacity in electrical and specialized mining engineering (civil, mechanical, electrical) but firms need support and access to procurement opportunities. Other capabilities such as EPCM and shaft sinking are not available.

The Engineering Institution of Zambia (EIZ) regulates the accreditation of engineers, technologists, technicians, and craftpersons. While there are an estimated 50,000 professionals, these include engineers who have changed career path, a number of non-practicing individuals, and retirees, some of whom continue to consult. EIZ currently manages a database of 25,000 members. A number of South African consulting and engineering firms have, in terms of mining law conditions, established local offices in the Copperbelt to provide specialized services such as hydrogeology, exploration, and other work. They tend to be small firms employing a few locals to meet localization requirements.

Finally, the Zambian Development Agency's (ZDA) investment promotion objectives often override domestic skills development objectives. Importing management and engineering expatriates is usually part of the investor's conditions of investment. The domestic labour market is quite open. There are engineering skills from India, China, South Africa, and South America, especially in the mining sector. Investors can bring their own engineering staff, and sometimes registration requirements with EIZ are waived. Respondents argue that the EIZ should be engaging with ZDA to impose tougher conditions and it should also provide more information on available Zambian skills to guide the ZDA. Yet, when the Engineering Board of Zambia tries to implementing some regulations in this direction, mining companies manage to oppose successfully through other government ministries. The lack of conditionality on FDI effectively undermines the development of local linkages and consulting engineering capabilities. Engineering and technical professions have been devalued in general in recent decades. In a parallel process, in poor, emerging, resource-rich African economies during a commodity supercycle, significant concessions have been made to foreign direct investors, which effectively allow the FDI to take place in 'enclave' fashion—with the bulk of goods and services required allowed to be imported (often free of duty).

6.2 Accreditation of qualifications

The professional competence of engineering graduates, technologists, and technicians training institutions are subject to their respective country's accreditation systems. These are usually legislated entities with responsibility of regulating the engineering profession. In South Africa, the ECSA is a statutory body mandated to regulate the engineering profession in terms of accreditation of engineering programmes, registration of persons as professionals in specified categories, and the regulation of the practice of registered persons (ECSA 2016).

For example, engineering graduates from the UNZA would have their professional training qualifications and work experience recognized and accredited by the Zambia's EIZ. That engineer or technologist would not be eligible to carry out certain professional duties in South Africa or Zimbabwe, without having to register with the ECSA or the Zimbabwe's ZIE, which would independently attest to their competence or require the candidate to undergo further training. The mobility of engineering skills can be enhanced by bilateral and multilateral agreements.

Cooperation between national engineering professional councils is deepening. The ECZ has signed a MoU with ECSA in South Africa under which they convene discussion platforms with the mining houses in South Africa, Zambia, and Malawi to discuss regional strategies, challenges, and opportunities as well as possible areas of coordination. The MoUs facilitates coordination and also serve to ensure fair treatment in the recognition of qualifications and experience of members.

There are three international mutual recognition agreements that recognize equivalence in the accreditation of national qualifications. The Washington Accord covers national engineering degrees. For example, an Australian engineer with an engineering degree conferred by an Australian educational institution who wishes to be accredited as a professional engineer in South Africa, would have the degree automatically recognized by the ECSA, since both countries are members of the Washington Accord. Similarly, signatories to the Sydney Accord confer mutual recognition to holders of engineering technology qualifications while Dublin Accord signatories mutually recognize engineering technician qualifications. Within SADC, only South Africa is a signatory of these accords, as Table 10 indicates.

The engineering profession is organized and represented in Botswana,[32] Zimbabwe,[33] and Zambia,[34] by respective professional institutions. None of these institutions are members of any of the above international engineering agreements, which recognize respective national academic qualifications and professional competencies. The University of Botswana is working with ECSA to qualify for the Washington Accord and it is expected that this process will be completed around 2019.

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[32] Botswana Institution of Engineers http://bie.org.bw/.

[33] Zimbabwe Institution of Engineers http://www.zie.org.zw/.

[34] Engineering Institution of Zambia http://www.eiz.org.zm/.

