

Early Development of a Southern African System of Innovation

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There is an extensive historiography of Africa's mineral resource endowment, but it has largely neglected the innovative capacity resulting from those resources. This article reduces that gap through an analysis of the system of innovation that developed in Southern Africa around the Kimberley diamond deposits. After a brief review of the systems of innovation concept, attention turns to describing the emergent system of innovation associated with mineral resource development. Before Western mining, economic development in Southern Africa had not meaningfully established a local knowledge base beyond relatively narrow capacity around descriptive natural sciences. With mining, and especially the Kimberley diamond deposits, local capacity emerged as an initial regional system of innovation. Detailing characteristics of that system of innovation, the analysis highlights the mining sector's early pattern of economic development as well as associated industrial and innovation policies. It also describes how the industry established routines and networks critical to the subsequent development of mineral resources and broader economic activities across Southern Africa.

A REGIONAL SYSTEM OF INNOVATION

The importance of South Africa's mining industry is widely acknowledged. However, the voluminous literature describing the mining sector has little analysis of its productive and technological systems as an interrelated feature. In fact, there is generally only cursory mention of technology dynamics in the literature reviewing mining's system of production. Using an innovation systems approach this article recounts early development

of a South African system of innovation as a result of the unique diamond deposits at Kimberley.

For nearly 150 years, the mining sector has featured in South Africa's economic growth and development experience. Nonetheless, there is remarkably little to guide dynamic understanding of the sector's systems of production and innovation. As a counter balance, this analysis adopts a systems of innovation approach.¹ Inter-related activities, both internal and external, form distinct innovation, production, and spatial systems in this approach. Focusing on technological dynamics, the approach also considers the influence of wider social, institutional, and economic structures. These are not static or uni-directional relationships, with technologies dynamically influencing and being influenced by the other structures.

The systems of innovation approach thereby focuses attention on the operation of horizontal and vertical linkages among a variety of agents. A dynamic structure of innovation is thereby identified that facilitates certain interactions and outcomes. These complementarities create a feedback process that generates inertia in the system.² That inertia establishes a dynamic that characterizes the system of innovation's development path. Depending on the nature of that path and its associated components, the system will be advantageously or disadvantageously predisposed to subsequent opportunities for growth. Understanding the system of innovation in a predominate sector like mining in South Africa is therefore an important input for contemporary industrial and innovation policy. It is also an important component in determining a firm's competitive advantage on a basis of internal and external capabilities. The article begins with a broad review of the

¹ For an overview of the systems of innovation approach see Issue 31 of *Research Policy* (2002).

² J. Fagerberg, 'Innovation: A guide to the Literature', in J. Fagerberg, D. Mowery and R. Nelson (eds.), *The Oxford Handbook of Innovation* (Oxford, University of Oxford Press, 2004), pp. 1-26.

mining sector's development during the 19th century and its relationship to the regional and international political-economy. Attention then turns to a relatively detailed description of the system of innovation that emerged around the kimberlite diamond deposits of the Kimberley district and the precedents it established.

INITIAL WESTERN MINING IN SOUTHERN AFRICA

This section briefly surveys development of a sectoral system of innovation in mining. Four dimensions are of primary concern: composition of the mining sector, the political system, the economic system, and the system of innovation. Geographically, while acknowledging contemporary authority structures across the region, focus is within the borders of modern South Africa.

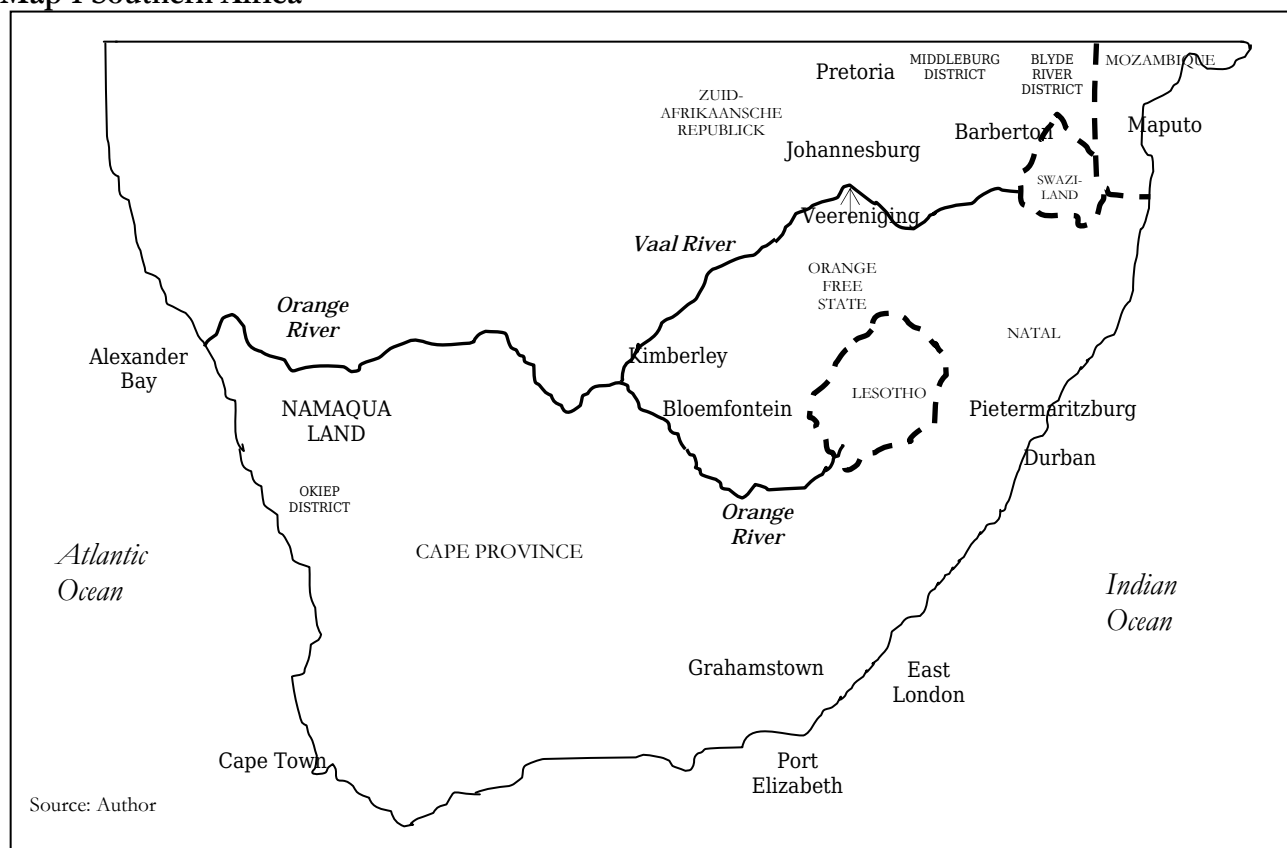
From the middle of the 19th century, western mining techniques were applied in the extraction of coal, copper, diamond, and gold deposits across Southern Africa. In general, these were imported techniques adapted to local conditions in an internationally familiar boom and bust cycle. Copper mining in the O'Kiep District of Namaqualand (Northern Cape) initiated western mining techniques in southern Africa. Following initial extraction in 1846, a rush of fortune seekers to the region occurred in 1853. Despite the remoteness of the location, by 1860 copper had risen to be the Cape Colony's second biggest export. By the early 1860s, the rush had given way to systematic mining of the deposits as the district struggled with commercial viability.³

