SYNTHETIC INDUSTRIAL DIAMOND: A TECHNOLOGICAL OUTLOOK

by

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ABSTRACT

Synthetic diamonds are successfully substituting for natural diamonds in the area of industrial application. Synthetic diamonds increased their market share from 10% in 1960 to 50% in 1968 and to 90% in 1994. The success of synthetic diamonds may be ascribed largely to technological advance in the area of diamond manufacture. Two technologies in particular contributed to this advance: (i) High pressure and high temperature (HPHT) processes for crystallising carbon material and (ii) chemical vapour deposition (CVD) of these materials. The substitution of synthetic for natural diamond occurred in a systematic and predictable manner. Further technological advance could threaten the concept of diamond as a unique and desirable substance in the minds of the consumers and may require the repositioning of its image.

Key Words: *Industrial diamond, synthetic diamond, management of technology, MOT, strategic technology analysis, substitution, high pressure and high temperature, HPHT, chemical vapour deposition, CVD.*

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CHAPTER ONE

INTRODUCTION

This research is concerned with industrial diamond - a resource of national importance to South Africa. Not much has been published about the industry and this is surprising since diamond mining is a major extractive industry and plays an important part in developing many South African industries. The research was prompted by the observation that substitution was taking place in industrial diamond manufacturing techniques and synthetic industrial diamonds were successfully substituting for their natural counterpart.

The research is also important from a theoretical perspective. Synthetic industrial diamonds are referred to as a "landmark" technology in this thesis - this is a technology expected to significantly affect the future path of many other technologies. Establishing the way in which such a key technology substitutes for natural industrial diamonds - theoretically and empirically - is important for the diamond industry and other natural resource industries facing synthetic substitutes.

This research probes the substitution of synthetic for natural industrial diamonds in the area of industrial applications. Synthetic diamonds increased their market share from 10% in 1960 to 50% in 1968 and to 90% in 1994. This substitution is remarkable considering that natural diamonds used in industrial applications are essentially a by-product of the natural gem industry and could therefore have been defensively priced offering fierce competition to any attacker.

Natural diamond is classified into three categories; gem, near-gem and industrial. The jewellery industry uses gem quality and more recently, near-gem material has been cut - although with a poor yield of twenty percent, i.e., eighty percent of the stone is cut away and used for industrial purposes (*Mazal U'Bracha*, 1993:82). The importance for the current research is that as more near-gem material is used in the jewellery industry, less material is available for industrial use.

The phenomenon of substitution prompted three key questions. Why were synthetic diamonds such successful competitors? Did the pattern of substitution of synthetic for natural industrial diamond take place in a systematic and consistent manner and could it have been predicted? What are the implications of this substitution for the diamond industry as a whole, including the gem industry? These three key questions guide the research in examining the technological outlook for synthetic industrial diamonds.

1.1 Background to the research

The pattern of synthetic material substituting for natural material is a common and well documented phenomenon. For instance; synthetic fibres displaced cotton and wool in the clothing industry (Schnaars *et al.*, 1993), composite materials replaced wood and metals in the yachting industry, and polymer materials replaced cotton cord as a tyre strengthener

(Ayres, 1988; Farrell, 1993). The current research examines the reasons behind successful synthetic industrial diamond substitution and traces a possible future outlook.

Synthetic industrial diamond was selected for four reasons:

i. The diamond industry is an important industry in the South African economy and an understanding of the technological forces at work in the industry is therefore significant from a national economic perspective,

ii. Data for the diamond industry are hard to come by, and responsible academic studies of the industry are relatively rare,

iii. The phenomenon of substitution threatens the long term economic status of all extractive industries. Lessons learned in the diamond industry could be of interest to other industries involved in primary products as well, such as gold, copper, platinum, iron and so on.

iv. Synthetic diamonds themselves have a particular status in the world of technological studies. Synthetic diamonds have been identified as a "landmark technology". This is a technology which is expected to have a significant impact on the future technological landscape because of a rapid improvement in its performance and its links with many other technologies (Japp, 1994a).

Regarding the theoretical background, the research is based on a discipline referred to as the management of technology (MOT). This field is emerging as an academic and business initiative that unites the management sciences on the one hand, with fields based on the natural sciences (eg. engineering, medicine, and agriculture), on the other. MOT is nurtured by areas such as research and development (R&D) management, innovation management, project management, technology forecasting, strategic technology analysis (STA) and substitution theory. The latter two fields are key to the current study. The juncture between these fields is a particular model for viewing technological change - a model referred to as the "cascade" model (Van Wyk, 1996c). Using the cascade model as a guide, the thesis presents reasons why synthetic diamonds have been successful. Substitution theory then provides the theoretical base for evaluating the systematic nature of the substitution process, the possibility of a delay in the process, and its general predictability. Having established the reasons behind successful technological advance and the substitution pattern, the thesis turns to examine the technological outlook. It is here that the business implications are presented and associated recommendations stated.

1.2 How the key questions are addressed

Why has substitution been successful?

The cascade model is used to identify material, performance and structural improvements that have occurred in the process of manufacturing synthetic diamonds as well as to synthetic diamond material itself. Technological advance and substitution follow these consistent improvements.

Has substitution been systematic and could it have been predicted?

If it can be established that substitution occurred in a systematic manner, then the predictability of the process can be documented. A database is compiled and presented as a contribution to the information resource base of the diamond industry. Substitution theory is then used to empirically model the replacement pattern. One version of the substitution model, the model by Sharif and Kabir (1976a), is modified to allow for the phenomenon of delayed substitution, a particular feature of synthetic diamond material in industrial application.

What is the technological outlook?

This is an outlook or forecast of the expected impact of further technological advance on the diamond industry. The key factors contributing towards advances in producing synthetic diamond material as well as the characteristics of the material itself are examined. The likelihood of any further breakthroughs is explored. The substitution model is used to quantify possible future trends in industrial application and to reflect on possible implications in other parts of the diamond industry.

1.3 Boundaries and limitations

The empirical analysis is based on global natural and synthetic industrial diamond production over the period 1920-1994. The reason for using data from a date as early as 1920, is to establish an accumulated stock position that may be useful in explaining a delay in substitution. The substitution model however, is applied to a more limited data base, i.e.,on data between 1958 and 1994, the period when synthetic material was produced.

An important issue concerns the way in which synthetic diamonds are referred to during this thesis. *Synthetic diamonds* refer to many individual diamond stones that are manufactured. The term - *Natural diamonds* is used to refer to mined material. *Synthetic diamond* refers to a diamond coating of homogenous material. This distinction becomes apparent when the "blurring of the boundaries" is discussed in chapter seven.

There are a number of limitations to this research:

i. Data secrecy is a limiting factor. No single well administered data base has been published covering natural and synthetic diamond data. The world's leading diamond company, De Beers Centenary AG probably has an authoritative data set, particularly with regard to synthetic manufacture, but does not divulge this information. The research had to overcome this limitation by compiling a data set from various sources and by using global rather than company specific data.

ii. Empirical evaluation of the substitution process has been kept as simple as possible bearing in mind the reservations expressed above as to the quality of the data. For instance, a period of serially correlated data was noted from 1969 to 1981. This would usually require a more rigorous analysis of the correlated differences and the subsequent modification of any statistical model. However, the emphasis in this study is on long-term substitution. And although the relatively short period of serial correlation is not considered disruptive to the main pattern of substitution, it did preclude refined statistical treatment of the data.

1.4 How the thesis is structured

The research is presented in eight chapters and three appendices. Chapter one introduces the topic and establishes the need for the research. Chapters two and three are concerned with establishing MOT as an area of enquiry underpinned by the theory of STA. The literature concerned with substitution and theoretical refinements are presented in chapter four. The three key questions addressing synthetic diamond's (i) technological advance, (ii) systematic substitution and (iii) industrial outlook are addressed in chapters five, six and seven respectively. The conclusions and recommendations are discussed in chapter eight, the final chapter.

CHAPTER TWO

TECHNOLOGY MANAGEMENT: THE THEORY

Introduction

Although the philosophy of technology has been the concern of a small group of devotees for many years, it is only recently that these concerns have been combined with management studies to create a new field of knowledge - management of technology (MOT). One impetus for this development has been the desire by many countries to avoid the trap of becoming technologically uncompetitive. The need for a new field has also been emphasised by the fact that existing policy sciences, such as economics, have not been able to adequately explain the technological differences between countries and the implication for international competitiveness. Within MOT, substitution theory and strategic technology analysis (STA) are introduced as two approaches that may assist in examining the three key questions of the current research.

2.1 MOT - A new field

The theoretical roots of this thesis lie in MOT, a new field of management defined as linking:

> *".... engineering, science, and management disciplines to plan, and implement technological capabilities to shape and accomplish the strategic and operational objectives of an organization"*
>
> (Task Force on Management of Technology, 1987:9).

Rather than viewing MOT from an engineering platform, the field has been defined with a stronger management bias as:

> *"...a branch of management concerned with exploring the potential of new technology and using this potential for the benefit of the organisation"*
>
> (Van Wyk, 1996a).

Although aspects of MOT have been dealt with in the literature for over twenty five years, it is only very recently that attempts have been made to establish a coherent field of knowledge. In this regard a key initiative was a USA report entitled *"MOT: the Hidden Competitive Advantage"* (Task Force on Management of Technology, 1987). In the UK, Collins *et al.*, on behalf of the JUPITER Consortium Limited, made an appeal for MOT training for engineers and scientists (Collins *et al.*, 1991), an appeal that was largely in response to the USA initiative, *MOT - The Hidden Competitive Advantage*. The interest in MOT came from two directions: social sciences with management at the forefront and physical science with engineering at the forefront.

In the USA the report was far reaching. For example, (i) it encouraged corporations and government organisations to reexamine their practices in MOT, (ii) it inspired the development of academic programs, and (iii) it spawned a number of national initiatives. These initiatives include those by the departments of Defence and of Commerce in the USA to identify critical and emerging technologies of national importance (US Department of Commerce, 1990).

What caused this national, and relatively recent focus on MOT? The following trends, alluded to in the report may offer an answer:

i. The need for a cross-functional approach, including technology, to solving problems,
ii. The focus in the USA on science versus the Japanese focus on technology,
iii. Declining economic and technological competitiveness in the USA compared to other countries,
iv. The rise of the technological capability of the Pacific Rim region,
v. The decline of military technologies following an end to the Cold War and the need to position military expertise differently,
vi. The link between technology and the environment.

In attempting to identify the critical technologies requiring national support, USA Public Administrators explicitly placed technology on the national agenda. The recently formulated Advanced Technology Programme (ATP) is an important component of this momentum (*The Economist*, June 3rd, 1995:91-92; Clinton and Gore, 1993). In other countries similar initiatives can be identified such as the Japanese-German cooperation in establishing a Technology Foresight programme (Breiner, *et al.*, 1993).

In raising the question of MOT to the level of national awareness, the Task Force provided a focal point for many subtle initiatives. In the following section four such initiatives are discussed:

i. The identification of technology as a distinct field of enquiry,
ii. The search for a holistic perspective,
iii. The emergence of an academic curriculum for MOT,
iv. The development of strategic technology analysis.

2.2 Technology as a field of enquiry

The implicit recognition of technology as a distinct field of enquiry may be attributed to Francis Bacon who in 1620, drew the distinction between science and "empirical invention" (Cardwell, 1994:79). In this connection the term "empirical invention" is taken as the equivalent of the more modern concept of “technology”. The distinction between science and technology is a crucial and significant distinction which is referred to again later. In 1877, Ernest Kapp who used the hand as a symbol for the extension of ability, offered an early attempt at defining technology by distinguishing between:

i. Technical inventions as material embodiments of the imagination,

ii. Technological activity as "organ projection",

iii. The hand as the model for all artifacts and interprets the hammer as an arm with a clenched fist (Rapp, 1981:4).

In 1935, Gilfillan proposed that technology developed incrementally with intermittent revolutionary shifts (Gilfillan, 1935). This view would be echoed in Kuhn's ideas of science progressing in two ways; a normal and a revolutionary way (Kuhn, 1964). In spite of these early insights attempts at finding a core field of knowledge concerning technology apparently met with little success. In this regard Skolimowski notes:

> *"....it is rather striking that even such mature and eminent philosophers of science like Popper have nothing better to say than to equate technology with computation rules. Neither Popper nor, to my knowledge, any other authority in the philosophy of science, has cared to examine the idea of technological progress"*
>
> (Skolimowski, 1974:77).

Skolimowski's view is a harsh indictment of the scientific community, but a useful reference point to indicate the time at which a small group of scholars began to embrace technological thinking in an increasingly systematic manner - even suggesting the emergence of a new discipline.

A burst of academic activity occurred between 1960 and 1980, largely concerned with forecasting (Bright, 1968; Ayres, 1968,1969; Cetron and Ralph, 1971; Commoner, 1971; Martino, 1972; Linstone and Sahal, 1976; Sahal, 1981; Rapp, 1981; Coates *et al.*, 1994). But as Coates *et al.* (1994) suggest, the visible manifestation of this activity were fragmented academic endeavours such as technology forecasting, innovation and R&D management, rather than a coherent grasp of MOT. In many cases the conceptual base was either economics or operations research, not technology as a manifestation in its own right. The role of economics is raised again below.

By 1980, there was still no unified view of technology, no universal definition of the concept and no academic subject dealing with technological phenomena as such. In this regard, and with specific reference to the philosophy of technology, Rapp concluded that:

> *"...there exists, in this area, no generally accepted theoretical frame of reference or inventory of methodological tools to which one can resort in any particular investigation"*
>
> (Rapp, 1981:20).

This shortcoming plagues the field to this day. As evidence one may cite the ongoing debate surrounding fundamental issues such as definition and classification. Defining technology is particularly difficult, as noted by Bayraktar (1990), Horner (1992) and Berry and Taggart (1994). A definition finding increasing acceptance is "the artificial capability created by people to facilitate the manipulation of physical things" (Van Wyk: 1984:195), or more cryptically - "created capability" (Van Wyk, 1990b:835). This definition reminds one very much of the symbolic definition of the extended hand used by Kapp (1877). In 1995 and 1996 the subject was a major issue on an Internet debate conducted under the auspices of the Technology and Innovation Management Division (TIM) of the Academy of Management (http:/www.aom.pace.edu/tim/).

In conclusion, it should be noted that most formal education in science and technology is based on the paradigms of science, not of technology. The emphasis is on scientific literacy while technology is rarely thought of as a subject at school or university. A prevalent view of technological progress is that it is a sequence of scientific achievements - even though much evidence exists that many breakthroughs are unscientific, serendipitous at times and perhaps more the result of a prepared mind capable of recognizing opportunities (Medawar, 1984). In practice, technology does not wait "cap in hand for science to open the door" (Cardwell, 1994:492).

2.3 Towards a holistic approach

The distinction between science and technology referred to in section 2.2 could well prove to be a turning point in academia and business thinking. The turning point is subtle and may be described as society beginning to think "technologically" rather than "scientifically". For example Skolimowski, writing in 1974 and referred to earlier, ventured a revolutionary view by suggesting that an understanding of technological patterns may eventually result in a new methodology of science - a bold challenge to the foundations of science indeed (Skolimowski, 1974). In order to sustain such a challenge, technology would have to offer its own paradigm and holistic view of the world.

To an extent the discipline of economics has already offered a niche to technology within economics' own macro perspective. Unfortunately these attempts have not been very successful. A few landmark writings trace the pattern of thought. Schumpeter in 1939 drew attention to the role of innovation as a force of "creative destruction" in the economic growth process. Abramovitz realised the importance of "technical change" in economic growth and attempted to measure its impact. He concluded that economic tools were too vague and merely gave us a "measure of our ignorance" (Abramovitz, 1956). Kuznets emphasized the importance of technology but was concerned by its unpredictability (Kuznets, 1967).

The impact of capital and labour was understood but technological advance became the residual and calculated by default. In this regard Nelson noted:

> *"Everybody knows that the residual accounts for a hodge-podge of factors, but these are difficult to sort out. If this `measure of our ignorance' is not completely mysterious, it certainly is not well understood"*
>
> (Nelson, 1981:1035).

Rosenberg expressed a similar view in concluding that research into the nature of technological progress is methodologically and conceptually difficult (Rosenberg, 1982:23). But perhaps the sharpest rebuke came from Majer who, in 1985, averred that economic theory had reached a "dead end" in attempting to explain the impact of technical progress on economic growth (Majer, 1985:335). Majer's views have subsequently been echoed by others and probably prevail to this day. For example, Schwartz concluded that economic theory had failed to explain the fundamental technological and economic differences between Japan and the USA (Schwartz, 1992:141).

A number of authors seeking to emphasise the holistic nature of technology compare technological progress to biological evolution (Gilfillan, 1935:63). New terminology is appearing - such as the concept of "technosphere" noted by Rapp in 1981 as expressing the created environment just as biosphere denoted the natural environment (Rapp, 1981:123). In keeping with the biological analogy, technological competition has been described with reference to competing organisms (Farrell, 1993; Pistorius, 1994).

A holistic view is also reflected in the field of technology assessment and the subsequent formation of the Office for Technology Assessment (OTA). And this reflected attempt *was* made to create an understanding of the external impacts of technological progress (Brooks and Bowers, 1970; Cleary and Lanford, 1978; Bereano *et al.*, 1991; Coates, 1995).

A further contribution to a holistic view was made by Sahal (1985) and by Grupp and Hohmeyer (1986) in proposing a field named "Technometrics". The emphasis was on different approaches to understanding technology indicators in attempting to express technological change in a multiplicity of measures. A similar approach was followed by Majer, who pursued a way of measuring improved functionality as a reflection of technological advance (Majer, 1985). In doing so, Majer was dependant on fixed rules and quantification. It now appears that the quest for empirical verification may have contradicted the demand for holistic and not reductionist tools.

2.4 The emergence of an academic curriculum in MOT

Recent years have seen a remarkable growth in MOT curricula, but starting from a very small base. These have been developed in two settings; (i) within business schools, and (ii) within engineering faculties. Many different types of programmes have emerged.

Within the business school settings there have either been new courses added to existing programmes or dedicated MBA programmes like the MBA (MOT) offered by some centres. A similar development is seen in engineering faculties. Either management subjects are introduced into existing engineering curricula or dedicated management programmes are created such as the Master of Science (MOT). In both settings the curriculum developers have faced a similar problem - how to integrate multiple perspectives into a coherent programme.

In the MBA context, the management of assets, processes, markets, finance and people are established fields of academic enquiry. In the case of technology however, the academic core is fragmented. Several individual subjects can be identified, such as the management of innovation, management of intellectual property, management of R&D, environmental technology and technology forecasting, to name a few. These individual components are being combined into a more comprehensive field, their academic foundations are being probed and authors are increasingly coordinating efforts to secure an identifiable academic domain (Shenhar, 1991).

These initiatives have helped to raise the level of national awareness but have also prompted business people to ask why MOT was *not* part of business school curricula? A report by the American Assembly of Collegiate Schools of Business has called for the remaking of the MBA degree to reflect the wish expressed by business executives to establish a technological focus in the MBA (Jaedicke, 1989). The "Boulton Report" supports this view and offers a first guide to MOT curricula (Boulton, 1993). A key finding of this report is that understanding technology is simply not widespread on the MBA agenda, except within selected European technical institutes, a few schools in the USA and an island of competence in South Africa. The call is for a more vigorous development of the field, for a holistic approach and for generalist managers to grasp the link between technology and business (Kanz and Waterhouse, 1995).

2.5 Strategic technology analysis

Strategic technology analysis is a field of knowledge developed in response to (i) the growing need for a holistic perspective in technology, (ii) for procedures to link technology and general management and, (iii) the need for structure in academic curricula.

STA may be defined as a field of enquiry that promotes a systematic understanding of all technologies by offering common frameworks for analysing individual technological entities as well as a broader technological landscape. The roots of MOT have been well documented in recent literature and are not explored further here (Van Wyk, 1988; Van Wyk, Haour and Japp, 1991; Horner, 1992; Boulton, 1993; Japp, 1994a; Steyn and De Wet, 1994; Van Wyk, 1996b). Suffice to say that STA has contributed to MOT in the following areas:

i. In support of environmental scanning,
ii. Showing how STA provided a theoretical base for MOT,
iii. Probing individual technologies,
iv. Management applications by identifying interactions between technologies,
v. Guiding company strategy.

CHAPTER THREE

THE THEORY OF STRATEGIC TECHNOLOGY ANALYSIS

Introduction

This chapter gives a brief overview of strategic technology analysis. It describes the various frameworks that constitute the elements of STA and discusses one framework in depth - the so called cascade model of technological change. This model provides the theoretical basis for explaining the technological forces that made synthetic diamonds such formidable competitors.

3.1 The theoretical structure of strategic technology analysis

In the previous chapter STA was introduced and defined as:

> *"...a field of enquiry that promotes a systematic understanding of all technologies by offering common frameworks for analysing individual technologies as well as broader technological landscapes"*
>
> (Van Wyk, 1996a).

Six frameworks constitute the elements of STA. Frameworks for:

i. Describing the essential features of individual technologies,

ii. Classifying technologies,

iii. Tracking technological trends,

iv. Charting potential break-through zones,

v. Reviewing technological interactions,

vi. Identifying preferences with respect to technology.

The relationship between these frameworks is shown in Figure 3.1.

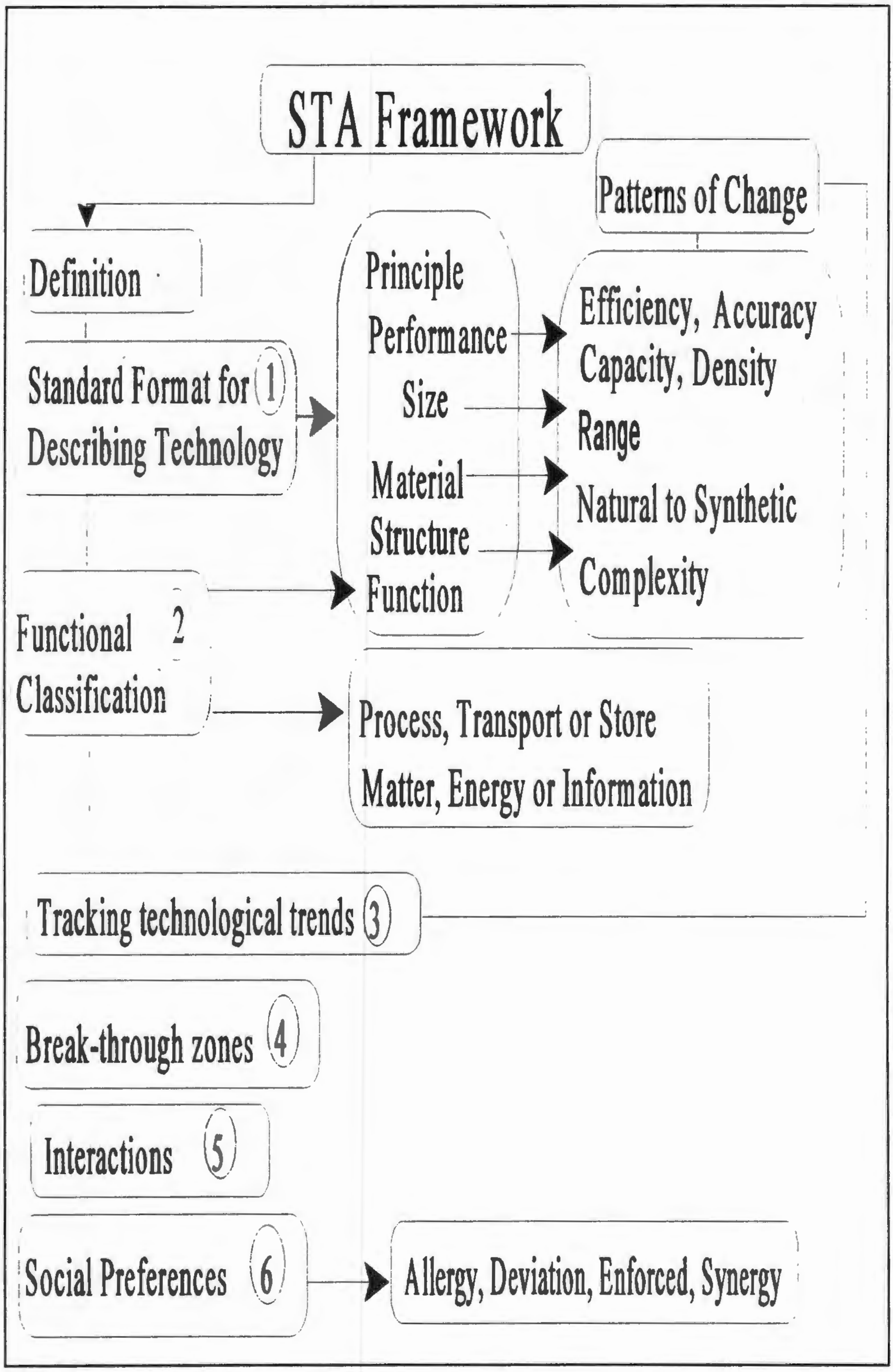

Figure 3.1 STA Framework

3.1.1 Describing the essential features of individual technologies

This framework describes an individual technological entity in terms of six features:

i. What it does - its *function* - described as processing, transporting or storing matter, energy of information,

ii. How it performs its function - the *principle of operation* - can be described in many ways. Examples are mechanical, electrical, chemical, biological and optical, and often as a combination of principles such as optoelectronic,

iii. How well it performs its function - *level of performance* - usually distinguishes between capacity, accuracy, density and efficiency,

iv. How is it structured - *shape, configuration and complexity* - refers to the technological entity, the number of sub-systems and the level of integration,

v. How large is it - *size* - refers to the mechanical size in metres as well as "intellectual size" such as the number of lines of code in a computer program or the number of possible steps in an algorithm,

vi. What is it made of - *material* - traditionally, differences between natural materials, metals, ceramics and polymers are used, but increasingly the differences are subtle and the material has to be described in terms of primary and secondary attributes, such as electrical conductivity, wear resistance, thermal conductivity and magnetic behaviour.

The framework is used as an analytical tool by itself to point to the distinguishing feature of a given technology, but also to contribute to other tools.

3.1.2 Classifying technologies

The second framework suggests a way of classifying technologies for management purposes. As discussed by Teichmann (1974), Ropohl (1979), Van Wyk (1988a), Horner (1992), and Farrell (1993), there is no universally accepted method of classifying technologies. Technology is not served by a "grand alphabet" such as the periodic table of the elements or the electromagnetic spectrum as in the case of science, or the International Standard Industrial Classification of economic sectors in economics.

The most popular approach in STA is the so called nine-cell functional classification, attributed to Ropohl (1979), and presented in Table 3.1.

Table 3.1 Classification Matrix

	Process	**Transport**	**Store**
Matter			
Energy			
Information			

Processing matter can be further refined by distinguishing between mechanical, chemical and biological processing. Refinements to the nine-cell functional classification may be introduced by using a set of categories described by Miller (1978) - differentiating information handling further for instance into input, output, encoding and decoding.

3.1.3 Tracking technological trends

Few authors have discussed methods of tracking technological change. Admittedly the history of technological forecasting reaches back for at least sixty years but most authors dealt with individual technologies, not a review of the technological landscape (Report of the National Resources Committee on the Social Implications of New Inventions, 1937; Schnaars, *et al.*, 1993). Bright (1963) offered the first macro view by suggesting a set of seven technological trends. This set is listed below. It is particularly noteworthy that the article appeared in a business journal - *Harvard Business Review* and not a scientific journal:

i. Transportation - The greater distances travelled in less time and cost were expected to usher in a new period of global trade, tourism and communications,

ii. Energy - The increased availability of power, controlled with precision, transported in bulk by new sources and storage devices was expected to initiate a period of microelectronics and technical endeavour,

iii. Organic and inorganic life - The alteration of living organisms to control growth rates, resistance to disease and the tolerance of harsh environmental conditions was anticipated. The result being that new production regions could be used and climatic conditions would have less of an influence on productivity,

iv. Materials - new material properties were anticipated. Synthetic materials, new products, structures and designs were expected to unfold,

v. Sensory capabilities - As visual, audio and memory technologies more accurately replicated reality, a range of entertainment, remote control and warfare capabilities were expected to emerge,

vi. Physical mechanization - The increased capacity to process and transport materials was expected to result in faster production responses and change to the labour and capital content of technologies,

vii. Intellectual mechanisation - This represented an early assessment of the implications for an information age based on computerisation.

For many years the set of trends identified by Bright was used as the basic template for tracking technological change. However, in practical application two deficiencies became apparent: (i) It was difficult to quantify these trends and to depict them graphically and, (ii) they were not suitable for keeping track of individual technological entities. Over time another model for tracking technological trends evolved, the "cascade" model. According to the model technological change could be viewed as a cascade of events manifested at different levels of the technological landscape. This model is shown in Figure 3.2.

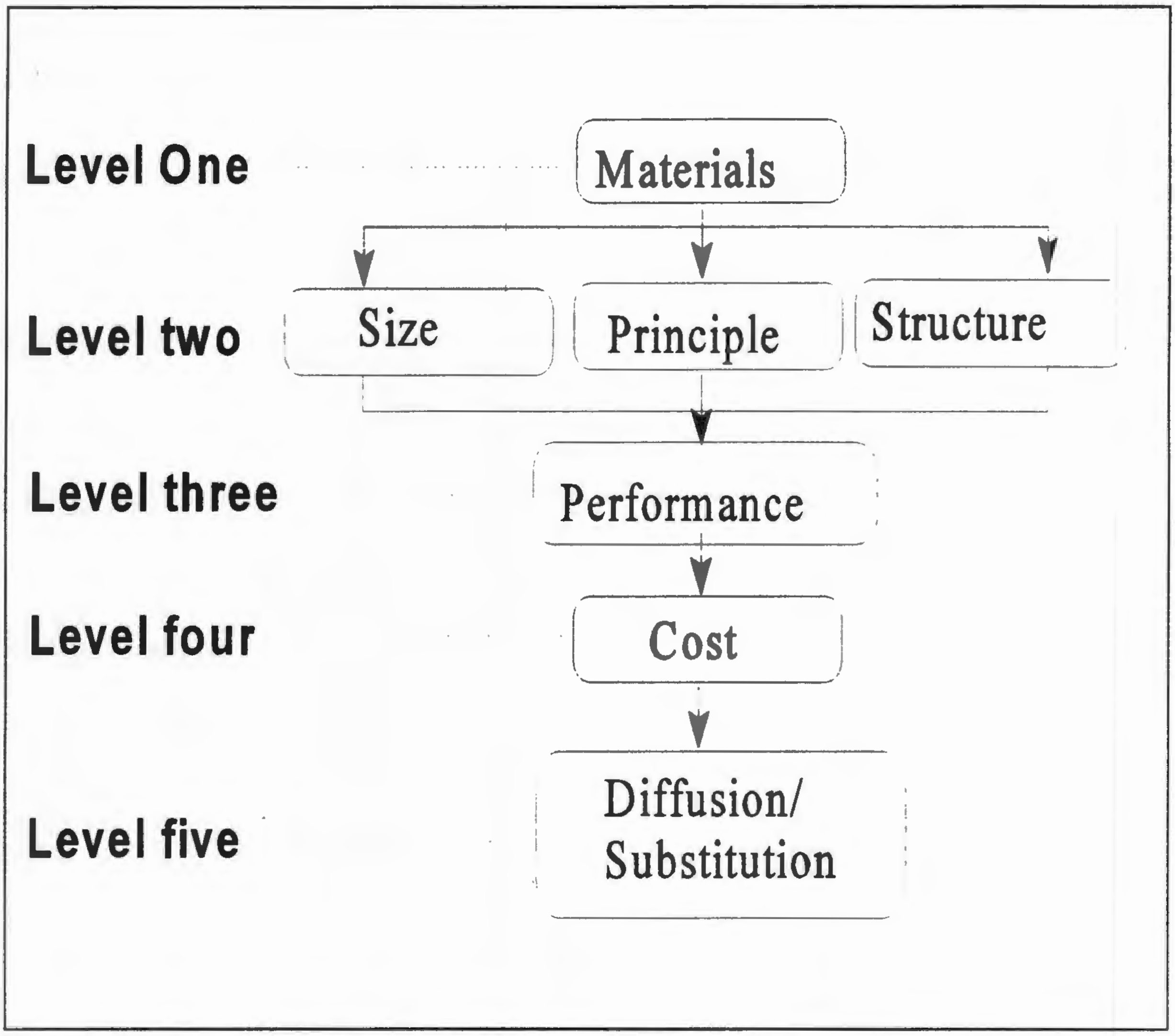

Figure 3.2 Cascade Model of Technological Change

Level one - Material : Technological change can be viewed in terms of changing material characteristics. New characteristics are being engineered into existing materials and existing properties are being improved.

Level two - Changing size, structure and principle : Over time, the size range of technologies is increasing. For technological entities that we can see with the naked

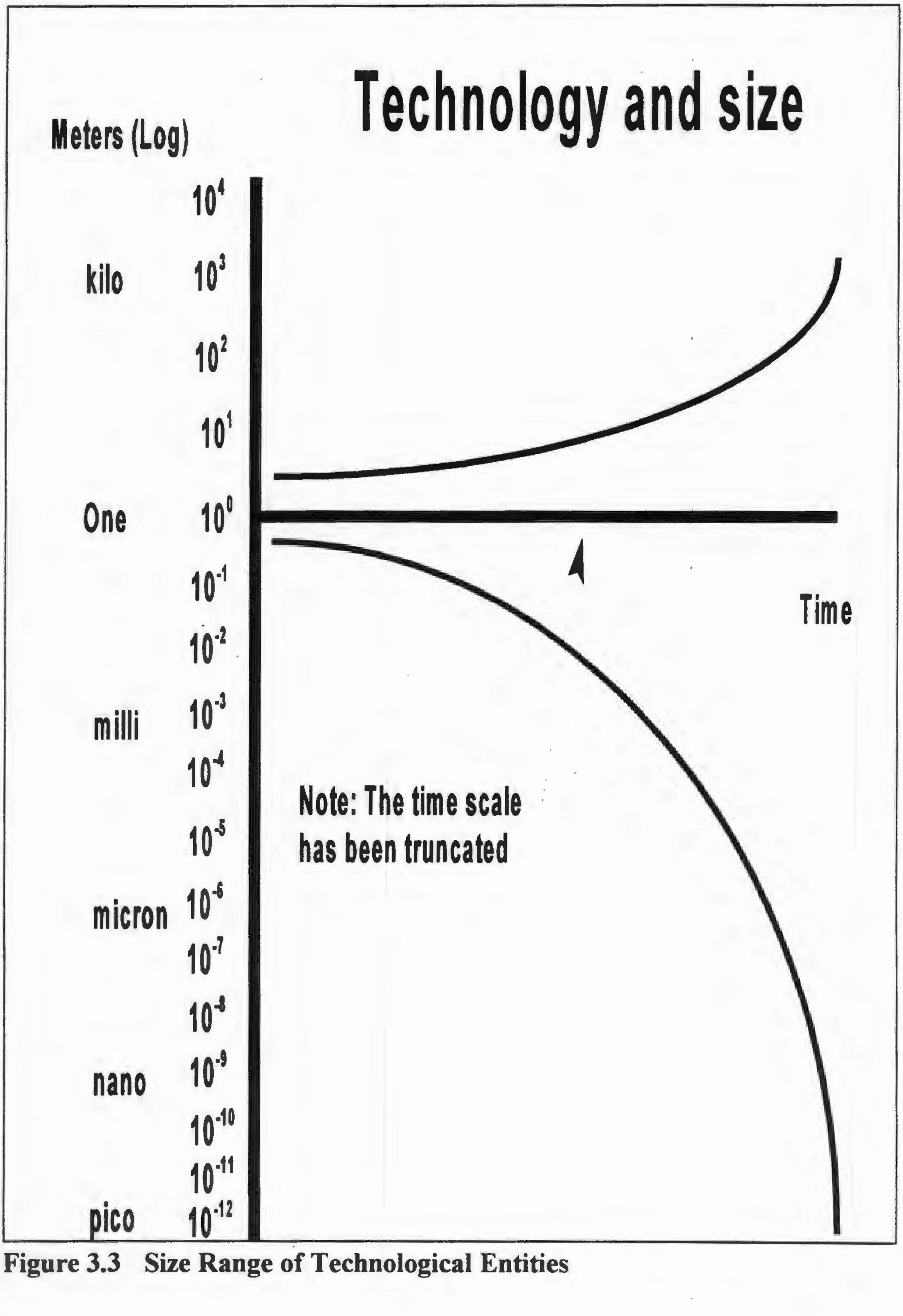

Figure 3.3 Size Range of Technological Entities

eye, individual structures do not get much larger than a kilometre - the tallest building for instance. But when we map technologies that we cannot inspect with the naked eye it appears that most recent developments are occurring between the millimetre and nanometre levels. This trend is depicted in Figure 3.3 and clearly demonstrates the vast area available for "small technology". Recent developments in nanotechnology, micromachines and biotechnology underscores the importance of this trend. Perhaps more importantly, the ability to manipulate ***structures*** at the sub-micron level is one of the key advances. This is probably where a change in *operating principle* is most obvious - the need to process, transport and store technological entities has required a shift toward electron and atomic force microscopes.