Table 10: International accreditation—Washington, Sydney, and Dublin Accord countries

Washington Accord	Sydney Accord	Dublin Accord	Represented by
Australia	Yes	Yes	Engineers Australia (1989)
Canada	Yes	Yes	Engineers Canada (1989), Canadian Council of Technicians and Technologists (2001)
Chinese Taipei	Yes		Institute of Engineering Education Taiwan (2007)
Hong Kong China	Yes		The Hong Kong Institution of Engineers (1995)
India			National Board of Accreditation (2014)
Ireland	Yes	Yes	Engineers Ireland (1989)
Japan			Japan Accreditation Board for Engineering Education (2005)
Korea	Yes		Accreditation Board for Engineering Education of Korea (2007)
Malaysia			Board of Engineers Malaysia (2009)
New Zealand	Yes	Yes	Institution of Professional Engineers NZ (1989)
Russia			Association for Engineering Education of Russia (2012)
Singapore			Institution of Engineers Singapore (2006)
South Africa	Yes	Yes	
Sri Lanka			Institution of Engineers Sri Lanka (2014)
Turkey			MUDEK (2011)
United Kingdom	Yes	Yes	Engineering Council UK (1989)
United States	Yes	Yes	Accreditation Board for Engineering and Technology (1989)
Washington Accord—Provisional Status[35]			
Bangladesh			Board of Accreditation for Engineering and Technical Education
China			China Association for Science and Technology
Costa Rica			Association of Engineers and Architects of Costa Rica
Germany			German Accreditation Agency for Study Programmes in Engineering and Informatics
Pakistan			Pakistan Engineering Council
Peru			ICACIT
Philippines			Philippine Technological Council

Source: International Engineering Alliance (2016).

The strength of domestic consulting engineering services appears to be impacted by three main factors. First, these capabilities are dependent on the quantum of engineering-intensive activities in the economy—around mining and infrastructure for example. In a growing world economy, engineering skills are sought after and are mobile. Second, consulting capabilities are influenced by the robustness of the respective domestic NSI skill development system to develop and sustain such capabilities. Third, the accreditation standards adopted by the respective authorities also make a difference. Accreditation standards provide assurance on the quality of engineering work. This often directly impacts on public and workplace safety. However, accreditation systems also provide a degree of protection from outside competition for the individual domestic engineering and consulting professionals. If such standards are too high, they confer an undue degree of protection, potentially raising domestic engineering service costs. Conversely, if such standards are not high enough or are not enforced fairly, it can undermine public safety and can lead to the failure of the engineering projects. But poorly enforced accreditation standards can also weaken the respective domestic consulting engineering fraternity to the point that it discourages domestic entrants and/or encourages domestic engineering and consulting professionals to look for opportunities outside of the country concerned. This, in turn, adversely impacts on that part of the respective country's NSI, which is geared towards the generation of national technical and engineering skills and capabilities.

[35] Organizations holding provisional status have qualification accreditation or recognition procedures that are potentially suitable for recognition from members of the Washington Accord but are not recognized yet (International Engineering Alliance 2016).

6.3 The regional dimension

There is significant movement of engineering skills across the region: many Zambian engineers are employed in the region, even more Zimbabwean engineers, and South African and Zimbabwean skills are employed in Zambia. International companies particularly in the mining sector are driving these trends. Engineering professionals tend to remain in Botswana, only some leave for South Africa. According to data from South Africa Chamber of Mines,[36] in 2014, the percentage of foreign workers in the mining sector was 14 per cent. Looking at the sectoral breakdown, foreign workers represented nine per cent of total engineers working in consultancy services.[37] They find it easier to find work in the consultancy sector rather than the mining companies because of BEE.

There is evidence of intra-SADC skill mobility also for technical skills. In Zambia, specific skills sourced from Zimbabwe include plastering of ceilings (construction), agricultural skills, and heavy equipment operators. Skills imported from South Africa include mining-related skills, coded welders, and steel fixers. In some cases, such skills are sourced even from South America.

The mining houses with operations in Africa tend to source engineering skills from South Africa, especially at the phase of designing and constructing a mine. With time, when the mine is operational, there is more interest in local employment and use of local engineers. Some mining houses with good training facilities in South Africa, relocate to the region personnel in charge of training to establish similar facilities (Glencore, Xstrata). This applies to greenfield projects rather than old mines in Zambia or Zimbabwe.

This research unveiled three key factors underlying the regional market for engineering services: 1) except for South Africa, domestic markets are relatively open to foreign professionals; 2) lack of enforcement of local content provisions; 3) Returning engineering skills struggle to enter the market and this calls for more linkages between foreign and domestic engineering firms.