In the 1860s, extraction of the large Southern African coal deposits began. The Cape government offered a £100 reward in 1852 to encourage the search for coal deposits. This led to the eventual establishment in 1864 of the first Southern African colliery in the Stormberg Mountains of the Eastern Cape. Shortly thereafter, coal mining began in KwaZulu-Natal for the Pietermaritzburg community and by the late 1860s, there was

³ J. Smalberger, *A History of Copper Mining in Namaqualand* (Cape Town, C. Struik, 1975).

localized coal mining in the Middleburg District of Mpumalanga.⁴ With the growth of Kimberley throughout the 1870s, demand for energy rapidly outstripped what the sparse surrounds could provide. Thus, 1879 saw establishment of the Vereeniging colliery on the edge of the Vaal River, its coal transported to the diamond mines via ox-wagon.⁵ Coal was not the only industry to get a kick-start from the diamond discoveries, the search for gold was part and parcel with diamond prospecting following the 1869 alluvial diamond rush.

Map 1 Southern Africa



As far back as 1853, the *Zuid-Afrikaansche Republiek* (ZAR) knew of alluvial gold deposits in its territory, but word of these early discoveries was suppressed by the nascent ZAR to avoid a rush of prospectors. Following the diamond discoveries, however, the

⁴ J. Lang, *Power Base: Coal Mining in the Life of South Africa* (Johannesburg, Jonathan Ball, 1995), pp. 13-15.

⁵ T. Coulter, 'The Coal Industry of South Africa', *Journal of the Chemical, Metallurgical and Mining Society of South Africa*, 30 (1930), pp. 261-281.

search for further mineral wealth could not be contained. In 1871, knowing that gold discoveries were imminent and with a pressing need for additional revenue, the ZAR revised its gold law to improve income flows.⁶

By 1873, a gold rush had commenced along the Blyde river watershed in the eastern portion of the ZAR. As with many gold rushes in the region, initial small-scale alluvial mining gave way to large-scale underground mining. These predecessors to the Witwatersrand were important contributors to the evolution of the gold mining law in the ZAR, instilling as part of the international gold rush phenomenon a legal system with Spanish origins that had developed following the 1849 California rush.⁷ Towards the early 1880s, several significant mines were developed in the Blyde River district. Around this time, alluvial gold was found near Barberton. Then in 1885, a significant gold bearing reef was discovered in the Barberton area. That discovery drove rapid development of a large mining equity market. The Kimberley community had a substantial role in the boom and bust of that market, which fostered scepticism during the initial stages of the next major gold rush, the Witwatersrand.

A variety of political authorities supported, and at times hindered, development of a Southern African mining sector during this period. The Portuguese were the first Europeans to explore the Southern African coast in the late 15th and early 16th centuries, but it was not until the mid 17th century that permanent European settlement of Southern Africa occurred when the Dutch East Indian Company established a refueling station in Table Bay (Cape Town). The Dutch did not aggressively promote settlement of the interior, but gradually over the 18th century settler communities reached what is today the

⁶ E. Rosenthal, *Gold! Gold! Gold! The Johannesburg Gold Rush* (Johannesburg, A.D. Donker, 1970), pp. 9-14, 81-83.

⁷ *Ibid.*, p. 24.

western portion of the Eastern Cape Province. By the late 18th century, European power was changing as the Napoleonic wars raged. As a result, Britain eventually took control of Table Bay and the hinterland in 1806.⁸

When the Cape was officially transferred to Britain in 1815, the colonial administration began encouraging a more 'British' character. Promoting settlement by British nationals was the principle means by which this policy was realized. There gradually emerged tensions between English speaking settlers and their Dutch-speaking predecessors. The British colonial government introduced several changes, which to settlers from the Dutch era (Afrikaners) marked a loss of local authority. Prominent among these administrative changes were those regarding the ownership of slaves and the replacement of Dutch with English as the language for public affairs. Prior to 1886, British Colonial authorities did not aggressively assert its rule over the Southern African interior. Nevertheless, in the 1880s that policy changed as European nations began to vie with each in the 'Scramble for Africa'.⁹

The native African inhabitants of the region met the Afrikaner migration into the Southern African interior with hostility. This resistance to their settlement augmented social cohesion among the Afrikaners and solidified a distinct identity.¹⁰ The first attempt at self-government by the Afrikaners was in Natal in 1839; however, in 1842 Britain seized control of Natal, making it a British colony. The loss of Afrikaner sovereignty in Natal did

⁸ R. Davenport and C. Saunders, *South Africa: A Modern History* (London, Macmillan, 2000), pp. 213-217.

⁹ *Ibid.*, ch. 2.

¹⁰ This gradual process led to the emergence of an identity rooted in their experience on the Southern Africa frontier. In 1879, 'the Bond' formalized this identity, uniting around the Afrikaans language and a system of education suited to rural whites. The Bond became a political movement and sign of Afrikaner distinction from other Europeans. See Davenport and Saunders, *South Africa*, pp. 107-111.

not end their pursuit of self-governance. In 1852, Afrikaner independence was recognized for the Transvaal i.e. the ZAR, as it was known from 1859. Similarly, in 1854 the Orange Free State (OFS) was granted self-governance. Although these republics were primarily subsistence agrarian communities, they inaugurated widespread European settlement across a Southern African interior that possessed immense mineral deposits.

