

This dissertation examines the evolution of research collaboration in South African gold mining between 1886 and 1933. It highlights the importance of collaborative research and its contribution to innovation and economic growth. Three distinct methodological approaches to understanding research co-operation are examined. Rather than argue for one approach over another, or propose a new approach altogether, it demonstrates that complementarities among the methodologies contribute to a deeper understanding of the collaborative research phenomenon. Two case studies on the collaborative development of key technologies illustrate the role of collaborative research in an innovation system as well as the evolution of collaborative research and its relationship to broader socio-economic conditions.

A majority of contemporary analyses on collaborative research examine it as a fundamental feature in the emergence of a modern knowledge-based economy. The analysis of the cases in this study illustrates several of the properties highlighted in this recent theoretical literature on research collaboration: the coordination of agents through non-market and non-hierarchical mechanisms, the importance of collaboration to developing an internationally competitive technology, and the often crucial coexistence of competition and cooperation. Hence, this analysis shows that while much vaunted in the current setting, research collaboration are established phenomenon with historic precedents to guide our modern understanding of them.

It is generally accepted that technological change is a crucial component of sustained economic growth. The dissertation uses case study material to reflect on three different theoretical approaches to collaborative co-ordination of the innovation process. This dissertation differentiates between three perspectives on research collaboration: industrial districts, collective action, and distributed innovation. These approaches are distinguished by their selection of events which cause research collaboration. Based on these focuses, three analytical models are formulated. Part One introduces the analytical approaches with chapters on each discussing their empirical and theoretical heritage, and specifying stylized models for use in analysis. Part One concludes with a chapter reviewing the approaches and their relationships in analyzing the phenomenon of collaborative research. Given the expansive literature the approaches cover: agglomeration externalities, collective action, and economics of technological change, there is no attempt at comprehensiveness. Interest is concentrated upon aspects of these literatures related to cooperative research.

Each perspective is described according to its structure, causal conditions, and effects. Static and dynamic components in the approaches are specified in the section on structure. The section on causal conditions specifies how ingredients described in the structure form events that generate collaboration in research and possibly other activities. Lastly, the section on effects specifies the resulting relationships within and between the collaborative system, the broader innovative system, and the socio-economic system. The distinction among the approaches by their causal conditions generating research collaboration, leads to a more comprehensive analysis of the case studies than would be possible unilaterally.

The case studies cover the periods before (Case One) and after (Case Two) the formation of the South African nation. Although analyzing only part of the sectoral and national systems of innovation, this study provides insight into the complex structure that is a system of innovation. Witwatersrand gold mining has played a central role in the economic development of South Africa.¹ It has also been a major force in shaping the political economic environment. As such, it instilled a predominant style on the national system of innovation. Analyzing the central

¹ The Witwatersrand is an ancient gold endowed basin around 350km long and 150km wide. A majority of the basin remains buried, but tectonics have exposed its northern edge, around the city of Johannesburg.

contribution made by technological change to industry dynamics, the dissertation also highlights a neglected dimension in South Africa's historiography.

Each case study illustrates the general evolution of research collaboration that occurred in the industry during their respective periods. Both cases consist of two chapters, the first provides a brief on the technology, its relationship to the productive structure, and the socio-economic context under which it was initiated, the second applies the stylized models to analyze the case. Each approach is applied in both cases. Owing to the complementarities in the approaches, the order of analysis is differentiated by their respective analytical insights over the two cases. In the first case study the industrial district approach is thoroughly reviewed before considering additional insights from features in the collective action and distributed innovation approaches. Similarly, in the second case the distributed innovation approach is thoroughly reviewed before examining additional insights from the collective action and industrial districts approaches.

The first case study, on the adaptation and refinement of a technological process that allowed cyanide extraction of gold from its host rock is presented in Part Two. This case falls within a general period of initial development of mining that occurred in South Africa between 1850 and 1902. This development corresponded in part to an international phenomenon and in part to geological features of the South African minerals. The research collaboration investigated covers a ten-year period from 1892 to 1902. During this time, technologies were developed that translated the promise of cyanide based gold extraction into a large-scale industrial reality. Local industrial development was paramount, with precedents from Kimberley's diamond mines facilitating establishment of a community that saw mutual benefits in pooling resources to solve pressing technical challenges. Hence, the industrial district approach was particularly informative in describing research collaboration in this case with a concentration of international metallurgical expertise and an open policy of technical performance release by the mines.

The second case, Part Three, is on transformation of stoping practices (underground production) in mining operations. It covers just over 30 years from 1903, when the Second Anglo-Boer War was over, to 1933, when the price of gold rose with the suspension of the gold standard. The transformation of stoping practices was another landmark in the technological development of the industry, which required the coordinated development of a multitude of inter-dependent technologies. It established an instituted economic process that was perpetuated from the gold mines on to the general economy, thereby limiting the potential economic opportunities for a majority of South Africa's people. With initial development behind it and industrial consolidation characterizing this era, research collaboration was quite different. The dominant mining-finance house intertwined research collaboration with entrenchment and exertion of control over the system of production. As a result, the distributed innovation approach captured many important dimensions of research collaboration in this instance.

This dissertation contributes to two areas of research, one theoretical, and the other empirical. Through its application and deconstruction of three distinct, but complementary, approaches to the analysis of research collaboration, a potential for congruence is developed. In economics, the market mechanism or hierarchical authority is typically assumed to govern actions. This comparative analysis of research collaboration shows that a third form of governance – i.e. collective governance – can be equally important. While the present analysis has concentrated upon research collaboration, several other economic activities are shown to operate under it as well. In this, a large and exciting area of further research and theoretical advance is possible. In our modern economy where communications are increasingly independent of physical distances, understanding the operation of collective governance is important. Through it, valuable insights into otherwise seemingly quizzical phenomenon are created. For instance, collective governance

has governed development of Apache, the most popular web server for nearly a decade, in which programmers donate their labor to debug and modify the software cooperatively.

Lastly, this analysis of the early Witwatersrand gold mining industry is fundamentally different from those that have preceded it. Placing technological change and its relationship to the socio-economic environment in a central position is unique in South African historiography. These two case studies are only illustrative of the broad range of research that can be conducted using the rich empirical data that the industry possesses. As such it is hoped that the present analysis encourages further examinations of technological change in the industry, for it holds many important keys to understanding current dynamics as well as illustrating and contributing to the literature on the economics of technology change.