6.3.1 Domestic markets open to foreign engineer professionals

Botswana, Zambia, and Zimbabwe engineering bodies confirm that it is relatively easy for foreign engineers to operate in their domestic markets. Zimbabwe's chief immigration officer reported 3,000 Chinese engineers operating in the country, yet only 1,000 were registered with ZIE. This points to the need for more effective management of accreditation systems. It appears that clauses contained in high-level government-to-government agreements on major engineering projects have granted the respective project developer exemption from a range of national regulations, including engineering registration requirements. This effectively acts to undermine the domestic NSI.

All the professional registration bodies experience challenges in verifying the qualifications of foreign engineers. For ZIE, when foreign engineers are affiliated with their home country council, it is easier for them to operate in Zimbabwe. ACEZ argues that the Zambian NSI is undermined by important gaps: firstly, the accreditation system, managed by the EIZ, is weak and does not undertake thorough verification of foreign qualifications. Foreign qualification holders are able to be licenced as consulting engineers without having to practice in Zambia for a stipulated period, as is the case in South Africa. The immigration system is relatively open such

[36] Data provided by Stella Carthy, Head of Skills Development for Chamber of Mines.

[37] Sub-sectoral breakdown: Coal diamond 2 per cent; Gold 27 per cent (agreements in place with Lesotho, Swaziland, Malawi, and Mozambique); Platinum 15 per cent; Others 7 per cent; Cement 1 per cent.

that foreign consulting engineers are able to enter the country on a visitor visa even if performing professional engineering services. Foreign consultants need to be accredited with EIZ but anyone can get the accreditation without verification. For example, there is weak verification of Chinese consultants with little knowledge of content of these CVs.

Similar problems are reported at technical level. Firms can import skills when they can justify that there are no locally available skills, and because local skilled labour is often not officially qualified, it is easy to put this justification forward. Moreover, there are loopholes: some technical personnel people enter the country as trainers, than they change their positions to floor supervisors and stay. TEVETA (Zambia) is trying to regulate the system, engaging the immigration department.

On the other hand, Botswana, Zambia, and Zimbabwe's respondents agree that it is difficult to register in South Africa if you have not studied there or in countries that subscribe to the Washington Accord. Zimbabwean stakeholders report issues with Zimbabwean engineers in South Africa being professionally recognized, with recognition denied or delayed by ECSA for no good reason. If a professional is not registered, they will be paid a lower fee as a technician. SADC confirms barriers to recognition of engineers in South Africa.

6.3.2 Lack of enforcement of local content provisions

All the countries reviewed have local content measures in place, usually by reserving a percentage value of the contract work for local companies. The Zimbabwean government has a statuary requirement that at least 30 per cent of consultancy has to be given to Zimbabwean firms. Moreover, engineering companies are required to have national understudies. However, enforcement and monitoring has lacked across all countries. In Botswana, the Engineering Board is moving towards including mentoring obligations on engineering practitioners in order to address the problem of graduates lacking practical experience. In other countries, there has been no movement in this direction.

6.3.3 Returning engineering skills struggle to enter the market and call for more linkages between foreign and domestic engineering firms

EIZ noticed a return of engineering skills. Zambian engineers are coming back to take advantage of the opportunities from massive infrastructure investment. Some set up their own independent businesses—consulting engineering firms with lots of intellectual capital, where size does not matter, others enter through JVs. According to ACEZ, however individual firms often fail to secure sufficient business. These cases prove that skills and experience are not sufficient to participate in the most valuable contracts related to mining.

Also Zimbabwe's stakeholders argue that whilst competence of Zimbabwean engineers is widely recognized, this is not translated into access to business opportunities with the mining houses. The latter prefer to contract with South African firms, and have domestic engineering firms involved as sub-contractors. One respondent indicated that he provides his services under the affiliation of a South African firm because of the lack of confidence in local capabilities.

The depth of a country's consulting engineering sector is an important indicator of the strength of the respective NSI. Our research shows that South Africa has the largest consulting engineering sector, which is also deeply integrated within a well-developed capital goods sector. The consulting and capital goods sector are increasingly exporting their capabilities, most significantly into the SADC area and other African countries.