Beginning in the 1850s, another group spread across Southern Africa, the European prospector. In their pursuit of mineral wealth, those prospectors represented a unique influence shaping the Southern African frontier. Across Southern Africa, this diverse citizenry pursued an international fever for precious minerals that held the promise of wealth and fame for the rugged individual.¹¹ In the prospectors' exploitation of the mineral deposits, impoverished Africans provided an immensely valuable resource endowment of low-cost labour.

Beyond mining, the Southern African economic system had an established but lacking agriculture sector. In the early 19th century, the British continued the mercantile economic policy of Dutch East Indian Company. Preferential tariffs were imposed on Cape wines in 1813 and by 1823, wine accounted for 88 percent of the Cape Colony's exports. Wine exports reached their peak in the mid 1820s, after which they declined as Britain repealed imperial preference duties and increased imports of Spanish and Portuguese wines. By the 1840s, wool overtook wine as the leading export from the Cape Colony. The Southern African wool industry emerged with British settlement of the Eastern Cape. Wool's economic contribution peaked in the 1860s at around 75 percent of exports, but by the 1870s with drought and the opening of the Suez Canal, the future of

¹¹ For details of this international phenomenon see W. Morrell, *The Gold Rushes* (Chester Springs, PA, Adam & Charles Black, 1968).

agricultural expansion in the Cape was doubtful.¹² Fortunately for the Cape's economy, diamonds were discovered in the 1870s just as the prospects of its agricultural exports declined. Besides just replacing agriculture, the emergent mining industry provided a better foundation for economic development.¹³

Before the mineral discoveries, Afrikaners were primarily subsistence agriculturists. When the first alluvial gold rush in the eastern Transvaal began in the early 1870s, the ZAR found itself in financial crisis and bureaucrats capable of running a modern nation state were scarce. By the mid-1870s, the Afrikaner republic faced a constituency reluctant to provide the infrastructure needed for further economic development and an uprising of Africans near the eastern Transvaal gold fields. Hence, the ZAR was perched on bankruptcy when the British occupied Pretoria in 1877 ostensibly to install good governance, but also in support of mining interests on the Kimberley diamond fields. In 1881, the British returned self-governance to the ZAR in order to conclude the First Anglo-Boer War.¹⁴ British occupation placed the Afrikaner republic in a better position, but on the eve of the 1886 Witwatersrand gold discoveries, the ZAR was encircled by European controlled colonies, a land-locked nation with virtually no infrastructure.

Financial development of the Southern African region largely traced the emergence of the mining economy. However, agriculture preceded mining in the development of the local banking system. The first modern bank in Southern Africa was the Cape of Good

¹² S.P. Viljoen, 'Industrial Achievement in South Africa', *South African Journal of Economics*, 51 (1983), pp. 29-57.

¹³ An indication of the limited capacity for agriculture based economic development is that by the mid-1860s only 18 towns in Southern Africa had populations greater than 1,000. See S. Frankel, *Capital Investment in Africa: its course and efforts* (London, Oxford University Press, 1938).

¹⁴ Davenport and Saunders, *South Africa*, pp. 213-217.

Hope in 1836.¹⁵ In 1862, Standard Bank, the first British imperial bank arrived in the Cape. While originally envisaged to finance primary sector exports, by the late 1870s it had become the *de facto* central bank for the Cape.¹⁶ The Kimberley diamond deposits shifted the economic heart of the Cape back to Cape Town from the agricultural economy of Port Elizabeth. The diamond diggings themselves did not generate a huge financial infrastructure, since early unification of the diamond companies was primarily an internal process of capital consolidation at the diggings. Only in the late 1880s, after the unification of pit ownership was imminent, did foreign investment become a significant factor.¹⁷ Nevertheless, the diamond deposits quickly gave rise to a pool of private and public finance that underwrote the provision of railroad infrastructure in the Southern African interior.

In terms of the regional system of innovation, Southern Africa's knowledge and innovative infrastructure paralleled the economic system, with extensive development occurring only after discovery of mineral resources. Museums are among the oldest scientific and educational institutions in Southern Africa, dating back to the early Dutch settlers at the Fort in Cape Town. Throughout this early period, most research across Southern Africa focused on describing and documenting the diverse natural environment.¹⁸

Basic education in 19th century Southern Africa was principally the product of Missionaries. In addition, several colleges began offering higher-level courses. Only two

¹⁵ S. Jones, 'Banking and Business in South Africa', in S. Jones (ed.), *Banking and Business in South Africa*. (London, Macmillan, 1988), ch. 1.

¹⁶ S. Jones, *The Great Imperial Banks in South Africa: A Study of the Business of Standard Bank and Barclays Bank 1861-1961* (Pretoria, University of South Africa, 1996), pp. 90-98.

¹⁷ Frankel, *Capital Investment*, ch. 3.

¹⁸ S. Naudé and A. Brown, 'The Growth of Scientific Institutions in South Africa', in A. Brown (ed.) *A History of Scientific Endeavor in South Africa* (Cape Town, Royal Society of South Africa, 1977), pp. 60-85.

institutes were teaching courses equivalent to university level during this period, the University of Cape Town (UCT) and University of Stellenbosch (UoS). However, these institutes were not allowed examine the students or bestow degrees. Only when an examining institution, the University of South Africa (UNISA), became established in 1873 was a Southern African tertiary system established.

In the early years of mining activities, international mobility of skilled individuals was the principal source of technical know-how. In general, the nature of the Southern African deposits led to a premium on individuals with a combination of practical experience deep-level mining in the Americas and formal mining education in Europe.¹⁹ The mining sector required many ancillary goods and services. As these products began to be domestically provided and mining production became more systematic, there was a shift in the focus of Southern African science away from descriptions of the local natural environment to a focus on utilizing the region's natural resources in industrial applications.²⁰

This section reviewed the context in which early Kimberley diamond production occurred. Besides diamond mining, coal, copper, and gold were other primary resource sectors. During this period, both copper and gold mining followed a general pattern of mineral rush followed by continued, but relatively marginal, systematic mining. In contrast and strongly linked to the growth of the diamond mining, the coal industry developed from localized operations to larger mines for distant, but still regional markets. Two British colonies and two Afrikaner republics were identified as the principal political authorities

¹⁹ E. de Waal, 'American Technology in South African Gold Mining before 1899', *Optima*, 33 (1983), pp. 81-85.