Level three - Performance : Can be quantified over time as:

i. Increasing efficiency - measured by the ratio of outputs to inputs,

ii. Increasing capacity - measured as the rate of output to time,

iii. Increasing density - measured as the ratio of output to space,

iv. Increasing accuracy - measured as the decrease in relative variation experienced.

Figure 3.4 represents a generalised graphic solution to the way in which these trends progress. They normally follow a logistic and authors such as Foster (1986), Van Wyk *et al.*(1991) and Asthana (1995) have demonstrated the importance of tracing the performance trends and switching technologies. This will be explored fully in the fourth framework - charting break-through zones.

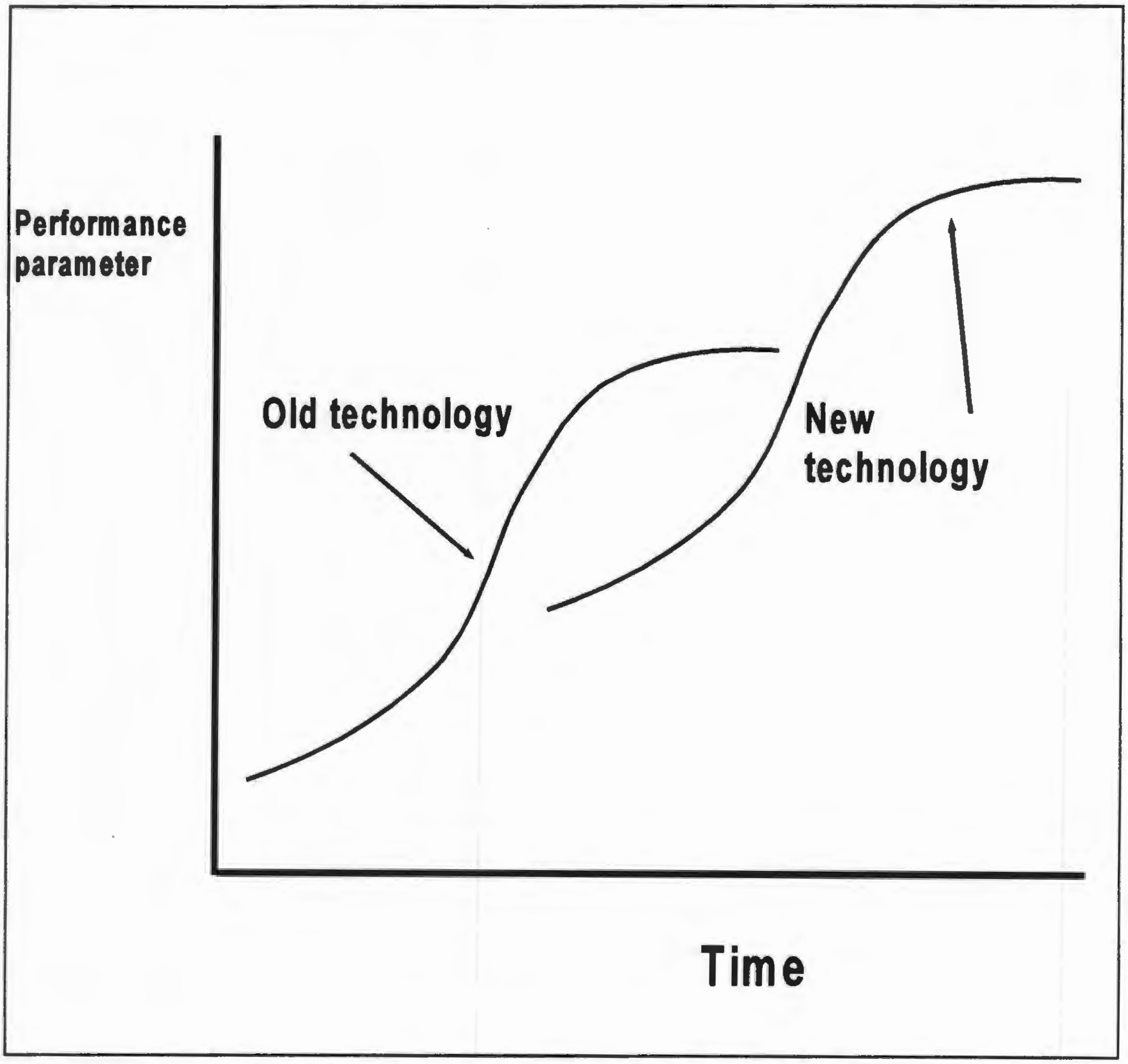

Figure 3.4 Tracking Performance Changes

Level four - Changing unit costs - Here the real unit cost per unit of output can be depicted as a decline in the cost curve. If the same principle of operation is used with a superior material, the performance benefits are more usually transferred through to a reduction in unit costs, depicted in Figure 3.5.

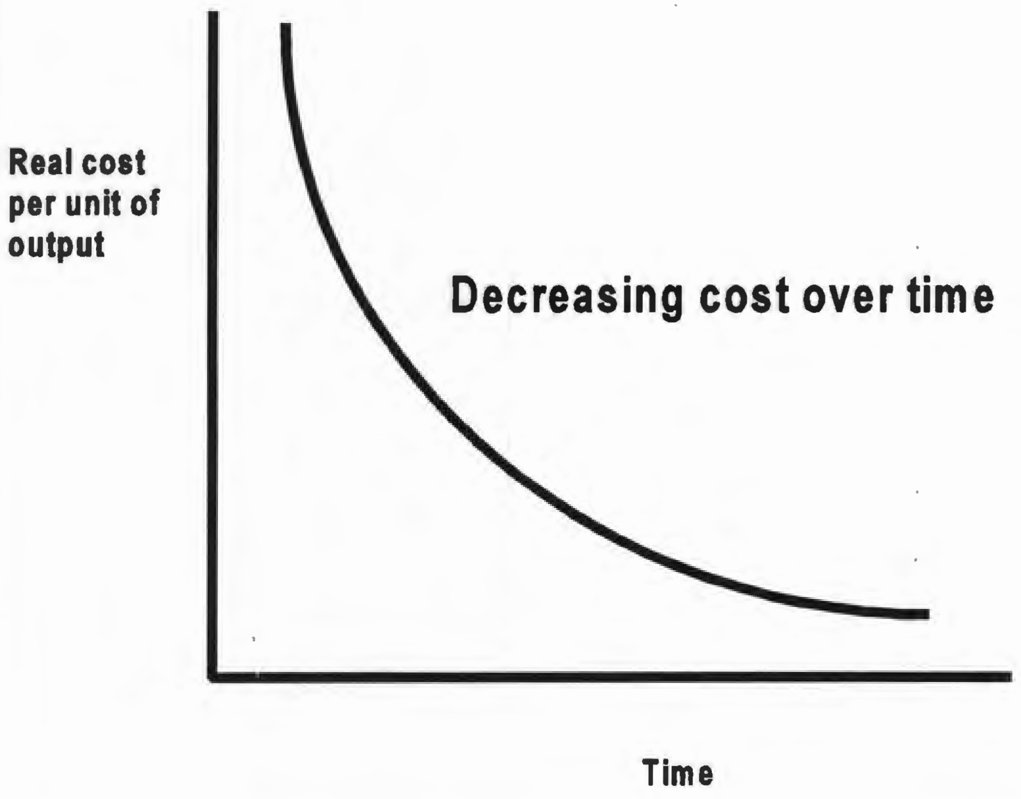

Figure 3.5 Decreasing Unit Costs

Level five - Substitution and diffusion trends : Diffusion and/or substitution may flow from any one of the changes in unit cost, performance, principle, material, size, structure or function, amongst others. A key aspect of the cascade model, is that it prepares the mind for the possibility of substitution. Figure 3.6 reflects the general pattern of substitution observed over many cases with the new technology displacing the old.

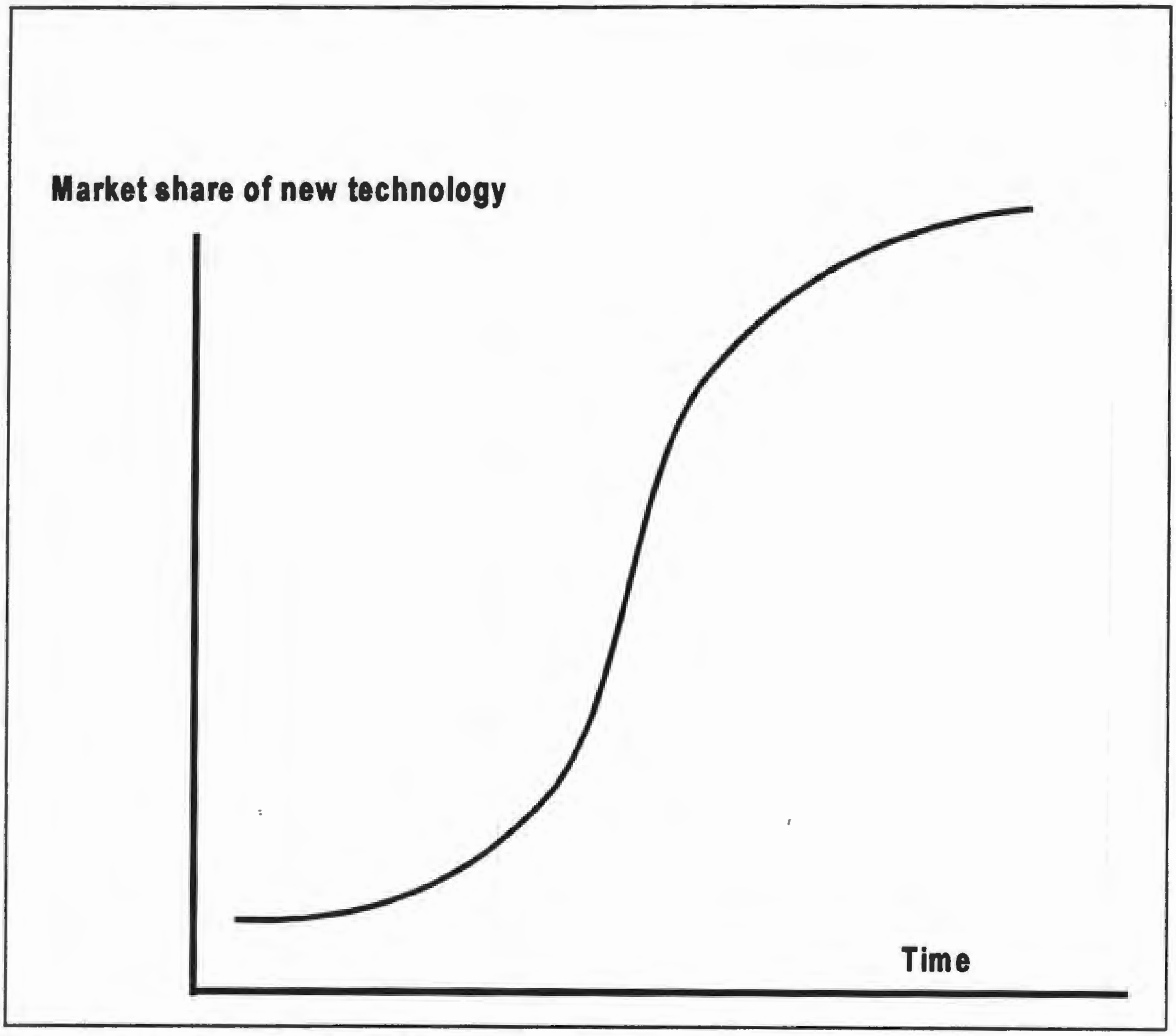

Figure 3.6 Substitution Curve

3.1.4 A chart of break-through zones

The fourth framework is a chart of break-through zones incorporating an analysis of barriers, limits and how technologies overcome them. The notion of breaking through barriers and their depiction as a succession of "S" curves has been well established.

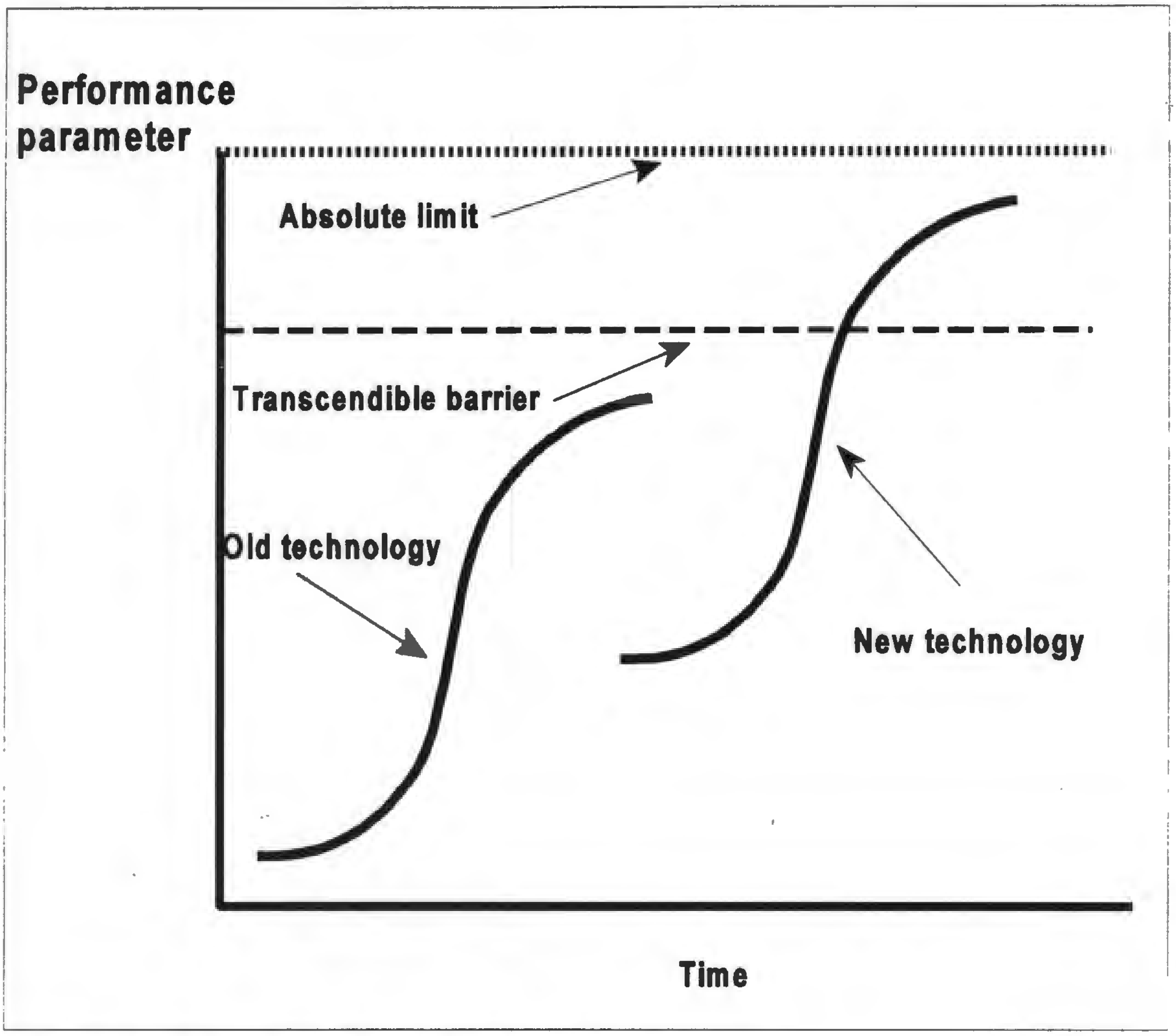

Figure 3.7 Charting Break-through Zones

Ayres (1988) incorporated the notions of barriers, breakthroughs, "S" curves and subsequent discontinuities into a dynamic model. A simple life-cycle model was applied to superconductivity and tyre technology.

Basic to an understanding of break-through zones is the identification of different types of constraints impeding the progress of the performance parameter. Two constraints are of importance here: (i) constraints of the "first order" which may be overcome by improvements in material, structure, size, principle of operation or structure, and (ii) constraints of the second order which reflect ultimate theoretical limits. This is an important distinction, since if the limit is much higher than the barrier, the feasible area for technological advance is significant.

Authors have examined how knowledge of the discontinuity between technologies could be used such that companies avoid technological obsolescence. Asthana (1995) examined information process technologies and showed how companies on the lookout for the attacking technology could "jump" to the competitor process before being wedded to a technology in decline - a process named "technology leapfrogging" by Asthana.

3.1.5 Technological interactions

The fifth framework is concerned with technological interaction. The economic equivalent would be an input-output table. For example, a change in one industrial sector may have a range of effects in all other sectors. For technology, a breakthrough or performance improvement would affect many other technologies - processes and products. Such a method for evaluating these associations has been proposed in the form of a *tableau technologique* (Van Wyk, 1992). Mahani and Wind (1986) described the possible associations as being contingent, supplementary, independent or competitive. But a more comprehensive view was required that identified technological relationships concentrating on common material, principle, structure and the extent to which technologies were dependant on each other.

3.1.6 Identifying social preferences with respect to technology

The final framework concerns the social preference for a technology. De Vulpian (1984) for instance has suggested that society reacts to certain technologies through allergy, deviation, enforced penetration or synergy. This "social value" changes over time. For example, nuclear power was widely used and accepted during the late 1950's (enforced penetration) but is not universally accepted today (allergy). There is still much work to be done concerning this relatively unquantifiable attribute of technology.

Although the last two theoretical constructs are not explored empirically in this thesis, they are presented briefly here for reference and completeness. The cascade model is central to the current investigation and also provides the theoretical link with substitution theory. Chapter four now turns to review the theory of substitution.

CHAPTER FOUR

THE THEORY OF SUBSTITUTION

Introduction

The use of substitution theory, and the sigmoid curve in particular in explaining technological advance, has a long history. Early contributions made by biologists include Verhulst (1838), Pearl (1924), Lotka (1924) and Volterra (1931) who modelled the growth of pumpkins, fruit flies, cells, and other biological organisms. The result was an "S" curve or more formally known as a Sigmoid, Pearl or Logistic. The subsequent contributions relevant to technology and the current study include:

i.	Mansfield (1961):	Logistic depends on investment size, profitability and proportion of new firms that have already adopted,

ii.	Floyd (1968):	Established a maximum market share that the new technology was unlikely to exceed,
iii.	Fisher-Pry (1971):	Stated the assumption that substitution will proceed to completion, and is dependent on the remaining market share,
iv.	Blackman(1974):	Modified Fisher-Pry and used Floyd's maximum market share ceiling concept,
v.	Sharif & Kabir (1976a):	Took account of data scatter, data extent, market share at time of forecast and effective lifespan.

4.1 Review of literature on substitution

The roots of substitution theories can be traced back to the nineteenth century. A law of natural growth was first proposed by Verhulst (1838) and simply stated by Modis (1993) as:

> *"The rate of growth at any given time is proportional to both the amount of growth already achieved and the amount of growth remaining"*
>
> (Modis, 1993:158).

The Verhulst equation is a differential and can be expressed as a change of population with respect to time as:

$$\frac{dP(t)}{dt} = \alpha P(t)(M - P(t)) \qquad (4.1)$$

where *P(t)* is the population at time *t*, *M* is the total market share possible and α is a constant. One form of the Verhulst equation represents a "S" curve whose mathematical expression takes the form:

$$P(t) = \frac{M}{1 + e^{-\alpha(t - t_o)}} \qquad (4.2)$$

In 1924 Pearl demonstrated that in a closed environment, fruit flies and pumpkins will develop following a logistic (Pearl, 1924; 1927). Pearl did not allow for competition.

The method for calculating the effect of more than one species was demonstrated by Gause (1932) who examined the competition between two yeast species. Lotka (1924) and Volterra (1931) refined this work. More recently, Marchetti *et al.* (1996) used a logistic to model the dynamics of population growth and to describe and predict patterns of life expectancy, fertility and the population age profile of different nations.

Just as biologists have used the logistic function to understand the behaviour of competing organisms, technology theorists have used it to model how two technologies compete for space in the technological landscape, i.e., for "market" share. The market share of the new technology, defined as *f*, can be expressed in relation to the remaining market share, or *1-f*. It can be shown that the curve for *f/(1-f)* is a pure exponential curve and its log transformation consequently linear and the regression coefficients can be found using Ordinary Least Squares (OLS). The curve for *f/(1-f)* can be extrapolated in an attempt to predict market share. The expected market share *f* can then be plotted on normal axes for each year resulting in an "S" curve dependant upon time.

Griliches (1957) applied a logistic function to explain how the diffusion of hybrid seed corn occurred in the United States. The origin, slope and ceiling of the diffusion function were used to show that the adoption of hybrid seed followed a predictable pattern. Griliches went on to suggest that the diffusion of many innovations may follow a similar pattern.

Mansfield (1961) extended the use of a logistic to explain the rates of imitation in process innovation by examining twelve innovations ranging across four industries; coal, iron and steel, brewing and railroads. The findings showed that the number of firms introducing an innovation depends on the firms already using the innovation, the profitability of using it, and the size of the investment required. The work by Mansfield was useful from a methodological perspective since it demonstrated that a logistic curve described technological diffusion. Mansfield made further contributions to method in explaining how to deal with serial correlation. The goodness-of-fit test was the root-mean-square deviation of the actual data from the computed. Mansfield also used the correlation coefficient between the transformed data and time to explain the significance of the relationship, but did not test for significance within confidence intervals.

It was economists such as Kuznets (1967) and technologists who moved the theory towards explaining the nature of diffusion. Kuznets notes the major assumptions in a logistic curve as:

i. Having a finite limit,

ii. Exhibiting a declining rate of a percentage increase,

iii. Showing that change is dependant on the remaining size or market share.

Kuznets showed that a logistic fits many cases of population growth (1967:64) and states the curve in its simplest form as:

$$y = \frac{L}{1 + e^{a-bx}} \qquad \textbf{\textit{(4.3)}}$$

As *x*, or time increases (and *b* is always positive), the denominator and *y* approach a value equal to "L" - the market share ceiling. This is the link between substitution theory and STA in that the cascade model of technological change suggests the possibility of diffusion or substitution as a possible consequence of technological advance in a particular technological entity.

Floyd (1968) shows that in certain cases the simple logistic requires modifications to allow for aberrations that occur in practice. In certain circumstances management of the old technology causes a delay in substitution requiring a modification to the model. This is an important refinement and we return to it in more detail.

4.2 A simple substitution model

As the evolution of substitution theory proceeded, the danger arose that it would become mathematically very complex - too complex for use as a practical analytical tool. This problem was addressed by Fisher and Pry (1971) who presented a simple substitution model that was applied to seventeen cases of substitution. Many of these cases concerned the substitution of synthetic for natural material. They offered the work as a contribution to the theory of technology forecasting and aimed the use of the technique at business managers concerned with tracking the progress of technological change. The model equation is given by:

$$\frac{f}{1-f} = e^{2\alpha(t-t_0)} \qquad (4.4)$$

where f is the market share of the new technology, t is time, t_0 the time at which substitution is half complete and 2α = the slope of the regression line. When used for forecasting purposes, the model is based on the key assumption that once started, substitution proceeds to completion.

Lenz and Lanford later showed that this assumption was robust in a number of cases, in particular, their analysis of steam substituting for sail in the case of shipping (Lenz and Lanford, 1972). Fisher and Pry refer to the notion of technologies struggling for dominance and infer that the dynamics of substitution may be such that the new technology attempts to establish a foothold of competence. Once the attacker has achieved this, the defending technology increases the effort at maintaining a dominant position.

The next refinement we take note of here was suggested by Blackman who extended the Mansfield (1961) and Floyd (1968) work to the jet engine, electrical utility and automotive sectors by examining substitution as a function of the market share captured by the new technology (Blackman, 1974:42). Blackman used a substitution ceiling. This is an upper limit to the market share and represents a value that the new technology is unlikely to exceed in the long run.

The general form of the equation posted by Blackman is:

$$\ln[\frac{m}{L-m}]=C_1+C_2(t-t_1) \qquad \textit{(4.5)}$$

where C_1 and C_2 are constants, t_1 is the year that the new technology first captures part of the market, L is the upper market limit and m is the market share at time t.

In addition to a delay factor a modification of the simple model may also be dictated by environmental change. Sharif and Uddin (1973) noted this in showing how the oil price crises of 1973 caused a disturbance in the substitution process. Analysts should therefore understand the data as well as associated environmental factors before choosing a particular model. Studies by Cooper and Schendel (1976) also noted deviations from the expected logistic in four out of seven cases observed. In these cases the old technology continued to expand rapidly or the new technology suffered setbacks. For example, ballpoint pens leaked initially which resulted in delayed substitution (Farrell, 1993).

In summary, many authors laid the groundwork to modify simple substitution analysis to take account of environmental factors that could delay the process. This review focuses now on how the delay can be incorporated simply.

4.3 Incorporating a delay coefficient

In comparing the available models, Sharif and Kabir (1976a) note that Floyd's model underestimates actual observations while Fisher and Pry, and Blackman overestimate actual data. Noting that a delay coefficient is an important contribution to substitution analysis, Sharif and Kabir recommend that the models be linearly combined in such a manner that incorporates the delay coefficient σ (sigma) and a value for F that denotes the maximum market share obtainable.

The Sharif and Kabir form of substitution is stated as:

$$(1-\sigma)[\ln\frac{f}{F-f}]+\sigma[\ln\frac{f}{F-f}+\frac{F}{F-f}]=C_1+C_2t \qquad \textit{(4.6)}$$

where:
F = market share ceiling,
f = market share at time t,
t = time,
C_1,C_2 = constants; and,
σ = dimensionless factor, $0 \leq \sigma \geq 1$,

Sharif and Kabir (1976a:11) suggested a function to take account of factors that could accommodate a delay in substitution and presented a simpler version as:

$$\ln\frac{f}{F-f}+\sigma\frac{F}{F-f}=C_1+C_2t. \qquad \textit{(4.7)}$$

The incorporation of a variable coeficient - sigma, is the theoretical modification used in this investigation. Sharif and Kabir based their delay on factors such as data scatter, data extent, last value and the effective life span of the technology but recommended the use of a variable delay. The current investigation bases the coefficient of the additions to the natural industrial diamond stockpile. This changes annually and is incorporated into the mathematical function 4.7. A value for "*f*" is calculated for each year - the way in which this is done is presented in appendix A. This is the basis for suggesting, and testing, the notion that substitution may have been delayed and provides the theoretical basis for evaluating the hypothesis stated later

CHAPTER FIVE

EVIDENCE OF TECHNOLOGICAL ADVANCE

Introduction

This chapter addresses the reasons why synthetic diamonds have been successful in industrial applications over the last forty years. The chapter commences with a short historical review and suggests that the main reason is to be found in persistent technological advance in both the process for manufacturing synthetic diamonds as well as in diamond material itself. To structure the discussion, use is made of the cascade model as presented in chapter three.

First the cascade model is used to seek evidence of technological advance in the area of synthetic diamond manufacture - i.e, in the manufacturing process. Next the model is used to seek evidence of technological advance in synthetic diamonds themselves - i.e., in material characteristics.

5.1 Synthetic diamond history

The first publicly recorded synthesis of diamond under laboratory conditions was announced in 1955 by a research team at General Electric Company (hereafter referred to as GE) in the USA (Bundy *et al.*, 1955). High pressure and high temperature (HPHT) procedures were used to simulate natural conditions. Although Bovenkerk *et al.* (1993) recently acknowledged an error in the results of the original claim, the process patent was the most significant catalyst in promoting technical advance. De Beers Consolidated Mines LTD, (hereafter De Beers Consolidated Mines LTD and De Beers Centenary AG will be referred to as De Beers) disputed the claim by GE and declared earlier success in 1953 under conditions of secrecy in Sweden (Liander, 1955; Liander and Lundblad, 1960; Liander, 1980).

The alternative method of producing synthetic diamond material is to use chemical vapour deposition (CVD) procedures at very low pressures (Note: The notation of synthetic *diamond* rather than *diamonds* is used hereafter since the reference is to a singular material rather than individual diamonds). Eversole pioneered the work in 1949, achieved diamond seed crystal growth during 1952 and was awarded the patent in 1961 (Eversole, 1961; Angus *et al.*, 1968; Derjaguin and Fedoseev, 1975; Angus and Hayman, 1988; Spear and Dismukes, 1994) This predates the GE and De Beers HPHT procedures.

The reason for limiting CVD diamond growth to the laboratory until the mid 1980's was probably due to skepticism, particularly from Western hemisphere countries (Roy, 1987).

It was considered unlikely that diamond growth could occur at such low pressures and "..those who stubbornly pursued this dream were considered foolish" (Angus and Hayman, 1988). Russian and, later Japanese, scientists were far less sceptical. They continued to pursue the applications and refine the technique. At present diamond material can be deposited on many different surfaces. Silicon is one example (Matsushita Electric Industrial Co., 1992), nickel another (National Institute for Research in Inorganic Materials, 1991).

5.2 Technological advance in the area of synthetic diamond manufacture

5.2.1 New principle of operation

HPHT and CVD can be differentiated with regard to operating principle - HPHT uses *compression* with electro-mechanical procedures, whereas CVD uses *deposition* with electro-chemical techniques.

HPHT subjects carbon to temperatures around 2000°C and pressures of 100 000 atmospheres. A tungsten carbide press is used with a reaction chamber containing a carbon seed immersed in a molten metal such as nickel. The carbon material nucleates onto the seed, forming monocrystalline or polycrystalline material depending on the chamber conditions and reaction time. This method is used to manufacture bulk industrial diamonds for mechanical or abrasive applications such as cutting, grinding and polishing.

A second principle of operation - CVD, deposits a carbon vapour onto a substrate at temperatures around 1000°C and pressures of less than one atmosphere. Rather than bulk crystals, coatings with controlled impurities can be produced. The significant change to the operating principle is to use pressures of less then one atmosphere. Alternative energy sources used include thermal, microwave, radio frequency and direct current (Zhu *et al.*, 1991; Celii and Butler, 1992). The procedure has been to vary the temperature using different energy sources and then adjust pressure, time, source gas and surface material.

A notable technological advance over the period has been the change in operating principle from compression to deposition. Compression is still the dominant technique for bulk manufacture of synthetic diamonds, but deposition procedures are now moving from the laboratory into industrial applications where synthetic diamond material is the output.

5.2.2 Changes in Size and Structure of the Manufacturing Facilities

This section is partly speculative since no data has been published on HPHT press size. Notwithstanding this limitation, the following observations are significant:

i. The presses in 1994, ascertained from De Beers' Diamond Research Laboratory in South Africa, occupy approximately 125m^3. This can be compared with photographs of GE and Russian presses of approximately 8 m^3. Presses in 1994 are larger and contain an increased reaction chamber volume (Fritsch and Rossman, 1990).

ii. The increased production by GE and De Beers has probably been brought about by an increase in reaction chamber volume, longer production runs, increased number of diamonds produced per production run and reduced setup times. The combination of all these developments would require a larger structure.

iii. CVD structures vary in size from a household microwave oven to structures around 10m^3.

It is sufficient to note here that HPHT structures will probably not increase in size due to the material constraint of containing high pressures while CVD systems appear to be unconstrained by size and many developments have taken place as a consequence. We return to these size trends later when the barriers to each process are considered.

5.2.3 Changes in performance

As a measure of increase in performance the two manufacturing processes are compared with deposition rates used as a capacity measure. The rate, measured in microns per hour (µm/hr) is illustrated in Figure 5.1. The underlying trend is an increase in production rate. The rates show a tapering off in HPHT monocrystalline manufacture (which is the high quality industrial material), vigorous growth in polycrystalline and a rapid advance in CVD during recent years.

A simple projection of the present graph suggests that the CVD deposition rate could equal and possibly even surpass the deposition rate achieved by HPHT within the next five years or so.