Apart from focusing on the capabilities of their respective manufacturing sectors to supply the mineral extraction and processing sectors, it is equally important that Botswana, Zambia, and Zimbabwe prioritize the internal processes required to accede to the Washington, Sydney, and Dublin Accords. The actions required are mainly associated with improving the quality of tertiary and vocational training systems and the associated national accreditation and quality management systems. This will greatly strengthen the individual NSIs. However, the impact of this will also be to increase competition amongst professional engineers and technicians because it will make it easier for foreign nationals to engage in professional work in the country concerned. This outcome may give rise to some resistance from indigenous professionals. On the other hand, indigenous professionals are likely to become more mobile as a result.

Our research shows that the professional associations in each of the countries are making efforts to improve the integrity of their accreditation, quality management, and training systems. But these associations have also raised concern about what they perceive to be unfair competition arising from their professional competitors being granted a range of exemptions from regulations and accreditation requirements as part of high-level government-to-government bilateral infrastructure project agreements and/or by similar exemptions being offered as part of national incentives to attract foreign investment. Such exemptions have unintended consequences of undermining the integrity of the respective accreditation systems and the NSI itself. We recommend that these exemptions be reviewed in each of the countries surveyed.

7 Conclusions: a southern African regional system of innovation?

A country's NSI covers a very wide range of sectors, activities and issues. We focus on that part of the NSI that impacts on the mineral extraction and mineral processing value chain. The boundaries of our analysis have extended across those parts of the vocational and tertiary training systems that impact on the mineral value chain. We have also chosen to focus particularly on production and utilization of consulting engineering skills, which is an important indicator of the strength of the respective NSI.

The mining sector has played an important role in shaping the economic trajectories of Botswana, Zambia, and Zimbabwe. In particular, Zambia and Zimbabwe have seen large-scale investment in the mining sector during the last decade. This has pulled demand for capital goods, technical skills, engineering services, mining-related technological solutions, and infrastructure. Such large-scale investments create opportunities to build NSIs and local manufacturing and service industries.

The evolution of country-level NSIs in relation to the mining sector reviewed in this paper differs greatly. Botswana is crafting a space for a strong domestic NSI, with high public investment in institution building, infrastructure, skills, and policies to attract FDI and talent. BITRI and BIH have not only important and broad mandates, but have also been endowed with the resources and political backing to achieve these. In order to compensate for a small domestic market and very small manufacturing sector, Botswana is to all effects re-defining its comparative advantages to attract knowledge-intensive economic activities. The response by industry, both domestic and foreign, will ultimately determine the success of this strategy. This process however is at an early stage, and it is not yet possible to make an assessment.

Zambia's potential to develop its mining-related NSI is in theory larger than Botswana: multiple large-scale mining houses, ongoing investment in new geographical areas and new mineral commodities, a more established mining inputs cluster with potentially large demand domestically and across the border, in the DRC, and an existing NSI infrastructure established in the 1970s and 1980, although ageing (university facilities, engineering and TVET skills, teaching body). However the political economy of mining in Zambia has resulted in limited room for policy makers to leverage mining investment to re-build the NSI or increase local value addition. As a result, these efforts have been left to industry initiatives, with voluntary participation and contribution of the mining houses to ZAMSET and the Zambia Mining Local Content Initiative. Nevertheless, there are legitimate concerns among stakeholders that without a comprehensive vision and policy framework set by the state; these initiatives will not achieve the overall objectives of re-building the NSI.

Zimbabwe's NSI, once the second most developed in southern Africa, has been affected by the overall economic crisis experienced since the 2000s. The erosion of Zimbabwe's NSI has been taking place at multiple levels: the brain drain of skilled workers, the decline of SIRDC and IMR, the closure of engineering manufacturing activities that had traditionally pulled significant demand for technologies and skills, and increased import penetration in engineering consultancy services. Whilst the government is focusing on indigenization and beneficiation, there is acute awareness that without reinvigorating the NSI, these goals will be difficult to achieve.

In regard to the R&D component of the NSI, our research reveals varied patterns. While all countries purport to be building central institutions to coordinate and facilitate science funding and research funding, Botswana appears to have the most ambitious programme, while Zimbabwe NSI systems (which used to be second to South Africa in breadth and depth) appear to be rapidly eroding.

In all countries surveyed, we noted a tension between investment promotion objectives and the construction of robust NSIs whereby, exemptions from regulations and accreditation requirements demanded by foreign investors have acted to undermine the integrity of the respective accreditation systems and the NSI itself resulting in a low contribution of the mining houses to NSIs and local value addition.