²⁰ W. Talbot, 'Pathfinders and Pioneers, Explorers and Scientists 1487-1976', in A. Brown (ed.) *A History of Scientific Endeavor in South Africa* (Cape Town, Royal Society of South Africa, 1977), pp. 1-32.

despite the presence of numerous native African nations. With its superior technological and economic resources the British exercised tempered hostility to the Afrikaner Republics, but more direct repression and dispossession toward the native African nations. The various mineral discoveries were also shown to support a constituency of prospectors who embraced frontier democracy and influenced development of mining regulation across Southern Africa.

The section also described British and Afrikaner territories' economic salvation through the mineral discoveries. It highlighted the contribution minerals made to development of the local financial system. Lastly, the broad influence of the mining sector on the regional system of innovation was reviewed. In particular, it facilitated a move away from descriptions of the natural environment to industrial applications directly and indirectly associated with the extraction of these natural resources. Supporting this shift was an influx of skilled individuals that arrived in Southern Africa because of the growing mining sector.

KIMBERLEY AND THE SECTORAL SYSTEM OF INNOVATION

This section highlights the Kimberley diamond fields' influence on and from development of a Southern African system of innovation. The section begins with a discussion of the evolution of diamond mining production in Southern Africa. Attention then turns to three dimensions of critical importance to Kimberley's legacy. First, it created critical physical and financial infrastructure. Second, it supported a hierarchy of production with distinct linkages to the broader socio-political system. Third, it adopted a system of production and innovation in which collaboration was given a central role.

In 1866, a Khoisan servant on the banks of the Orange River picked up a peculiar pebble. The farmer's children acquired the stone and used it as a toy until a visitor spotted it and suspecting it to be a diamond sought verification. Geologic knowledge was

particularly scarce in those days. The 'Eureka' diamond, as it would become known, travelled nearly 600kms from the farm near Hopetown to Grahamstown in order to get positive verification.²¹ Despite announcement of the discovery in the press throughout Europe and North America, scepticism about the geology of the Southern African deposits delayed a rush to the diamond fields.²² Nonetheless, by 1869 further discoveries led to a full-scale rush for alluvial diamonds. These alluvial diggings were typically mined by a claim holder and assisted by local Africans in the digging and sorting of the diamond bearing soil. The alluvial deposits were quickly cleared and late in 1870 activity at the alluvial diggings rapidly declined.

However, early in 1870 the first non-alluvial, kimberlite, diamond pipes were discovered. This marked an entirely new geological occurrence and era of diamond mining. By 1871 mining on the 'dry-diggings' centred around four diamond pipes: Kimberley, DeBeers, Bultfontein, and Dutoitspan. On the dry-diggings each claim was a mere 2.9 square meters, only individuals could own a claim, no individual could own more than two claims and the owner forfeited his claim if it was inactive for eight consecutive days.²³ Besides claim restrictions, the surface area of these diamond bearing pipes was small although they continued to substantial depths. In 1872, the combined area mined at the Kimberley and DeBeers pipes encompassed 12.8 hectares, at Dutoitspan six hectares and at Bultfontein 3.2 hectares.

²¹ W. de Klerk, 'Albany Museum', in C. Anhaeusser (ed.) *A Century of Geological Endeavour in Southern Africa: 1895-1995* (Linden, South Africa, Geological Society of South Africa, 1997), pp. 324-336.

²² Rosenthal, *Johannesburg*, pp. 27-28.

²³ W. Worger, *South Africa's City of Diamonds: Mine Workers and Monopoly Capitalism in Kimberley, 1867-1895* (Craighall, South Africa, A. D. Donker, 1987), p. 16.

The geology of the deposits quickly led to a situation where many individuals were interested in mining a small area to greater and greater depths. As the claims were dug deeper, significant differences in the quality of the pipes' diamonds deposits became apparent. The Kimberley pipe was the richest, followed by DeBeers and more distantly the pipes at Dutoitspan and Bultfontein. The concentration of the richer diamond deposits led to substantial sub-division of the already small claims.²⁴ Even with sub-division, the scarcity of claims led to rapid price escalation and claims quickly became unaffordable to most prospectors on the fields.

The increasing exclusivity of claim ownership led to the emergence of claim-owner and share-worker classes. The share-workers worked the claim for the claim-owners. Despite paying for the equipment and African labour to extract the diamonds from the claims, the share-workers also gave up to 50% of the diamonds they extracted to the claim-owners. Nevertheless, there were many individuals seeking opportunities for share-work, so claim-owners began to hire share-workers with the largest supply of African labourers so that the diamonds on their claims were extracted as fast as possible.

Originally, the dry-diggings used ancient labour intensive techniques from India that required little capital investment.²⁵ These were relatively inefficient techniques, particularly as mining in the pipes went deeper. By the mid-1870s production problems were occurring at all four pipes because of the general depth and retention of single claims as the unit of production. The multitude of distinct and increasingly deep mining operations on the Kimberley pipe were originally accessed by an elaborate roadway scaffolding, but by 1872 its collapse in places necessitated replacement by a haulage system

²⁴ For example, Kimberley went from 450 claims early in 1870 to over 1,600 by the middle of that year.

Worger, *Kimberley*, p. 18.

²⁵ G. Williams, *The Diamond Mines of South Africa* (New York, B.F. Buck & Co., 1905), ch. 5.

with wires emanating in a web like fashion to the edge of the pit.²⁶ While some relief came in 1873 when the maximum number of claims an individual could own rose from two to ten, it was only when claim ownership restrictions were removed late in 1876 that significant consolidation began to occur.

Relaxation of claim ownership restrictions initiated a new era of corporate ownership and production on the diamond fields. This consolidation generally increased the capital intensity of production with an introduction of mechanical equipment that required increasingly skilled workers. European, mainly British, miners were needed to operate and maintain this equipment and so another class of labour began work on the diamond fields. Share-work was no longer available as consolidation occurred and these individuals either left or took-up jobs supervising the African labourers. The new methods of production restored profitability to many operations, but economies in production drove a race to secure ever larger claims on all of the pipes. Adding to productive pressures favouring larger operators, the 1876 relaxation of claim ownership also re-instituted mining boards with a structural favour to larger operations. The services controlled by the mining board, such as pumping of water from the pits and clearing collapsed areas of the pit made them increasingly important forces over the various claim's competitiveness especially as the pits grew deeper and deeper. Thus, the lack of influence over the mining boards and productive economies of scale put smaller claim holders in a position of accelerating disadvantage compared to larger operations.