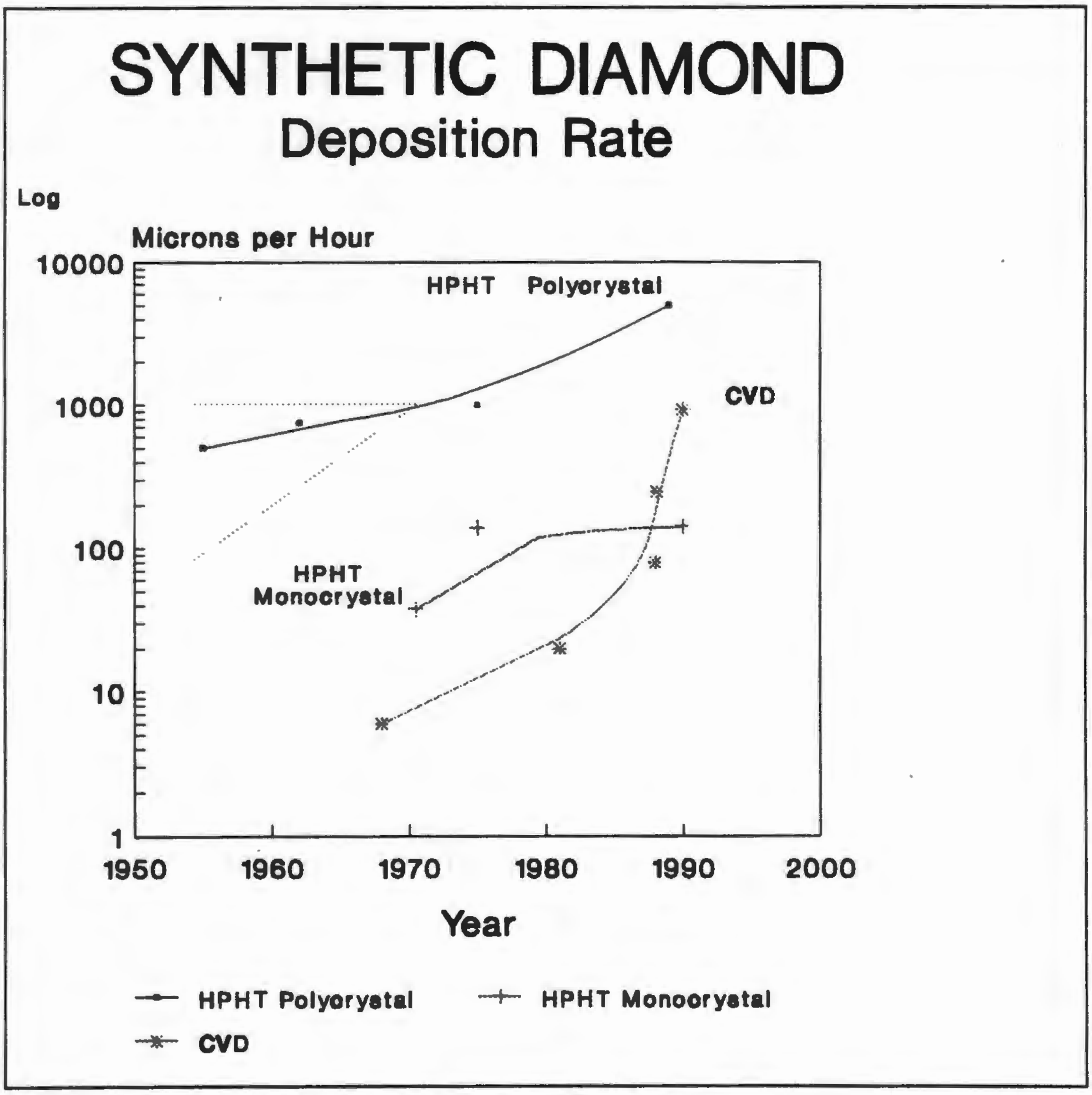

Figure 5.1 HPHT vs CVD Deposition Rate

In evaluating this graph, the following must be borne in mind:

i. Many authors express the capacity of the processing system in carats while others use µm/hr. The approximate conversion rate employed to produce Figure 5.1 is 1 carat = 6 mm (Scarratt, 1987). If information on the energy required per carat was freely available for both processes and for both single and polycrystalline diamond, then a more accurate comparison would be possible,

ii. A barrier seems to exist for HPHT processing, in the sense of a constrained reaction chamber volume of approximately one litre (Fritsch and Rossman, 1990). Although larger chambers can be built, the materials required to contain the larger press are not adequate to consistently accommodate the extended high pressures. The constraint is of the first order, relates directly to the material properties and because of this constraint, HPHT systems are unlikely to exceed $125m^3$.

iii. The dotted lines on the HPHT polycrystalline trend represent a period of estimated deposition rates of 100 to 1000 µm/hr.

An important performance trend may be in tracing the deposition surface area. The *Ceramic Bulletin* (1991:1845) reported a large-area CVD deposition reactor capable of depositing a 20 cm diameter diamond film over a variety of shapes. For instance, the growth of $20cm^2$ diamond sheets using an acetylene-oxygen-hydrogen flame technique, or simply stated - modified home gas welding equipment (Hahn, 1996).

5.2.4 Unit cost

Although the costs are difficult to obtain, it is assumed that companies such as De Beers and GE, who collectively control 83% of the market, have optimised their production runs (Mining Annual Review, 1980:137, Business Week, 10 August, 1992). By this, it is inferred that the companies are further down the long-run cost curve than new entrants. So for example, both these companies would have long production runs, reduced setup times, press replacement and maintenance programs and the ability to vary quality according to time, temperature, pressure, solvent and source material. The only conclusion this research can make concerning the costs of industrial production is that the largest producers, GE and De Beers, probably have significant cost and patent advantages that secure this market dominance. However, more producers have entered the market resulting in restrictions on public access to company specific data (Cullingworth, 1994).

The position regarding industrial diamond material of high quality, or monocrystals, is even more uncertain as few companies are prepared to divulge their costs and synthesis time. In the absence of accurate details, this thesis focuses on broad trends. Table 5.1 traces some key developments. These may be summarised in four points:

i. An increase in size (De Beers 34.8 ct in 1993),

ii. An increase in purity (GE produces isotropically pure ^{12}C in 1990),

iii. A decrease in cost (Sumitomo and USSR offer a carat for US$500),

iv. No discernable changes in the time taken to synthesize.

A useful proxy for cost is the number of hours taken to produce a high quality synthetic diamond. The data used in Figure 5.2 have been sourced from De Beers, GE, Sumitomo in Japan and from Russia.

Table 5.1 Gem Quality Synthetic Diamond Growth

Company	**Year**	**Time hours**	**Weight carats**	**Per carat cost $US MOD**	**Reference**
GE	1970		0.5-1.1		Lenzen (1983:45)
GE	1971	168	1	20 000	Russell (1990:3) Liddicoat (1986:191)
De Beers	1975		11.14		Nassau (1990:57)
De Beers	1975	60	1		Shigley *et al.* (1987:191)
De Beers	1975	180	5		Shigley *et al.* (1987:191)
GE	1980	167	1		*International Diamond Annual*, (1971:163)
GE	1984	168	0.5		Koivula & Fryer (1984:147)
Sumitomo	1985		1-2		Shigley *et al.* (1987:198)
Sumitomo	1986		0.45	145	Shigley *et al.* (1986:194)
Sumitomo	1989		5		Fritsch & Rossman (1990:67)
Sumitomo	1990		9		*Gem Trade Lab Notes* (1990:295)
De Beers	1990	500	14.2		*Gem News* (1990:300)
GE - ^{12}C	1990	72-240	1	20-30000	Ashley (1990:3)
Russia & Chatham	1993	960	1-1.5	10% of natural cost	*Diamond International* (1993:27)
De Beers	1993	600	34.8		*Gem News* (1993:130)
Russia	1996		0.5-2.29	Approx 650	*Gem News* (1996:52)

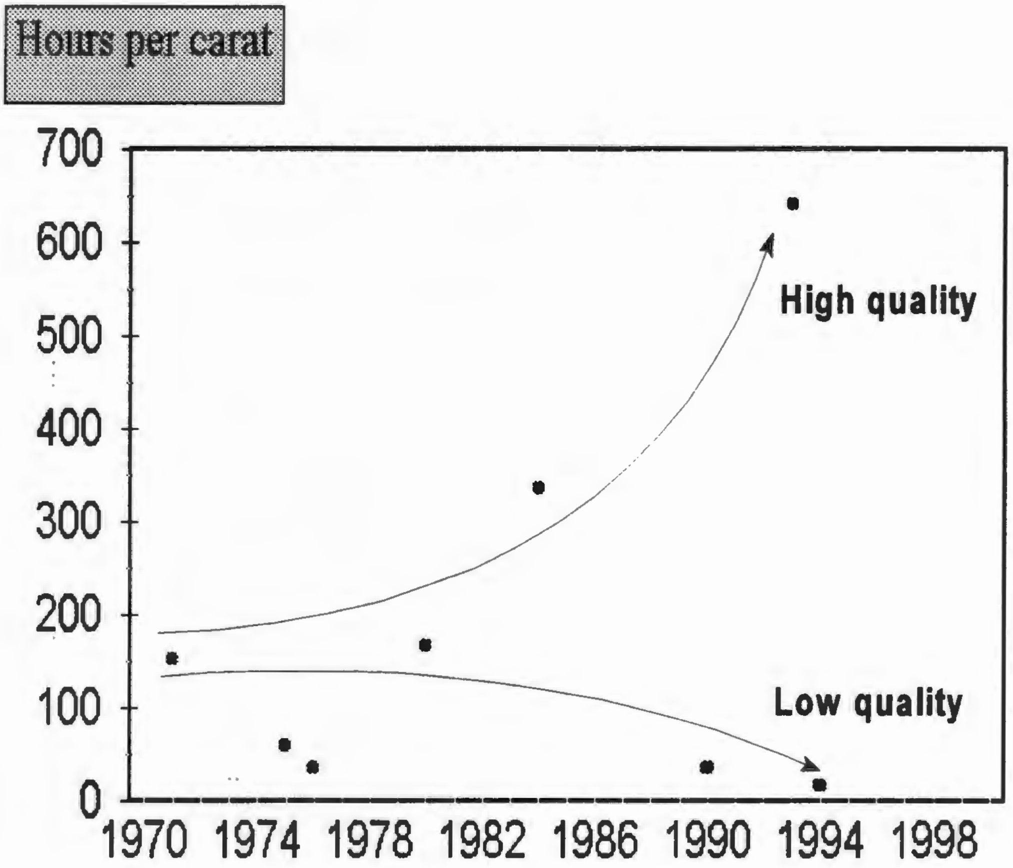

Figure 5.2 Gem Quality Synthetic Diamond - Throughput

The trend is a reduction in the number of hours per carat and by implication, a reduction in cost. The exception being the Russian observation of 650 hours per carat in 1993. This is also the material reported on the market for sale as "Chatham created diamond" (Diamond International, 1993:27) at 10% of the natural cost. However, the report did not state how many stones can be produced in a single production run.

This decrease in "'cost", depicted as a reduced production hour per carat, could be due to both increased quality material and perhaps a refinement in procedure. The indication is that the quality range available is increasing - also depicted in Figure 5.2. For example, Russian researchers have reported advances in lower cost HPHT gems with no quality compromise (*Gems and Gemology*, 1991a). Evidence of this claim is the availability of synthetic diamonds at between US$265 - 1 750 per carat (*Gems and Gemology*, 1996b:52). To place the costs in perspective, a natural faceted one carat stone classified D-flawless was priced at US$60,000 in 1980 (Boyajian, 1988:140). A stone classified as purplish-red, internally flawless was sold for US$926 000 per carat in 1987 (Boyajian, 1988:145) or US$ 4,6 billion per kilogram. On 15 March 1993 when Sumitomo Electric Industries of Japan received a patent for manufacturing red and pink diamonds (*Patent Journal*, 1994:262), it became clear that the diamond industry was facing an intellectual property threat of significant proportion (Japp, 1994a).

5.2.5 Process substitution: three stages

The developments in CVD have been rapid and could begin to challenge HPHT, particularly in areas where complex surfaces require a diamond coat. Three stages of technological advance are distinguished in Table 5.2.

Both HPHT and CVD processes have the disadvantage of operating at high temperatures with carefully controlled pressures. As synthetic diamond material enters stage two and three, the CVD process will have the advantage of being unconstrained by the size and structure required to contain the high pressures required by HPHT.

Table 5.2 Stages of Synthetic Diamond Development

Stage 1	Synthetics used as distinct parts in cutting, abrasives and polishing,
Stage 2	The extension of uses to include surface coatings, for example, used in construction with other materials,
Stage 3	A proliferation of applications, using the mechanical property of hardness, *and* the thermal, wear resistance, chemical, electrical and optical properties.

In summary, the trends suggest that technological advance in CVD is more likely than for HPHT. Further, the applications requiring that diamond be used in complex systems and structures could result in CVD replacing HPHT. This could accelerate the substitution of CVD for HPHT. The presence of more than 450 companies conducting CVD research worldwide (Maurer, 1994:2) may give reason to forecast that breakthroughs are likely in the CVD area rather than the more difficult and dangerous area of high pressures and temperatures.

5.3 Technological advance in the area of material characteristics

5.3.1 Changes to the material properties of diamond

Irradiation: Diamond irradiation was first reported by Crookes (1909) using radium. Today most gems will respond to radiation treatments such as alpha and beta particles, gamma rays or neutrons (Ashbaugh, 1988). The equipment is common and can be found in most countries that allow food irradiation. In attempting to create exotic colours the danger of exposing the stone to high levels of radiation is real. For example, a green diamond in the USA treated with americium-241 has been withheld from public release until 6507 AD.! (*Gems and Gemology*, 1993a:49). Uranium has also been used to "create" a rare black diamond of 6.6 carats (*Gems and Gemology*, 1987b:111).

The debate concerning irradiation disclosure is ongoing and turns around the need to inform the public about altering the material properties of something considered to be natural and rare. Diamonds display colour changes due to natural irradiation, as seen in blue diamonds (*Gems and Gemology*, 1991a:291) that command a price premium. The gem industry is concerned that treated gem quality material could undermine the position that coloured natural gem diamonds currently occupy.

Colour treatment and fracture filling: Changing the colour of a diamond through heat treatment or a combination of irradiation and annealing, achieving red diamonds, has caused debate within the gem industry (*Gems and Gemology*, 1995a:121-122; 1995b:53-54). The debate again pivots around selling a "treated" diamond - perhaps under the pretense that the material is natural. The diamond gem industry is clear on this issue - as soon as the stone has been altered, besides cutting and polishing, then the treatment must be disclosed.

Since fancy, or coloured material commands a price premium, establishing the true origin of colour is financially significant. Equally, the filling of diamond fractures with a range of materials has resulted in detailed research to determine the treatment (Kammerling *et al.*, 1995). A procedure attracting particular attention is laser drilling where inclusions are removed and the void filled with vapour deposited diamond or glass (*Gems and Gemology*, 1994a:115-116; 1995c:52). The debate goes beyond price related issues - the material is being altered which undermines the notion of rarity, uniqueness and most importantly, the idea that a "diamond is forever" is being seriously challenged.

Coating and adding to the weight: Two procedures feared by the gem trade are: (i) the coating of a cubic zirconia, thereby creating an external appearance of diamond, and (ii) coating a natural gem, thereby adding to the weight (Fritsch *et al.*, 1989; *Gems and*

Gemology, 1991b, 1991c). Although gemologists have researched and documented many of the differences, the threats have been conveyed to the gem community (Koivula and Fryer, 1984; Shigley *et al.*, 1986; Shigley *et al.*, 1987; Nassau, 1990).

5.3.2 Changes in performance

Doping and ion implantation: By doping synthetic diamond material with boron, diamond can be changed from an insulator into a semiconductor. By growing the material either under HPHT or CVD in association with infusing the correct impurities through ion implantation or through a controlled growth process, synthetic material would be viable in printed circuit boards, integrated circuits and a vast range of electronic equipment discussed by Yoder (1992). The important trend though is the ability to control *accurately* the concentration and type of inclusion.

Carbon-12 (^{12}C): The breakthrough of isotopically pure ^{12}C achieved by GE resulted in improvements to many performance parameters of synthetic diamonds. First the new GE synthetics are reportedly 1000 times more resistant to lasers than their natural counterparts (Russell, 1990:3). This is a significant improvement in the ability to dissipate heat. GE also reported isotopically pure ^{12}C as having the highest *density* of atoms per cubic centimetre of any solid at room temperature. *(Metals and Minerals Annual Review*, 1991:120; *Design News*, December 1, 1991).

5.3.3 Substitution of synthetic for natural industrial diamonds

Synthetic diamond is expected to attain 95% of the industrial market by the year 2038. Simply stated, the final 5% of the market will take approximately forty years to acquire and the manner in which this will unfold is detailed in chapter six. Figure 5.3 depicts the historical evolution of synthetic industrial diamonds substituting for natural industrial diamonds. The direction is crucial for industrial diamond producers for two reasons. First, natural producers should be mindful of justifying a mining venture based on industrial grade material. Second, synthetic producers should be mindful of the vast natural stocks that may still compete with manufactured stocks.

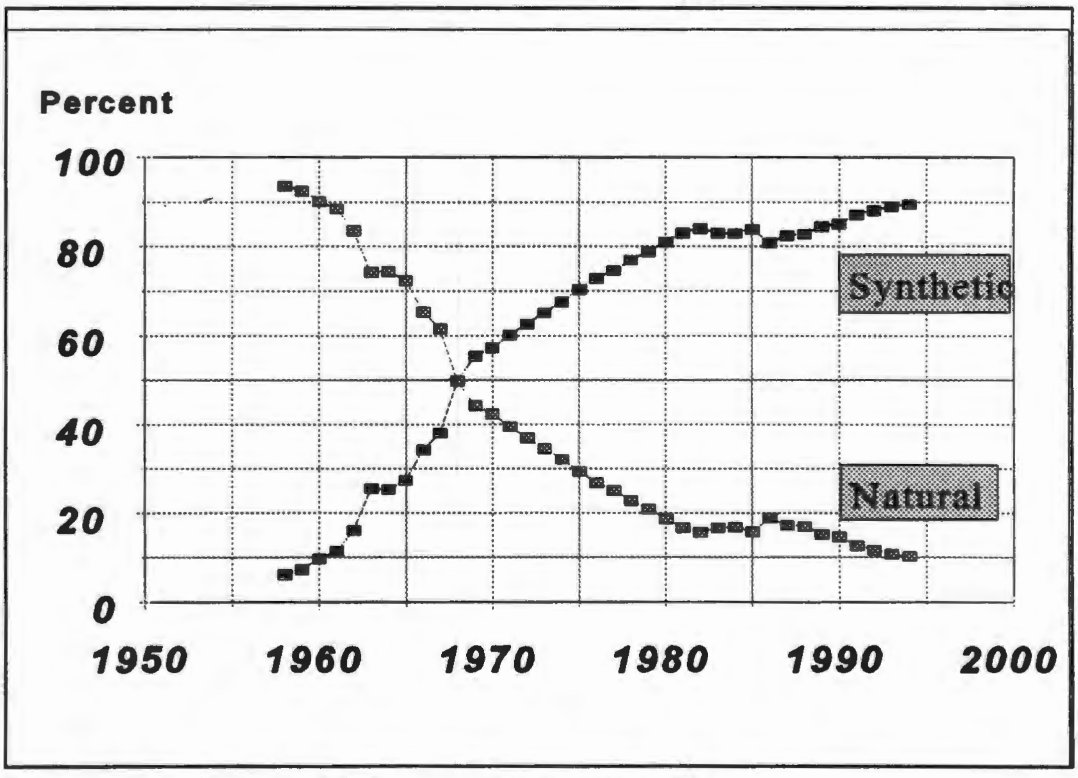

Figure 5.3 Industrial Diamonds Market Shares

The possibility of substitution in the gem market is of greater concern. An issue of crucial importance to the gem industry is the possibility of substitution of synthetic for natural gem diamonds. Compared to the industrial market, the gem market is much smaller in volume, but larger in value. The industrial market has a turnover of 500 million carats whereas the gem market involves around 50 million carats per annum. Already, there is some speculation about the presence of synthetic gems. Though produced for research or scientific applications, a synthetic stone appeared in the gem trade as early as 1987 (*Gems and Gemology*, 1987a). In 1996, conjecture concerning synthetic diamond gems in the marketplace has turned into a reality with the material openly available at gem trade meetings (*Gem Trade Lab Notes*, 1996:44). In chapter seven - the future outlook - the implications of these developments will be addressed.

5.4 Summary

This chapter used the cascade model to address the key question of the manner in which synthetic diamond technology is advancing. Changes in the manufacturing technology and changes to the material were presented as evidence in support of the notion that significant technological advance is taking place. These changes are summarised below and account for the material's technological success:

i. The size and structure of HPHT processing systems have increased to the point where larger reaction chambers cannot be contained with existing materials,

ii. The quality range of synthetic HPHT material available has increased,

iii. The identification of the reaction chamber barrier has probably promoted CVD advances,

iv. CVD is opening up the possibility of using diamond's vast array of qualities,

v. Synthetic diamond is no longer used independently, but can now be incorporated into other technological entities, largely due to CVD and coating developments.

Successful synthetic diamond manufacture stimulated a period of industrial activity based primarily on the material's mechanical properties. For forty years diamond's property of hardness dictated developments. Thermal, chemical, electrical and optical applications remained underutilised. Why was this so? Part of the answer is that the level of impurities, or accuracy, could not be controlled within the crystal structure.

Reflecting on the key question of why technological advance has been consistent and pervasive - the changes in manufacturing operating principle and improvements in material performance have been the primary catalysts in promoting technological advance.

These two developments moved the applications frontier beyond the mechanical applications towards technologies that took advantage of the thermal, optical and chemical properties. Synthetic diamonds became the preferred material for industrial applications. Indications are that this technological success will cause a challenging set of conditions for the gem industry as well.

CHAPTER SIX

EVIDENCE OF SUBSTITUTION

Introduction

In this chapter the second key question of the thesis is addressed: Did the substitution of synthetic for natural diamonds in industrial applications follow a systematic pattern and could it have been predicted? To answer the question it was necessary to obtain a usable time series on synthetic diamond production and to investigate whether the series followed a recognisable "law". In this case the "law" is the mathematical function of the substitution curve discussed in chapter four.

The chapter presents a time series for diamond production over the period 1920 to 1994. Levinson *et al.* (1992) and Janse (1996) have compiled notable time series for natural diamond production. However, they did not provide details as to grade or the presence of synthetic material. Hopefully, the addition of synthetic and grade data in this time series will constitute a contribution to the information resources in the diamond industry.

The data are presented in the following sequence:

i. Natural diamond production,

ii. Industrial stockpile trend,

iii. Natural gem, near-gem and industrial material,

iv. Synthetic diamond market share.

The reason for investing so much effort in generating a data series is that data on both natural and synthetic diamonds are difficult to obtain. The research is based on secondary data sources.

Following the presentation of the data, four substitution models are used to show the systematic pattern of substitution. All the models are mathematically similar but incorporate increasing "delay" coefficients. These are coefficients which tend to retard the rate of substitution.

6.1 Diamond production

6.1.1 Natural diamond production

The data depicted in Figure 6.1 and Tables 6.1, 6.2 and 6.3 detail the annual country production between 1920 to 1994. The full time series and sources for the period is presented in Appendix B and C respectively.

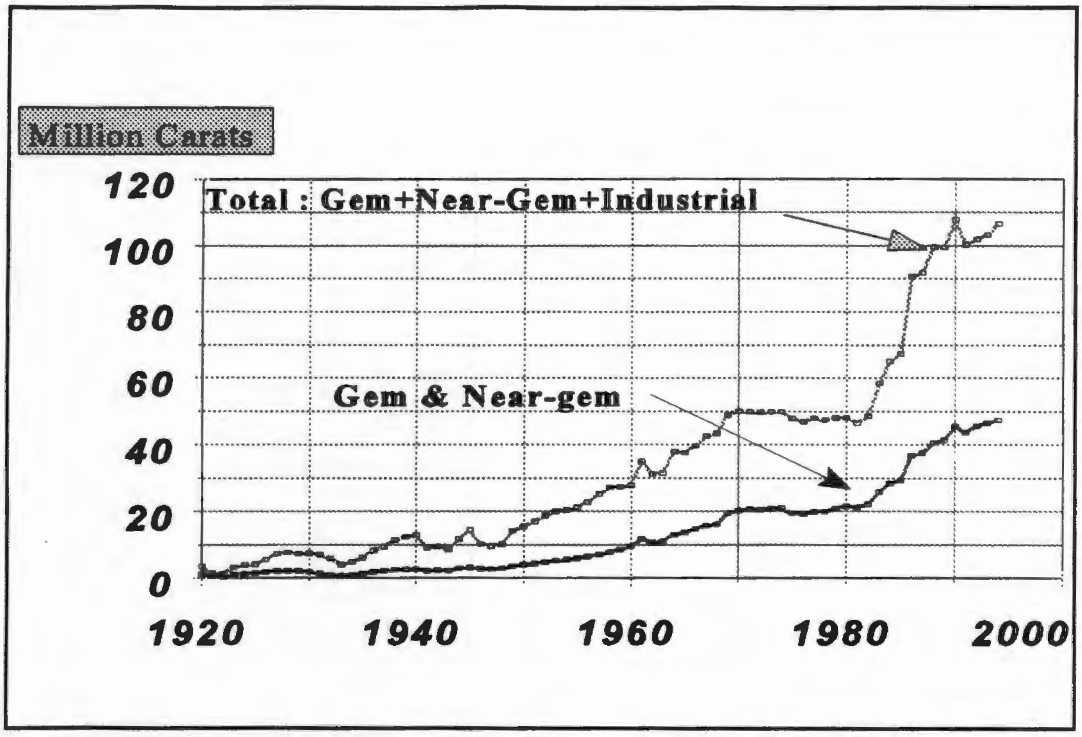

Figure 6.1 Total Natural Diamond Production : 1920-1994

In compiling this time series, sources of higher scientific standing were preferred to popular sources. For instance, *Mining Annual Review*, *Gems and Gemology* and *World Mineral Statistics* were selected before data from popular journals such as *Diamond International* and *Diamond News and SA Jeweller*.

Table 6.1 World Natural Diamond Production (Mct) 1920-1945

	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945
India	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brazil	0.05	0.05	0.06	0.06	0.06	0.05	0.05	0.05	0.19	0.14	0.13	0.09	0.04	0.03	0.04	0.04	0.14	0.12	0.11	0.21	0.33	0.33	0.30	0.28	0.37	0.28
South Africa	2.55	0.83	0.67	2.05	2.44	2.43	3.22	4.71	4.37	3.66	3.16	2.12	0.80	0.51	0.44	0.68	0.62	1.03	1.24	1.25	0.54	0.16	0.12	0.30	0.93	1.22
Namibia	0.61	0.17	0.14	0.43	0.49	0.52	0.68	0.72	0.50	0.60	0.42	0.07	0.02	0.00	0.00	0.13	0.18	0.20	0.15	0.04	0.03	0.05	0.06	0.09	0.15	0.15
Guyana	0.04	0.11	0.17	0.22	0.19	0.19	0.17	0.18	0.14	0.13	0.11	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
Zaire	0.27	0.28	0.25	0.41	0.55	0.88	1.11	1.04	1.65	1.91	2.52	3.53	3.87	2.26	1.45	3.17	4.63	4.93	7.21	8.36	9.60	5.87	6.02	4.88	7.53	10.39
Angola	0.09	0.11	0.10	0.09	0.12	0.12	0.15	0.20	0.24	0.31	0.33	0.35	0.37	0.37	0.43	0.48	0.58	0.63	0.65	0.69	0.78	0.79	0.79	0.79	0.80	0.80
Ghana	0.00	0.00	0.01	0.02	0.05	0.08	0.30	0.46	0.70	0.66	0.86	0.88	0.84	0.80	2.39	1.35	1.41	1.58	1.30	1.09	0.57	1.08	1.06	1.32	1.17	0.81
Tanzania						0.00	0.01	0.02	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.05	0.09	0.12
C.A.R.											0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.03	0.03	0.05	0.06	0.06	0.08
Guinea																	0.01	0.05	0.05	0.06	0.07	0.06	0.05	0.04	0.07	0.08
Sierra Leone													0.00	0.03	0.07	0.30	0.62	0.91	0.69	0.68	0.89	0.85	1.05	0.83	0.61	0.50
Venezuela																			0.01	0.01	0.01	0.03	0.03	0.02	0.02	0.01
Ivory Coast															0.00											
Liberia																										
Botswana																										
Lesotho																										
Russia																										
Indonesia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00					
Australia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00
China																										
Swaziland																										
Others	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00		0.00	0.00			0.02					
World Total	3.61	1.55	1.40	3.30	3.90	4.28	5.70	7.38	7.81	7.44	7.55	7.12	6.00	4.06	4.87	6.20	8.24	9.49	11.47	12.44	12.91	9.30	9.58	8.69	11.82	14.47

Note 1. Where a value of 0.00 is recorded a value of less than 5000 carats are mined. The detail is listed in Appendix B.

Table 6.2 World Natural Diamond Production (Mct) 1946-1971

	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
India	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02
Brazil	0.33	0.28	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.30	0.30	0.30	0.60	0.60	0.60	0.23	0.28	0.25	0.19	0.16
South Africa	1.35	1.24	1.38	1.26	1.73	2.23	2.38	2.72	2.86	2.63	2.59	2.58	2.70	2.84	3.14	3.79	3.92	4.38	4.45	5.03	6.04	6.69	5.46	7.91	8.16	7.58
Namibia	0.17	0.18	0.20	0.28	0.50	0.50	0.54	0.61	0.68	0.81	0.99	1.00	0.90	0.93	0.94	0.91	1.03	1.19	1.54	1.66	1.76	1.70	1.72	2.15	1.87	1.65
Guyana	0.03	0.02	0.04	0.03	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.06	0.10	0.11	0.10	0.10	0.11	0.11	0.10	0.07	0.05	0.07	0.06	0.06
Zaire	6.03	5.47	5.82	9.65	10.15	10.56	11.61	12.58	12.62	13.04	14.01	15.65	16.67	14.86	13.45	18.14	14.66	14.76	19.77	17.50	17.43	18.20	17.50	17.20	17.50	17.00
Angola	0.81	0.80	0.80	0.77	0.54	0.73	0.74	0.73	0.72	0.74	0.74	0.86	1.00	1.02	1.06	1.15	1.08	1.08	1.15	1.16	1.27	1.29	1.67	2.02	2.24	2.43
Ghana	0.81	0.75	0.88	0.96	1.19	1.75	2.19	2.18	2.14	2.26	2.54	3.12	3.13	3.08	3.27	3.21	3.21	2.68	2.67	2.27	2.82	3.60	5.00	4.15	2.87	2.85
Tanzania	0.12	0.09	0.15	0.19	0.16	0.11	0.14	0.17	0.33	0.33	0.36	0.39	0.52	0.64	0.55	0.69	0.66	0.59	0.65	0.76	0.95	0.93	0.70	0.78	0.71	0.97
C.A.R.	0.09	0.11	0.12	0.12	0.11	0.15	0.16	0.14	0.15	0.14	0.15	0.11	0.11	0.09	0.07	0.11	0.27	0.40	0.44	0.54	0.54	0.52	0.61	0.53	0.48	0.43
Guinea	0.05	0.05	0.08	0.09	0.12	0.10	0.14	0.18	0.22	0.32	0.39	0.09	0.12	0.66	1.12	1.20	0.35	0.05	0.30	0.30	0.30	0.07	0.09	0.10	0.08	
Sierra Leone	0.56	0.61	0.47	0.49	0.66	0.47	0.45	0.48	0.40	0.42	0.65	0.86	1.49	1.29	1.91	2.30	1.64	1.78	1.65	1.46	1.44	1.56	1.66	1.93	2.05	2.28
Venezuela	0.02	0.06	0.08	0.06	0.06	0.06	0.09	0.08	0.10	0.14	0.09	0.12	0.09	0.09	0.07	0.13	0.18	0.07	0.12	0.09	0.08	0.09	0.14	0.22	0.50	0.65
Ivory Coast												0.16	0.16	0.19	0.20	0.55	0.28	0.18	0.20	0.20	0.18	0.18	0.19	0.19	0.21	0.40
Liberia								0.01	0.00	0.03	0.04	0.02	0.01	0.64	0.87	1.10	0.91	0.75	0.60	0.60	0.60	0.55	0.75	0.85	0.55	0.54
Botswana										0.00	0.00	0.00	0.01	0.01	0.00										0.54	0.83
Lesotho																			0.00	0.01	0.01		0.01	0.03	0.02	0.01
Russia								0.01	0.00	0.03	0.04	0.02	0.01	0.80	0.95	1.50	2.75	3.25	3.70	5.35	5.50	7.00	7.50	10.50	12.00	12.00
Indonesia								0.01	0.00	0.03	0.04	0.02	0.01									0.00	0.02		0.02	0.03
Australia	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00											
China																										
Swaziland																										
Others				0.00		0.00	0.00	0.00	0.00											0.05	0.05					
World Total	10.36	9.66	10.26	14.18	15.52	16.97	18.73	20.20	20.50	21.20	22.90	25.30	27.22	27.39	27.89	35.19	31.32	31.58	37.95	37.68	39.66	42.69	43.36	48.88	50.06	49.87

Table 6.3 World Natural Diamond Production (Mct) 1972-94

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
India	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01						0.02
Brazil	0.20	0.30	0.30	0.40	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.75	0.80	0.45	0.64	0.74	0.70	0.75	1.55	1.50	2.09	2.12	2.00
South Africa	7.70	7.80	8.00	7.80	7.30	7.90	8.00	8.60	8.70	9.50	8.90	10.00	9.80	9.90	10.20	9.60	9.00	9.00	8.50	8.20	10.00	10.11	10.70
Namibia	1.60	1.60	1.60	1.74	1.69	2.00	1.90	1.65	1.56	1.25	1.00	0.96	0.93	0.91	1.00	1.00	0.90	0.90	0.80	1.40	1.60	1.62	1.30
Guyana	0.05	0.05	0.03	0.02	0.01	0.02	0.02	0.02	0.01	0.01,	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.02	0.02	0.02	0.50
Zaire	17.00	17.00	17.00	17.00	17.00	17.00	17.00	15.50	14.00	12.50	12.20	13.00	18.50	19.60	20.50	21.00	23.00	20.00	24.00	19.00	15.00	15.17	18.00
Angola	2.20	2.20	1.94	0.50	0.40	0.50	0.65	0.84	1.50	1.40	1.30	1.00	0.92	0.90	0.20	0.90	1.00	1.20	1.30	1.30	2.70	2.73	1.40
Ghana	2.50	2.30	2.40	2.25	2.22	2.22	1.50	1.50	1.10	1.00	1.00	0.80	0.33	0.60	0.55	0.44	0.30	0.20	0.20	0.20	0.50	0.51	0.60
Tanzania	0.60	0.60	0.60	0.60	0.50	0.40	0.35	0.34	0.26	0.37	0.38	0.37	0.36	0.35	0.30	0.15	0.13	0.08		0.11	0.11	0.11	
C.A.R.	0.40	0.40	0.40	0.40	0.40	0.40	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.50	0.60	0.60	0.45	0.60	0.50	0.50	0.40	0.40	0.50
Guinea	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.04	0.04	0.04	0.04	0.05	0.09				0.20	0.10	0.10	0.10	0.10	0.50
Sierra	1.80	1.70	1.70	1.09	1.10	0.75	0.80	0.85	0.60	0.30	0.25	0.25	0.42	0.40	0.40	0.36	0.30	0.60	0.70	0.60	0.45	0.45	0.40
Venezuela	0.40	0.50	0.50	0.60	0.60	0.80	0.80	0.80	0.80	0.75	0.75	0.25	0.27	0.22	0.21	0.11	0.15	0.15	0.15	0.50	0.51	0.51	0.50
Ivory Coast	0.30	0.30	0.30	0.30	0.20	0.10	0.10	0.10	0.10	0.10	0.10	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	
Liberia	0.50	0.60	0.60	0.60	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.40	0.40	0.30	0.35	0.35	0.30	0.30	0.10			
Botswana	2.40	2.40	2.40	2.37	2.36	2.66	2.80	4.40	5.10	4.96	7.77	10.70	12.90	12.60	13.00	13.00	15.00	15.20	17.35	16.51	15.90	16.07	15.60
Lesotho	0.01	0.01	0.01	0.00	0.01	0.02	0.05	0.05	0.05	0.05	0.04												
Russia	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	15.00	13.00	11.25	11.37	11.50
Indonesia	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03							0.01
Australia											0.46	6.20	5.70	7.06	29.20	30.00	34.83	37.00	36.00	36.00	40.00	40.44	43.80
China									0.90	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.02	1.03	0.30
Swaziland													0.02	0.02	0.04	0.04	0.07						
Others	0.03	0.02	0.04	0.06	0.06	0.05	0.02	0.02	0.07	0.07	0.08	0.11	0.17	0.31	0.41	0.35	0.36	0.19	0.19	0.28	0.28	0.28	0.30
WorldTotal	49.80	49.90	49.94	47.85	46.97	47.93	47.40	48.08	48.12	46.58	48.61	58.38	65.12	67.56	90.80	91.90	99.76	99.58	107.85	100.53	102.13	103.26	107.93

6.1.2 The stockpile calculation

The industrial stockpile may be significant in determining a delay coefficient. For example, the natural stockpile provides low priced material that may compete with synthetic diamond material and thereby extend the substitution process. It could be that an adequate coefficient is found by simply taking the additions to the stockpile - and this will be tested later in the chapter. For further research and completeness of the data set, the accumulated stockpile is presented here as a contribution to the diamond industry data resources.

