Strategies for Maximizing the Social Benefit from the Exploitation of Gypsum Mineral Resource of Thailand

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Abstract

The study begins by investigating Thailand's administration of its mineral resources and those of some other leading mineral-exporting countries for comparison. The notion of 'resource curse', which affects many resource-rich countries, and an analysis how Thailand fought and won the 'curse' is critically explored. The principle of sustainable development and its implication to Thailand are presented, together with various computed indicators of sustainable development for Thailand. The role of mineral resources and Hotelling's model in the context of sustainable development are discussed.

The essence of this study is the development of economic models to determine the optimal extraction paths of Thailand's gypsum resources based on Hotelling's concept of maximizing Net Present Value (NPV) of benefits accrued to the country. This study finds that under all assumptions and all scenarios, at a certain point in time, Thailand should stop exporting its gypsum and devote the remainder of its gypsum resources to domestic consumption only. In addition, Thailand should push gypsum price up to a certain level. The model determining gypsum consumption in Thailand and some countries imported gypsum from Thailand, which are the basis to determine the optimal extraction paths of gypsum in Thailand, is also developed. It shows that the price of gypsum had no effect on its consumption. In other words, the demand for gypsum might be highly inelastic. Finally, the long-term policies for Thailand to manage its gypsum resource are recommended.

Acknowledgements

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Declaration

I declare that this thesis has been composed by myself and that it embodies the results of my own research. It has neither been accepted nor submitted for any other degrees. All information from other sources has been properly acknowledged.

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Table of Contents

List of Figures

List of Tables

Chapter 1 An Introduction to the Construction Mineral Industries in Thailand

1.1 Introduction

1.1.1 What are the Construction Mineral Industries?

To construct most structures: buildings, concrete bridges, and roads, Portland cement and aggregates[1] are required. For decorating a building, dimension stones[2] are among consumers' choices. Therefore, construction minerals can be divided into three groups: Portland cement group, aggregate group, and dimension stone group.

Important chemical compositions of Portland cement consist of calcium oxide (CaO), silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3). Therefore, minerals used in the production of Portland cement are low-magnesium limestone, shale, and iron ore. In addition to the three aforementioned minerals, gypsum is normally added to the product as the retarder to prolong the setting time of the Portland cement.

The aggregate group comprises sand, pebbles, and crushed stones. In Thailand, the production of pebbles is negligible, while the production of sand for construction is huge and widespread. However, their industries, which are not overseen by the Department of Primary Industries and Mines, DPIM, will not be studied in this research because their problems are not prominent and their statistics are scant and difficult to compile. The resources of crushed stones are limestone, granite, basalt, and hard sandstone. In Thailand, to produce crushed stones, limestone rock is the first choice.

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[1] Aggregates comprise sand, gravel, and crushed stone that are mixed with Portland cement to make concrete or with asphalt to make road pavement.

[2] Dimension stones are solid rocks that, after cut and polished, are used as floor or wall tiles, tables, etc.

Granite, basalt, and hard sandstone are crushed locally where limestone outcrops[3] are absent.

Dimension stone group is composed of marble, granite, limestone, and some other calcium carbonate minerals. Minerals in this group need to be solid and have an attractive colour suitable to make floor and wall tiles.

1.1.2 An Overview of the Construction Mineral Industries in Thailand

From geological points of view, Thailand is rather well endowed with a variety of mineral resources. At present, Thailand produces about 40 kinds of minerals mainly for domestic consumption. In the past, mining industry as a whole used to play a significant role in the economic development of the country. For a long period of time, until a couple of decades ago, export of minerals was a major source of Thailand's foreign exchange earnings, and income from mineral royalties was an important source of the government revenue. However, the rapid economic growth over the last two decades has made the country increasingly less dependent on the exploitation of its mineral resources. From 1993 to 2005, the average contribution of the mining and quarrying[4] sector (excluding petroleum) to the GDP of Thailand was only about 2.0 per cent (Bank of Thailand, 2006). Figure 1.1 shows the share of the mining and quarrying sector to the nation's GDP. Because of its small contribution to the national economy together with its past mistake of not taking environmental concerns seriously, the mining industry, as a whole, is not well supported by the public and is treated as an annoying sunset industry.

[3] Outcrop is a large mass of rock that stands above the surface of the ground.
[4] A quarry is a place where large amounts of stone are extracted using explosives or dug out of the ground.