A key research question investigated by this paper concerns the regional dynamics affecting NSIs in Botswana, Zambia, and Zimbabwe in relation to South Africa. The findings point to four NSIs, which are partly interconnected. Whilst we did find evidence of a Southern Africa Regional System of Innovation, this system seems to be characterized by a 'hub and spokes' structure. South Africa, as a hub, has the most developed NSI in relation to mining: a large and well established mining sector and a mining inputs cluster that is, in some areas, globally competitive; centres of excellence in engineering skills development, R&D, and innovation; and a large engineering consultancy sector with domestic and international engineering firms based in South Africa to serve the regional market.

South Africa's NSI interaction with the rest of the region is complex. Whilst TVET skills development is a challenge across the four NSIs and has remained framed within national contexts, engineering skills development has a strong regional dimension.

All of the countries investigated have conscious public policy objectives of skills development through the primary, secondary, tertiary, and vocational segments of the respective education systems. Poor human capital development planning in Botswana, Zambia, and Zimbabwe has been revealed through our research. Our research has outlined the various processes that are underway that need to be accelerated—in particular, the coherent implementation of existing TVET and NQF qualification frameworks.

Given the scale of mining-related activities in the countries surveyed, there is considerable potential for collaborative and synergistic initiatives between firms and the TVET systems acting to accelerate their evolution. Collaboration within this part of the NSI should extend to the associations representing the engineering and technical professions. Our research shows that the professional associations in each of the countries are making efforts to improve the integrity of their accreditation, quality management, and training systems. But as outlined earlier, these efforts are being undermined by the unintended consequences of conceding to exemption demands by foreign investors.

Our findings suggest that it is important that Botswana, Zambia, and Zimbabwe prioritize the internal processes required to accede to the Washington, Sydney, and Dublin Accords. The actions required are mainly associated with improving the quality of tertiary and vocational training systems and the associated national accreditation and quality management systems. This will greatly strengthen the individual NSIs and contribute towards their integration into a Regional System of Innovation.

Analysis of intra-SADC student flow reveals that significant engineering skills development for the region is taking place in South Africa, but these skills tend to remain in South Africa. To a large extent, this can be explained by different economic opportunities in the home countries: engineering students from Botswana tend to return home, to pursue employment in government or the mining sector, although employment opportunities in other economic activities are limited. Zimbabwean students are increasingly pursuing undergraduate and postgraduate studies in South Africa, where they remain, as a coping strategy to the decline of their education system, and reduced opportunities with private firms and government. Zambia is the most negatively affected by the regional dynamics of the engineering education system, because its students pursue post graduate studies in South Africa and most do not return. Hence whilst investing public resources in its education system until undergraduate levels, Zambia loses engineers with advanced tertiary degrees, which could feed back into the demand for lecturers, professionals, and government officials. Poor employment conditions at the universities and the struggle to find business opportunities as individual professionals make returning a difficult choice for postgraduate students. This is particularly concerning as Zambia recorded high GDP growth rates during the past decade, 7.76 per cent on average between 2004 and 2013, well above the 5 per cent SSA average (World Bank 2016).

South Africa taps into the flows of regional skills to address its own skills deficit. Hence regional skills are employed in the engineering services sector and contribute significantly to South Africa's R&D and innovation capabilities. Very different dynamics however take place within these two sectors: South African R&D and innovation institutions tend to have a weak regional focus, with research areas and customers that are narrowly defined in terms of domestic interests, notwithstanding the demand for mining technologies across the region. The evidence is found in Mintek's domestic mandate, and in scarce and weak formal linkages between universities and research institutions across the region. Conversely, South Africa-based engineering firms have a strong regional outlook, irrespective of whether they are international or South African owned. Through these firms, regional engineers conduct projects in their own countries, but with little spillovers into their domestic economies: sub-contracting and knowledge transfers are limited—notwithstanding the existence of local content measures in the legislation of neighbouring countries.