Accumulated natural industrial stock is estimated at around 1.5 bn carats for 1994

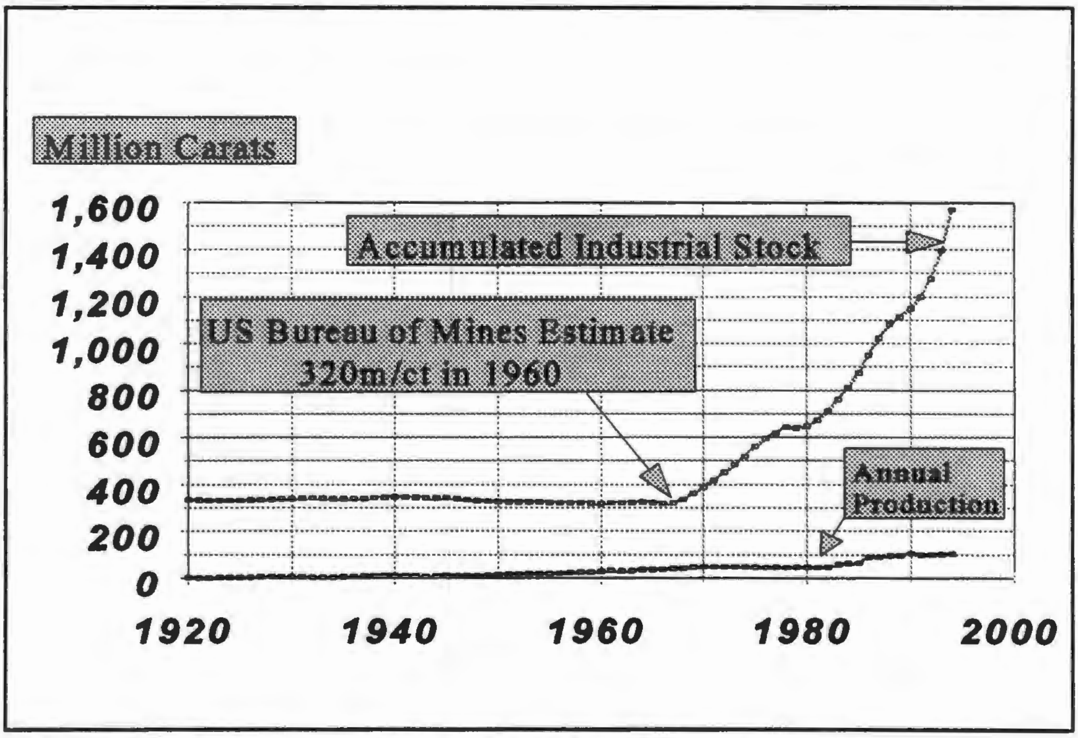

Figure 6.2 Stockpile of Natural Industrial Diamonds

depicted in Figure 6.2. The high base of approximately 320 Mct is a cited figure from the USA Bureau of Mines (*Mining Annual Review*, 1965:87).

The stock was calculated by adding the natural material not used in the current year to the accumulated stock. Natural material not used is derived in the following manner:

1. Total industrial used *less*,
2. Synthetic production that is assumed to be used in the current year rather than being made for stock, *to give* :
3. Unused natural - which is the natural by-product not used and added to stock.

Undoubtedly, an important finding regarding the stock position is the vast stock on hand. Even the most conservative scenario of allocating all near-gem material to the jewellery market would still result with stock greater than one billion carats.

6.1.3 The importance of grade distinction

The diamond industry definition of near-gem material has changed at times (*International Diamond Annual*, 1971, 1972; *Diamond Intelligence Briefs*, 1992:936) which adds to the difficulty of establishing the role of the stockpile in affecting the substitution process. A trend that emerged over the last ten years or so has been Indian cutters working with near-gem material previously considered uncuttable (*Diamond Intelligence Briefs*, 1990:677).

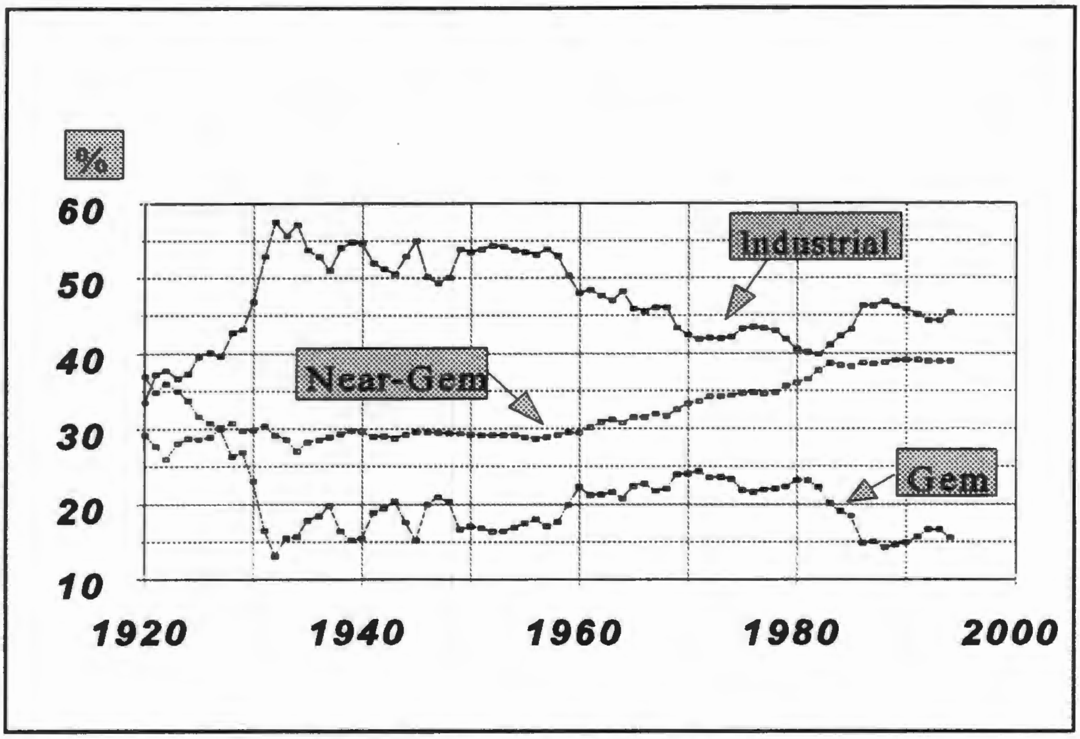

Figure 6.3 Gem, Near-Gem and Industrial Diamonds

This trend has been incorporated into the diamond data model by decreasing the industrial use of near-gem material from 100% in 1920 by 1% per year until a value of 26% in 1994.

The differentiation between near-gem and industrial has more to do with De Beers' company policy than the quality of the material. For example, the De Beers revises its selling procedure from time to time and merely informs the public in the following manner:

> *"Because a revision of selling procedure introduced as from January, 1961, has invalidated any comparison between current and earlier sales of gem and industrial diamonds and made any automatic classification of sales into gem and industrials impossible....only the net sales of all classes of diamonds will be announced"*
>
> (*International Diamonds*, 1972:8)

Table 6.4 Natural Diamond Grades 1920-1994

Country	Grade	%
India	Gem	70
	Industrial	30
Brazil	Gem	55
	Near-Gem	35
	Industrial	10
South Africa	Gem	25
	Near-Gem	37
	Industrial	38
Namibia	Gem	95
	Industrial	5
Guyana	Gem	50
	Industrial	50
Zaire	Gem	5
	Near-Gem	30
	Industrial	65
Angola	Gem	70
	Near-Gem	20
	Industrial	10
Ghana	Gem	8
	Near-Gem	25
	Industrial	67
Tanzania	Gem	50
	Near-Gem	40
	Industrial	10
C.A.R.	Gem	55
	Near-Gem	35
	Industrial	10
Guinea	Gem	70
	Near-Gem	15
	Industrial	15
Sierra Leone	Gem	55
	Near-Gem	35
	Industrial	10
Venezuela	Gem	29
	Near-Gem	36
	Industrial	35
Ivory Coast	Gem	50
	Near-Gem	40
	Industrial	10
Liberia	Gem	25
	Near-Gem	40
	Industrial	35
Botswana	Gem	19
	Near-Gem	51
	Industrial	30
Lesotho	Gem	60
	Industrial	40
Russia	Gem	26
	Near-Gem	44
	Industrial	30
Indonesia	Gem	95
	Industrial	5
Australia	Gem	5
	Near-Gem	40
	Industrial	55
China	Gem	20
	Near-Gem	40
	Industrial	40
Swaziland	Gem	40
	Industrial	60
Others	Gem	52
	Near-Gem	38
	Industrial	10
World Total	Gem	15
	Near-Gem	39
	Industrial	46

An important assumption regarding grade by country statistics is that the production ratio of gem, near-gem and industrial remains constant over the data period. The values by country are listed in Table 6.4. Periods of poor quality production, particularly at the end of the mine life, may differ from the data in Figure 6.3. However, the inconsistencies in the literature concerning grade information were not numerous.

It is crucial to bear in mind though that this concerns diamond selling and marketing. The current thesis is concerned with production statistics with mining journals being an important data source. There is little doubt that De Beers is in a position to decide on what constitutes gem or near-gem but there is not much debate over what constitutes industrial quality diamond material. The only issue for this thesis is to take cognisance of the Indian cutters ability to work with low grade material. This is done by reducing the amount of near-gem available for industrial use.

6.2 Synthetic diamond data : calculations and assumptions

The calculated synthetic and natural market shares are presented in Tables 6.5 and 6.6. The time series was calculated using the following data sources :

i. Total natural industrial production,

ii. The total world synthetic production,

iii. The split between natural gem, near-gem and industrial production,

iv. Total volume of diamonds used in industrial applications.

The time series is calculated in the following sequence:

1. *Start* with total world HPHT synthetic diamond production

2. *Add* world natural near-gem used for industrial use

3. *Add* world natural industrial diamond

4. *Add* a salvage estimate of 2% of natural material

5. *Equals* total industrial material available for use

6. *Subtract* the industrial material used per annum

7. *To equal* excess or over-utilisation that is added to accumulated stock

8. **Synthetic market share** is the total synthetic produced as a fraction of total used

9. **Natural market share** is the total natural used as a fraction of total used.

Table 6.5 Diamond Market Share Model 1958-1976 (Mct)

Synthetic	**1958**	**1959**	**1960**	**1961**	**1962**	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**
US[1]	1	2	2	3	3	5	5	5	6	8	11	13	15	17	19	21	23	26	29
USSR				0.002					3	6	8	10	10	11	12	14	15	17	19
South Africa[1]				1	1	1	3	3	2	3	5	7	7	8	8	9	10	11	12
Ireland						0.33	0.40	1	1	1	4	6	7	8	8	9	10	11	12
Sweden						0.25	0.25	0.25	0.25	0.25	1	3	3	3	4	4	5	6	7
Japan								0.25	0.25	0.25	1	1	1	1	1	1	2	2	2
others										0.25	1	1	1	1	1	1	2	2	2
Total HPHT	1	2	2	3	4	7	8	9	13	18	30	41	44	49	54	61	68	75	84
+ near-gem	5	5	5	6	6	6	7	7	7	7	7	8	8	8	8	8	8	7	7
+ industrial	14	14	13	17	15	15	18	17	18	20	20	21	21	21	21	21	21	21	20
+ salvage										3	3	3	3	3	3	3	3	3	3
= Available	21	20	20	26	25	28	33	33	38	48	60	73	77	81	87	93	100	107	115
less used	20	21	22	23	25	26	30	36	43	45	46	47	49	50	55	60	65	65	80
= excess	1	-1	-2	3	-0	1	3	-3	-5	3	14	26	28	31	32	33	35	42	34
Add to stock	323	322	320	323	323	324	328	325	320	323	337	363	391	421	453	486	521	563	597
synthetic	**6%**	**7%**	**10%**	**11%**	**16%**	**26%**	**25%**	**28%**	**34%**	**38%**	**50%**	**56%**	**57%**	**60%**	**63%**	**65%**	**68%**	**70%**	**73%**
natural	**94%**	**93%**	**90%**	**89%**	**84%**	**74%**	**75%**	**72%**	**66%**	**62%**	**50%**	**44%**	**43%**	**40%**	**37%**	**35%**	**32%**	**30%**	**27%**

Note 1 Although the total synthetic production are cited figures, the company specific data are estimates. For example, GE and De Beers share 80% of the market (*Business Week*, August 10, 1992). 40 % is allocated to De Beers and split evenly between the three production facilities in South Africa, Ireland and Sweden.

Table 6.6 Diamond Market Share Model 1977-1994 (Mct)

Synthetic	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**
US	33	37	41	46	51	57	64	71	80	89	100	112	125	140	156	175	195	218
USSR	21	23	26	28	32	35	9	43	48	53	59	65	73	80	80	80	80	80
South Africa	14	15	17	18	20	22	24	27	29	32	35	39	43	47	52	57	63	69
Ireland	14	15	17	18	20	22	24	27	29	32	35	39	43	47	52	57	63	69
Sweden	8	9	10	11	13	14	16	19	21	24	28	32	36	41	47	54	61	70
Japan	2	3	3	4	4	5	5	6	7	8	9	10	12	13	15	17	20	26
others	2	3	3	4	4	5	5	6	7	8	9	10	12	13	15	17	20	25
Total HPHT	**93**	**104**	**116**	**129**	**144**	**160**	**178**	**199**	**222**	**247**	**275**	**307**	**343**	**382**	**417**	**456**	**501**	**557**
+ near-gem	7	7	7	7	7	7	8	9	9	12	12	12	12	13	11	11	11	11
+ industrial	21	20	20	20	19	19	24	28	29	42	43	47	46	50	45	45	46	50
+ salvage	3	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5
= Available	125	135	146	159	173	190	215	239	264	305	334	371	405	448	478	518	562	622
less used	101	110	150	150	150	150	165	190	200	230	260	312	374	412	428	441	441	441
= excess	23	25	-4	9	23	40	50	49	64	75	74	59	31	36	50	76	121	181
Add to stock	621	645	642	651	673	714	763	812	876	952	1025	1084	1115	1151	1201	1278	1398	1579
synthetic	**75%**	**77%**	**79%**	**81%**	**83%**	**84%**	**83%**	**83%**	**84%**	**81%**	**82%**	**83%**	**85%**	**85%**	**87%**	**88%**	**89%**	**90%**
natural	**25%**	**23%**	**21%**	**19%**	**17%**	**16%**	**17%**	**17%**	**16%**	**19%**	**18%**	**17%**	**15%**	**15%**	**13%**	**12%**	**11%**	**10%**

6.3 The Hypothesis:

H_1 The substitution of synthetic for natural industrial diamonds has occurred in a systematic and predictable manner.

H_0 The substitution of synthetic for natural industrial diamonds has not followed any discernable pattern.

The validity of the hypothesis will be tested using four simplified logistic functions described in chapter four : (i) with no delay and 100% market share (Fisher and Pry solution), (ii) with a zero delay (Blackman's solution), (iii) a delay value of one (Floyd's solution), and (iv) a variable delay (a modified Sharif and Kabir solution). The following statistics will be calculated to ascertain the validity of the hypothesis and then later for evaluating the delay coefficient:

i. Regression coefficient R^2 of the transformed data,

ii. The mean squared deviations (MSD) and the mean absolute deviation (MAD) of the untransformed data (errors in the predicted "S" curve),

iii. Durban-Watson test for serial correlation.

6.4 Evaluating the hypothesis

The hypothesis is concerned with the evidence that supports the idea that substitution has been systematic and predictable. The data in Table 6.7 supports this notion that substitution has been systematic. All four functions return high correlation coefficients with low values for the mean square of the deviations. There is sufficient evidence to reject the null hypothesis - that a mathematical function in the form of a logistic, does not explain the behaviour of the historical data.

Table 6.7 Logistic Models Compared

	Fisher and Pry	**Blackman**	**Floyd**	**Modified Sharif & Kabir**
Market share ceiling	100%	95%	95%	95%
σ - Sigma - delay coefficient	0	0	1	Variable
R^2 - Correlation Coefficient	.8799	0.9078	0.9314	**0.9612**
C_1 - Y intercept	-1.834	-1.872	-3.422	-2.606
C_2 - Slope	0.1231	0.1379	0.5112	0.3439
MSD - Mean Square Deviations	0.0064	0.0046	0.0010	**0.0004**
MAD -Mean Absolute Deviation	0.0694	0.0577	0.0244	**0.0152**
Durban-Watson	0.09	0.12	0.45	**0.92**

6.5 The validity of the variable delay coefficient

Three substitution models were then evaluated using a market share ceiling of 95% in attempting to ascertain the validity of the delay coefficient. As discussed earlier, this may be an appropriate assumption given the substantial natural diamond stocks that could be competing with synthetic material at low prices. The models are compared in the following sequence:

i. Blackman with a delay of zero,

ii. Floyd with a full delay of one,

iii. Sharif and Kabir with a variable delay.

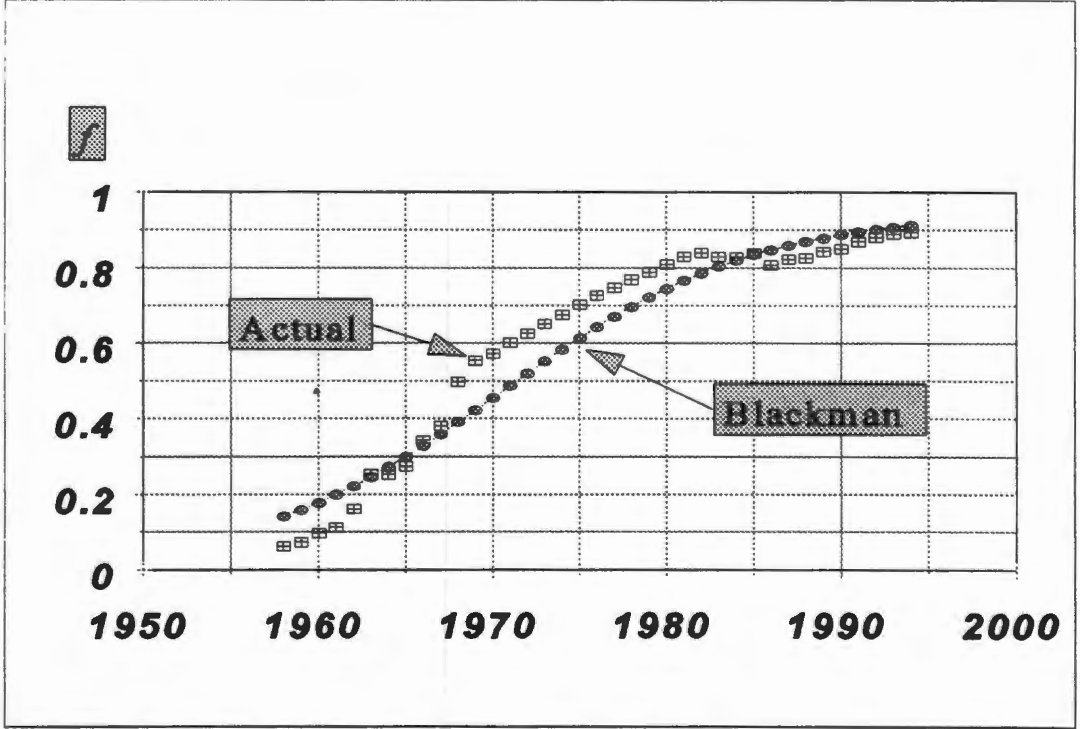

Figure 6.4 Blackman Logistic - Zero Delay

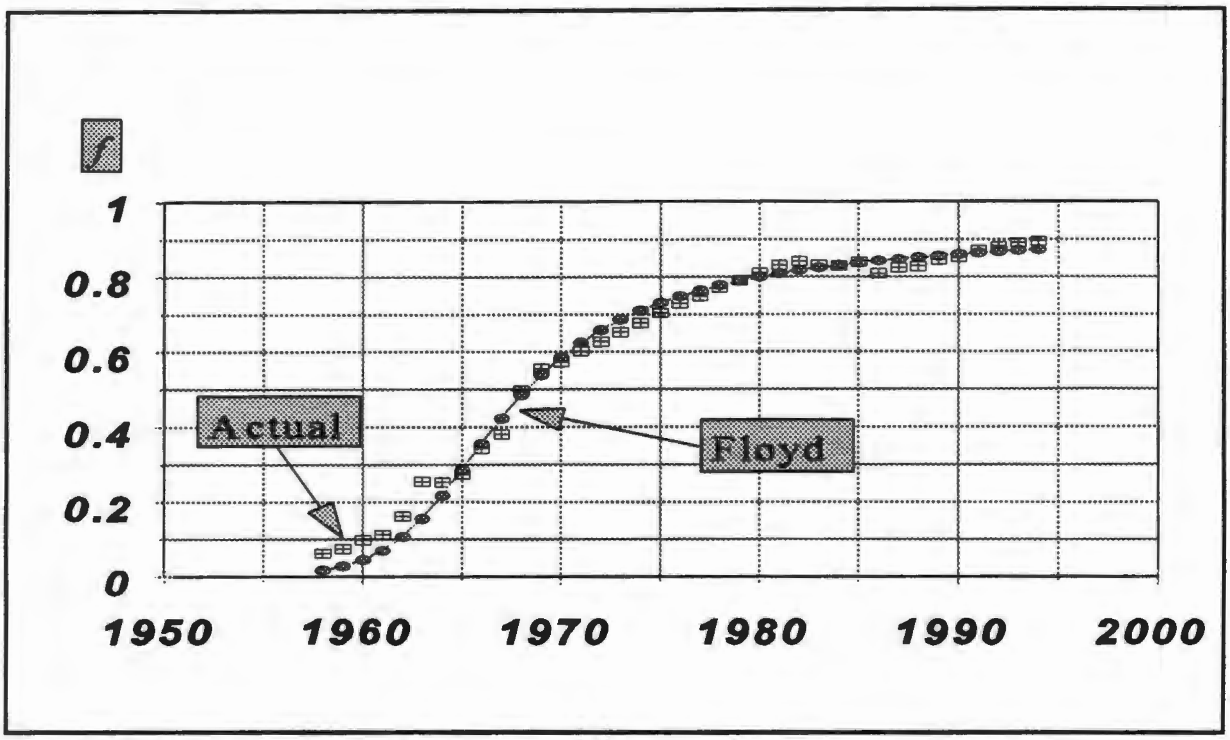

Figure 6.5 Floyd Logistic - Delay of One

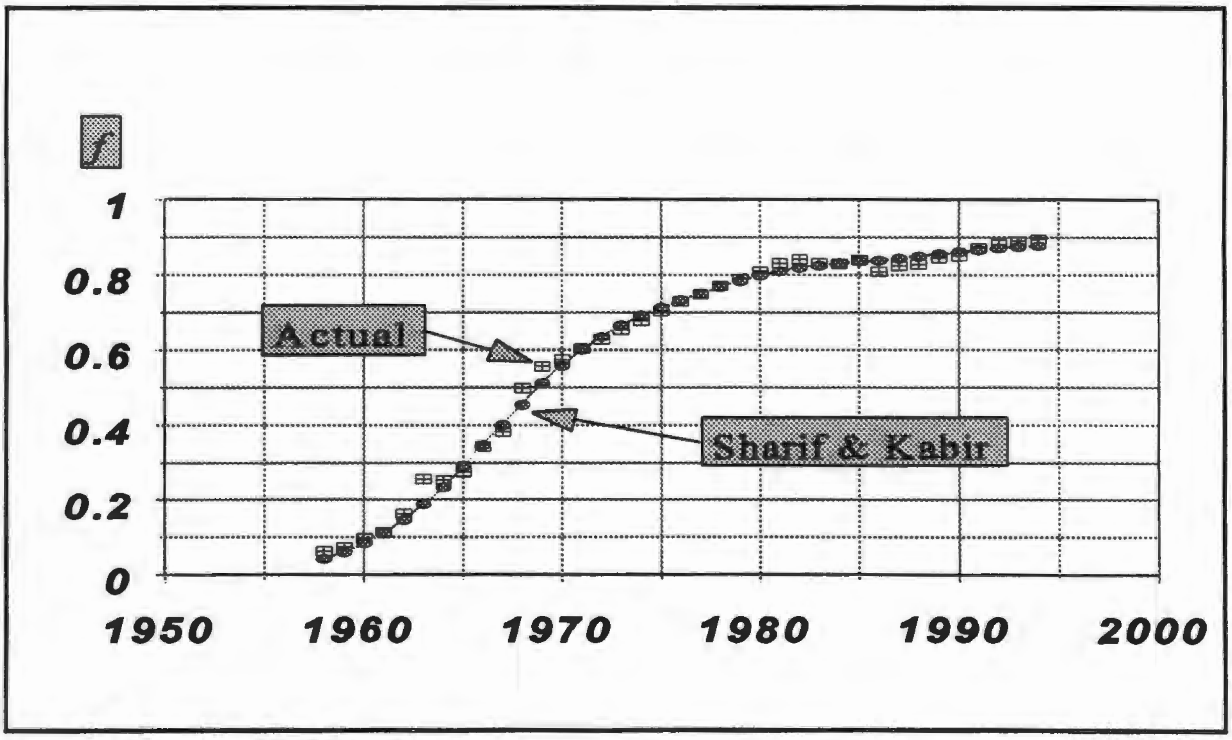

Figure 6.6 Sharif & Kabir Logistic - Variable Delay

Turning to the validity of the delay coefficient - Sharif and Kabir, and Floyd, who incorporate a delay, fit the actual data with greater precision than Blackman - the improved regression coefficients supporting this contention.

Further, Sharif and Kabir, using a *variable* delay, models the data with greater accuracy than Floyd who uses a delay of one. The statistics supporting this contention are the improved regression coefficients and reduced Mean Square of the Deviations (MSD).

The superior fit achieved through the use of a variable delay coefficient shows that substitution has occurred with a notable delay. The only caveat about accepting the variable delay coefficient is the presence of serial correlation, as indicated in a Durban-Watson statistic of less than one. This is addressed in section 6.6 below.

6.6 Serial correlation

The data do follow a logistic function and the very low mean square of the deviations and mean absolute deviation of the errors are cited in support. However, the Durban-Watson value would have to exceed 1.4 before serial correlation can be ruled out. All the models tested in this thesis return a Durban-Watson value less than one, suggesting this autocorrelation. Any further statistical interpretation would not be proper. Yet in examining the data, the serial correlation is clearly due to data between the period 1970 and 1985, depicted in Figure 6.7 - the synthetic market share.

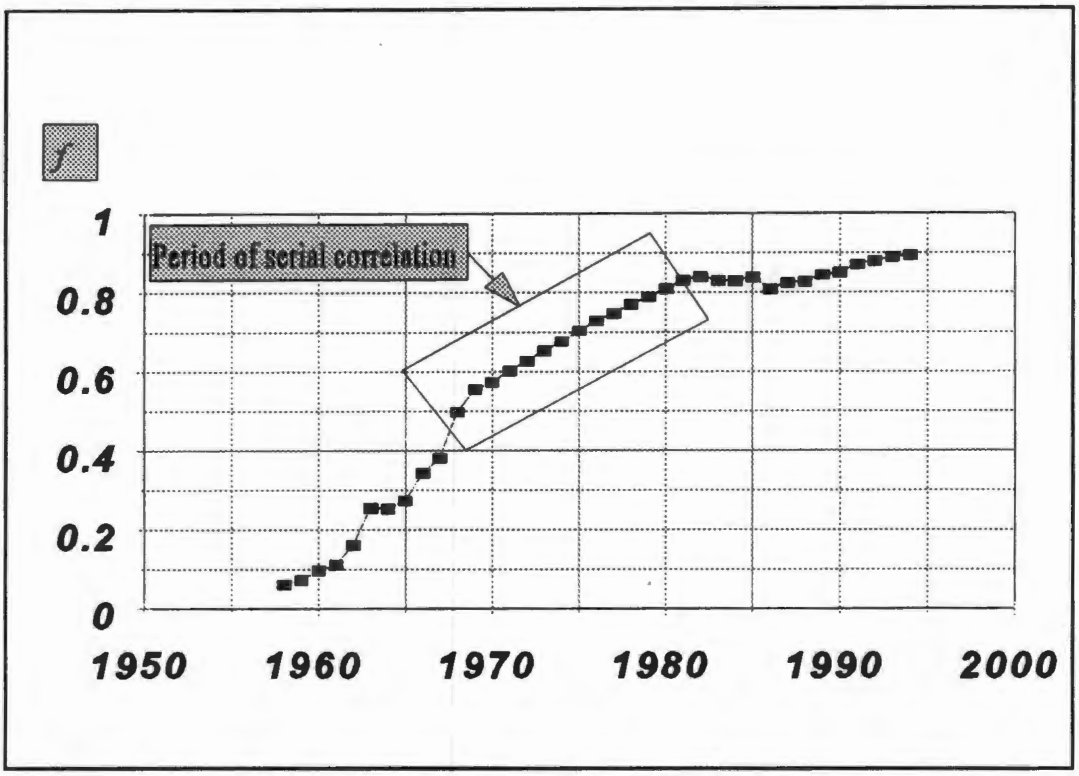

Figure 6.7 Period of Serial Correlation Identified

After 1970 the data sources appear merely to increase the annual diamond consumption by approximately 50 Mct, a trend depicted in Figure 6.7. Variability in the data occurs after 1985, when the large Australian industrial producers enter the market.

6.7 Summary

Chapter five was concerned with the cascade model of change and demonstrated how the possibility of material substitution may be the outcome of two competing materials - synthetic for natural industrial diamond. The current chapter answered the second key question concerning the systematic behaviour of synthetic diamond substituting for natural industrial diamond. To do this, the synthetic and natural data were presented. The manner in which the time series was calculated was also addressed. Then, the hypothesis concerned with the systematic behaviour of the substitution pattern was evaluated. Four logistic functions were tested and sufficient evidence was found to reject the null hypothesis. A systematic and predictable pattern of substitution has occurred.

A further useful finding surfaces when the diamond substitution process is reviewed over the full period. For more than thirty-seven years, a natural material, diamond, has been replaced by a synthetic equivalent. The synthetic material took just ten years to reach 50% of the market but the next 40% share has taken twenty-six years. This process has been delayed and a variable delay coefficient, as suggested by Sharif and Kabir (1976a) and presented in this thesis is valid.

The substitution of synthetic industrial diamond for natural industrial diamond has been systematic and predictable with the data following "law". The contribution to substitution theory is that a variable delay is shown to be valid, as suggested by Sharif and Kabir in 1976.

CHAPTER SEVEN

TECHNOLOGICAL OUTLOOK

Introduction

The final key question addressed in this thesis is concerned with the possibility for further developments in synthetic diamond manufacture, substitution and application. Since technological advance and a predictable substitution pattern have been established, the issue now is the technological outlook. The chapter examines four possible outcomes: (i) process improvements, (ii) continued substitution, (iii) expected future applications and finally (iv) a blurring of the boundaries between synthetic diamond material and natural diamond.

7.1 Further process improvements

Despite the corporate confidentiality and official secrecy associated with the production of synthetic diamond, there is evidence that a surge of activity is taking place. The process of manufacturing synthetic material is advancing rapidly, leading to a reduction in unit costs and multiple applications. A rapid increase in the CVD deposition rate and the linkage to other new technologies supports this view. Companies that have associations with the diamond industry should actively scan the environment and be on the lookout for breakthroughs, particularly in CVD processes.

7.2 Further substitution

Any attempt to undermine the idea that diamond is anything but unique would conflict with the gem diamond industry. An early indicator regarding the severity of the conflict surrounded naming conventions occurred when the USA courts decided that they will not support the double use of the word *synthetic*, both as a noun and adjective (Love, 1987:169-170). This missed the crucial issue however, and that is the artificial distinction between the same material. This conflict surfaced in 1993 when Chatham, a gem trading company, attempted to sell synthetic material using the name diamond. A legal battle followed between Chatham and the American Gem Trade Association (AGTA). The outcome being that Chatham retained membership of the Association after agreeing to use the terms “lab grown”, “lab created” and “Chatham created” but not to use the terms real, natural, genuine or identical (*Diamantaire*, 1994).

One possibility of insulating the name diamond from the synthetic threat may be in fingerprinting the material using laser engraving (*Diamond International*, 1992:25) or by ion implantation that would implant identifiable impurities (DeVries *et al.*, 1989). An alternative route has been to fingerprint the natural material by detailing the embedded impurities and inclusions that may be unique to each mine (*Diamond News and S.A. Jeweller*, 1994a:22). The unanswered question though would still be what happens when gemologists cannot scientifically establish the difference? This is a possibility when synthetic and natural material is mixed in a diamond parcel entering an established marketing channel (*Diamond News and S.A. Jeweller*, 1994b:19).

7.3 Proliferation of use

Diamond applications are beginning to use the chemical, electrical and thermal properties rather than the mechanical properties of hardness and wear resistance. Applications that manipulate energy and information may gain in importance over applications that process matter, an area traditionally occupied by synthetic diamond. Alternatively, applications that require the chemical and electrical properties require greater accuracy regarding impurities in combination with the ability to bond with foreign surfaces.

A functional change in diamond's applications is taking place. To explore the way in which this is advancing, a functional classification attributed to Ropohl (1979), provides a simple construct to map a wide range of technological entities. Table 7.1 provides this map and is followed with a discussion concerning the possible migration of diamond from the mechanical applications of handling matter to manipulating energy and information.

In Matter Processing

The hard property of diamond has resulted in widespread cutting, grinding and polishing applications. Patents by De Beers for cutting tools *(Patent Journal*, 1992a, 1992e) and by Sumitomo for a CVD cutting tool (*Patent Journal*, 1992b) shows that the research frontier continues to be active for matter processing. Tools, such as drill bits, and larger surfaces such as turbine blades would benefit from a fine coating. Patents by GE for a coated drill bit and a reaction chamber to hold drill bits (*Patent Journal*, 1992d), confirms the expected research direction of wider coating applications.

The implications for tool manufacturers are vast. A process technology is advancing that may alter the direction of the industry. The idea that many components merely require a coated surface, while the base can be a simple, ductile and inexpensive material, may transform the tool industry. The impact extends beyond the tool industry and into consumer products, illustrated by Gillette being awarded a patent to coat razor blades with a layer of diamond material (*Patent Journal*, 1993).