By the early 1880s, the greater wealth of deposits at the De Beers and Kimberley pipes meant unification of control at either of them would effectively enable consolidation at the other three pipes and monopolize global production of diamonds. Hence, a terrific

²⁶ A. Hocking, *A Court of Kings: The Story of South Africa's Association of Mine Managers* (Bethulie, South Africa, Hollards, 1997), p. 36.

urgency characterized efforts to control both of these central pipes. Worger identifies distinct processes of unification between the Kimberley and DeBeers pipes.²⁷ Owing to the comparative richness of the Kimberley deposits it was able to attract investment from the London diamond merchants. DeBeers in contrast did not initially attract significant foreign investment inflows, but by the early 1880s local joint-stock companies were driving large speculative investment.

In this intermediate era of corporate production, smaller companies were largely eliminated and a few companies controlled operations at each pipe. However, consolidation remained incomplete and the remaining companies were perpetuating the productive difficulties of diversified ownership at a larger scale. At both the Kimberley and De Beers pipes, the two companies at the forefront of ownership consolidation were the two companies with the greatest influence on the mining boards. These two firms were the DeBeers Diamond Corporation headed by Cecil John Rhodes and Charles D. Rudd and the Kimberley Central Diamond Corporation headed by Barney Barnato.

Faster development at the Kimberley pipe, because of its richer deposits, created lessons in production that informed operations at the DeBeers pipe and compensated for its lower-grade deposits. Unification of the diamond pipes and industry only came after discovery of the Witwatersrand gold deposits. In the end, the DeBeers Diamond Corporation securing financial support from Nathan Rothschild in 1888 gave it the power to consolidate ownership at DeBeers and Kimberley in turn. Only then could production focus on the physical geology of the deposits rather than legal ownership boundaries and full-scale industrial production begin.²⁸

²⁷ Worger, *Kimberley*.

²⁸ This consolidation also facilitated control of diamond supplies and the general stability of the industry.

The nature of the kimberlite deposits and broader social-cultural environment thereby influenced the development of the associated system of innovation. Initially production and related innovations were dictated by foreign technologies and claim ownership restrictions. As local know-how developed and some claim ownership restrictions relaxed, production systems emerged around competing contingents of interests. Underlying economies of scale in production and consolidation of downstream supply translated into the contingents' know-how, systems of production and innovations becoming important to their exertion of authority and survival. Incentives for collaborative innovation decreased between contingents, but simultaneously increased within contingents. When unification was eventually complete this collaboration continued to characterise intra-sectoral relationships within the mining industry.

The diamond deposits significantly contributed to development of Southern Africa's infrastructure. In terms of physical infrastructure, one of the most important legacies was the railroad transportation system. The Cape Town parliament inaugurated construction of a railroad to Kimberley in 1872. Covering 960 kilometres, the line reached Kimberley in 1885. Following territorial conflicts with the Orange Free State, a shorter 750-kilometer Port Elizabeth-line joined the Cape Town-line at De Aar joined it in 1884. Access to the Kimberley market also generated other rail ventures. While the real take-off of rail infrastructure awaited the gold discoveries of the Witwatersrand, by 1886 there was a substantial foundation.²⁹

Another legacy of Kimberley was development of the financial system. Despite ownership restrictions, Kimberley launched Southern Africa's first stock exchange in

²⁹ T. Reunert, 'Inaugural Presidential Address: The Progress of Engineering in South Africa during the Last Thirty Years', *Proceedings of the South African Association of Engineers and Architects*, 4, (1898), pp. 188-196.

1875.³⁰ The slow evolution of capital-intensive mining facilitated a largely self-financed industry to develop outside of the London diamond merchants' investment on the Kimberley pipe. However, while the Standard Bank and a couple of other banks established branches in Kimberley; by the mid-1880s, its greatest impact on the local financial infrastructure was facilitating associated investments in railroad infrastructure.³¹

Kimberley was the first industrial town in Southern Africa; diamonds exceeded wool exports in 1880, thereby inaugurating South Africa's mineral based economy. While the local population fluctuated rather dramatically in the early years, its significance is reflected in the fact that the Cape Colony's White population rose from 181,592 in 1865 to 287,121 in 1881.³² This population's demand for goods and services led to the emergence of a significant merchant class in Kimberley. In order to get supplies to Kimberley before the completion of the railroads transport riders were used. Rural Afrikaners played a significant role in this transport riding industry, marking an important break from that community's focus on subsistence agriculture.

Electric telegraphs reached Kimberley in 1876, with local manufacture of beer and soda water occurring there in the 1870s.³³ Following industry consolidation around DeBeers Mining Corporation (DBMC) in 1886, an important source of domestic capital investment was created. DBMC engaged in several substantial investments in Kimberley's

³⁰ Rosenthal, *Johannesburg*, p. 38.

³¹ Frankel, *Capital*.

³² Rosenthal, *Johannesburg*, p. 40.

³³ *Ibid.*, p. 37.

municipal services, KwaZulu Natal collieries, railroads, fruit orchards, explosive production, and exploration companies such as the British South Africa Company.³⁴

As production techniques on the Kimberley diamond fields evolved, the social hierarchy of production changed. Throughout, a fundamental division in the system of production existed between the African and non-African (White) populations. When mining began on the Kimberlite pipes some Africans became claim-owners on the lower-grade deposits.³⁵ This class of claim-owning Africans was severely disliked by the local White population who prohibited African claim-ownership in 1871. As the British Colonial government refused to sanction these racial restrictions a small class of African claim-owners persisted throughout early mining operations at Kimberley. For the vast majority of Africans the Kimberley diamond mines represented an important means to earn a living, particularly following confrontation for land among Europeans and Africans during the 1850s and 1860s.

Initially, the Kimberley diamond fields opened a range of opportunities for Africans. Not only because of demand for their labour on the mines, but a significant number also found employment on the railroads. Demand for foodstuff also created an opportunity for African agriculturalists who began producing food for the growing mining industry. However, racial discrimination prevailed and by the mid-1870s increasing restrictions were placed upon the Africans to reduce their self-sufficiency and institutionalize them as a disenfranchised class of low-cost labour.³⁶

³⁴ D. Farnie, 'The mineral revolution in South Africa', *South African Journal of Economics*, 24 (1956), pp. 125-134.