At SADC level, the regional legal frameworks to support flows of skills and knowledge lag behind. For example, progress on the RQF is hampered by the fact that countries first have to establish effective NQFs. Regional cooperation on R&D and innovation has only just started. Whilst, laying the groundwork for important institutional frameworks for the RSI, South Africa needs to consider whether a multifaceted approach would be more effective. Whilst supporting SADC efforts for multilateral and highly institutionalized frameworks is important, South Africa could pursue cooperation with selected countries on mining-related skills development, R&D, and consulting engineering aimed at creating a more balanced distribution of benefits. In the words of one Zambian high-level government official: 'regional cooperation can by driven by shared interests or by shared problems. In terms of cooperation driven by shared interests, there is a great potential for South Africa and Zambia to cooperate because of the long, shared history of the mining sector' (Field interview).

Relating these findings to the NSI literature, we would like to highlight four themes. Firstly, whilst the literature analyses the NSI through its individual components and their inter-relationships, macro-economic variables cannot be taken for granted and will determine the overall trajectory of the NSI. Macro-economic variables explain the erosion of Zimbabwe's NSI, and the advantages of Botswana's NSI in terms of skills retention and resources available for public investment. Secondly, the quality of relationships between different elements in the NSI, namely industry, mining houses in particular, and government institutions is shaped to a large extent by political economy. Political power, or lack thereof, has greatly contributed to determine the type of interaction between industry and institutions in every aspect of the NSI reviewed in this paper: skills development, R&D, and engineering consultancy services. Thirdly, whilst the NSI literature provides an important framework to guide policy-making, there is no one size fits all approach, at least within the countries reviewed. R&D is critical in Botswana's NSI development strategy given the inherent limitations of its manufacturing sector; while TVET skills are more important than R&D for Zambia's NSI and linkage development strategies. Finally, within southern Africa, focusing on country-level NSIs without looking at regional dynamics would miss very important spaces of competency building and industry linkages, which underpin, explain, and should be tapped by country-level NSIs.

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Appendix 1: List of respondents

Institution	Respondent details
Botswana	
Botswana Diamond Manufacturers Association (BDMA)	Kfir Teichman MD of Diacore, Chairperson of BDMA
Botswana Innovation Hub (BIH)	Dr Budzanani Tacheba Director
Botswana Institute for Technology Research and Innovation (BITRI)	Prof. Nelson Torto CEO
Botswana Institute of Engineering (BIE) University of Botswana Faculty of Engineering & Technology	Eng. Oagile Kanyeto Dean of Faculty and BIE Chairman
Ministry of Trade and Industry (MTI)	Jamah S. Mudarikiriegopane Policy Officer
Tokafala (De Beers, Anglo American)	Ineke van der Weijden Programme Director
South Africa	
Department of Trade and Industry	Tapiwa Samanga Chief Director for Mineral Processing and Construction Tshepiso Kadiaka Manager: Mineral beneficiation sector
Mintek	Dr Marian Lydall Head: Market Development
South Africa Capital Equipment Export Council (SACEEC)	Sybil Rhomberg MD
South African Minerals to Metals Research Institute (SAMMRI)	Dr Victor Ross Executive committee members (ex-chairman)
Chamber of Mines	Stella Carthy Head: Skills Development
Wits Centre for Mechanised Mining Systems	Declan Vogt Director
Zambia	
Association of Consulting Engineering of Zambia (ACEZ)	Charles M. Haanyika MD Utilink Ltd, ACEZ Chairman
Copperbelt University School of Natural Resources	Felix Calaba Senior Lecturer
Copperbelt University School of Business	Humphrey Fandamu Head of Department
Copperbelt University School of Mines and Mineral Sciences	Dr Peter Chileshe Postgraduate Coordinator and Senior Lecturer
Engineering Institute of Zambia	Eng. Newton Zulu Deputy Registrar
Ministry of Commerce, Trade and Industry Domestic Trade Department	John Mulungoti Director: Domestic Trade Department
Ministry of Commerce, Trade and Industry Industry Department	Aaron Mutale Principal Economist
Ministry of Education, Science, Vocational Training and Early Education	Dr Patrick Kona Nkanza Permanent Secretary (Science and Vocational Training)
Technical and Vocational Training Authority (TEVETA)	Catherine M. Kanyensha Director Development Kennedy Bowa Manager Curriculum Development
University of Zambia School of Mines	Dr Osbert Sikazwe Dean
University of Zambia School of Engineering	Prof. Mundia Muya Dean
Zambia Development Agency (ZDA)	Mukula Makasa Director: Enterprise Development
Zambia Manufacturers Association (ZAM)	Maybin Nsupila CEO