Diamond material also features in the development of new composites. One example is a diamond and steel combination called "Diasteel"(*The Economist*, July 25 1992). Here, fullerenes - the third form of carbon, are used to manufacture rapidly cooled Rhondite forming the steel and diamond combination.

Table 7.1 Functional Classification of Synthetic Diamond

	PROCESS	TRANSPORT	STORE
MATTER	Abrasives/Cutting Polishing Coatings/paint Coated razer blades Turbines/Tools X-Ray windows	Bearings Micromachines Biocompatible implants Nuclear waste	Toxic waste storage Carbon-12 (^{12}C)
ENERGY	Speaker diaphragms Light emitting diode Rectifier Resistors & capacitors Printed circuit boards Lasers	Heat sinks Superconductivity Infrared window Coating lenses, windows, cruise missiles Photovoltaic	Battery casing Magnetics
INFORMATION	Semiconductors Thermistor Integrated circuits Sensors Transmitters/VCR's	Flat panel display Photonics Fibre-optics Cutting fibre-optics Decoy virus	Non-volatile RAM Optical computing

Some items would benefit from CVD diamond coatings by having their lifespan extended. Items such as fire grills, razor blades, pots, scalpels and machine-gears would all last longer. Synthetic diamond material has also been used in X-ray windows (Van Enckevort, 1990). Here, the optical properties act the role of a barrier between two environments. This may affect glass technology if thin film can be deposited onto large surfaces to enhance the property of glass. Authors have suggested that coating aeroplane and bus windshields are possible applications. Coating missile warheads is an early indicator of diamond coatings being used in such a protective manner (Harris, 1992:4). A recent development in this area has been a process to spray low cost diamond film onto surfaces (*Inside R&D*, 1996:1). In December 1996 for instance, Hahn achieved a diamond coating over an area of twenty cm^2 (Hahn, 1996:1).

In Matter Transporting

A diamond coated bearing takes advantage of the wear resistance, low coefficient of friction, thermal and chemical properties of diamond. Bearings would last longer and operate in harsh environments (Ramesham, 1990). Using diamond coated bearings in micromachines may also provide an interesting research vein (*Scientific American*, 1995). Here the mechanical advantage of increased wear resistance may be more important than the ability to carry a heavy load.

Since diamond is biocompatible, the possibility of coating body implants is being researched. Coating artificial hip joints and materials that require protection from body fluids may be possibilities (Bachmann and Messier, 1989).

In Matter Storing

The chemical stability of diamond may also encourage containment technologies for waste disposal. Nuclear material and toxic waste need to be transported and stored in a stable chemical environment. Finding a safe storage medium will be vital. Diamond may be part of the solution.

GE has manufactured a diamond with the highest number of atoms per cubic centimetre of any solid at room temperature and this may be a natural density limit of matter storage. GE used carbon-12 (^{12}C) as the source material (*Metals and Minerals Annual Review*, 1991:120; *Design News*, December 1, 1991; Shigley *et al.*, 1993). Perhaps more important, this achievement was made possible by first forming the nucleation material in a CVD chamber and then subjecting the hybrid material to HPHT. Such a route may be crucial to the formation of high quality gem material, since they may more accurately control impurities and growth patterns, and then challenge the gem market.

In Energy Processing

The issue is no longer whether the electronic properties of diamond will be useful but when will the barriers of large area single crystal growth and n-type doping be overcome (Prins, 1996:24). Collins (1989) expressed reservations based on the structural barriers of the material and is indicative of many of the reservation expressed concerning the difficulties of using diamond's electronic capability.

Notwithstanding the reservations, many energy processing applications, such as light-emitting diodes and rectifying diodes have been developed but are not yet commercially viable (Yarbrough and Messier, 1990). De Beers have also explored the electronic frontier and have recently patented a 'light emitting diode device' and a 'diamond compact body' emitting light of a particular wavelength (*Patent Journal*, 1992e).

Coated speaker diaphragms are available commercially and take advantage of the high elastic modulus and low thermal expansion properties of diamond (Zhu *et al.*, 1991). VCR cassette components are diamond coated to take advantage of the low coefficient of friction and wear resistance properties. Diamond material has already taken hold in the market for consumer goods and is expected to expand into other areas.

In Energy Transporting

The use of synthetic diamond is well established as a heat sink - in fact the first synthetic gem appearing on the market was traced back to a diamond heat sink that had been taken out of the electronic component and faceted *(Gems and Gemology*, 1987a). The use of thermal heat sinks may gain momentum as information processors increasingly have to cope with the problem of dissipating heat. Yoder (1992) for example has detailed possible uses as transistors, photovoltaics, resistors, capacitors, printed circuit boards, integrated circuits and non-volatile random access memory (RAM).

In Energy Storing

There may be an application for diamond as a battery casing. Here, the material would provide storage for a toxic substance (Bachmann and Messier, 1989), almost acting as a chemically inert barrier material in the same way that body fluids are prevented from attacking implants. Carbon, as commercially viable synthetic diamond, may well provide the legislators and industrial designers with a suitable compromise.

In Information Process, Transport and Storage

The distinction between processing, transporting and storing information is not easy to make. Unfolding applications suggest that diamond may challenge traditional semiconductor materials. Tokai University in Japan, for instance, has developed a diamond chip that can operate at 1000°C (Okano, 1991). Sensor applications have already emerged such as a neutron detector (*Patent Journal*, 1992c), rheometer and a fluid flow sensor (*Patent Journal*, 1992e).

An interesting development has been the use of diamond as a virus decoy (*Diamond Deposition Science and Technology*, July 18, 1994). Here they are investigating the possibility of attaching virus proteins onto a diamond micron crystal. Carbon, being biocompatible, acts as the carrier of the virus information to the immune system and by that stimulating a response.

There is a move towards using photonics such as fibre-optics for transporting and lasers for processing information. Optical data processing may require a more efficient and robust material to amplify, switch and store data. The underlying trend has been to use photonics, or light as the medium to transport information - in compact disc and Digital Versatile Disc technology for instance (Bell, 1996). This is a fundamental change in the principle of operation to the way in which data is processed, transported and stored. Already, a one square inch flat panel diamond display has been demonstrated to the public at the International Symposium of the Society for Information Display in San Jose California during July 1994. The optical properties may catapult this material to the centre stage of optical computing and telecommunications.

7.4 Blurring of the boundaries

The presence of gem quality synthetic diamonds and diamond material has been well documented in the journal *Gems and Gemology* (Shigley *et al.*, 1995). GE produced the first synthetic gem in 1970, De Beers in late 1970 and Sumitomo followed in 1985. Although gemologists can distinguish synthetic material from natural diamond, there are indications that advanced techniques are now required to perform the distinction (Shigley *et al*, 1992, 1996; Sunagawa, 1995; *Gems and Gemology*, 1996a:44, 1996b:52). It is not surprising therefore that De Beers have developed verification instruments for widespread use (Welbourn *et al.*, 1996).

From evidence presented thus far it appears that synthetic diamond material is poised to enter a period based on the industrial properties. Widespread industrial applications could challenge the mystique of diamond as perceptions concerning the uniqueness of natural diamond change. If the public associate diamond with a carbon based manufactured industrial material, the word 'diamond' may conjure up completely different social connotations with limited romantic appeal. There is potential for conflict between natural diamond as an item of value, based largely on rarity and uniqueness, and the industrial material marketed for the hard, chemical and electrical properties.

In this respect the name *diamond* cannot be registered. This is where the puzzling threat to the industry occurs since the value is in the name, not the material. Lenzen (1983) and more recently, Nassau (1993) proposed that natural diamond material is not under threat. Because synthetic emerald, ruby, sapphire, opal and turquoise have not caused a decline in demand for the natural material, they argue that natural gems may retain a high value associated with rarity. However there is the possibility of a threat to the position that diamond currently occupies in the mind of the holder - a threat that goes beyond the material properties.

Further advances in diamond technology could progressively narrow the gap between synthetic and naturally occurring gems. This will pose a particular challenge to the diamond industry and specifically the custodians of intellectual property for some time.

This chapter has addressed the key question concerning a technological outlook for industrial diamond. The forecast for natural industrial diamond is bleak. The outlook for synthetic diamonds and diamond material is significantly different, and the continued technological advance will promote this material in many different applications. The implications for natural gem diamonds however, is one of concern. There is evidence suggesting that the ubiquitous use of the name “diamond” initiates a slow attack of the unique position occupied by gem diamonds.

CHAPTER EIGHT

CONCLUSION AND RECOMMENDATIONS

Introduction

This thesis began by asking three questions: (i) why have synthetic diamonds been successful? (ii) is the pattern of substitution systematic? (iii) what is the technological outlook for synthetic industrial diamonds? Before these questions could be addressed a number of theoretical points had to be constructed: a philosophy of technology and MOT in particular was provided. Next, STA and substitution theories were presented with the cascade model positioned as the theoretical link. Chapters five, six and seven then presented evidence in support of the three key questions.

This chapter is concerned with the conclusions and recommendation with regard to three major areas: (i) the national level with particular reference to extractive industries, (ii) the diamond industry with reference to further substitution and technological advance, and (iii) further research.

8.1 The national level and extractive industries

Synthetic diamond technologies advanced rapidly in response to changes in the manufacturing principle of operation and performance improvements in the manufacturing process and diamond material. A synthetic material has replaced the natural equivalent. The way this occurred was due to consistent technological advance that was systematic and predictable. Many other extractive industries may be facing a similar challenge, particularly in South Africa. The recommendation for these industries, is to trace the technological path of substitutes. Examine the key changes and note where and when breakthroughs may occur. In doing so, the impact on existing reserves, manufacturing techniques and markets can be assessed. This is far greater than competitor analysis - the underlying technological parameters forcing change must be understood within the extractive industry, the material and technologies that affect the product and process.

8.2 Could the substitution pattern be predicted?

Synthetic industrial diamonds have successfully substituted for natural industrial diamonds. This substitution phenomenon was shown to be systematic and predictable with the data showing an observable delay. The delay could have been due to a by-product affording the defending material a measure of protection. This could have been achieved for example by keeping prices artificially low - a clear possibility when the main product, gem quality material, is highly priced. But in this case the defence has been phyrric since the accumulated natural industrial stock is estimated at around 1,5 billion carats or over 30 years of natural industrial supply.

Considering the final 10 % market share - it is unlikely that substitution will proceed beyond 95%. The reason being that the industrial stockpile is vast and additions to this stock, particularly from Australia and Zaire are substantial.

It is also likely that the move from 90% to 95% market share for synthetic industrial diamond will take place over the next thirty years or so. The delay is expected to persist and the substitution process can be controlled in a way that phases out the final 5% of the natural industrial diamond material.

8.3 The implications for the diamond industry

Chapter seven dealt with the outlook and the implications for the diamond industry. Further process improvements in HPHT are not obvious given the identified barrier in the form of a constrained reaction chamber. Improvements in CVD are expected to continue and to meet the anticipated demands of technological advance outlined as stage three. Here, diamond is expected to be used increasingly in complex structures and environments. As entities demand the favourable chemical, optical, thermal and spread of properties, it is likely that the capability to manufacture the material with precision will be developed under CVD conditions.

There seems little doubt that natural material will not meet the technological challenge beyond mechanical applications. The level of impurities and irregular structure provides the required product imperfections that should lead to the ultimate fate of natural industrial material.

The more challenging substitution battle now appears to be with the gem market. Already noted is the clash over the use of the name "diamond" since synthetic material is on the gem market. De Beers has taken significant steps to identify synthetic material. But this research has raised a far more subtle threat: the image of diamond may be diluted and the concept of rarity and uniqueness may be challenged. Substitution in this vein cannot be modelled or empirically evaluated and the dilution of intellectual capital, or the name diamond, under conditions where such property cannot be legally protected, presents a vast challenge to the creators of the diamond image.

8.4 Recommendations

The recommendation regarding further technological advance in manufacturing technique is to scan the technological landscape for breakthroughs in CVD. For example, the following CVD achievements would be significant:

i. Large surface single crystal growth,

ii. Sound bonding with materials of different thermal expansion rates,

iii. Deposition rates exceeding 1000 microns per hour,

iv. A decline in the capital cost of equipment to less than US$ 1000 000,

v. The manufacture of semiconducting diamond,

vi. A significant decrease in operating temperature.

Regarding further industrial diamond substitution, the following is recommended:

i. The financial feasibility of moving natural industrial grade material to market must be undertaken,

ii. Mining ventures based on the viability of natural industrial material should be questioned,

iii. The extent to which natural industrial material can be used in the gem trade or alternative niche markets should be explored.

With regard to possible gem substitution, the following is recommended:

i. Developing equipment that can differentiate the material easily will be crucial from mine to Point of Sale,

ii. Exploring the possibility of fingerprinting natural material,

iii. Exploring the possibility of branding the material before the image is tainted,

8.5 Further research

The further research projects concern the use of the existing industrial stockpile and the manner in which the diamond name can be protected. Both may prove crucial for the future health of the gem diamond industry. For the synthetic producers, further research in bonding techniques such that diamond's favourable properties can be imparted onto foreign surfaces would be useful.

Now that substitution in the industrial diamond industry has been shown to be systematic, further useful research would be to examine other extractive industries, such as iron and copper. Also, the variable delay coefficient improved the accuracy of the model and it would be useful to model other industries where a by-product may offer the defending technology an advantage.

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APPENDIX A

MATHEMATICS UNDERPINNING THE DELAYED LOGISTIC

The Sharif and Kabir form of substitution can be stated as:

$$(1-\sigma)[\ln\frac{f}{F-f}]+\sigma[\ln\frac{f}{F-f}+\frac{F}{F-f}]=C_1+C_2t \tag{A.1}$$

where:

F = market share ceiling,
f = market share at time t,
t = time,
C_1, C_2 = constants; and,
σ = dimensionless factor, $0 \leq \sigma \geq 1$,

and simplified as follows;

$$\ln\frac{f}{F-f}+\sigma\frac{F}{F-f}=C_1+C_2t. \tag{A.2}$$

Sigma (σ) is noted here at time t_1 which conforms to the hypothesised time dependant delay coefficient. For Fisher and Pry, Blackman, and Floyd the delay coefficient is constant and not time dependant. In this form all the models can be evaluated. For example the Fisher and Pry solution of :

$$\ln\frac{f}{1-f}=C_1+C_2t. \qquad (A.3)$$

is simply the Sharif and Kabir function with $F = 100\%$ and $\sigma =$ to zero.

The log transformation of this function may result in a linear relationship between time and the function, the coefficients of which are estimated using Ordinary Least Squares (OLS). Once the OLS function has been established, the corresponding "S" curve values can be derived as follows: For the Fisher and Pry predicted "S" curve:

Predicted Log Linear "f/1-f" Value/[1+ Predicted Log Linear "f/1-f" Value]

The "S" curve solution for Blackman, Floyd and Sharif and Kabir functions can be simplified and evaluated iteratively in the following way:

$$e^{\ln\frac{f}{F-f}+\sigma\frac{F}{F-f}}=e^{C_1+C_2t_1} \qquad (A.4)$$

$$\frac{f}{F-f}e^{\frac{\sigma}{F-f}}=e^{C_1+C_2t_1} \qquad (A.5)$$

$$\frac{f}{F-f}e^{\sigma[F-f]^{-1}}=e^{C_1+C_2t_1} \tag{A.6}$$

Then to solve for f where values for F and σ are known the following function must iterate to reach a target value of approximately zero to say 4 decimal places or an appropriate accuracy level.

$$[e^{C_1+C_2t_1}]-[\frac{f}{F-f}e^{\sigma[F-f]^{-1}}]=0 \tag{A.7}$$

APPENDIX B

DIAMOND DATA : 1920-1994

Natural Diamond						
Carats	1920	1921	1922	1923	1924	1925
India	85	126	171	115	67	48
Brazil	45,000	50,000	60,000	60,000	60,000	50,000
South Africa	2,545,017	828,036	669,559	2,053,095	2,440,398	2,430,128
Namibia	606,424	171,321	144,156	433,229	492,696	515,860
Guyana	39,363	105,325	167,981	220,162	190,501	187,743
Zaire	274,103	280,655	250,292	414,954	548,274	883,903
Angola	93,526	106,719	98,683	94,478	118,016	123,282
Ghana	215	1,789	6,535	23,342	53,035	84,985
Tanzania						411
C.A.R.						
Guinea						
Sierra Leone						
Venezuela						
Ivory Coast						
Liberia						
Botswana						
Lesotho						
Russia						
Indonesia	410	1,770	1,948	1,139	349	667
Australia	3,523	1,563	1,000	175	284	210
China						
Swaziland						
Others	249	141	256	543	596	189
World Total	3,607,915	1,547,445	1,400,581	3,301,232	3,904,216	4,277,426

Natural Diamond

Carats	1926	1927	1928	1929	1930	1931
India	69	113	824	1,628	1,321	639
Brazil	50,000	50,000	190,000	144,000	132,500	90,000
South Africa	3,217,967	4,708,038	4,372,857	3,661,212	3,163,591	2,119,156
Namibia	683,801	723,877	503,142	597,189	415,047	71,532
Guyana	168,507	178,402	135,993	125,799	110,042	63,479
Zaire	1,114,384	1,041,544	1,647,700	1,907,765	2,518,100	3,528,379
Angola	154,369	200,809	237,511	311,903	329,824	351,495
Ghana	299,835	460,959	698,826	660,536	861,119	880,479
Tanzania	6,695	18,766	24,681	24,432	12,295	7,658
C.A.R.					34	1,258
Guinea						
Sierra Leone						
Venezuela						
Ivory Coast						
Liberia						
Botswana						
Lesotho						
Russia						
Indonesia	277	250	242	585	459	294
Australia	64	199	28	119	667	725
China						
Swaziland						
Others	106	126	54	232	19	9
World Total	5,696,074	7,383,083	7,811,858	7,435,400	7,545,018	7,115,103

Natural Diamond

Carats	1932	1933	1934	1935	1936	1937
India	1,254	2,342	2,480	1,401	1,457	1,178
Brazil	37,000	34,000	42,500	39,100	136,462	119,303
South Africa	798,382	506,553	440,313	676,722	623,923	1,030,434
Namibia	17,944	2,374	4,126	128,464	184,917	196,803
Guyana	61,780	49,855	46,008	47,785	41,067	35,958
Zaire	3,872,171	2,256,771	1,450,000	3,169,090	4,634,266	4,925,228
Angola	367,334	373,624	425,963	481,615	577,531	626,424
Ghana	842,297	803,985	2,391,609	1,349,847	1,414,677	1,577,661
Tanzania	1,387	1,432	1,155	1,446	2,704	3,234
C.A.R.	1,480	570	354	138	1,998	6,197
Guinea					5,500	54,687
Sierra Leone	749	32,017	68,633	295,483	616,200	913,401
Venezuela						
Ivory Coast			49			
Liberia						
Botswana						
Lesotho						
Russia						
Indonesia	274	445	1,069	4,219	773	981
Australia	251	123	49	50	650	200
China						
Swaziland						
Others	300		12		11	10
World Total	6,002,603	4,064,091	4,874,320	6,195,360	8,242,136	9,491,699

Natural Diamond						
Carats	1938	1939	1940	1941	1942	1943
India	1,729	1,604	1,526	2,107	2,823	2,533
Brazil	114,205	208,244	325,000	325,000	300,000	275,000
South Africa	1,238,608	1,249,828	543,463	158,422	118,821	302,329
Namibia	154,856	36,410	30,014	46,578	56,420	94,427
Guyana	32,522	34,266	28,194	26,710	22,791	18,751
Zaire	7,205,921	8,360,166	9,602,837	5,865,756	6,018,236	4,881,742
Angola	651,265	690,447	784,271	786,979	791,853	794,990
Ghana	1,296,763	1,087,651	572,560	1,084,294	1,055,735	1,317,795
Tanzania	3,576	3,445	6,221	29,052	40,327	52,998
C.A.R.	15,914	17,461	31,927	33,565	46,235	56,185
Guinea	52,934	56,316	65,709	57,735	49,866	36,193
Sierra Leone	686,622	683,560	885,414	849,912	1,046,187	834,492
Venezuela	13,599	7,969	14,525	29,416	34,048	22,846
Ivory Coast						
Liberia						
Botswana						
Lesotho						
Russia						
Indonesia	1,618	2,344	3,554			
Australia	300	103		300	183	429
China						
Swaziland						
Others			17,225			
World Total	11,470,432	12,439,814	12,912,440	9,295,826	9,583,525	8,690,710

Natural Diamond						
Carats	1944	1945	1946	1947	1948	1949
India	1,837	1,380	1,107	1,284	2,426	1,632
Brazil	370,000	275,000	325,000	275,000	250,000	250,000
South Africa	933,682	1,222,945	1,349,099	1,242,423	1,382,327	1,264,759
Namibia	154,379	152,629	165,150	179,554	200,691	280,501
Guyana	16,339	15,852	31,732	24,669	36,563	34,790
Zaire	7,533,365	10,385,955	6,033,452	5,474,517	5,824,567	9,649,968
Angola	799,120	803,887	806,962	799,210	795,509	769,981
Ghana	1,165,857	812,450	809,000	747,034	878,092	963,435
Tanzania	90,067	119,139	120,045	87,943	149,926	194,874
C.A.R.	57,052	82,849	87,230	107,076	118,800	122,928
Guinea	69,726	79,802	51,834	53,749	77,970	94,996
Sierra Leone	608,734	503,999	559,232	605,554	465,698	494,119
Venezuela	22,037	12,762	20,912	61,634	75,512	56,662
Ivory Coast						
Liberia						
Botswana						
Lesotho						
Russia						
Indonesia						
Australia	198	73	50	73		5
China						
Swaziland						
Others						6
World Total	11,822,393	14,468,722	10,360,805	9,659,720	10,258,081	14,178,656

Natural Diamond						
Carats	1950	1951	1952	1953	1954	1955
India	2,769	1,674	2,054	2,207	1,955	1,787
Brazil	250,000	250,000	250,000	250,000	250,000	250,000
South Africa	1,731,510	2,228,911	2,383,211	2,717,620	2,858,688	2,628,917
Namibia	504,604	502,983	537,450	610,332	683,560	812,848
Guyana	37,462	43,260	38,305	35,306	30,073	33,300
Zaire	10,147,470	10,564,755	11,608,828	12,580,270	12,620,114	13,041,497
Angola	538,867	734,324	743,302	729,376	721,606	743,377
Ghana	1,187,915	1,752,879	2,189,557	2,180,728	2,135,459	2,258,270
Tanzania	164,996	108,625	143,023	172,304	326,009	325,523
C.A.R.	111,407	147,791	156,708	140,143	152,528	136,958
Guinea	124,568	100,980	136,080	179,850	217,650	318,520
Sierra Leone	655,485	474,821	452,618	481,709	400,076	418,077
Venezuela	60,389	63,226	92,291	84,784	96,983	141,147
Ivory Coast						
Liberia				11,543	1,244	29,533
Botswana						450
Lesotho						
Russia				11,543	1,244	29,533
Indonesia				11,543	1,244	29,532
Australia	130	129	49	736	1,564	731
China						
Swaziland						
Others		40	48	6	2	
World Total	15,517,572	16,974,398	18,733,524	20,200,000	20,499,999	21,200,000

Natural Diamond						
Carats	1956	1957	1958	1959	1960	1961
India	1,499	790	1,540	682	1,159	1,313
Brazil	250,000	250,000	250,000	200,000	200,000	300,000
South Africa	2,585,728	2,578,975	2,702,250	2,838,332	3,141,463	3,787,862
Namibia	988,653	996,965	903,576	930,659	935,382	905,815
Guyana	29,816	29,037	33,091	62,328	101,004	112,679
Zaire	14,010,478	15,646,730	16,673,474	14,855,170	13,453,563	18,143,000
Angola	740,035	864,372	1,001,236	1,015,688	1,056,827	1,147,438
Ghana	2,539,429	3,124,825	3,131,695	3,076,072	3,273,000	3,214,000
Tanzania	358,717	390,971	521,064	643,277	548,376	691,668
C.A.R.	145,837	109,231	105,000	86,571	69,641	111,484
Guinea	389,880	92,000	116,000	657,000	1,116,000	1,200,000
Sierra Leone	647,797	863,202	1,490,037	1,290,964	1,909,180	2,295,279
Venezuela	93,833	122,597	90,004	94,986	70,867	134,176
Ivory Coast		155,000	164,315	187,950	199,120	549,330
Liberia	39,098	24,164	9,733	638,000	866,500	1,095,000
Botswana	620	2,500	6,664	8,713	95	
Lesotho						
Russia	39,098	24,164	9,733	800,000	950,000	1,500,000
Indonesia	39,099	24,165	9,733			
Australia	383	312	158	37	6	
China						
Swaziland						
Others						
World Total	22,900,000	25,300,000	27,219,303	27,386,429	27,892,183	35,189,044

Natural Diamond

Carats	1962	1963	1964	1965	1966	1967
India	1,131	1,432	2,260	4,466	2,113	7,250
Brazil	300,000	300,000	600,000	600,000	600,000	230,000
South Africa	3,917,891	4,375,572	4,449,978	5,025,598	6,036,677	6,693,600
Namibia	1,027,233	1,194,630	1,541,544	1,656,234	1,758,956	1,699,169
Guyana	100,145	99,748	109,682	112,873	98,887	71,000
Zaire	14,656,000	14,764,000	19,770,000	17,503,874	17,428,483	18,200,000
Angola	1,081,104	1,083,571	1,149,068	1,155,725	1,268,141	1,288,540
Ghana	3,210,060	2,681,700	2,668,000	2,273,000	2,815,500	3,600,000
Tanzania	660,029	590,949	650,461	756,969	946,656	926,758
C.A.R.	265,417	402,186	442,281	538,810	539,935	524,000
Guinea	350,000	54,000	300,000	300,000	300,000	70,000
Sierra Leone	1,637,402	1,783,547	1,649,847	1,461,145	1,436,722	1,560,000
Venezuela	176,493	69,674	115,604	88,800	84,695	85,500
Ivory Coast	283,911	179,660	200,270	198,179	183,435	176,000
Liberia	905,000	748,000	600,000	600,000	600,000	550,000
Botswana						0
Lesotho			2,472	5,492	12,506	0
Russia	2,750,000	3,250,000	3,700,000	5,350,000	5,500,000	7,000,000
Indonesia						3,400
Australia						0
China						0
Swaziland						0
Others				45,534	47,887	0
World Total	31,321,816	31,578,669	37,951,467	37,676,699	39,660,593	42,685,217

Natural Diamond						
Carats	1968	1969	1970	1971	1972	1973
India	8,764	11,896	16,000	20,000	20,009	21,427
Brazil	275,000	250,000	190,000	160,000	200,000	300,000
South Africa	5,459,749	7,908,541	8,160,101	7,581,272	7,700,000	7,800,000
Namibia	1,722,259	2,148,941	1,865,439	1,646,238	1,600,000	1,600,000
Guyana	51,549	66,312	59,470	59,000	48,666	52,502
Zaire	17,500,000	17,200,000	17,500,000	17,000,000	17,000,000	17,000,000
Angola	1,669,187	2,021,534	2,239,912	2,425,000	2,200,000	2,200,000
Ghana	5,000,000	4,150,000	2,871,971	2,850,000	2,500,000	2,300,000
Tanzania	702,377	777,266	707,230	971,000	600,000	600,000
C.A.R.	609,360	526,946	482,447	430,000	400,000	400,000
Guinea	93,000	95,000	75,000	0	80,000	80,000
Sierra Leone	1,660,000	1,934,979	2,047,072	2,275,000	1,800,000	1,700,000
Venezuela	140,400	220,287	500,000	650,000	400,000	500,000
Ivory Coast	187,000	190,000	212,808	400,000	300,000	300,000
Liberia	753,000	852,000	553,026	540,000	500,000	600,000
Botswana	0	0	544,006	825,000	2,400,000	2,400,000
Lesotho	11,914	29,788	16,539	8,014	9,018	9,000
Russia	7,500,000	10,500,000	12,000,000	12,000,000	12,000,000	12,000,000
Indonesia	20,400	0	15,000	30,000	15,000	15,000
Australia	0	0	0	0		
China	0	0	0	0		
Swaziland	0	0	0	0		
Others	0	0	0	0	27,307	22,071
World Total	43,363,959	48,883,490	50,056,021	49,870,524	49,800,000	49,900,000

Natural Diamond

Carats	1974	1975	1976	1977	1978	1979
India	20,975	19,994	20,487	18,297	15,942	15,229
Brazil	300,000	400,000	500,000	500,000	500,000	500,000
South Africa	8,000,000	7,800,000	7,300,000	7,900,000	8,000,000	8,600,000
Namibia	1,600,000	1,740,000	1,690,000	2,000,000	1,900,000	1,650,000
Guyana	29,976	20,762	13,897	16,679	17,226	15,824
Zaire	17,000,000	17,000,000	17,000,000	17,000,000	17,000,000	15,500,000
Angola	1,940,000	500,000	400,000	500,000	650,000	840,000
Ghana	2,400,000	2,250,000	2,220,000	2,224,000	1,500,000	1,500,000
Tanzania	600,000	600,000	500,000	400,000	350,000	340,000
C.A.R.	400,000	400,000	400,000	400,000	300,000	300,000
Guinea	80,000	80,000	80,000	80,000	80,000	85,000
Sierra Leone	1,700,000	1,090,000	1,100,000	750,000	800,000	850,000
Venezuela	500,000	600,000	600,000	800,000	800,000	800,000
Ivory Coast	300,000	300,000	200,000	100,000	100,000	100,000
Liberia	600,000	600,000	500,000	500,000	500,000	500,000
Botswana	2,400,000	2,370,000	2,360,000	2,660,000	2,800,000	4,400,000
Lesotho	11,798	3,466	7,051	22,688	48,977	52,421
Russia	12,000,000	12,000,000	12,000,000	12,000,000	12,000,000	12,000,000
Indonesia	15,000	15,000	15,000	15,000	15,000	15,000
Australia						
China						
Swaziland						
Others	42,251	60,778	63,565	47,336	22,855	16,526
World Total	49,940,000	47,850,000	46,970,000	47,934,000	47,400,000	48,080,000

Natural Diamond						
Carats	1980	1981	1982	1983	1984	1985
India	14,432	14,834	13,007	14,286	15,887	16,271
Brazil	500,000	500,000	500,000	750,000	800,927	450,000
South Africa	8,700,000	9,500,000	8,900,000	10,000,000	9,800,000	9,900,000
Namibia	1,560,000	1,250,000	1,000,000	960,000	930,000	910,000
Guyana	10,236	9,533	11,492	12,362	7,496	11,868
Zaire	14,000,000	12,500,000	12,200,000	13,000,000	18,500,000	19,600,000
Angola	1,500,000	1,400,000	1,300,000	1,000,000	920,000	900,000
Ghana	1,100,000	1,000,000	1,000,000	800,000	330,000	600,000
Tanzania	256,000	370,000	380,000	370,000	360,000	350,000
C.A.R.	300,000	300,000	300,000	300,000	300,000	500,000
Guinea	38,000	38,000	40,000	40,000	48,300	87,800
Sierra Leone	600,000	300,000	250,000	250,000	420,000	400,000
Venezuela	800,000	750,000	750,000	250,000	272,922	215,272
Ivory Coast	100,000	100,000	100,000	200,000	200,000	200,000
Liberia	500,000	500,000	500,000	400,000	400,000	400,000
Botswana	5,100,000	4,960,000	7,770,000	10,700,000	12,900,000	12,600,000
Lesotho	53,714	52,921	42,119	0	0	0
Russia	12,000,000	12,000,000	12,000,000	12,000,000	12,000,000	12,000,000
Indonesia	15,000	15,000	15,000	27,000	27,000	27,000
Australia			457,000	6,200,000	5,700,000	7,060,000
China	900,000	950,000	1,000,000	1,000,000	1,000,000	1,000,000
Swaziland					16,837	21,128
Others	68,618	69,712	78,382	106,352	174,480	305,933
World Total	48,116,000	46,580,000	48,607,000	58,380,000	65,123,849	67,555,272

Natural Diamond

Carats	1986	1987	1988	1989	1990	1991
India	16,116	18,915	14,613			
Brazil	638,269	737,000	698,200	750,000	1,550,000	1,500,000
South Africa	10,200,000	9,600,000	9,000,000	9,000,000	8,500,000	8,200,000
Namibia	1,000,000	1,000,000	900,000	900,000	800,000	1,400,000
Guyana	9,379	7,469	4,242	8,803	14,877	21,909
Zaire	20,500,000	21,000,000	23,000,000	20,000,000	24,000,000	19,000,000
Angola	200,000	900,000	1,000,000	1,200,000	1,300,000	1,300,000
Ghana	550,000	440,000	300,000	200,000	200,000	200,000
Tanzania	300,000	150,000	130,000	76,000	0	110,000
C.A.R.	600,000	600,000	450,000	600,000	500,000	500,000
Guinea	0	0	0	200,000	100,000	100,000
Sierra Leone	400,000	360,000	300,000	600,000	700,000	600,000
Venezuela	211,731	113,000	151,800	150,000	150,000	500,000
Ivory Coast	200,000	200,000	200,000	200,000	200,000	200,000
Liberia	300,000	350,000	350,000	300,000	300,000	100,000
Botswana	13,000,000	13,000,000	15,000,000	15,200,000	17,351,727	16,506,461
Lesotho	0	0	0	0	0	0
Russia	12,000,000	12,000,000	12,000,000	12,000,000	15,000,000	13,000,000
Indonesia	27,000	30,000				0
Australia	29,200,000	30,000,000	34,826,000	37,000,000	36,000,000	36,000,000
China	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,011,000
Swaziland	39,144	40,000	72,676			0
Others	408,361	353,616	358,469	191,197	185,123	278,091
World Total	90,800,000	91,900,000	99,756,000	99,576,000	107,851,727	100,527,461

Natural Diamond			
Carats	1992	1993	1994
India			18,000
Brazil	2,094,500	2,117,540	2,000,000
South Africa	10,000,000	10,110,000	10,700,000
Namibia	1,600,000	1,617,600	1,300,000
Guyana	22,150	22,394	500,000
Zaire	15,000,000	15,165,000	18,000,000
Angola	2,700,000	2,729,700	1,400,000
Ghana	500,000	505,500	600,000
Tanzania	111,210	112,433	0
C.A.R.	400,000	404,400	500,000
Guinea	100,000	101,100	500,000
Sierra Leone	450,000	454,950	400,000
Venezuela	505,500	511,061	500,000
Ivory Coast	200,000	202,200	0
Liberia	0	0	0
Botswana	15,900,000	16,074,900	15,600,000
Lesotho	0	0	0
Russia	11,250,000	11,373,750	11,500,000
Indonesia	0	0	10,000
Australia	40,000,000	40,440,000	43,800,000
China	1,022,121	1,033,364	300,000
Swaziland	0	0	0
Others	277,850	280,906	300,000
World Total	102,133,331	103,256,798	107,928,000