³⁵ In 1870 around 100 Africans owned claims at Bultfontein. Worger, *Kimberley*, pp. 71-72.

³⁶ C. Bundy, 'The Emergence and Decline of a South African Peasantry', *African Affairs*, 71 (1972), pp. 369-388.

Within the White population there were at least three distinct communities directly involved in production: prospectors-supervisors; European Miners; and Mining Professionals. Among the earliest White population was the prospector. As mentioned above, the geology of the non-alluvial diamond deposits quickly limited opportunities for prospectors. Those prospectors who were unable to secure claim-ownership or those claim-owners who lost ownership had only share-work available to them as an alternative. However, following initial industrial production after the relaxation of claim ownership restriction in 1876, the only employment opportunity for these individuals on the mines was as a supervisor of the African labourers. Through-out these early years the white prospectors, come share-workers, come supervisors, continued to identify with their more successful brethren who formed the Mining Professional community. This identification with the Mining Professional community occurred despite their comparative economic impoverishment.³⁷

While relaxation of claim-restrictions in the mid-1870s effectively eliminated share-workers it heralded the entry of another class of white workers, the European Miners. European Miners were skilled miners and artisans who came to Kimberley as increasingly systematic mining methods and equipment began being deployed under industrial consolidation. The overwhelming proportion of these European miners was from the tin mines of Cumberland and the coal mine of Cornwall in England.³⁸ These European Miners brought a legacy of trade unionism to Kimberley and Southern Africa in turn, initiating the first industrial action on the diamond fields in 1883. There was little binding the European Miners to the White Supervisor or the Mining Professional communities.

³⁷Worger, *Kimberley*, p. 158.

³⁸ Williams, *Diamond*, ch. 14.

Mining professionals were originally a community of claim-owners, but as company ownership began to develop diamond merchants took an increasing role. Turrell describes this transformation and development of an upper class of mining capitalists as the Kimberley diamond merchants took an increasingly active role in diamond production.³⁹ Another component of the mining professional community was the mining engineer. Until the late 1880s, mining engineers with experience in Europe introduced systematic mining.⁴⁰ Mining capitalists led the mining professional community during this era of Kimberley diamond mining. The race to consolidate ownership required frequent interactions amongst these individuals and created a learning environment where a critical understanding of mining operations formed under a collective identity.

Alliances and competition between the various contingents fighting for industry consolidation gradually increased in-group production cooperation. In this drive, strategic inter-personal relations were exploited and developed. These interpersonal business relations within the mining professional community were crucial to the eventual consolidation of operations.⁴¹ The shared identity that emerged at Kimberley provided an important foundation for co-operation once the Witwatersrand gold deposits were discovered.⁴² Two prominent dimensions of this identity were political and ethnic.

³⁹ R. Turrell, *Capital and Labour on the Kimberley Diamond Fields 1871-1890* (Cambridge, U.K., Cambridge University Press, 1987).

⁴⁰ These methods proved inadequate and by the late 1880s, international experience in hard rock, deep mining had accumulated in the Americas and so it fell to an American mining engineer, Gardner Williams, to implement a comprehensive mining system for the Kimberley diamond pipes.

⁴¹ Turrell, *Capital and Labour*.

⁴² For details of ties to Kimberley by mining capitalists from major mining-finance group on the Witwatersrand see P. Emden, *Randlords* (London, Hodder & Stoughton, 1935).

British Colonial expansion in this Victorian Era dominated the political identity of the Kimberley mining professional community Cecil John Rhodes exemplifies an individual from Kimberley associated with this identity. Rhodes nurtured an alliance with the Cape Afrikaners from the late 1870s that he eventually parlayed into his election as prime minister of the Cape in 1890.⁴³ Rhodes entered the Cape parliament in 1881 and used his connections there to advance his business interests. In his biography of Rhodes, Rotberg noted that his natural instinct for collaboration found a fostering environment in the technical imperatives of early diamond mining at Kimberley.⁴⁴

Several social institutions were associated with this British Colonial identity. One of the first to make a mark on Kimberley was the colonial Victorian all-male club. Modelled after the socially exclusive clubs in London, this provided prominent members of the mining professional community an informal environment to meet, socialize, and conduct business across the boundaries of their organizations. A few of the more important of these clubs established on the Southern African frontier were the Kimberley club established in 1881, the Rand Club established in 1887, and the Salisbury Club established in 1893.⁴⁵ Another social institution associated with this British Colonial identity was English Freemasonry. In 1872, the first lodge was established in Kimberley, Rhodes joined

⁴³ Davenport and Saunders, *South Africa*, p. 109.

⁴⁴ R. Rotberg, *The Founder: Cecil Rhodes and the Pursuit of Power* (Johannesburg, Southern Book Publishers, 1988), p. 111.

⁴⁵ For more on the role played by these clubs in Southern African communities other than Johannesburg see: C. Black, *Sable: The Story of the Salisbury Club* (Salisbury, Salisbury Club, 1980); B. Roberts, *History of the Kimberley Club* (Kimberley, Kimberley Club, 1978); C. Warner, *History of the Kimberley Club* (Kimberley, Kimberley Club, 1965); and R. DeVilliers and S. Brooke-Norris, *The Story of the Rand Club* (Johannesburg, The Rand Club, 1976).

that lodge in 1881, and Ernest Oppenheimer joined in 1886.⁴⁶ In 1878, the first English Freemasonry lodge in the Transvaal was established in Pretoria.⁴⁷ This lodge emerged because of the 1877 installation of British civil servants in.

The ethnic ties of the Jewish community were another important social institution associated with the rise of diamond mining in Kimberley. With a long historic tradition in diamond dealing and cutting, many early Jewish arrivals to the diamond fields had kinship ties with the large European diamond dealers.⁴⁸ Jewish ethnicity thereby formed an important social network with significant commercial experience, which supported identity development of the mining professional community. That identity enabled the establishment of several co-operative precedents in the system of production that would be emulated on the Witwatersrand.