Zimbabwe	
Confederation of Zimbabwe Industries (CZI)	Sifelani Jabangwe Committee member
Engineering Council of Zimbabwe	Eng. Farai Mavhiya-Bhiza Membership Committee
Institute of Mining Research (IMR)	Lyman Mlambo Chairman and Mineral Economist
Ministry of Economic Planning and Investment Promotion	Dr D. Sibanda Permanent Secretary
National Manpower Advisory Council of Zimbabwe (NAMACO) Counsel, ZACE, ECZ	Eng. Peter Mutsinya Microhold Mining (Pvt) Limited, Group CEO
Scientific and Industrial Research and Development Centre	Philemon Kwaramba Director: Business Operations Unit
SRK Consulting	Wonder Mutematska Mining Consultant
University of Zimbabwe Department of Mining and Metallurgical Engineering	Tulani W. Mukarati Lecturer
Zimbabwe Institute of Engineers	Wilson Banda Membership and training officer
Zimbabwe Institute of Engineers	Dr S Diarra CEO
Regional Institution	**Respondent details**
SADC Education Desk	Lomthandazo Mavimbela Senior Programme Manager for Education Training
SADC Industrial Development Desk	Alisoa Vololoniaina Senior Programme Officer, Industrial Productive Competitiveness
SADC Science and Technology Desk	Anneline Morgan Senior Programme Officer
Southern African Institute of Mining and Metallurgy (SAIMM)	Malcolm Walker Regional Development Manager

Appendix 2: Acronyms and abbreviations used in the Working Paper

ACEZ	Association of Consulting Engineers of Zambia
ACPM	Association of Construction Project Managers
ASAQS	Association of South African Quantity Surveyors
BEE	Black Economic Empowerment
BEPEC	Built Environment Professions Export Council
BIH	Botswana Innovation Hub
BITRI	Botswana Institute of Technology, Research and Innovation
BIUST	Botswana International University of Science and Technology
BOTA	Botswana Training Authority
BOTEC	Botswana Technology Centre
BRSTFA	Botswana, Research Science and Technology Funding Agency
BUSE	Bindura University of Science Education
CBU	Copperbelt University
CESA	Consulting Engineers South Africa
COMRO	Chamber of Mines Research Organisation
CSIR	Council for Scientific and Industrial Research
CUT	Chinhoyi University of Technology
CZI	Confederation of Zimbabwe Industries
ECSA	Engineering Council of South Africa
ECZ	Engineering Council of Zimbabwe
EIZ	Engineering Institution of Zambia
EPCM firms	Engineering, Procurement, Construction and Management firms
FDI	Foreign direct investment
HIT	Harare Institute of Technology
IMR	Institute of Mining Research
IP	Intellectual property

JV	Joint Venture
MNEs	Multinational Enterprises
MoU	Memorandum of Understanding
MSMEs	Micro, Small and Medium Enterprises
NAMACO	National Manpower Advisory Council of Zimbabwe
NIEs	Newly Industrialized Countries
NQF	National Qualifications Frameworks
NSI	National System of Innovation
NUST	National University of Science and Technology
OEMs	Original Equipment Manufacturers
PGM	Platinum Group Metals
R&D	Research and Development
RIPCO	Rural Industries Promotion Company
RQF	Regional Qualification Framework
S&T	Science and Technology
SACEEC	South African Capital Equipment Export Council
SADC	Southern African Development Community
SAIA	South African Institute of Architects
SAIMM	Southern African Institute of Mining and Metallurgy
SAIS	Southern Africa Innovation Support
SOE	State Owned Enterprise
SSA	Sub Saharan Africa
STEM	Science, Technology, Engineering and Math
TEVETA	Technical Education, Vocational and Entrepreneurship Training Authority
TVET	Technical Vocational Education and Training
UB	University of Botswana
UCT	University of Cape Town

UNZA	University of Zambia
UP	University of Pretoria
UZ	University of Zimbabwe
Wits	University of the Witwatersrand
ZACE	Zimbabwe Association of Consulting Engineers
ZAM	Zambia Association of Manufacturer
ZAMSET	Zambia Mining Skills and Education Trust
ZCCM	Zambia Consolidated Copper Mines
ZDA	Zambian Development Agency
ZEPARU	Zimbabwe Economic Policy Analysis and Research Unit
ZIE	Zimbabwe Institution of Engineers
Zim Asset	Zimbabwe Agenda for Sustainable Socio-Economic Transformation