NATURAL DIAMOND GRADES 1920-1994

	%	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
India	Gem	70	70	70	70	70	70	70	70	70	70
	Industrial	30	30	30	30	30	30	30	30	30	30
Brazil	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
South Africa	Gem	25	25	25	25	25	25	25	25	25	25
	Near-Gem	37	37	37	37	37	37	37	37	37	37
	Industrial	38	38	38	38	38	38	38	38	38	38
Namibia	Gem	95	95	95	95	95	95	95	95	95	95
	Industrial	5	5	5	5	5	5	5	5	5	5
Guyana	Gem	50	50	50	50	50	50	50	50	50	50
	Industrial	50	50	50	50	50	50	50	50	50	50
Zaire	Gem	5	5	5	5	5	5	5	5	5	5
	Near-Gem	30	30	30	30	30	30	30	30	30	30
	Industrial	65	65	65	65	65	65	65	65	65	65
Angola	Gem	70	70	70	70	70	70	70	70	70	70
	Near-Gem	20	20	20	20	20	20	20	20	20	20
	Industrial	10	10	10	10	10	10	10	10	10	10
Ghana	Gem	8	8	8	8	8	8	8	8	8	8
	Near-Gem	25	25	25	25	25	25	25	25	25	25
	Industrial	67	67	67	67	67	67	67	67	67	67
Tanzania	Gem	50	50	50	50	50	50	50	50	50	50
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	10	10	10	10	10	10	10	10	10	10
C.A.R	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
Guinea	Gem	70	70	70	70	70	70	70	70	70	70
	Near-Gem	15	15	15	15	15	15	15	15	15	15
	Industrial	15	15	15	15	15	15	15	15	15	15
Sierra Leone	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
Venezuela	Gem	29	29	29	29	29	29	29	29	29	29
	Near-Gem	36	36	36	36	36	36	36	36	36	36
	Industrial	35	35	35	35	35	35	35	35	35	35
Ivory Coast	Gem	50	50	50	50	50	50	50	50	50	50
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	10	10	10	10	10	10	10	10	10	10
Liberia	Gem	25	25	25	25	25	25	25	25	25	25
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	35	35	35	35	35	35	35	35	35	35
Botswana	Gem	19	19	19	19	19	19	19	19	19	19
	Near-Gem	51	51	51	51	51	51	51	51	51	51
	Industrial	30	30	30	30	30	30	30	30	30	30
Lesotho	Gem	60	60	60	60	60	60	60	60	60	60
	Industrial	40	40	40	40	40	40	40	40	40	40
Russia	Gem	26	26	26	26	26	26	26	26	26	26
	Near-Gem	44	44	44	44	44	44	44	44	44	44
	Industrial	30	30	30	30	30	30	30	30	30	30
Indonesia	Gem	95	95	95	95	95	95	95	95	95	95
	Industrial	5	5	5	5	5	5	5	5	5	5
Australia	Gem	5	5	5	5	5	5	5	5	5	5
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	55	55	55	55	55	55	55	55	55	55
China	Gem	20	20	20	20	20	20	20	20	20	20
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	40	40	40	40	40	40	40	40	40	40
Swaziland	Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	60	60	60	60	60	60	60	60	60	60
Others	Gem	52	52	52	52	52	52	52	52	52	52
	Near-Gem	38	38	38	38	38	38	38	38	38	38
	Industrial	10	10	10	10	10	10	10	10	10	10
World Total	Gem	37	35	36	35	34	32	31	30	26	27
	Near-Gem	29	28	26	28	29	29	29	30	31	30
	Industrial	34	37	38	37	37	40	40	40	43	43

	%	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939
India	Gem	70	70	70	70	70	70	70	70	70	70
	Industrial	30	30	30	30	30	30	30	30	30	30
Brazil	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
South Africa	Gem	25	25	25	25	25	25	25	25	25	25
	Near-Gem	37	37	37	37	37	37	37	37	37	37
	Industrial	38	38	38	38	38	38	38	38	38	38
Namibia	Gem	95	95	95	95	95	95	95	95	95	95
	Industrial	5	5	5	5	5	5	5	5	5	5
Guyana	Gem	50	50	50	50	50	50	50	50	50	50
	Industrial	50	50	50	50	50	50	50	50	50	50
Zaire	Gem	5	5	5	5	5	5	5	5	5	5
	Near-Gem	30	30	30	30	30	30	30	30	30	30
	Industrial	65	65	65	65	65	65	65	65	65	65
Angola	Gem	70	70	70	70	70	70	70	70	70	70
	Near-Gem	20	20	20	20	20	20	20	20	20	20
	Industrial	10	10	10	10	10	10	10	10	10	10
Ghana	Gem	8	8	8	8	8	8	8	8	8	8
	Near-Gem	25	25	25	25	25	25	25	25	25	25
	Industrial	67	67	67	67	67	67	67	67	67	67
Tanzania	Gem	50	50	50	50	50	50	50	50	50	50
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	10	10	10	10	10	10	10	10	10	10
C.A.R	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
Guinea	Gem	70	70	70	70	70	70	70	70	70	70
	Near-Gem	15	15	15	15	15	15	15	15	15	15
	Industrial	15	15	15	15	15	15	15	15	15	15
Sierra Leone	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
Venezuela	Gem	29	29	29	29	29	29	29	29	29	29
	Near-Gem	36	36	36	36	36	36	36	36	36	36
	Industrial	35	35	35	35	35	35	35	35	35	35
Ivory Coast	Gem	50	50	50	50	50	50	50	50	50	50
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	10	10	10	10	10	10	10	10	10	10
Liberia	Gem	25	25	25	25	25	25	25	25	25	25
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	35	35	35	35	35	35	35	35	35	35
Botswana	Gem	19	19	19	19	19	19	19	19	19	19
	Near-Gem	51	51	51	51	51	51	51	51	51	51
	Industrial	30	30	30	30	30	30	30	30	30	30
Lesotho	Gem	60	60	60	60	60	60	60	60	60	60
	Industrial	40	40	40	40	40	40	40	40	40	40
Russia	Gem	26	26	26	26	26	26	26	26	26	26
	Near-Gem	44	44	44	44	44	44	44	44	44	44
	Industrial	30	30	30	30	30	30	30	30	30	30
Indonesia	Gem	95	95	95	95	95	95	95	95	95	95
	Industrial	5	5	5	5	5	5	5	5	5	5
Australia	Gem	5	5	5	5	5	5	5	5	5	5
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	55	55	55	55	55	55	55	55	55	55
China	Gem	20	20	20	20	20	20	20	20	20	20
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	40	40	40	40	40	40	40	40	40	40
Swaziland	Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	60	60	60	60	60	60	60	60	60	60
Others	Gem	52	52	52	52	52	52	52	52	52	52
	Near-Gem	38	38	38	38	38	38	38	38	38	38
	Industrial	10	10	10	10	10	10	10	10	10	10
World Total	Gem	23	17	13	16	16	18	18	20	16	15
	Near-Gem	30	30	29	29	27	28	29	29	29	30
	Industrial	47	53	58	56	57	54	53	51	54	55

	%	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949
India	Gem	70	70	70	70	70	70	70	70	70	70
	Industrial	30	30	30	30	30	30	30	30	30	30
Brazil	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
South Africa	Gem	25	25	25	25	25	25	25	25	25	25
	Near-Gem	37	37	37	37	37	37	37	37	37	37
	Industrial	38	38	38	38	38	38	38	38	38	38
Namibia	Gem	95	95	95	95	95	95	95	95	95	95
	Industrial	5	5	5	5	5	5	5	5	5	5
Guyana	Gem	50	50	50	50	50	50	50	50	50	50
	Industrial	50	50	50	50	50	50	50	50	50	50
Zaire	Gem	5	5	5	5	5	5	5	5	5	5
	Near-Gem	30	30	30	30	30	30	30	30	30	30
	Industrial	65	65	65	65	65	65	65	65	65	65
Angola	Gem	70	70	70	70	70	70	70	70	70	70
	Near-Gem	20	20	20	20	20	20	20	20	20	20
	Industrial	10	10	10	10	10	10	10	10	10	10
Ghana	Gem	8	8	8	8	8	8	8	8	8	8
	Near-Gem	25	25	25	25	25	25	25	25	25	25
	Industrial	67	67	67	67	67	67	67	67	67	67
Tanzania	Gem	50	50	50	50	50	50	50	50	50	50
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	10	10	10	10	10	10	10	10	10	10
C A R	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
Guinea	Gem	70	70	70	70	70	70	70	70	70	70
	Near-Gem	15	15	15	15	15	15	15	15	15	15
	Industrial	15	15	15	15	15	15	15	15	15	15
Sierra Leone	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
Venezuela	Gem	29	29	29	29	29	29	29	29	29	29
	Near-Gem	36	36	36	36	36	36	36	36	36	36
	Industrial	35	35	35	35	35	35	35	35	35	35
Ivory Coast	Gem	50	50	50	50	50	50	50	50	50	50
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	10	10	10	10	10	10	10	10	10	10
Liberia	Gem	25	25	25	25	25	25	25	25	25	25
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	35	35	35	35	35	35	35	35	35	35
Botswana	Gem	19	19	19	19	19	19	19	19	19	19
	Near-Gem	51	51	51	51	51	51	51	51	51	51
	Industrial	30	30	30	30	30	30	30	30	30	30
Lesotho	Gem	60	60	60	60	60	60	60	60	60	60
	Industrial	40	40	40	40	40	40	40	40	40	40
Russia	Gem	26	26	26	26	26	26	26	26	26	26
	Near-Gem	44	44	44	44	44	44	44	44	44	44
	Industrial	30	30	30	30	30	30	30	30	30	30
Indonesia	Gem	95	95	95	95	95	95	95	95	95	95
	Industrial	5	5	5	5	5	5	5	5	5	5
Australia	Gem	5	5	5	5	5	5	5	5	5	5
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	55	55	55	55	55	55	55	55	55	55
China	Gem	20	20	20	20	20	20	20	20	20	20
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	40	40	40	40	40	40	40	40	40	40
Swaziland	Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	60	60	60	60	60	60	60	60	60	60
Others	Gem	52	52	52	52	52	52	52	52	52	52
	Near-Gem	38	38	38	38	38	38	38	38	38	38
	Industrial	10	10	10	10	10	10	10	10	10	10
World Total	Gem	16	19	19	21	18	15	20	21	20	17
	Near-Gem	30	29	29	29	29	30	30	30	30	29
	Industrial	55	52	51	51	53	55	50	49	50	54

	%	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
India	Gem	70	70	70	70	70	70	70	70	70	70
	Industrial	30	30	30	30	30	30	30	30	30	30
Brazil	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
South Africa	Gem	25	25	25	25	25	25	25	25	25	25
	Near-Gem	37	37	37	37	37	37	37	37	37	37
	Industrial	38	38	38	38	38	38	38	38	38	38
Namibia	Gem	95	95	95	95	95	95	95	95	95	95
	Industrial	5	5	5	5	5	5	5	5	5	5
Guyana	Gem	50	50	50	50	50	50	50	50	50	50
	Industrial	50	50	50	50	50	50	50	50	50	50
Zaire	Gem	5	5	5	5	5	5	5	5	5	5
	Near-Gem	30	30	30	30	30	30	30	30	30	30
	Industrial	65	65	65	65	65	65	65	65	65	65
Angola	Gem	70	70	70	70	70	70	70	70	70	70
	Near-Gem	20	20	20	20	20	20	20	20	20	20
	Industrial	10	10	10	10	10	10	10	10	10	10
Ghana	Gem	8	8	8	8	8	8	6	6	8	8
	Near-Gem	25	25	25	25	25	25	25	25	25	25
	Industrial	67	67	67	67	67	67	67	67	67	67
Tanzania	Gem	50	50	50	50	50	50	50	50	50	50
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	10	10	10	10	10	10	10	10	10	10
C.A.R.	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
Guinea	Gem	70	70	70	70	70	70	70	70	70	70
	Near-Gem	15	15	15	15	15	15	15	15	15	15
	Industrial	15	15	15	15	15	15	15	15	15	15
Sierra Leone	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
Venezuela	Gem	29	29	29	29	29	29	29	29	29	29
	Near-Gem	36	36	36	36	36	36	36	36	36	36
	Industrial	35	35	35	35	35	35	35	35	35	35
Ivory Coast	Gem	50	50	50	50	50	50	50	50	50	50
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	10	10	10	10	10	10	10	10	10	10
Liberia	Gem	25	25	25	25	25	25	25	25	25	25
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	35	35	35	35	35	35	35	35	35	35
Botswana	Gem	19	19	19	19	19	19	19	19	19	19
	Near-Gem	51	51	51	51	51	51	51	51	51	51
	Industrial	30	30	30	30	30	30	30	30	30	30
Lesotho	Gem	60	60	60	60	60	60	60	60	60	60
	Industrial	40	40	40	40	40	40	40	40	40	40
Russia	Gem	26	26	26	26	26	26	26	26	26	26
	Near-Gem	44	44	44	44	44	44	44	44	44	44
	Industrial	30	30	30	30	30	30	30	30	30	30
Indonesia	Gem	95	95	95	95	95	95	95	95	95	95
	Industrial	5	5	5	5	5	5	5	5	5	5
Australia	Gem	5	5	5	5	5	5	5	5	5	5
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	55	55	55	55	55	55	55	55	55	55
China	Gem	20	20	20	20	20	20	20	20	20	20
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	40	40	40	40	40	40	40	40	40	40
Swaziland	Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	60	60	60	60	60	60	60	60	60	60
Others	Gem	52	52	52	52	52	52	52	52	52	52
	Near-Gem	38	38	38	38	38	38	38	38	38	38
	Industrial	10	10	10	10	10	10	10	10	10	10
World Total	Gem	17	17	16	16	17	18	18	17	18	20
	Near-Gem	29	29	29	29	29	29	29	29	29	30
	Industrial	54	54	54	54	54	54	53	54	53	50

	%	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
India	Gem	70	70	70	70	70	70	70	70	70	70
	Industrial	30	30	30	30	30	30	30	30	30	30
Brazil	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
South Africa	Gem	25	25	25	25	25	25	25	25	25	25
	Near-Gem	37	37	37	37	37	37	37	37	37	37
	Industrial	38	38	38	38	38	38	38	38	38	38
Namibia	Gem	95	95	95	95	95	95	95	95	95	95
	Industrial	5	5	5	5	5	5	5	5	5	5
Guyana	Gem	50	50	50	50	50	50	50	50	50	50
	Industrial	50	50	50	50	50	50	50	50	50	50
Zaire	Gem	5	5	5	5	5	5	5	5	5	5
	Near-Gem	30	30	30	30	30	30	30	30	30	30
	Industrial	65	65	65	65	65	65	65	65	65	65
Angola	Gem	70	70	70	70	70	70	70	70	70	70
	Near-Gem	20	20	20	20	20	20	20	20	20	20
	Industrial	10	10	10	10	10	10	10	10	10	10
Ghana	Gem	8	8	8	8	8	8	8	8	8	8
	Near-Gem	25	25	25	25	25	25	25	25	25	25
	Industrial	67	67	67	67	67	67	67	67	67	67
Tanzania	Gem	50	50	50	50	50	50	50	50	50	50
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	10	10	10	10	10	10	10	10	10	10
C.A.R	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
Guinea	Gem	70	70	70	70	70	70	70	70	70	70
	Near-Gem	15	15	15	15	15	15	15	15	15	15
	Industrial	15	15	15	15	15	15	15	15	15	15
Sierra Leone	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
Venezuela	Gem	29	29	29	29	29	29	29	29	29	29
	Near-Gem	36	36	36	36	36	36	36	36	36	36
	Industrial	35	35	35	35	35	35	35	35	35	35
Ivory Coast	Gem	50	50	50	50	50	50	50	50	50	50
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	10	10	10	10	10	10	10	10	10	10
Liberia	Gem	25	25	25	25	25	25	25	25	25	25
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	35	35	35	35	35	35	35	35	35	35
Botswana	Gem	19	19	19	19	19	19	19	19	19	19
	Near-Gem	51	51	51	51	51	51	51	51	51	51
	Industrial	30	30	30	30	30	30	30	30	30	30
Lesotho	Gem	60	60	60	60	60	60	60	60	60	60
	Industrial	40	40	40	40	40	40	40	40	40	40
Russia	Gem	26	26	26	26	26	26	26	26	26	26
	Near-Gem	44	44	44	44	44	44	44	44	44	44
	Industrial	30	30	30	30	30	30	30	30	30	30
Indonesia	Gem	95	95	95	95	95	95	95	95	95	95
	Industrial	5	5	5	5	5	5	5	5	5	5
Australia	Gem	5	5	5	5	5	5	5	5	5	5
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	55	55	55	55	55	55	55	55	55	55
China	Gem	20	20	20	20	20	20	20	20	20	20
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	40	40	40	40	40	40	40	40	40	40
Swaziland	Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	60	60	60	60	60	60	60	60	60	60
Others	Gem	52	52	52	52	52	52	52	52	52	52
	Near-Gem	38	38	38	38	38	38	38	38	38	38
	Industrial	10	10	10	10	10	10	10	10	10	10
World Total	Gem	22	21	21	22	21	22	23	22	22	24
	Near-Gem	30	30	31	31	31	32	32	32	32	33
	Industrial	48	48	48	47	48	46	46	46	46	43

	%	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
India	Gem	70	70	70	70	70	70	70	70	70	70
	Industrial	30	30	30	30	30	30	30	30	30	30
Brazil	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
South Africa	Gem	25	25	25	25	25	25	25	25	25	25
	Near-Gem	37	37	37	37	37	37	37	37	37	37
	Industrial	38	38	38	38	38	38	38	38	38	38
Namibia	Gem	95	95	95	95	95	95	95	95	95	95
	Industrial	5	5	5	5	5	5	5	5	5	5
Guyana	Gem	50	50	50	50	50	50	50	50	50	50
	Industrial	50	50	50	50	50	50	50	50	50	50
Zaire	Gem	5	5	5	5	5	5	5	5	5	5
	Near-Gem	30	30	30	30	30	30	30	30	30	30
	Industrial	65	65	65	65	65	65	65	65	65	65
Angola	Gem	70	70	70	70	70	70	70	70	70	70
	Near-Gem	20	20	20	20	20	20	20	20	20	20
	Industrial	10	10	10	10	10	10	10	10	10	10
Ghana	Gem	8	8	8	8	8	8	8	8	8	8
	Near-Gem	25	25	25	25	25	25	25	25	25	25
	Industrial	67	67	67	67	67	67	67	67	67	67
Tanzania	Gem	50	50	50	50	50	50	50	50	50	50
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	10	10	10	10	10	10	10	10	10	10
C.A.R.	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
Guinea	Gem	70	70	70	70	70	70	70	70	70	70
	Near-Gem	15	15	15	15	15	15	15	15	15	15
	Industrial	15	15	15	15	15	15	15	15	15	15
Sierra Leone	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
Venezuela	Gem	29	29	29	29	29	29	29	29	29	29
	Near-Gem	36	36	36	36	36	36	36	36	36	36
	Industrial	35	35	35	35	35	35	35	35	35	35
Ivory Coast	Gem	50	50	50	50	50	50	50	50	50	50
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	10	10	10	10	10	10	10	10	10	10
Liberia	Gem	25	25	25	25	25	25	25	25	25	25
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	35	35	35	35	35	35	35	35	35	35
Botswana	Gem	19	19	19	19	19	19	19	19	19	19
	Near-Gem	51	51	51	51	51	51	51	51	51	51
	Industrial	30	30	30	30	30	30	30	30	30	30
Lesotho	Gem	60	60	60	60	60	60	60	60	60	60
	Industrial	40	40	40	40	40	40	40	40	40	40
Russia	Gem	26	26	26	26	26	26	26	26	26	26
	Near-Gem	44	44	44	44	44	44	44	44	44	44
	Industrial	30	30	30	30	30	30	30	30	30	30
Indonesia	Gem	95	95	95	95	95	95	95	95	95	95
	Industrial	5	5	5	5	5	5	5	5	5	5
Australia	Gem	5	5	5	5	5	5	5	5	5	5
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	55	55	55	55	55	55	55	55	55	55
China	Gem	20	20	20	20	20	20	20	20	20	20
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	40	40	40	40	40	40	40	40	40	40
Swaziland	Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	60	60	60	60	60	60	60	60	60	60
Others	Gem	52	52	52	52	52	52	52	52	52	52
	Near-Gem	38	38	38	38	38	38	38	38	38	38
	Industrial	10	10	10	10	10	10	10	10	10	10
World Total	Gem	24	24	24	24	23	22	22	22	22	22
	Near-Gem	33	34	34	34	34	35	35	35	35	36
	Industrial	42	42	42	42	42	43	44	43	43	42

	%	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
India	Gem	70	70	70	70	70	70	70	70	70	70
	Industrial	30	30	30	30	30	30	30	30	30	30
Brazil	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
South Africa	Gem	25	25	25	25	25	25	25	25	25	25
	Near-Gem	37	37	37	37	37	37	37	37	37	37
	Industrial	38	38	38	38	38	38	38	38	38	38
Namibia	Gem	95	95	95	95	95	95	95	95	95	95
	Industrial	5	5	5	5	5	5	5	5	5	5
Guyana	Gem	50	50	50	50	50	50	50	50	50	50
	Industrial	50	50	50	50	50	50	50	50	50	50
Zaire	Gem	5	5	5	5	5	5	5	5	5	5
	Near-Gem	30	30	30	30	30	30	30	30	30	30
	Industrial	65	65	65	65	65	65	65	65	65	65
Angola	Gem	70	70	70	70	70	70	70	70	70	70
	Near-Gem	20	20	20	20	20	20	20	20	20	20
	Industrial	10	10	10	10	10	10	10	10	10	10
Ghana	Gem	8	8	8	8	8	8	8	8	8	8
	Near-Gem	25	25	25	25	25	25	25	25	25	25
	Industrial	67	67	67	67	67	67	67	67	67	67
Tanzania	Gem	50	50	50	50	50	50	50	50	50	50
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	10	10	10	10	10	10	10	10	10	10
C A R	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
Guinea	Gem	70	70	70	70	70	70	70	70	70	70
	Near-Gem	15	15	15	15	15	15	15	15	15	15
	Industrial	15	15	15	15	15	15	15	15	15	15
Sierra Leone	Gem	55	55	55	55	55	55	55	55	55	55
	Near-Gem	35	35	35	35	35	35	35	35	35	35
	Industrial	10	10	10	10	10	10	10	10	10	10
Venezuela	Gem	29	29	29	29	29	29	29	29	29	29
	Near-Gem	36	36	36	36	36	36	36	36	36	36
	Industrial	35	35	35	35	35	35	35	35	35	35
Ivory Coast	Gem	50	50	50	50	50	50	50	50	50	50
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	10	10	10	10	10	10	10	10	10	10
Liberia	Gem	25	25	25	25	25	25	25	25	25	25
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	35	35	35	35	35	35	35	35	35	35
Botswana	Gem	19	19	19	19	19	19	19	19	19	19
	Near-Gem	51	51	51	51	51	51	51	51	51	51
	Industrial	30	30	30	30	30	30	30	30	30	30
Lesotho	Gem	60	60	60	60	60	60	60	60	60	60
	Industrial	40	40	40	40	40	40	40	40	40	40
Russia	Gem	26	26	26	26	26	26	26	26	26	26
	Near-Gem	44	44	44	44	44	44	44	44	44	44
	Industrial	30	30	30	30	30	30	30	30	30	30
Indonesia	Gem	95	95	95	95	95	95	95	95	95	95
	Industrial	5	5	5	5	5	5	5	5	5	5
Australia	Gem	5	5	5	5	5	5	5	5	5	5
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	55	55	55	55	55	55	55	55	55	55
China	Gem	20	20	20	20	20	20	20	20	20	20
	Near-Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	40	40	40	40	40	40	40	40	40	40
Swaziland	Gem	40	40	40	40	40	40	40	40	40	40
	Industrial	60	60	60	60	60	60	60	60	60	60
Others	Gem	52	52	52	52	52	52	52	52	52	52
	Near-Gem	38	38	38	38	38	38	38	38	38	38
	Industrial	10	10	10	10	10	10	10	10	10	10
World Total	Gem	23	23	22	20	19	19	15	15	14	15
	Near-Gem	36	37	38	39	38	38	39	39	39	39
	Industrial	41	40	40	41	42	43	46	46	47	46

	%	1990	1991	1992	1993	1994
India	Gem	70	70	70	70	70
	Industrial	30	30	30	30	30
Brazil	Gem	55	55	55	55	55
	Near-Gem	35	35	35	35	35
	Industrial	10	10	10	10	10
South Africa	Gem	25	25	25	25	25
	Near-Gem	37	37	37	37	37
	Industrial	38	38	38	38	38
Namibia	Gem	95	95	95	95	95
	Industrial	5	5	5	5	5
Guyana	Gem	50	50	50	50	50
	Industrial	50	50	50	50	50
Zaire	Gem	5	5	5	5	5
	Near-Gem	30	30	30	30	30
	Industrial	65	65	65	65	65
Angola	Gem	70	70	70	70	70
	Near-Gem	20	20	20	20	20
	Industrial	10	10	10	10	10
Ghana	Gem	8	8	8	8	8
	Near-Gem	25	25	25	25	25
	Industrial	67	67	67	67	67
Tanzania	Gem	50	50	50	50	50
	Near-Gem	40	40	40	40	40
	Industrial	10	10	10	10	10
C.A.R.	Gem	55	55	55	55	55
	Near-Gem	35	35	35	35	35
	Industrial	10	10	10	10	10
Guinea	Gem	70	70	70	70	70
	Near-Gem	15	15	15	15	15
	Industrial	15	15	15	15	15
Sierra Leone	Gem	55	55	55	55	55
	Near-Gem	35	35	35	35	35
	Industrial	10	10	10	10	10
Venezuela	Gem	29	29	29	29	29
	Near-Gem	36	36	36	36	36
	Industrial	35	35	35	35	35
Ivory Coast	Gem	50	50	50	50	50
	Near-Gem	40	40	40	40	40
	Industrial	10	10	10	10	10
Liberia	Gem	25	25	25	25	25
	Near-Gem	40	40	40	40	40
	Industrial	35	35	35	35	35
Botswana	Gem	19	19	19	19	19
	Near-Gem	51	51	51	51	51
	Industrial	30	30	30	30	30
Lesotho	Gem	60	60	60	60	60
	Industrial	40	40	40	40	40
Russia	Gem	26	26	26	26	26
	Near-Gem	44	44	44	44	44
	Industrial	30	30	30	30	30
Indonesia	Gem	95	95	95	95	95
	Industrial	5	5	5	5	5
Australia	Gem	5	5	5	5	5
	Near-Gem	40	40	40	40	40
	Industrial	55	55	55	55	55
China	Gem	20	20	20	20	20
	Near-Gem	40	40	40	40	40
	Industrial	40	40	40	40	40
Swaziland	Gem	40	40	40	40	40
	Industrial	60	60	60	60	60
Others	Gem	52	52	52	52	52
	Near-Gem	38	38	38	38	38
	Industrial	10	10	10	10	10
World Total	Gem	23	23	22	20	19
	Near-Gem	36	37	38	39	38
	Industrial	41	40	40	41	42

DIAMOND GRADES IN CARATS: 1920-1994

	carats	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
India	Gem	60	88	120	81	47	34	48	79	577	1,140
	Industrial	26	38	51	35	20	14	21	34	247	488
Brazil	Gem	24,750	27,500	33,000	33,000	33,000	27,500	27,500	27,500	104,500	79,200
	Near-Gem	15,750	17,500	21,000	21,000	21,000	17,500	17,500	17,500	66,500	50,400
	Industrial	4,500	5,000	6,000	6,000	6,000	5,000	5,000	5,000	19,000	14,400
South Africa	Gem	636,254	207,009	167,390	513,274	610,100	607,532	804,492	1,177,010	1,093,214	915,303
	Near-Gem	941,656	306,373	247,737	759,645	902,947	899,147	1,190,648	1,741,974	1,617,957	1,354,648
	Industrial	967,106	314,654	254,432	780,176	927,351	923,449	1,222,827	1,789,054	1,661,686	1,391,261
Namibia	Gem	576,103	162,755	136,948	411,568	468,061	490,067	649,611	687,683	477,985	567,330
	Industrial	30,321	8,566	7,208	21,661	24,635	25,793	34,190	36,194	25,157	29,859
Guyana	Gem	19,682	52,663	83,991	110,081	95,251	93,872	84,254	89,201	67,997	62,900
	Industrial	19,682	52,663	83,991	110,081	95,251	93,872	84,254	89,201	67,997	62,900
Zaire	Gem	13,705	14,033	12,515	20,748	27,414	44,195	55,719	52,077	82,385	95,388
	Near-Gem	82,231	84,197	75,088	124,486	164,482	265,171	334,315	312,463	494,310	572,330
	Industrial	178,167	182,426	162,690	269,720	356,378	574,537	724,350	677,004	1,071,005	1,240,047
Angola	Gem	65,468	74,703	69,078	66,135	82,611	86,297	108,058	140,566	166,258	218,332
	Near-Gem	18,705	21,344	19,737	18,896	23,603	24,656	30,874	40,162	47,502	62,381
	Industrial	9,353	10,672	9,868	9,448	11,802	12,328	15,437	20,081	23,751	31,190
Ghana	Gem	17	143	523	1,867	4,243	6,799	23,987	36,877	55,906	52,843
	Near-Gem	54	447	1,634	5,836	13,259	21,246	74,959	115,240	174,707	165,134
	Industrial	144	1,199	4,378	15,639	35,533	56,940	200,889	308,843	468,213	442,559
Tanzania	Gem						206	3,348	9,383	12,341	12,216
	Near-Gem						164	2,678	7,506	9,872	9,773
	Industrial						41	670	1,877	2,468	2,443
C.A R	Gem										
	Near-Gem										
	Industrial										
Guinea	Gem										
	Near-Gem										
	Industrial										
Sierra Leone	Gem										
	Near-Gem										
	Industrial										
Venezuela	Gem										
	Near-Gem										
	Industrial										
Ivory Coast	Gem										
	Near-Gem										
	Industrial										
Liberia	Gem										
	Near-Gem										
	Industrial										
Botswana	Gem										
	Near-Gem										
	Industrial										
Lesotho	Gem										
	Industrial										
Russia	Gem										
	Near-Gem										
	Industrial										
Indonesia	Gem	390	1,682	1,851	1,082	332	634	263	238	230	556
	Industrial	21	89	97	57	17	33	14	13	12	29
Australia	Gem	176	78	50	9	14	11	3	10	1	6
	Near-Gem	1,409	625	400	70	114	84	26	80	11	48
	Industrial	1,938	860	550	96	156	116	35	109	15	65
China	Gem										
	Near-Gem										
	Industrial										
Swaziland	Gem										
	Industrial										
Others	Gem	129	73	133	282	310	98	55	66	28	121
	Near-Gem	95	54	97	206	226	72	40	48	21	88
	Industrial	25	14	26	54	60	19	11	13	5	23
World Total	Gem	1,336,734	540,727	505,597	1,158,126	1,321,381	1,357,243	1,757,338	2,220,689	2,061,421	2,005,333
	Near-Gem	1,059,900	430,540	365,692	930,139	1,125,631	1,228,041	1,651,039	2,234,973	2,410,880	2,214,801
	Industrial	1,211,281	576,179	529,292	1,212,968	1,457,203	1,692,141	2,287,697	2,927,421	3,339,557	3,215,266
Total		3,607,915	1,547,445	1,400,581	3,301,232	3,904,216	4,277,426	5,696,074	7,383,083	7,811,858	7,435,400

	carats	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939
India	Gem	925	447	878	1,639	1,736	981	1,020	825	1,210	1,123
	Industrial	396	192	376	703	744	420	437	353	519	481
Brazil	Gem	72,875	49,500	20,350	18,700	23,375	21,505	75,054	65,617	62,813	114,534
	Near-Gem	46,375	31,500	12,950	11,900	14,875	13,685	47,762	41,756	39,972	72,885
	Industrial	13,250	9,000	3,700	3,400	4,250	3,910	13,646	11,930	11,421	20,824
South Africa	Gem	790,898	529,789	199,596	126,638	110,078	169,181	155,981	257,609	309,652	312,457
	Near-Gem	1,170,529	784,088	295,401	187,425	162,916	250,387	230,852	381,261	458,285	462,436
	Industrial	1,202,165	805,279	303,385	192,490	167,319	257,154	237,091	391,565	470,671	474,935
Namibia	Gem	394,295	67,955	17,047	2,255	3,920	122,041	175,671	186,963	147,113	34,590
	Industrial	20,752	3,577	897	119	206	6,423	9,246	9,840	7,743	1,821
Guyana	Gem	55,021	31,740	30,890	24,928	23,004	23,893	20,534	17,979	16,261	17,133
	Industrial	55,021	31,740	30,890	24,928	23,004	23,893	20,534	17,979	16,261	17,133
Zaire	Gem	125,905	176,419	193,609	112,839	72,500	158,455	231,713	246,261	360,296	418,008
	Near-Gem	755,430	1,058,514	1,161,651	677,031	435,000	950,727	1,390,280	1,477,568	2,161,776	2,508,050
	Industrial	1,636,765	2,293,446	2,516,911	1,466,901	942,500	2,059,909	3,012,273	3,201,398	4,683,849	5,434,108
Angola	Gem	230,877	246,047	257,134	261,537	298,174	337,131	404,272	438,497	455,886	483,313
	Near-Gem	65,965	70,299	73,467	74,725	85,193	96,323	115,506	125,285	130,253	138,089
	Industrial	32,982	35,150	36,733	37,362	42,596	48,162	57,753	62,642	65,127	69,045
Ghana	Gem	68,890	70,438	67,384	64,319	191,329	107,988	113,174	126,213	103,741	87,012
	Near-Gem	215,280	220,120	210,574	200,996	597,902	337,462	353,669	394,415	324,191	271,913
	Industrial	576,950	589,921	564,339	538,670	1,602,378	904,397	947,834	1,057,033	868,831	728,726
Tanzania	Gem	6,148	3,829	694	716	578	723	1,352	1,617	1,788	1,723
	Near-Gem	4,918	3,063	555	573	462	578	1,082	1,294	1,430	1,378
	Industrial	1,230	766	139	143	116	145	270	323	358	345
C.A.R.	Gem	19	692	814	314	195	76	1,099	3,408	8,753	9,604
	Near-Gem	12	440	518	200	124	48	699	2,169	5,570	6,111
	Industrial	3	126	148	57	35	14	200	620	1,591	1,746
Guinea	Gem							3,850	38,281	37,054	39,421
	Near-Gem							825	8,203	7,940	8,447
	Industrial							825	8,203	7,940	8,447
Sierra Leone	Gem			412	17,609	37,748	162,516	338,910	502,371	377,642	375,958
	Near-Gem			262	11,206	24,022	103,419	215,670	319,690	240,318	239,246
	Industrial			75	3,202	6,863	29,548	61,620	91,340	68,662	68,356
Venezuela	Gem									3,944	2,311
	Near-Gem									4,896	2,869
	Industrial									4,760	2,789
Ivory Coast	Gem					25					
	Near-Gem					20					
	Industrial					5					
Liberia	Gem										
	Near-Gem										
	Industrial										
Botswana	Gem										
	Near-Gem										
	Industrial										
Lesotho	Gem										
	Industrial										
Russia	Gem										
	Near-Gem										
	Industrial										
Indonesia	Gem	436	279	260	423	1,016	4,008	734	932	1,537	2,227
	Industrial	23	15	14	22	53	211	39	49	81	117
Australia	Gem	33	36	13	6	2	3	33	10	15	5
	Near-Gem	267	290	100	49	20	20	260	80	120	41
	Industrial	367	399	138	68	27	28	358	110	165	57
China	Gem										
	Near-Gem										
	Industrial										
Swaziland	Gem										
	Industrial										
Others	Gem	10	5	156		6		6	5		
	Near-Gem	7	3	114		5		4	4		
	Industrial	2	1	30		1		1	1		
World Total	Gem	1,746,330	1,177,176	789,235	631,922	763,685	1,108,497	1,523,402	1,886,587	1,887,704	1,899,418
	Near-Gem	2,258,782	2,168,317	1,755,593	1,164,104	1,320,537	1,752,650	2,356,609	2,751,725	3,374,751	3,711,467
	Industrial	3,539,906	3,769,610	3,457,775	2,268,084	2,790,098	3,334,213	4,362,125	4,853,388	6,207,977	6,828,930
Total		7,545,018	7,115,103	6,002,603	4,064,091	4,874,320	6,195,360	8,242,136	9,491,699	11,470,432	12,439,814