Collaboration occurred in several areas, generally focusing on benefits to the mining professional community. Technical knowledge gained from leading producers in the Kimberley community created a knowledge resource with distinct benefits and costs among diamond producers. As mentioned previously, the Kimberley diamond pipe was often the first to encounter technical challenges and develop solutions. These solutions were incorporated into operations at the other diamond pipes enabling them to catch-up with the leading edge producers from Kimberley.⁴⁹ This structure of local knowledge externalities enhanced the aggregate productivity of producers on the Kimberly diamond

⁴⁶ P. Butterfield, *Centenary: The first 100 years of English Freemasonry in the Transvaal, 1878-1978* (Johannesburg, Ernest Stanton, 1978), p. 40.

⁴⁷ *Ibid.*, p. 76.

⁴⁸ Alfred Beit, Jules Wernher, Barney Barnato, George Albu, Sammy Marks and Lionel Phillips are a few prominent examples of members from the Jewish community who, after being established at Kimberley, subsequently played an important role in the development of the Witwatersrand.

⁴⁹ Williams, *Diamond*, ch. 8.

fields, but it also gave a productive advantage to intra-industry rivals at the DeBeers pipe and played a significant role in shaping the eventual consolidation of the Kimberley diamond industry in 1889.

In other areas of production collaboration was relatively difficult to achieve. The initial diffused structure of claim ownership undoubtedly made collaboration a challenge. As consolidation occurred the industry was increasingly able to realize collaboration in areas like participation in African labour registration, limit local and formalizing recruitment channels for African labour recruitment and contracting, imposing mandatory strip-searches of mining workers for illicit diamonds, and closing the African labour living quarters or compounds. Obviously, these areas of collaboration enhanced the mining professional's interests. Understanding why these areas of collaboration only occurred when industrial consolidation was well underway is facilitated by referring to the collective action approach to collaboration.⁵⁰

There are four fundamental structural factors in the collective action approach; two are structural relationships: 1) the collective supply function and 2) the convention system; and two are structural components: 1) overlapping activities and 2) the public - collective good produced. The collective supply function (CSF) defines how individual contributions to collective action are combined to produce a specific quantity of collective good. The nature of the public good produced also determines which CSF is appropriate.

A public good is a generic title under which a variety of goods can be distinguished. When a good (or service) is both non-excludable and non-rival, it is a pure public good. Non-excludability means the good's providers cannot limit its consumption from non-providers. Non-rivalry means one person's consumption does not reduce the amount

⁵⁰ For details see: T. Pogue, 'The Evolution of Research Collaboration in South African Gold Mining: 1886-1933' (PhD thesis, Maastricht University, 2006), ch. 3.

available to others. If a good is partially excludable and/or partially rival, it is an impure public good.⁵¹ Impure public goods can be further differentiated. If a good is excludable but non-rival, such as a musical performance, it is a club good.⁵² Similarly, when a good is rival but not excludable, such as a quiet picnic spot in a park, it is a rival public good. A third type of impure public good are inherently private goods, but are treated as public goods because of social consensus, public education is an example of this type of quasi-public good. Lastly, all of these types of public goods can be discrete, continuous, or step. If a public good is discrete, its provision either occurs or does not. If a public good is continuous, the amount of the good provided is variable. Lastly, if a public good is step, within discrete provision levels, the quantity of the good provided is variable.

There are an infinite number of possible CSFs, but in the context of this era of Kimberley mining a summation CSF is a reasonable approximation. It assumes that everyone shares the provision and benefits of collective action equally. It can be expressed by the equation: $Q = \sum_{i=1}^n q_i$ where Q is aggregate supply of the collective good, q_i is individual i 's provision, and n is the group size. Under the summation CSF we assume provision can be either discrete or continuous, but that there are no scale or scope economies in provision, no moral or material overlapping activities in the convention system, and no strategic influences on the costs and benefits of cooperation. Thus, collective action is only successful in providing an output without any institutional mechanisms when the group is "privileged". A privileged group is one in which at least one

⁵¹ A private market good is both excludable and rival.

⁵² For a select review of the vast literature on club goods, see: R. Cornes and T. Sandler (1996) *The theory of externalities, public goods, and club goods*. (Cambridge, U.K., Cambridge University Press, 1996).

member of the group finds the benefit from the collectively provided good to be greater than the costs of the collectively provided good.⁵³

Table 1 The Type of Public Good and Collective Action⁵⁴

	Number of Members (n)	Total Costs (c)	Ratio of Group Benefit to Total Cost ($n*V_i/c$)	Cost per Person (c/n)	Value of Good to Member- i (V_i)	Group Benefit ($n*V_i$)	Return to Member- i per Expenditure (V_i/c)	Disincentive to Pay ($1-V_i/c$)	Minimum Sub-group Size (k)*
Row/Column	1	2	3	4	5	6	7	8	9
1	5	5	4	1	4	20	0.8	0.2	2
2	100	100	2	1	2	200	0.02	0.98	51

* This is the minimum number of members needed to provide the good, *i.e.* ($\min k | k*V_i > c$)

With these analytical tools we analyze the challenge faced in achieving collaboration during this era of Kimberley diamond mining in Table 1. In the table there are two rows with nine columns. Column one indicates the number of members in the group. Column two indicates the total cost of providing the collective good. Column five represents the value of the collective good to each individual in the group, while column six represents the total value of the collective good to the group. Column three indicates the group benefit from the collective good relative to its total costs. Column four reports the costs of collective provision per member of the group. Column seven gives the value of the collective good to each group member relative to its total costs, and column eight reports the compliment of this value per member relative to its total costs or the disincentive to

⁵³ A more formal definition of a “privileged group” is: The net benefit of collective action to a member, i , of the group is given by the equation $A_i = V_i - C$, where A_i is the advantage to member- i of its contribution to collective provision; V_i is the gross return from the collective good to member- i ; and C is the total contribution member- i makes to provision. If for some member- i of the group, $A_i > 0$, then the group is privileged. See: R. Hardin, *Collective Action* (Baltimore, Johns Hopkins University Press, 1982), ch. 3.

⁵⁴ Adapted from R. Hardin, *Collective Action* (Baltimore, Johns Hopkins University Press, 1982).

pay. Lastly, column nine reports the minimum size of the sub-group necessary to provide the collective good. This is the minimum number of agents needed to provide the collective good. More specifically, this “ k -value” is the total number of individuals whose collective value per member, column seven, just exceeds the total costs of provision, column two.⁵⁵

Initially under the system of restricted claim ownership, the cost of providing these collective goods rose with each additional member while the benefits from them remained fixed. In the early years of Kimberley diamond mining, provision of collective goods therefore approximated the situation detailed in row two. However, as the industry consolidated towards the mid-1880s we shifted to a situation more akin to row one. In row one, the industry is still not ‘privileged’ but the absolute and relative number sub-group members necessary to achieve collective action decreased. The minimum size of a sub-group of agents that could provide the collective good decreased from 51 agents out of the 100 members to two agents out of the five members. Further supporting collective action with industry consolidation were previously mentioned social networks and cohesion among Mining Professionals, which acted as an institutional mechanisms for collective action.