	carats	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949
India	Gem	1,068	1,475	1,976	1,773	1,286	966	775	899	1,698	1,142
	Industrial	458	632	847	760	551	414	332	385	728	490
Brazil	Gem	178,750	178,750	165,000	151,250	203,500	151,250	178,750	151,250	137,500	137,500
	Near-Gem	113,750	113,750	105,000	96,250	129,500	96,250	113,750	96,250	87,500	87,500
	Industrial	32,500	32,500	30,000	27,500	37,000	27,500	32,500	27,500	25,000	25,000
South Africa	Gem	135,866	39,606	29,705	75,582	233,421	305,736	337,275	310,606	345,582	316,190
	Near-Gem	201,081	58,616	43,964	111,862	345,462	452,490	499,167	459,697	511,461	467,961
	Industrial	206,516	60,200	45,152	114,885	354,799	464,719	512,658	472,121	525,284	480,608
Namibia	Gem	28,513	44,249	53,599	89,706	146,660	144,998	156,893	170,576	190,656	266,476
	Industrial	1,501	2,329	2,821	4,721	7,719	7,631	8,258	8,978	10,035	14,025
Guyana	Gem	14,097	13,355	11,396	9,376	8,170	7,926	15,866	12,335	18,282	17,395
	Industrial	14,097	13,355	11,396	9,376	8,170	7,926	15,866	12,335	18,282	17,395
Zaire	Gem	480,142	293,288	300,912	244,087	376,668	519,298	301,673	273,726	291,228	482,498
	Near-Gem	2,880,851	1,759,727	1,805,471	1,464,523	2,260,010	3,115,787	1,810,036	1,642,355	1,747,370	2,894,990
	Industrial	6,241,844	3,812,741	3,911,853	3,173,132	4,896,687	6,750,871	3,921,744	3,558,436	3,785,969	6,272,479
Angola	Gem	548,990	550,885	554,297	556,493	559,384	562,721	564,873	559,447	556,856	538,987
	Near-Gem	156,854	157,396	158,371	158,998	159,824	160,777	161,392	159,842	159,102	153,996
	Industrial	78,427	78,698	79,185	79,499	79,912	80,389	80,696	79,921	79,551	76,998
Ghana	Gem	45,805	86,744	84,459	105,424	93,269	64,996	64,720	59,763	70,247	77,075
	Near-Gem	143,140	271,074	263,934	329,449	291,464	203,113	202,250	186,759	219,523	240,859
	Industrial	383,615	726,477	707,342	882,923	781,124	544,342	542,030	500,513	588,322	645,501
Tanzania	Gem	3,111	14,526	20,164	26,499	45,034	59,570	60,023	43,972	74,963	97,437
	Near-Gem	2,488	11,621	16,131	21,199	36,027	47,656	48,018	35,177	59,970	77,950
	Industrial	622	2,905	4,033	5,300	9,007	11,914	12,005	8,794	14,993	19,487
C.A.R.	Gem	17,560	18,461	25,429	30,902	31,379	45,567	47,977	58,892	65,340	67,610
	Near-Gem	11,174	11,748	16,182	19,665	19,968	28,997	30,531	37,477	41,580	43,025
	Industrial	3,193	3,357	4,624	5,619	5,705	8,285	8,723	10,708	11,880	12,293
Guinea	Gem	45,996	40,415	34,906	25,335	48,808	55,861	36,284	37,624	54,579	66,497
	Near-Gem	9,856	8,660	7,480	5,429	10,459	11,970	7,775	8,062	11,696	14,249
	Industrial	9,856	8,660	7,480	5,429	10,459	11,970	7,775	8,062	11,696	14,249
Sierra Leone	Gem	486,978	467,452	575,403	458,971	334,804	277,199	307,578	333,055	256,134	271,765
	Near-Gem	309,895	297,469	366,165	292,072	213,057	176,400	195,731	211,944	162,994	172,942
	Industrial	88,541	84,991	104,619	83,449	60,873	50,400	55,923	60,555	46,570	49,412
Venezuela	Gem	4,212	8,531	9,874	6,625	6,391	3,701	6,064	17,874	21,898	16,432
	Near-Gem	5,229	10,590	12,257	8,225	7,933	4,594	7,528	22,188	27,184	20,398
	Industrial	5,084	10,296	11,917	7,996	7,713	4,467	7,319	21,572	26,429	19,832
Ivory Coast	Gem										
	Near-Gem										
	Industrial										
Liberia	Gem										
	Near-Gem										
	Industrial										
Botswana	Gem										
	Near-Gem										
	Industrial										
Lesotho	Gem										
	Industrial										
Russia	Gem										
	Near-Gem										
	Industrial										
Indonesia	Gem	3,376									
	Industrial	178									
Australia	Gem		15	9	21	10	4	3	4		
	Near-Gem		120	73	172	79	29	20	29		2
	Industrial		165	101	236	109	40	28	40		3
China	Gem										
	Near-Gem										
	Industrial										
Swaziland	Gem										
	Industrial										
Others	Gem	8,957									3
	Near-Gem	6,546									2
	Industrial	1,723									1
World Total	Gem	2,003,421	1,757,750	1,867,128	1,782,043	2,088,781	2,199,792	2,078,752	2,030,021	2,084,964	2,357,008
	Near-Gem	3,840,865	2,700,770	2,795,028	2,507,842	3,473,783	4,298,062	3,076,198	2,859,780	3,028,380	4,173,874
	Industrial	7,068,154	4,837,306	4,921,369	4,400,824	6,259,828	7,970,867	5,205,856	4,769,920	5,144,736	7,647,773
Total		12,912,440	9,295,826	9,583,525	8,690,710	11,822,393	14,468,722	10,360,805	9,659,720	10,258,081	14,178,656

	carats	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
India	Gem	1,938	1,172	1,438	1,545	1,369	1,251	1,049	553	1,078	477
	Industrial	831	502	616	662	587	536	450	237	462	205
Brazil	Gem	137,500	137,500	137,500	137,500	137,500	137,500	137,500	137,500	137,500	110,000
	Near-Gem	87,500	87,500	87,500	87,500	87,500	87,500	87,500	87,500	87,500	70,000
	Industrial	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	20,000
South Africa	Gem	432,878	557,228	595,803	679,405	714,672	657,229	646,432	644,744	675,563	709,583
	Near-Gem	640,659	824,697	881,788	1,005,519	1,057,715	972,699	956,719	954,221	999,833	1,050,183
	Industrial	657,974	846,986	905,620	1,032,696	1,086,301	998,988	982,577	980,011	1,026,855	1,078,566
Namibia	Gem	479,374	477,834	510,578	579,815	649,382	772,206	939,220	947,117	858,397	884,126
	Industrial	25,230	25,149	26,873	30,517	34,178	40,642	49,433	49,848	45,179	46,533
Guyana	Gem	18,731	21,630	19,153	17,653	15,037	16,650	14,908	14,519	16,546	31,164
	Industrial	18,731	21,630	19,153	17,653	15,037	16,650	14,908	14,519	16,546	31,164
Zaire	Gem	507,374	528,238	580,441	629,014	631,006	652,075	700,524	782,337	833,674	742,759
	Near-Gem	3,044,241	3,169,427	3,482,648	3,774,081	3,786,034	3,912,449	4,203,143	4,694,019	5,002,042	4,456,551
	Industrial	6,595,856	6,867,091	7,545,738	8,177,176	8,203,074	8,476,973	9,106,811	10,170,375	10,837,758	9,655,861
Angola	Gem	377,207	514,027	520,311	510,563	505,124	520,364	518,025	605,060	700,865	710,982
	Near-Gem	107,773	146,865	148,660	145,875	144,321	148,675	148,007	172,874	200,247	203,138
	Industrial	53,887	73,432	74,330	72,938	72,161	74,338	74,004	86,437	100,124	101,569
Ghana	Gem	85,033	140,230	175,165	174,458	170,837	180,662	203,154	249,986	250,536	246,086
	Near-Gem	296,979	438,220	547,389	545,182	533,865	564,568	634,857	781,206	782,924	769,018
	Industrial	795,903	1,174,429	1,467,003	1,461,088	1,430,758	1,513,041	1,701,417	2,093,633	2,098,236	2,060,968
Tanzania	Gem	82,498	54,313	71,512	86,152	163,005	162,762	179,359	195,486	260,532	321,639
	Near-Gem	65,998	43,450	57,209	68,922	130,404	130,209	143,487	156,388	208,426	257,311
	Industrial	16,500	10,863	14,302	17,230	32,601	32,552	35,872	39,097	52,106	64,328
C.A.R.	Gem	61,274	81,285	86,189	77,079	83,890	75,327	80,210	60,077	57,750	47,614
	Near-Gem	38,992	51,727	54,848	49,050	53,385	47,935	51,043	38,231	36,750	30,300
	Industrial	11,141	14,779	15,671	14,014	15,253	13,696	14,584	10,923	10,500	8,657
Guinea	Gem	87,198	70,686	95,256	125,895	152,355	222,964	272,916	64,400	81,200	459,900
	Near-Gem	18,685	15,147	20,412	26,978	32,648	47,778	58,482	13,800	17,400	98,550
	Industrial	18,685	15,147	20,412	26,978	32,648	47,778	58,482	13,800	17,400	98,550
Sierra Leone	Gem	360,517	261,152	248,940	264,940	220,042	229,942	356,288	474,761	819,520	710,030
	Near-Gem	229,420	166,187	158,416	168,598	140,027	146,327	226,729	302,121	521,513	451,837
	Industrial	65,549	47,482	45,262	48,171	40,008	41,808	64,780	86,320	149,004	129,096
Venezuela	Gem	17,513	18,336	26,764	24,587	28,125	40,933	27,212	35,553	26,101	27,546
	Near-Gem	21,740	22,761	33,225	30,522	34,914	50,813	33,780	44,135	32,401	34,195
	Industrial	21,136	22,129	32,302	29,674	33,944	49,401	32,842	42,909	31,501	33,245
Ivory Coast	Gem								77,500	82,158	93,975
	Near-Gem								62,000	65,726	75,180
	Industrial								15,500	16,432	18,795
Liberia	Gem				2,886	311	7,383	9,775	6,041	2,433	159,500
	Near-Gem				4,617	498	11,813	15,639	9,666	3,893	255,200
	Industrial				4,040	435	10,337	13,684	8,457	3,407	223,300
Botswana	Gem						86	118	475	1,266	1,655
	Near-Gem						230	316	1,275	3,399	4,444
	Industrial						135	186	750	1,999	2,614
Lesotho	Gem										
	Industrial										
Russia	Gem				3,001	323	7,679	10,165	6,283	2,531	208,000
	Near-Gem				5,079	547	12,995	17,203	10,632	4,283	352,000
	Industrial				3,463	373	8,860	11,729	7,249	2,920	240,000
Indonesia	Gem				10,966	1,182	28,055	37,144	22,957	9,246	
	Industrial				577	62	1,477	1,955	1,208	487	
Australia	Gem	7	6	2	37	78	37	19	16	8	2
	Near-Gem	52	52	20	294	626	292	153	125	63	15
	Industrial	72	71	27	405	860	402	211	172	87	20
China	Gem										
	Near-Gem										
	Industrial										
Swaziland	Gem										
	Industrial										
Others	Gem		21	25	3	1					
	Near-Gem		15	18	2	1					
	Industrial		4	5	1	0					
World Total	Gem	2,659,040	2,863,656	3,069,077	3,325,499	3,474,238	3,713,103	4,134,018	4,325,363	4,816,903	5,465,037
	Near-Gem	4,552,040	4,966,047	5,472,134	5,912,220	6,002,482	6,134,283	6,577,059	7,328,193	7,966,399	8,107,921
	Industrial	8,306,493	9,144,694	10,192,313	10,962,281	11,023,279	11,352,614	12,188,923	13,646,445	14,436,001	13,813,471
Total		15,517,572	16,974,398	18,733,524	20,200,000	20,499,999	21,200,000	22,900,000	25,300,000	27,219,303	27,386,429

	carats	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
India	Gem	811	919	792	1,002	1,582	3,126	1,479	5,075	6,135	8,327
	Industrial	348	394	339	430	678	1,340	634	2,175	2,629	3,569
Brazil	Gem	110,000	165,000	165,000	165,000	330,000	330,000	330,000	126,500	151,250	137,500
	Near-Gem	70,000	105,000	105,000	105,000	210,000	210,000	210,000	80,500	96,250	87,500
	Industrial	20,000	30,000	30,000	30,000	60,000	60,000	60,000	23,000	27,500	25,000
South Africa	Gem	785,366	946,966	979,473	1,093,893	1,112,495	1,256,400	1,509,169	1,673,400	1,364,937	1,977,135
	Near-Gem	1,162,341	1,401,509	1,449,620	1,618,962	1,646,492	1,859,471	2,233,570	2,476,632	2,020,107	2,926,160
	Industrial	1,193,756	1,439,388	1,488,799	1,662,717	1,690,992	1,909,727	2,293,937	2,543,568	2,074,705	3,005,246
Namibia	Gem	888,613	860,524	975,871	1,134,899	1,464,467	1,573,422	1,671,008	1,614,211	1,636,146	2,041,494
	Industrial	46,769	45,291	51,362	59,732	77,077	82,812	87,948	84,958	86,113	107,447
Guyana	Gem	50,502	56,340	50,073	49,874	54,841	56,437	49,444	35,500	25,775	33,156
	Industrial	50,502	56,340	50,073	49,874	54,841	56,437	49,444	35,500	25,775	33,156
Zaire	Gem	672,678	907,150	732,800	738,200	988,500	875,194	871,424	910,000	875,000	860,000
	Near-Gem	4,036,069	5,442,900	4,396,800	4,429,200	5,931,000	5,251,162	5,228,545	5,460,000	5,250,000	5,160,000
	Industrial	8,744,816	11,792,950	9,526,400	9,596,600	12,850,500	11,377,518	11,328,514	11,830,000	11,375,000	11,180,000
Angola	Gem	739,779	803,207	756,773	758,500	804,348	809,008	887,699	901,978	1,168,431	1,415,074
	Near-Gem	211,365	229,488	216,221	216,714	229,814	231,145	253,628	257,708	333,837	404,307
	Industrial	105,683	114,744	108,110	108,357	114,907	115,573	126,814	128,854	166,919	202,153
Ghana	Gem	261,840	257,120	256,805	214,536	213,440	181,840	225,240	288,000	400,000	332,000
	Near-Gem	818,250	803,500	802,515	670,425	667,000	568,250	703,875	900,000	1,250,000	1,037,500
	Industrial	2,192,910	2,153,380	2,150,740	1,796,739	1,787,560	1,522,910	1,886,385	2,412,000	3,350,000	2,780,500
Tanzania	Gem	274,188	345,834	330,015	295,475	325,231	378,485	473,328	463,379	351,189	388,633
	Near-Gem	219,350	276,667	264,012	236,380	260,184	302,788	378,662	370,703	280,951	310,906
	Industrial	54,838	69,167	66,003	59,095	65,046	75,697	94,666	92,676	70,238	77,727
C.A.R.	Gem	38,303	61,316	145,979	221,202	243,255	296,346	296,964	288,200	335,148	289,820
	Near-Gem	24,374	39,019	92,896	140,765	154,798	188,584	188,977	183,400	213,276	184,431
	Industrial	6,964	11,148	26,542	40,219	44,228	53,881	53,994	52,400	60,936	52,695
Guinea	Gem	781,200	840,000	245,000	37,800	210,000	210,000	210,000	49,000	65,100	66,500
	Near-Gem	167,400	180,000	52,500	8,100	45,000	45,000	45,000	10,500	13,950	14,250
	Industrial	167,400	180,000	52,500	8,100	45,000	45,000	45,000	10,500	13,950	14,250
Sierra Leone	Gem	1,050,049	1,262,403	900,571	980,951	907,416	803,630	790,197	858,000	913,000	1,064,238
	Near-Gem	668,213	803,348	573,091	624,241	577,446	511,401	502,853	546,000	581,000	677,243
	Industrial	190,918	229,528	163,740	178,355	164,985	146,115	143,672	156,000	166,000	193,498
Venezuela	Gem	20,551	38,911	51,183	20,205	33,525	25,752	24,562	24,795	40,716	63,883
	Near-Gem	25,512	48,303	63,537	25,083	41,617	31,968	30,490	30,780	50,544	79,303
	Industrial	24,803	46,962	61,773	24,386	40,461	31,080	29,643	29,925	49,140	77,100
Ivory Coast	Gem	99,560	274,665	141,956	89,830	100,135	99,090	91,718	88,000	93,500	95,000
	Near-Gem	79,648	219,732	113,564	71,864	80,108	79,272	73,374	70,400	74,800	76,000
	Industrial	19,912	54,933	28,391	17,966	20,027	19,818	18,344	17,600	18,700	19,000
Liberia	Gem	216,625	273,750	226,250	187,000	150,000	150,000	150,000	137,500	188,250	213,000
	Near-Gem	346,600	438,000	362,000	299,200	240,000	240,000	240,000	220,000	301,200	340,800
	Industrial	303,275	383,250	316,750	261,800	210,000	210,000	210,000	192,500	263,550	298,200
Botswana	Gem	18									
	Near-Gem	48									
	Industrial	29									
Lesotho	Gem					1,483	3,295	7,504	0	7,148	17,873
	Industrial					989	2,197	5,002	0	4,766	11,915
Russia	Gem	247,000	390,000	715,000	845,000	962,000	1,391,000	1,430,000	1,820,000	1,950,000	2,730,000
	Near-Gem	418,000	660,000	1,210,000	1,430,000	1,628,000	2,354,000	2,420,000	3,080,000	3,300,000	4,620,000
	Industrial	285,000	450,000	825,000	975,000	1,110,000	1,605,000	1,650,000	2,100,000	2,250,000	3,150,000
Indonesia	Gem								3,230	19,380	
	Industrial								170	1,020	
Australia	Gem										
	Near-Gem										
	Industrial										
China	Gem										
	Near-Gem										
	Industrial										
Swaziland	Gem										
	Industrial										
Others	Gem						23,678	24,901			
	Near-Gem						17,303	18,197			
	Industrial						4,553	4,789			
World Total	Gem	6,237,083	7,484,105	6,673,539	6,833,367	7,902,716	8,466,700	9,044,636	9,286,768	9,591,104	11,733,634
	Near-Gem	8,247,174	10,647,466	9,701,756	9,875,934	11,711,460	11,890,343	12,527,172	13,686,623	13,765,915	15,918,400
	Industrial	13,407,925	17,057,473	14,946,521	14,869,369	18,337,291	17,319,656	18,088,785	19,711,826	20,006,939	21,231,456
Total		27,892,183	35,189,044	31,321,816	31,578,669	37,951,467	37,676,699	39,660,593	42,685,217	43,363,959	48,883,490

	carats	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
India	Gem	11,200	14,000	14,006	14,999	14,683	13,996	14,341	12,808	11,159	10,660
	Industrial	4,800	6,000	6,003	6,428	6,293	5,998	6,146	5,489	4,783	4,569
Brazil	Gem	104,500	88,000	110,000	165,000	165,000	220,000	275,000	275,000	275,000	275,000
	Near-Gem	66,500	56,000	70,000	105,000	105,000	140,000	175,000	175,000	175,000	175,000
	Industrial	19,000	16,000	20,000	30,000	30,000	40,000	50,000	50,000	50,000	50,000
South Africa	Gem	2,040,025	1,895,318	1,925,000	1,950,000	2,000,000	1,950,000	1,825,000	1,975,000	2,000,000	2,150,000
	Near-Gem	3,019,237	2,805,071	2,849,000	2,886,000	2,960,000	2,886,000	2,701,000	2,923,000	2,960,000	3,182,000
	Industrial	3,100,838	2,880,883	2,926,000	2,964,000	3,040,000	2,964,000	2,774,000	3,002,000	3,040,000	3,268,000
Namibia	Gem	1,772,167	1,563,926	1,520,000	1,520,000	1,520,000	1,653,000	1,605,500	1,900,000	1,805,000	1,567,500
	Industrial	93,272	82,312	80,000	80,000	80,000	87,000	84,500	100,000	95,000	82,500
Guyana	Gem	29,735	29,500	24,333	26,251	14,988	10,381	6,949	8,340	8,613	7,912
	Industrial	29,735	29,500	24,333	26,251	14,988	10,381	6,949	8,340	8,613	7,912
Zaire	Gem	875,000	850,000	850,000	850,000	850,000	850,000	850,000	850,000	850,000	775,000
	Near-Gem	5,250,000	5,100,000	5,100,000	5,100,000	5,100,000	5,100,000	5,100,000	5,100,000	5,100,000	4,650,000
	Industrial	11,375,000	11,050,000	11,050,000	11,050,000	11,050,000	11,050,000	11,050,000	11,050,000	11,050,000	10,075,000
Angola	Gem	1,567,938	1,697,500	1,540,000	1,540,000	1,358,000	350,000	280,000	350,000	455,000	588,000
	Near-Gem	447,982	485,000	440,000	440,000	388,000	100,000	80,000	100,000	130,000	168,000
	Industrial	223,991	242,500	220,000	220,000	194,000	50,000	40,000	50,000	65,000	84,000
Ghana	Gem	229,758	228,000	200,000	184,000	192,000	180,000	177,600	177,920	120,000	120,000
	Near-Gem	717,993	712,500	625,000	575,000	600,000	562,500	555,000	556,000	375,000	375,000
	Industrial	1,924,221	1,909,500	1,675,000	1,541,000	1,608,000	1,507,500	1,467,400	1,490,080	1,005,000	1,005,000
Tanzania	Gem	353,615	485,500	300,000	300,000	300,000	300,000	250,000	200,000	175,000	170,000
	Near-Gem	282,892	388,400	240,000	240,000	240,000	240,000	200,000	160,000	140,000	136,000
	Industrial	70,723	97,100	60,000	60,000	60,000	60,000	50,000	40,000	35,000	34,000
C.A.R	Gem	265,346	236,500	220,000	220,000	220,000	220,000	220,000	220,000	165,000	165,000
	Near-Gem	168,856	150,500	140,000	140,000	140,000	140,000	140,000	140,000	105,000	105,000
	Industrial	48,245	43,000	40,000	40,000	40,000	40,000	40,000	40,000	30,000	30,000
Guinea	Gem	52,500	0	56,000	56,000	56,000	56,000	56,000	56,000	56,000	59,500
	Near-Gem	11,250	0	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,750
	Industrial	11,250	0	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,750
Sierra Leone	Gem	1,125,890	1,251,250	990,000	935,000	935,000	599,500	605,000	412,500	440,000	467,500
	Near-Gem	716,475	796,250	630,000	595,000	595,000	381,500	385,000	262,500	280,000	297,500
	Industrial	204,707	227,500	180,000	170,000	170,000	109,000	110,000	75,000	80,000	85,000
Venezuela	Gem	145,000	188,500	116,000	145,000	145,000	174,000	174,000	232,000	232,000	232,000
	Near-Gem	180,000	234,000	144,000	180,000	180,000	216,000	216,000	288,000	288,000	288,000
	Industrial	175,000	227,500	140,000	175,000	175,000	210,000	210,000	280,000	280,000	280,000
Ivory Coast	Gem	106,404	200,000	150,000	150,000	150,000	150,000	100,000	50,000	50,000	50,000
	Near-Gem	85,123	160,000	120,000	120,000	120,000	120,000	80,000	40,000	40,000	40,000
	Industrial	21,281	40,000	30,000	30,000	30,000	30,000	20,000	10,000	10,000	10,000
Liberia	Gem	138,257	135,000	125,000	150,000	150,000	150,000	125,000	125,000	125,000	125,000
	Near-Gem	221,210	216,000	200,000	240,000	240,000	240,000	200,000	200,000	200,000	200,000
	Industrial	193,559	189,000	175,000	210,000	210,000	210,000	175,000	175,000	175,000	175,000
Botswana	Gem	103,361	156,750	456,000	456,000	456,000	450,300	448,400	505,400	532,000	836,000
	Near-Gem	277,443	420,750	1,224,000	1,224,000	1,224,000	1,208,700	1,203,600	1,356,600	1,428,000	2,244,000
	Industrial	163,202	247,500	720,000	720,000	720,000	711,000	708,000	798,000	840,000	1,320,000
Lesotho	Gem	9,923	4,808	5,411	5,400	7,079	2,080	4,231	13,613	29,386	31,453
	Industrial	6,616	3,206	3,607	3,600	4,719	1,386	2,820	9,075	19,591	20,968
Russia	Gem	3,120,000	3,120,000	3,120,000	3,120,000	3,120,000	3,120,000	3,120,000	3,120,000	3,120,000	3,120,000
	Near-Gem	5,280,000	5,280,000	5,280,000	5,280,000	5,280,000	5,280,000	5,280,000	5,280,000	5,280,000	5,280,000
	Industrial	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000
Indonesia	Gem	14,250	28,500	14,250	14,250	14,250	14,250	14,250	14,250	14,250	14,250
	Industrial	750	1,500	750	750	750	750	750	750	750	750
Australia	Gem										
	Near-Gem										
	Industrial										
China	Gem										
	Near-Gem										
	Industrial										
Swaziland	Gem										
	Industrial										
Others	Gem			14,200	11,477	21,971	31,605	33,054	24,615	11,885	8,594
	Near-Gem			10,377	8,387	16,055	23,096	24,155	17,988	8,685	6,280
	Industrial			2,731	2,207	4,225	6,078	6,357	4,734	2,286	1,653
World Total	Gem	12,064,869	12,173,053	11,750,200	11,813,377	11,689,970	10,495,111	10,184,324	10,522,445	10,475,293	10,773,368
	Near-Gem	16,724,963	16,804,471	17,084,377	17,145,387	17,200,055	16,649,796	16,351,755	16,611,088	16,521,685	17,159,530
	Industrial	21,266,189	20,893,001	20,965,424	20,941,236	21,049,975	20,705,093	20,433,922	20,800,467	20,403,022	20,147,102
Total		50,056,021	49,870,524	49,800,000	49,900,000	49,940,000	47,850,000	46,970,000	47,934,000	47,400,000	48,080,000

	carats	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
India	Gem	10,102	10,384	9,105	10,000	11,121	11,390	11,281	13,241	10,229	
	Industrial	4,330	4,450	3,902	4,286	4,766	4,881	4,835	5,675	4,384	
Brazil	Gem	275,000	275,000	275,000	412,500	440,510	247,500	351,048	405,350	384,010	412,500
	Near-Gem	175,000	175,000	175,000	262,500	280,324	157,500	223,394	257,950	244,370	262,500
	Industrial	50,000	50,000	50,000	75,000	80,093	45,000	63,827	73,700	69,820	75,000
South Africa	Gem	2,175,000	2,375,000	2,225,000	2,500,000	2,450,000	2,475,000	2,550,000	2,400,000	2,250,000	2,250,000
	Near-Gem	3,219,000	3,515,000	3,293,000	3,700,000	3,626,000	3,663,000	3,774,000	3,552,000	3,330,000	3,330,000
	Industrial	3,306,000	3,610,000	3,382,000	3,800,000	3,724,000	3,762,000	3,876,000	3,648,000	3,420,000	3,420,000
Namibia	Gem	1,482,000	1,187,500	950,000	912,000	883,500	864,500	950,000	950,000	855,000	855,000
	Industrial	78,000	62,500	50,000	48,000	46,500	45,500	50,000	50,000	45,000	45,000
Guyana	Gem	5,118	4,767	5,746	6,181	3,748	5,934	4,690	3,735	2,121	4,401
	Industrial	5,118	4,767	5,746	6,181	3,748	5,934	4,690	3,735	2,121	4,401
Zaire	Gem	700,000	625,000	610,000	650,000	925,000	980,000	1,025,000	1,050,000	1,150,000	1,000,000
	Near-Gem	4,200,000	3,750,000	3,660,000	3,900,000	5,550,000	5,880,000	6,150,000	6,300,000	6,900,000	6,000,000
	Industrial	9,100,000	8,125,000	7,930,000	8,450,000	12,025,000	12,740,000	13,325,000	13,650,000	14,950,000	13,000,000
Angola	Gem	1,050,000	980,000	910,000	700,000	644,000	630,000	140,000	630,000	700,000	840,000
	Near-Gem	300,000	280,000	260,000	200,000	184,000	180,000	40,000	180,000	200,000	240,000
	Industrial	150,000	140,000	130,000	100,000	92,000	90,000	20,000	90,000	100,000	120,000
Ghana	Gem	88,000	80,000	80,000	64,000	26,400	48,000	44,000	35,200	24,000	16,000
	Near-Gem	275,000	250,000	250,000	200,000	82,500	150,000	137,500	110,000	75,000	50,000
	Industrial	737,000	670,000	670,000	536,000	221,100	402,000	368,500	294,800	201,000	134,000
Tanzania	Gem	128,000	185,000	190,000	185,000	180,000	175,000	150,000	75,000	65,000	38,000
	Near-Gem	102,400	148,000	152,000	148,000	144,000	140,000	120,000	60,000	52,000	30,400
	Industrial	25,600	37,000	38,000	37,000	36,000	35,000	30,000	15,000	13,000	7,600
C.A.R	Gem	165,000	165,000	165,000	165,000	165,000	275,000	330,000	330,000	247,500	330,000
	Near-Gem	105,000	105,000	105,000	105,000	105,000	175,000	210,000	210,000	157,500	210,000
	Industrial	30,000	30,000	30,000	30,000	30,000	50,000	60,000	60,000	45,000	60,000
Guinea	Gem	26,600	26,600	28,000	28,000	33,810	61,460				140,000
	Near-Gem	5,700	5,700	6,000	6,000	7,245	13,170				30,000
	Industrial	5,700	5,700	6,000	6,000	7,245	13,170				30,000
Sierra Leone	Gem	330,000	165,000	137,500	137,500	231,000	220,000	220,000	198,000	165,000	330,000
	Near-Gem	210,000	105,000	87,500	87,500	147,000	140,000	140,000	126,000	105,000	210,000
	Industrial	60,000	30,000	25,000	25,000	42,000	40,000	40,000	36,000	30,000	60,000
Venezuela	Gem	232,000	217,500	217,500	72,500	79,147	62,429	61,402	32,770	44,022	43,500
	Near-Gem	288,000	270,000	270,000	90,000	98,252	77,498	76,223	40,680	54,648	54,000
	Industrial	280,000	262,500	262,500	87,500	95,523	75,345	74,106	39,550	53,130	52,500
Ivory Coast	Gem	50,000	50,000	50,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
	Near-Gem	40,000	40,000	40,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000
	Industrial	10,000	10,000	10,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Liberia	Gem	125,000	125,000	125,000	100,000	100,000	100,000	75,000	87,500	87,500	75,000
	Near-Gem	200,000	200,000	200,000	160,000	160,000	160,000	120,000	140,000	140,000	120,000
	Industrial	175,000	175,000	175,000	140,000	140,000	140,000	105,000	122,500	122,500	105,000
Botswana	Gem	969,000	942,400	1,476,300	2,033,000	2,451,000	2,394,000	2,470,000	2,470,000	2,850,000	2,888,000
	Near-Gem	2,601,000	2,529,600	3,962,700	5,457,000	6,579,000	6,426,000	6,630,000	6,630,000	7,650,000	7,752,000
	Industrial	1,530,000	1,488,000	2,331,000	3,210,000	3,870,000	3,780,000	3,900,000	3,900,000	4,500,000	4,560,000
Lesotho	Gem	32,228	31,753	25,271							
	Industrial	21,486	21,168	16,848							
Russia	Gem	3,120,000	3,120,000	3,120,000	3,120,000	3,120,000	3,120,000	3,120,000	3,120,000	3,120,000	3,120,000
	Near-Gem	5,280,000	5,280,000	5,280,000	5,280,000	5,280,000	5,280,000	5,280,000	5,280,000	5,280,000	5,280,000
	Industrial	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000
Indonesia	Gem	14,250	14,250	14,250	25,650	25,650	25,650	25,650	28,500		
	Industrial	750	750	750	1,350	1,350	1,350	1,350	1,500		
Australia	Gem			22,850	310,000	285,000	353,000	1,460,000	1,500,000	1,741,300	1,850,000
	Near-Gem			182,800	2,480,000	2,280,000	2,824,000	11,680,000	12,000,000	13,930,400	14,800,000
	Industrial			251,350	3,410,000	3,135,000	3,883,000	16,060,000	16,500,000	19,154,300	20,350,000
China	Gem	180,000	190,000	200,000	200,000	200,000	200,000	200,000	200,000	200,000	200,000
	Near-Gem	360,000	380,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000
	Industrial	360,000	380,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000
Swaziland	Gem					6,735	8,451	15,658	16,000	29,070	
	Industrial					10,102	12,677	23,486	24,000	43,606	
Others	Gem	35,681	36,250	40,759	55,303	90,730	159,085	212,348	183,880	186,404	99,423
	Near-Gem	26,075	26,491	29,785	40,414	66,302	116,255	155,177	134,374	136,218	72,655
	Industrial	6,862	6,971	7,838	10,635	17,448	30,593	40,836	35,362	35,847	19,120
World Total	Gem	11,192,980	10,806,403	10,877,281	11,786,634	12,452,351	12,516,399	13,516,076	13,829,175	14,211,156	14,591,824
	Near-Gem	17,387,175	17,059,791	18,353,785	22,596,414	25,069,624	25,862,422	35,216,294	35,501,004	38,735,136	38,921,555
	Industrial	19,535,845	18,713,806	19,375,934	23,996,952	27,601,875	29,176,451	42,067,630	42,569,821	46,809,707	46,062,621
Total		48,116,000	46,580,000	48,607,000	58,380,000	65,123,849	67,555,272	90,800,000	91,900,000	99,756,000	99,576,000

	carats	1990	1991	1992	1993	1994
India	Gem					12,600
	Industrial					5,400
Brazil	Gem	852,500	825,000	1,151,975	1,164,647	1,100,000
	Near-Gem	542,500	525,000	733,075	741,139	700,000
	Industrial	155,000	150,000	209,450	211,754	200,000
South Africa	Gem	2,125,000	2,050,000	2,500,000	2,527,500	2,675,000
	Near-Gem	3,145,000	3,034,000	3,700,000	3,740,700	3,959,000
	Industrial	3,230,000	3,116,000	3,800,000	3,841,800	4,066,000
Namibia	Gem	760,000	1,330,000	1,520,000	1,536,720	1,235,000
	Industrial	40,000	70,000	80,000	80,880	65,000
Guyana	Gem	7,439	10,955	11,075	11,197	250,000
	Industrial	7,439	10,955	11,075	11,197	250,000
Zaire	Gem	1,200,000	950,000	750,000	758,250	900,000
	Near-Gem	7,200,000	5,700,000	4,500,000	4,549,500	5,400,000
	Industrial	15,600,000	12,350,000	9,750,000	9,857,250	11,700,000
Angola	Gem	910,000	910,000	1,890,000	1,910,790	980,000
	Near-Gem	260,000	260,000	540,000	545,940	280,000
	Industrial	130,000	130,000	270,000	272,970	140,000
Ghana	Gem	16,000	16,000	40,000	40,440	48,000
	Near-Gem	50,000	50,000	125,000	126,375	150,000
	Industrial	134,000	134,000	335,000	338,685	402,000
Tanzania	Gem		55,000	55,605	56,217	0
	Near-Gem		44,000	44,484	44,973	0
	Industrial		11,000	11,121	11,243	0
C.A.R.	Gem	275,000	275,000	220,000	222,420	275,000
	Near-Gem	175,000	175,000	140,000	141,540	175,000
	Industrial	50,000	50,000	40,000	40,440	50,000
Guinea	Gem	70,000	70,000	70,000	70,770	350,000
	Near-Gem	15,000	15,000	15,000	15,165	75,000
	Industrial	15,000	15,000	15,000	15,165	75,000
Sierra Leone	Gem	385,000	330,000	247,500	250,223	220,000
	Near-Gem	245,000	210,000	157,500	159,233	140,000
	Industrial	70,000	60,000	45,000	45,495	40,000
Venezuela	Gem	43,500	145,000	146,595	148,208	145,000
	Near-Gem	54,000	180,000	181,980	183,982	180,000
	Industrial	52,500	175,000	176,925	178,871	175,000
Ivory Coast	Gem	100,000	100,000	100,000	101,100	0
	Near-Gem	80,000	80,000	80,000	80,880	0
	Industrial	20,000	20,000	20,000	20,220	0
Liberia	Gem	75,000	25,000			
	Near-Gem	120,000	40,000			
	Industrial	105,000	35,000			
Botswana	Gem	3,296,828	3,136,228	3,021,000	3,054,231	2,964,000
	Near-Gem	8,849,381	8,418,295	8,109,000	8,198,199	7,956,000
	Industrial	5,205,518	4,951,938	4,770,000	4,822,470	4,680,000
Lesotho	Gem					
	Industrial					
Russia	Gem	3,900,000	3,380,000	2,925,000	2,957,175	2,990,000
	Near-Gem	6,600,000	5,720,000	4,950,000	5,004,450	5,060,000
	Industrial	4,500,000	3,900,000	3,375,000	3,412,125	3,450,000
Indonesia	Gem					9,500
	Industrial					500
Australia	Gem	1,800,000	1,800,000	2,000,000	2,022,000	2,190,000
	Near-Gem	14,400,000	14,400,000	16,000,000	16,176,000	17,520,000
	Industrial	19,800,000	19,800,000	22,000,000	22,242,000	24,090,000
China	Gem	200,000	202,200	204,424	206,673	60,000
	Near-Gem	400,000	404,400	408,848	413,346	120,000
	Industrial	400,000	404,400	408,848	413,346	120,000
Swaziland	Gem					0
	Industrial					0
Others	Gem	96,264	144,607	144,482	146,071	156,000
	Near-Gem	70,347	105,675	105,583	106,744	114,000
	Industrial	18,512	27,809	27,785	28,091	30,000
World Total	Gem	16,112,531	15,754,989	16,997,656	17,184,630	16,560,100
	Near-Gem	42,206,228	39,361,370	39,790,470	40,228,166	41,829,000
	Industrial	49,532,969	45,411,102	45,345,204	45,844,002	49,538,900
Total		107,851,727	100,527,461	102,133,331	103,256,798	107,928,000

SYNTHETIC DIAMOND PRODUCTION

Synthetic	**1920**	**1921**	**1922**	**1923**	**1924**
USA					
Russia					
South Africa					
Irish Republic (b)					
Sweden					
Japan					
Others					
Total HPHT	0	0	0	0	0
Near-Gem Use	100%	99%	98%	97%	96%
	1,059,900	426,234	358,378	902,235	1,080,606
Natural Industrial	1,211,281	576,179	529,292	1,212,968	1,457,203
Synthetic HPHT	0	0	0	0	0
Salvage					
Total Industrial Available	2,271,182	1,002,414	887,671	2,115,203	2,537,810
Actual/Estimate Used	2,000,000	2,140,000	2,289,800	2,450,086	2,621,592
Percent Growth		7.0%	7.0%	7.0%	7.0%
Synthetic Percent	0%	0%	0%	0%	0%
Natural Percent	100%	100%	100%	100%	100%
Excess/(Shortfall)	271,182	(1,137,586)	(1,402,129)	(334,883)	(83,782)
Accumulated Stock	337,000,000	335,862,414	334,460,285	334,125,402	334,041,620
Ind % of Total Natural	33.57%	37.23%	37.79%	36.74%	37.32%

Synthetic	**1925**	**1926**	**1927**	**1928**	**1929**
USA					
Russia					
South Africa					
Irish Republic (b)					
Sweden					
Japan					
Others					
Total HPHT	0	0	0	0	0
Near-Gem Use	95%	94%	93%	92%	91%
	1,166,639	1,551,977	2,078,525	2,218,010	2,015,469
Natural Industrial	1,692,141	2,287,697	2,927,421	3,339,557	3,215,266
Synthetic HPHT	0	0	0	0	0
Salvage					
Total Industrial Available	2,858,782	3,839,675	5,005,947	5,557,567	5,230,736
Actual/Estimate Used	2,805,103	3,001,461	3,211,563	3,436,372	3,676,918
Percent Growth	7.0%	7.0%	7.0%	7.0%	7.0%
Synthetic Percent	0%	0%	0%	0%	0%
Natural Percent	100%	100%	100%	100%	100%
Excess/(Shortfall)	53,678	838,214	1,794,384	2,121,195	1,553,817
Accumulated Stock	334,095,298	334,933,512	336,727,896	338,849,091	340,402,908
Ind % of Total Natural	39.56%	40.16%	39.65%	42.75%	43.24%

Synthetic	**1930**	**1931**	**1932**	**1933**	**1934**
USA					
Russia					
South Africa					
Irish Republic (b)					
Sweden					
Japan					
Others					
Total HPHT	0	0	0	0	0
Near-Gem Use	90%	89%	88%	87%	86%
	2,032,904	1,929,802	1,544,922	1,012,771	1,135,662
Natural Industrial	3,539,906	3,769,610	3,457,775	2,268,064	2,790,098
Synthetic HPHT	0	0	0	0	0
Salvage					
Total Industrial Available	5,572,811	5,699,413	5,002,698	3,280,836	3,925,761
Actual/Estimate Used	3,934,303	4,209,704	4,504,383	4,819,690	5,157,068
Percent Growth	7.0%	7.0%	7.0%	7.0%	7.0%
Synthetic Percent	0%	0%	0%	0%	0%
Natural Percent	100%	100%	100%	100%	100%
Excess/(Shortfall)	1,638,508	1,489,709	498,315	(1,538,854)	(1,231,307)
Accumulated Stock	342,041,416	343,531,125	344,029,440	342,490,586	341,259,279
Ind % of Total Natural	46.92%	52.98%	57.60%	55.81%	57.24%

Synthetic	**1935**	**1936**	**1937**	**1938**	**1939**
USA					
Russia					
South Africa					
Irish Republic (b)					
Sweden					
Japan					
Others					
Total HPHT	0	0	0	0	0
Near-Gem Use	85%	84%	83%	82%	81%
	1,489,752	1,979,551	2,283,932	2,767,295	3,006,288
Natural Industrial	3,334,213	4,362,125	4,853,388	6,207,977	6,828,930
Synthetic HPHT	0	0	0	0	0
Salvage					
Total Industrial Available	4,823,966	6,341,677	7,137,320	8,975,273	9,835,218
Actual/Estimate Used	5,518,063	5,904,327	6,317,630	6,759,865	7,233,055
Percent Growth	7.0%	7.0%	7.0%	7.0%	7.0%
Synthetic Percent	0%	0%	0%	0%	0%
Natural Percent	100%	100%	100%	100%	100%
Excess/(Shortfall)	(694,097)	437,350	819,690	2,215,409	2,602,163
Accumulated Stock	340,565,182	341,002,532	341,822,221	344,037,630	346,639,793
Ind % of Total Natural	53.82%	52.92%	51.13%	54.12%	54.90%

Synthetic	**1940**	**1941**	**1942**	**1943**	**1944**
USA					
Russia					
South Africa					
Irish Republic (b)					
Sweden					
Japan					
Others					
Total HPHT	0	0	0	0	0
Near-Gem Use	80%	79%	78%	77%	76%
	3,072,692	2,133,608	2,180,122	1,931,039	2,640,075
Natural Industrial	7,068,154	4,837,306	4,921,369	4,400,824	6,259,828
Synthetic HPHT	0	0	0	0	0
Salvage					
Total Industrial Available	10,140,847	6,970,915	7,101,491	6,331,864	8,899,904
Actual/Estimate Used	7,630,873	8,050,571	8,493,353	8,960,487	9,453,314
Percent Growth	5.5%	5.5%	5.5%	5.5%	5.5%
Synthetic Percent	0%	0%	0%	0%	0%
Natural Percent	100%	100%	100%	100%	100%
Excess/(Shortfall)	2,509,974	(1,079,656)	(1,391,861)	(2,628,623)	(553,409)
Accumulated Stock	349,149,768	348,070,112	346,678,251	344,049,627	343,496,218
Ind % of Total Natural	54.74%	52.04%	51.35%	50.64%	52.95%

Synthetic	**1945**	**1946**	**1947**	**1948**	**1949**
USA					
Russia					
South Africa					
Irish Republic (b)					
Sweden					
Japan					
Others					
Total HPHT	0	0	0	0	0
Near-Gem Use	75%	74%	73%	72%	71%
	3,223,547	2,276,386	2,087,639	2,180,434	2,963,451
Natural Industrial	7,970,867	5,205,856	4,769,920	5,144,736	7,647,773
Synthetic HPHT	0	0	0	0	0
Salvage					
Total Industrial Available	11,194,415	7,482,243	6,857,560	7,325,171	10,611,225
Actual/Estimate Used	9,973,246	10,521,774	11,100,472	11,710,998	12,355,103
Percent Growth	5.5%	5.5%	5.5%	5.5%	5.5%
Synthetic Percent	0%	0%	0%	0%	0%
Natural Percent	100%	100%	100%	100%	100%
Excess/(Shortfall)	1,221,169	(3,039,532)	(4,242,913)	(4,385,827)	(1,743,878)
Accumulated Stock	344,717,387	341,677,855	337,434,943	333,049,115	331,305,237
Ind % of Total Natural	55.09%	50.25%	49.38%	50.15%	53.94%

Synthetic	**1950**	**1951**	**1952**	**1953**	**1954**
USA					
Russia					
South Africa					
Irish Republic (b)					
Sweden					
Japan					
Others					
Total HPHT	0	0	0	0	0
Near-Gem Use	70%	69%	68%	67%	66%
	3,186,428	3,426,573	3,721,051	3,961,187	3,961,638
Natural Industrial	8,306,493	9,144,694	10,192,313	10,962,281	11,023,279
Synthetic HPHT	0	0	0	0	0
Salvage					
Total Industrial Available	11,492,921	12,571,268	13,913,365	14,923,469	14,984,918
Actual/Estimate Used	13,034,634	13,751,538	14,507,873	15,305,806	16,147,625
Percent Growth	5.5%	5.5%	5.5%	5.5%	5.5%
Synthetic Percent	0%	0%	0%	0%	0%
Natural Percent	100%	100%	100%	100%	100%
Excess/(Shortfall)	(1,541,713)	(1,180,271)	(594,508)	(382,337)	(1,162,708)
Accumulated Stock	329,763,525	328,583,254	327,988,746	327,606,409	326,443,702
Ind % of Total Natural	53.53%	53.87%	54.41%	54.27%	53.77%

Synthetic	**1955**	**1956**	**1957**	**1958**	**1959**
USA				1,300,000	1,500,000
Russia					
South Africa					
Irish Republic (b)					
Sweden					
Japan					
Others					
Total HPHT	0	0	0	1,300,000	1,500,000
Near-Gem Use	65%	64%	63%	62%	61%
	3,987,284	4,209,318	4,616,761	4,939,168	4,945,832
Natural Industrial	11,352,614	12,188,923	13,646,445	14,436,001	13,813,471
Synthetic HPHT	0	0	0	1,300,000	1,500,000
Salvage					
Total Industrial Available	15,339,899	16,398,241	18,263,207	20,675,169	20,259,303
Actual/Estimate Used	17,035,745	17,972,711	18,961,210	20,004,076	21,104,301
Percent Growth	5.5%	5.5%	5.5%	5.5%	5.5%
Synthetic Percent	0%	0%	0%	6%	7%
Natural Percent	100%	100%	100%	94%	93%
Excess/(Shortfall)	(1,695,846)	(1,574,470)	(698,003)	671,093	(844,997)
Accumulated Stock	324,747,856	323,173,386	322,475,383	323,146,475	322,301,478
Ind % of Total Natural	53.55%	53.23%	53.94%	53.04%	50.44%

Synthetic	**1960**	**1961**	**1962**	**1963**	**1964**
USA	2,000,000	2,500,000	3,000,000	5,000,000	5,200,000
Russia		2,000			
South Africa		500,000	998,519	1,475,231	2,638,598
Irish Republic (b)				333,333	400,000
Sweden				250,000	250,000
Japan					
Others					
Total HPHT	2,000,000	3,002,000	3,998,519	7,058,564	8,488,598
Near-Gem Use	60%	59%	58%	57%	56%
	4,948,305	6,282,005	5,627,018	5,629,282	6,558,418
Natural Industrial	13,407,925	17,057,473	14,946,521	14,869,369	18,337,291
Synthetic HPHT	2,000,000	3,002,000	3,998,519	7,058,564	8,488,598
Salvage					
Total Industrial Available	20,356,231	26,341,479	24,572,059	27,557,215	33,384,307
Actual/Estimate Used	22,265,037	23,489,614	24,781,543	26,144,528	30,000,000
Percent Growth	5.5%	5.5%	5.5%	5.5%	14.7%
Synthetic Percent	10%	11%	16%	26%	25%
Natural Percent	90%	89%	84%	74%	75%
Excess/(Shortfall)	(1,908,807)	2,851,865	(209,484)	1,412,688	3,384,307
Accumulated Stock	320,392,671	323,244,536	323,035,052	324,447,740	327,832,046
Ind % of Total Natural	48.07%	48.47%	47.72%	47.09%	48.32%

Synthetic	1965	1966	1967	1968	1969
USA	5,400,000	6,000,000	8,000,000	11,000,000	13,000,000
Russia		3,250,000	6,000,000	8,000,000	10,000,000
South Africa	2,562,824	2,487,050	2,500,000	5,000,000	7,000,000
Irish Republic (b)	600,000	800,000	1,000,000	4,000,000	6,000,000
Sweden	250,000	250,000	250,000	1,000,000	3,000,000
Japan	250,000	250,000	250,000	500,000	500,000
Others			250,000	500,000	1,000,000
Total HPHT	9,062,824	13,037,050	18,250,000	30,000,000	40,500,000
Near-Gem Use	55%	54%	53%	52%	51%
	6,539,689	6,764,673	7,253,910	7,158,276	8,118,384
Natural Industrial	17,319,656	18,088,785	19,711,826	20,006,939	21,231,456
Synthetic HPHT	9,062,824	13,037,050	18,250,000	30,000,000	40,500,000
Salvage			2,500,000	3,000,000	3,000,000
Total Industrial Available	32,922,169	37,890,508	47,715,737	60,165,216	72,849,840
Actual/Estimate Used	36,250,000	42,500,000	44,625,000	45,963,750	47,342,663
Percent Growth	20.8%	17.2%	5.0%	3.0%	3.0%
Synthetic Percent	28%	34%	38%	50%	56%
Natural Percent	72%	66%	62%	50%	44%
Excess/(Shortfall)	(3,327,831)	(4,609,492)	3,090,737	14,201,466	25,507,178
Accumulated Stock	324,504,216	319,894,724	322,985,461	337,186,927	362,694,105
Ind % of Total Natural	45.97%	45.61%	46.18%	46.14%	43.43%

Synthetic	**1970**	**1971**	**1972**	**1973**	**1974**
USA	15,000,000	16,770,000	18,748,860	20,961,225	23,434,650
Russia	10,000,000	11,100,000	12,321,000	13,676,310	15,180,704
South Africa	7,000,000	7,700,000	8,470,000	9,317,000	10,248,700
Irish Republic (b)	7,000,000	7,700,000	8,470,000	9,317,000	10,248,700
Sweden	3,000,000	3,420,000	3,898,800	4,444,632	5,066,880
Japan	1,000,000	1,138,000	1,295,044	1,473,760	1,677,139
Others	1,000,000	1,138,000	1,295,044	1,473,760	1,677,139
Total HPHT	44,000,000	48,966,000	54,498,748	60,663,688	67,533,913
Near-Gem Use	50%	49%	48%	47%	46%
	8,362,481	8,234,191	8,200,501	8,058,332	7,912,025
Natural Industrial	21,266,189	20,893,001	20,965,424	20,941,236	21,049,975
Synthetic HPHT	44,000,000	48,966,000	54,498,748	60,663,688	67,533,913
Salvage	3,000,000	3,060,000	3,121,200	3,183,624	3,247,296
Total Industrial Available	76,628,671	81,153,192	86,785,873	92,846,880	99,743,210
Actual/Estimate Used	48,762,942	50,225,831	55,000,000	60,000,000	65,000,000
Percent Growth	3.0%	3.0%	9.5%	5.0%	8.3%
Synthetic Percent	57%	60%	63%	65%	68%
Natural Percent	43%	40%	37%	35%	32%
Excess/(Shortfall)	27,865,729	30,927,361	31,785,873	32,846,880	34,743,210
Accumulated Stock	390,559,834	421,487,195	453,273,068	486,119,948	520,863,158
Ind % of Total Natural	42.48%	41.89%	42.10%	41.97%	42.15%

Synthetic	1975	1976	1977	1978	1979
USA	26,199,939	29,291,532	32,747,932	36,612,188	40,932,427
Russia	16,850,582	18,704,146	20,761,602	23,045,378	25,580,369
South Africa	11,273,570	12,400,927	13,641,020	15,005,122	16,505,634
Irish Republic (b)	11,273,570	12,400,927	13,641,020	15,005,122	16,505,634
Sweden	5,776,244	6,584,918	7,506,806	8,557,759	9,755,846
Japan	1,908,584	2,171,969	2,471,700	2,812,795	3,200,961
Others	1,908,584	2,171,969	2,471,700	2,812,795	3,200,961
Total HPHT	75,191,072	83,726,386	93,241,780	103,851,159	115,681,831
Near-Gem Use	45%	44%	43%	42%	41%
	7,492,408	7,194,772	7,142,768	6,939,108	7,035,407
Natural Industrial	20,705,093	20,433,922	20,800,467	20,403,022	20,147,102
Synthetic HPHT	75,191,072	83,726,386	93,241,780	103,851,159	115,681,831
Salvage	3,312,242	3,378,487	3,446,057	3,514,978	3,585,278
Total Industrial Available	106,700,817	114,733,568	124,631,073	134,708,267	146,449,618
Actual/Estimate Used	65,000,000	80,275,000	101,146,500	110,000,000	150,000,000
Percent Growth	0.0%	23.5%	26.0%	10.0%	36.4%
Synthetic Percent	70%	73%	75%	77%	79%
Natural Percent	30%	27%	25%	23%	21%
Excess/(Shortfall)	41,700,817	34,458,568	23,484,573	24,708,267	(3,550,382)
Accumulated Stock	562,563,974	597,022,542	620,507,115	645,215,382	641,665,000
Ind % of Total Natural	43.27%	43.50%	43.39%	43.04%	41.90%

Synthetic	**1980**	**1981**	**1982**	**1983**	**1984**
USA	45,762,453	51,162,422	57,199,588	63,949,140	71,495,138
Russia	28,394,210	31,517,573	34,984,506	38,832,802	43,104,410
South Africa	18,156,197	19,971,817	21,968,999	24,165,899	26,582,488
Irish Republic (b)	18,156,197	19,971,817	21,968,999	24,165,899	26,582,488
Sweden	11,121,664	12,678,697	14,453,714	16,477,234	18,784,047
Japan	3,642,693	4,145,385	4,717,448	5,368,456	6,109,303
Others	3,642,693	4,145,385	4,717,448	5,368,456	6,109,303
Total HPHT	128,876,108	143,593,096	160,010,702	178,327,885	198,767,178
Near-Gem Use	40%	39%	38%	37%	36%
	6,954,870	6,653,318	6,974,438	8,360,673	9,025,065
Natural Industrial	19,535,845	18,713,806	19,375,934	23,996,952	27,601,875
Synthetic HPHT	128,876,108	143,593,096	160,010,702	178,327,885	198,767,178
Salvage	3,656,983	3,730,123	3,804,725	3,880,820	3,958,436
Total Industrial Available	159,023,807	172,690,344	190,165,800	214,566,330	239,352,554
Actual/Estimate Used	150,000,000	150,000,000	150,000,000	165,000,000	190,000,000
Percent Growth	0.0%	0.0%	0.0%	10.0%	15.2%
Synthetic Percent	81%	83%	84%	83%	83%
Natural Percent	19%	17%	16%	17%	17%
Excess/(Shortfall)	9,023,807	22,690,344	40,165,800	49,566,330	49,352,554
Accumulated Stock	650,688,806	673,379,151	713,544,951	763,111,281	812,463,835
Ind % of Total Natural	40.60%	40.18%	39.86%	41.10%	42.38%

Synthetic	**1985**	**1986**	**1987**	**1988**	**1989**
USA	79,931,564	89,363,489	99,908,381	111,697,569	124,877,883
Russia	47,845,895	53,108,943	58,950,927	65,435,529	72,633,437
South Africa	29,240,737	32,164,811	35,381,292	38,919,421	42,811,363
Irish Republic (b)	29,240,737	32,164,811	35,381,292	38,919,421	42,811,363
Sweden	21,413,814	24,411,748	27,829,393	31,725,508	36,167,079
Japan	6,952,387	7,911,816	9,003,647	10,246,150	11,660,119
Others	6,952,387	7,911,816	9,003,647	10,246,150	11,660,119
Total HPHT	221,577,521	247,037,434	275,458,578	307,189,749	342,621,363
Near-Gem Use	35%	34%	33%	32%	31%
	9,051,848	11,973,540	11,715,331	12,395,244	12,065,682
Natural Industrial	29,176,451	42,067,630	42,569,821	46,809,707	46,062,621
Synthetic HPHT	221,577,521	247,037,434	275,458,578	307,189,749	342,621,363
Salvage	4,037,605	4,118,357	4,200,724	4,284,739	4,370,434
Total Industrial Available	263,843,425	305,196,962	333,944,455	370,679,439	405,120,100
Actual/Estimate Used	200,000,000	230,000,000	260,000,000	312,000,000	374,400,000
Percent Growth	5.3%	15.0%	13.0%	20.0%	20.0%
Synthetic Percent	84%	81%	82%	83%	85%
Natural Percent	16%	19%	18%	17%	15%
Excess/(Shortfall)	63,843,425	75,196,962	73,944,455	58,679,439	30,720,100
Accumulated Stock	876,307,260	951,504,222	1,025,448,676	1,084,128,115	1,114,848,215
Ind % of Total Natural	43.19%	46.33%	46.32%	46.92%	46.26%

Synthetic	**1990**	**1991**	**1992**	**1993**	**1994**
USA	139,613,473	156,087,863	174,506,230	195,097,966	218,119,526
Russia	80,000,000	80,000,000	80,000,000	80,000,000	80,000,000
South Africa	47,092,500	51,801,750	56,981,925	62,680,117	68,948,129
Irish Republic (b)	47,092,500	51,801,750	56,981,925	62,680,117	68,948,129
Sweden	41,230,470	47,002,735	53,583,118	61,084,755	69,636,621
Japan	13,269,215	15,100,367	17,184,218	19,555,640	26,000,000
Others	13,269,215	15,100,367	17,184,218	19,555,640	25,000,000
Total HPHT	381,567,372	416,894,831	456,421,633	500,654,234	556,652,404
Near-Gem Use	30%	29%	28%	27%	26%
	12,661,868	11,414,797	11,141,332	10,861,605	10,875,540
Natural Industrial	49,532,969	45,411,102	45,345,204	45,844,002	49,538,900
Synthetic HPHT	381,567,372	416,894,831	456,421,633	500,654,234	556,652,404
Salvage	4,457,842	4,546,999	4,637,939	4,730,698	4,825,312
Total Industrial Available	448,220,052	478,267,730	517,546,109	562,090,538	621,892,156
Actual/Estimate Used	411,840,000	428,313,600	441,163,008	441,163,008	441,163,008
Percent Growth	10.0%	4.0%	3.0%	0.0%	0.0%
Synthetic Percent	85%	87%	88%	89%	90%
Natural Percent	15%	13%	12%	11%	10%
Excess/(Shortfall)	36,380,052	49,954,130	76,383,101	120,927,530	180,729,148
Accumulated Stock	1,151,228,267	1,201,182,397	1,277,565,497	1,398,493,027	1,579,222,175
Ind % of Total Natural	45.93%	45.17%	44.40%	44.40%	45.90%

APPENDIX C

DATA REFERENCES

1. DATE ORDER

1920-1948	*The Mineral Industry of the British Empire and Foreign Countries*, Statistical Summary, (Production, Imports and Exports).
1934	Central African Republic (C.A.R.) Production average of 1933 and 1935.
1940-1963	Diamond use growth at 5.5% to get 30 Mct use in 1964 - *Mining Annual Review*, (1965), p.87.
1958	C.A.R. as reported in *Diamond International*, (1993), 'Canadians lead revival in the C.A.R.', May/June, p.91.
1960	US Bureau of Mines estimate industrial diamond stockpile at 320 Mct. *Mining Annual Review*, (1965), p.87.
1960	Liberia production estimated to be average of 1961 and 1959.
1961	2000 carats of synthetic from USSR - *Mining Annual Review*, (1964), p.85.
1961	USSR natural production revised per *Mining Annual Review*, (1964), p.83 and (1965), p.89.
1963	Irish Synthetics - A third of South Africa's production capacity was moved to Shannon in May 1963 - *Mining Annual Review*, (1964), p.85.
1963	Komatsu Manufacturing Co planned 100 000 carat synthetic diamond production - *Mining Annual Review*, (1964), p.85.
1964	Ghana industrial split as per *Mining Annual Review*, (1965), p.91, 67% Industrial. Cross reference with Johnson *et al.* (1989).

1964-1968	Congo Kinshasa and Congo Brazzaville combined see *Mining Annual Review*, (1968), p.113.
1965	Russian natural production for 1965 and 1966 estimated to be average of 1964 and 1967.
1965	Sweden and Japan synthetic estimated at 250000 ct see *Mining Annual Review*, (1966), p.95.
1965	USA Synthetic production 5.4 Mct, *Mining Annual Review*, (1968), p.112.
1966	World synthetic capacity at least one fifth of requirements - ie: 13 million of 42 Mct, *Mining Annual Review*, (1968), p.111. (18.2 Mct is the actual used).
1967	Gem to industrial split in 1967 sourced from *Mining Annual Review*, (1968), p.111 - cross references with Johnson *et al.* (1989) and also indicates that near-gem was originally classified as industrial. But, particularly since 1970, near-gem has been cuttable by Indian cutters. Therefore model phases out near-gem from industrial category as follows:
1920	100% near-gem used for industrial, reduced by 1% per year. This appears plausible since the yield is low - 20%, the remaining 80% is used for industrial. Further, the USA sell-off of industrial stockpile at $80 per carat in 1992 indicates that original industrial grade contained near-gem material. This assumption has been confirmed by *Diamond Intelligence Briefs*, (1993), March, p.979.
1968	Sweden/USA/USSR Synthetic Diamond and USA salvage production per *Mining Annual Review*, (1970), 123-124.
1968	C.A.R. industrial production updated, *Mining Annual Review*, (1970), p.117.
1968	Indian gem-industrial split as per *Mining Annual Review*, (1970), p.119.
1968-1970	Synthetic production from Collins, D. I. C., (1971), *Mining Annual Review*, June, p.19.
1969	Total synthetic-natural split of 46%:54% is confirmed by De Beers' *International Diamond Annual*, (1971), Vol. 1, p.258.
1970	Tanzania update: 'Tanzania Revisited', *Diamond International*, (1992), November/December, 79-84.
1969-71	Natural per country production as per *Mining Annual Review*, (1972), p.121.
1970	Russian natural 1969 - 1972 revised by *International Diamond Annual*, as cited in *Mining Annual Review*, (1973), p.121.
1971-1990	Synthetic growth for Russia of 11% to get 80 Mct 1990 - *Diamond International*, (1994), March/April, No. 28, p.56. (1991-94 constant at 80 Mct).

1971	Distinction between gem and industrial depends on market demand. *Mining Annual Review*, (1971), p.119. This appears to be a major turning point in the definition of gem grades and followed the announcement that GE achieved gem quality synthesis.
1971	Guinea production taken to be average of 1970 and 1972.
1972	55 Mct of synthetic consumed, *Mining Annual Review*, (1973), p.124.
1972-1994	USSR gem split - 40% industrial, *Diamond Intelligence Briefs*, (1990), `Diamonds today a reference review of the diamond industry', August 29, Vol. 6, No. 114-115, p.681. Cross referenced with Johnson, *et al.* (1989), reports 30% industrial in 1987.
1973	Synthetic consumption of 60 Mct, *Mining Annual Review*, (1973), p.124.
1973	25% increase reported in Japan for industrial consumption *Mining Annual Review*, (1974), p.129.
1976	Rise in near-gem industrial use reported by *Mining Annual Review*, (1977), p.127. (This is doubtful given the already substantial stocks).
1976	Rise in industrial consumption to 80 Mct from 65 Mct, *Mining Annual Review*, (1977), p.127.
1977 - 92	Synthetic consumption as per *Mining Annual Review*, (1977-92).
1978	Total industrial consumption of 110 Mct = 10 % increase see *Mining Annual Review*, (1979), p.128.
1980	De Beers and GE account for 83 % of West's synthetic output, *Mining Annual Review*, (1980), p.137.
1980	Synthetic statistics for 1979 - West produced 100 Mct and East 50 Mct *Mining Annual Review*, (1980), p.137.
1982	Industrial consumption of 110 Mct plus approximately 40 Mct in the East. *Mining Annual Review*, (1983), p.121.
1983-1993	Ivory Coast mined 200000 carats - *Mazal U'Bracha*, (1993), `The State of the Diamond Industry', December, Vol. 9, No. 54. p.100.
1983	125 Mct of industrial diamonds consumed in the West and 50 million estimate in the East. *Mining Annual Review*, (1984), p.123.
1984	150 Mct in West plus East of 50 Mct consumed. *Mining Annual Review*, (1984:127; 1985:148).

1986-1992	Natural source (Excluding China) - *Mazal U'Bracha*, (1993), `The state of the diamond industry', No. 55, December, p.86.
1986	170 Mct produced in West - Industrial - plus 60 Mct in East, *Mining Annual Review*, (1987), p.125.
1987	200 Mct of industrial produced in West plus 60 Mct in East, *Mining Annual Review*, p. 28.
1987	Gem, near-gem and industrial split assumed constant at 1987 levels as per Johnson *et al.*, (1989), p.93.
1988	250 Mct produced in West plus 60 Mct in East, *Metals and Minerals Annual Review*, (1989).
1988	Chinese natural production estimated to remain constant at 1 Mct 1988-1990.
1990	Industrial actual use - 400 Mct + CPE economies see *Metals and Minerals Annual Review*, (1991), p.120.
1990	Ghana gem production 15-25%, *Diamond International*, (1992), March/April, No. 28, p.84.
1990	Synthetic production of 250 Mct (assume in the West) - *Mining Journal* as cited in - *Diamond Intelligence Briefs*, (1992), 24 August, p.919.
1990	66 tons synthetic and 20 tons natural used. (330 Mct vs 100 Mct) see - Teresko, J., (1990), `Diamond films: will they be Norton's best friend?', *Industry Week*, Nov 5, Vol. 239, No. 21, pp 44-46. (Stay with my numbers - close enough).
1991	Guinea natural production updated from *Diamond Intelligence Briefs*, (1990), 21 October, p.940.
1991	Natural production updated from *Diamond Intelligence Briefs*, (1993), 1 February, p.969, (Note - No Chinese production mentioned).
1991	*Diamond Intelligence Briefs*, (1993), 1 February, p. 969 - Implies near-gem now not used for Industrial Purposes. This is consistent with my assumption that Indian cutters are working with poor quality material.
1991	Brazil & Venezuela production updated from *Diamond Intelligence Briefs*, (1993), 21 October, p.941.
1991	Sierra Leone's production updated from *Diamond Intelligence Briefs*, (1993), 21 October, p.941.
1991	China's gem percent of 20% - *Diamond Intelligence Briefs*, Vol. 8, No. 155, p.940.

1991	GE Synthetic production reported to be 150 Mct in 1990 (156 Mct in 1990 above), *Mechanical Engineering-CIME*, (1990), Oct, Vol. 112, No. 10, p.2.
1992	Belgium indicates that gem and near-gem (70 Mct) are used for jewellery, Geneva Ref - *Diamond Intelligence Briefs*, (1992), Geneva, 2 November, p. 1.
1992	Natural statistics source - *SA Minerals Bureau* as cited in *Diamond News and SA Jeweller*, (1994), 1, p.23.
1992	USA Bureau of Mines estimate synthetic production for cutting and drilling at 88 tons per year or 440 Mct, *Journal of Commerce*, (1993), 7 June, p.9a. (Note - this must surely be the Industrial Market).
1992	Natural diamond updated - *Diamond Intelligence Briefs*, (1992), Vol. 8, No. 155, p.933 (China's production of 1 Mct is used).
1992	Interesting to note the arbitrary definition of gem, near-gem and industrial - *Diamond Intelligence Briefs*, (1992), Vol. 8, No. 155, p.936.
1992	USSR/CIS natural production estimated at 12-22 Mct annually rather than 15 Mct. - *Diamond Intelligence Briefs*, (1992), Vol. 8, No. 155, p.939. (USA Bureau=15, Mining Journal=12, DIB=22 Mct's all for 1991!).
1993	Natural production growth of 1.1 % from Johnson, C. J., *et al.*, (1989), p.97.
1994	Natural diamond production - Terraconsult as cited in *Diamond International*, (1994), March/April,‘Can diamond supplies keep up with demand', No 34,39-48.
1994	Janse, A. J. A., (1996), ‘A history of diamond sources in Africa: part II’, *Gems and Gemology*, Vol. 31, No. 1, 2-31. This reference confirms the 90% synthetic share predicted by the model for 1994. There are however data discrepancies cited in *Metals and Minerals Annual Review*, (1995), ‘Precious metals and minerals: diamonds’, Page 26, for the period 1990 through 1994.

2. ALPHABETIC ORDER

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