Even before industry consolidation, the collective interests of the mining professional community were advanced in several ways. The best examples of these early advances of the mining professional community’s interests were in the co-optation of the State. The influx of prospectors in search of diamonds generated tensions with the Afrikaners in the district. In response to this hostility, the initial alluvial miners declared their own independent diggers democracy. When the non-alluvial diamond pipes near

⁵⁵ If any of these scenarios were “privileged” the minimum sub-group size, k -value, for the row would equal one, *i.e.* a single agent finds it in their interest to unilaterally provide the collective good.

Kimberley were discovered there were four groups claiming governing authority: the mixed race Griquas, the ZAR, the OFS, and the diggers themselves. Under British arbitration, political authority of the Kimberley pipes was granted in 1871 to the Griqua and became the British colony of Griqualand-West with political authority vested with the British Colonial Office. In order to increase local control, Griqualand-West was transferred to the Cape Colony in 1880 with the Cape parliament becoming responsible for enacting legislation over the region. Thus, annexation and eventual incorporation of Griqualand-West into the Cape Colony was intertwined with attainment of political authority to realize legislation needed for technical consolidation.⁵⁶

Another demonstration of the State's early willingness to act in the interest of the Kimberley diamond industry was its occupation of the ZAR. When the British occupied Pretoria in 1877 one of their first acts was the removal of the transit or exit tax on African labourers crossing the territory.⁵⁷ Both the ZAR and OFS had imposed these mobility taxes in order to reduce the number of Africans going to work on the diamond fields. In other efforts to assist the diamond industry with its supply of African labourers, the State enacted regulations in 1872 that required Africans to carry passes in order to limit the African community's ability to leave the diamond mines.⁵⁸

Industrial consolidation was accompanied by refined policies by the State in support. To reduce the opportunities for livelihood outside of engagement with the mining industry, the State passed a hut tax on the African communities in 1879. A Police

⁵⁶ C. Newbury, *The Diamond Ring: Business, Politics, and Precious Stones in South Africa, 1867-1947* (Oxford, Clarendon, 1989), ch. 2.

⁵⁷ Worger, *Kimberley*, p. 98.

⁵⁸ These regulations were ineffective as limited capacity to enforce them made them prohibitively expensive for producers. *Ibid.*, ch. 3.

Magistrate Court was also established in 1879 to significantly enhance enforcement of the 1872 pass laws.⁵⁹ This court was assisted by municipal regulations that designated racial locations in order to make police enforcement of these racial physical mobility restrictions easier.⁶⁰

The State adoption of a presumption of guilt in the Diamond Trade Act of 1882 clearly signalled its alignment with the mining professional community. After some initial dithering, with repeal of claim restrictions in 1876, the State had already established its bias towards the interests of larger diamond producers.⁶¹ Other evidence of the mining professional community's influence over life in Kimberley comes from its ability to cover-up a large outbreak of small-pox in 1883-1884.⁶² Lastly, State co-optation with increasingly large operators on the diamond fields was reflected in the fact that the mines were under no legal obligation to compensate a miner or his heirs from death or injury on the mines.⁶³

Co-operative exertion of mining's economic authority on the political sphere continued to evolve and adapt when the large gold deposits of the Witwatersrand began to be exploited. Kimberley's early development showed collective action could be a critical determinant for success. In production and innovation these early co-operative initiatives thereby established precedents and routines that were subsequently transferred to other mining endeavours across Southern Africa.

CONCLUSION

⁵⁹ For further details on the role played by pass laws and hut taxes in securing a stable supply of low-wage Africans for the Witwatersrand gold mines see: Pogue, *Collaboration*, ch. 9.

⁶⁰ Worger, *Kimberley*, p. 130.

⁶¹ *Ibid.*, ch. 1.

⁶² *Ibid.*, p. 106.

⁶³ *Ibid.*, p. 152.

This paper described the role of Western mining activities before the Witwatersrand gold rush on the development of a Southern African system of innovation. The associated productive and innovation system that emerged in this period was characterized by collaboration and coordinated action among agents. Those agents' activities were not just around narrow production and innovation demands, but influenced the regional political and socio-economic systems as they were influenced by those systems' dynamics in kind.

In its legacy, the most important precedent to the Witwatersrand was the Kimberley diamond deposits. Kimberley expanded the mining know-how and financial capacity of Southern Africa. Building this capacity, it created momentum to overcome technical hurdles and uncertainties associated with early development of the Witwatersrand. It also created a distinct class of entrepreneurs within a community of miners that subsequently pioneered the Witwatersrand's systematic extraction.

The review of the inter-related development of production and innovation systems at Kimberley highlighted the complexity and specificity associated with effecting collaboration. Changes in claim ownership simultaneously encouraged and discouraged collaboration. The analysis clearly illustrates that inadequate understanding of these countervailing incentives can undermine policies promoting collaboration, be they in an historic or contemporary setting.

While a great deal has been written on the early development of Southern Africa's mining sector, this analysis shows that very little of that literature considers the role played by innovation. These early mining endeavours critically transformed the emergent Southern African system of innovation. They developed and established local capabilities in adopting and adapting foreign technologies. Early mining activities also established a local pool of international expertise in mining and extraction technology. At a broader level, it

deepened the regional knowledge-base and expanded scientific and technical capacity beyond its previous focus on descriptions of the natural environment. Mining in this era also supported development of a tertiary education system as well as creating a critical stimulus for economic development across the region.

South Africa placed itself at the international forefront in its adoption of a system of innovation approach for science and technology policy.⁶⁴ Given the centrality of innovation to sustained economic development, this paper marks important progress in our understanding of a neglected dimension in the region's contemporary comparative advantages in mining and related sectors of the economy. That understanding is critical in designing policies that support existing and develop additional science and technological expertise, which can be leveraged for the benefit of all.

⁶⁴ See for example *The White Paper on Science and Technology*, Republic of South Africa (1996).