However, because the marginal extraction costs of almost all construction minerals are low, transportation costs per ton take big portions in the prices paid by customers. For example, in U.S.A., the average annual free on board plant price, which included all costs of mining, processing, in-plant transportation, overhead costs, and profit of crushed stones in 2006 was $8.19 per metric ton (Willett, 2009). But, freight and logistics costs can be 50% to 70% of delivered cost of mineral to customer (Barker, 2007). This means that, in 2006, users in U.S.A. had to pay for crushed stones at prices up to $16.3 – 27.3 per metric ton, or between two to three times the free on board plant price. It can be deducted from such importance of the transportation costs that price disparities between imported and domestic construction minerals could be very large, if the sources of the minerals are far from the border. In the case of Thailand, if there was no domestic production of crushed stones, people who live in Bangkok might have to pay for the crushed stones from Myanmar about triple the prices they pay now simply because of the high costs of transportation by trucks of about 0.07 – 0.10 US$/ton/kilometre. If Thailand was not producing gypsum, users in Thailand would be expected to pay for imported gypsum from Australia about the same price paid by Japanese, which is almost double the domestic gypsum price now. Prices of gypsum will be discussed in some details later in Chapter 5. This is the reason why countries, even rich ones, normally do not attempt to suppress mining for construction materials, except for small countries that have very limited land. Hence, the industry is really a necessary one. In this category of minerals, Thailand has ample resources of limestone, granite and other dimension stones, sand and glass sand, shale, clays, and gypsum.

In 2005, Thailand had a gross national product per capita of about $2,660, which was classified by the World Bank as an upper-middle-income developing country. Its average GDP growth rate in the last five year was about five per cent. At this fairly good level of economic prosperity, together with the size of its population of about sixty-five million, we can certainly see a huge demand for construction materials in the region of several million tons annually. Undoubtedly, mining for construction materials is a big and growing industry in Thailand which means that mining and quarrying still play an important role to upstream industries in supporting downstream industries.

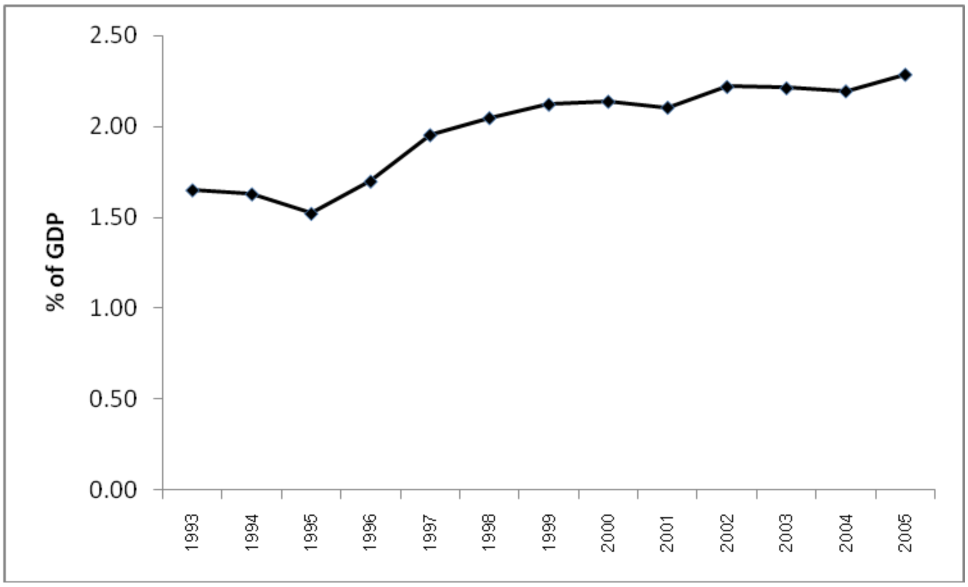

Figure 1.1 The Share of the Mining and Quarrying Sector to the GDP of Thailand from 1993 to 2005

Source: Bank of Thailand (2006)

1.2 Current Situation of the Construction Mineral Industries in Thailand

The time period to be studied started from 1995, the year the Thai Government transferred the quarrying and rock crushing industry to be under the supervision of the Department of Mineral Resources (now the DPIM), when Thailand began to systematically compile data and information about the construction mineral industries. Because of the very strong and traumatic impacts of the Far East Asian financial and economic crisis of 1997, the study will divide the time period to be studied from 1995 to 2005 into three sub-periods: first, the period before the economic crisis; second, the period immediately after the economic crisis; and third, the period of full recovery.

1.2.1 The Mining and Quarrying Sector and the Construction Sector, in General

As shown in Figure 1.2, before the economic crisis, from 1995 to 1996, the values, at 1988 Prices, of the mining and quarrying sector and the construction sector grew at the annual rate of 9.6% and 7.1%, respectively. Immediately after the economic crisis, the values of the mining and quarrying sector decreased for two years, from 1997 to 1998, at the average annual rate of 20.8%. But the construction sector endured the lash of the economic crisis two years longer, since its values showed negative growth from 1997 to 2000, at the average annual rate of - 20.0%. The average growth rate, during the period of full recovery, of the values of the mining and quarrying sector was 6.6%, from 1999 to 2005, and that of the construction sector were and 5.1%, from 2001 to 2005 (Bank of Thailand, 2006).

As for the prospect in the near future, these two industries are expected to remain bright because of the big government construction projects and the flourishing of house markets as the result of the good economic growth.

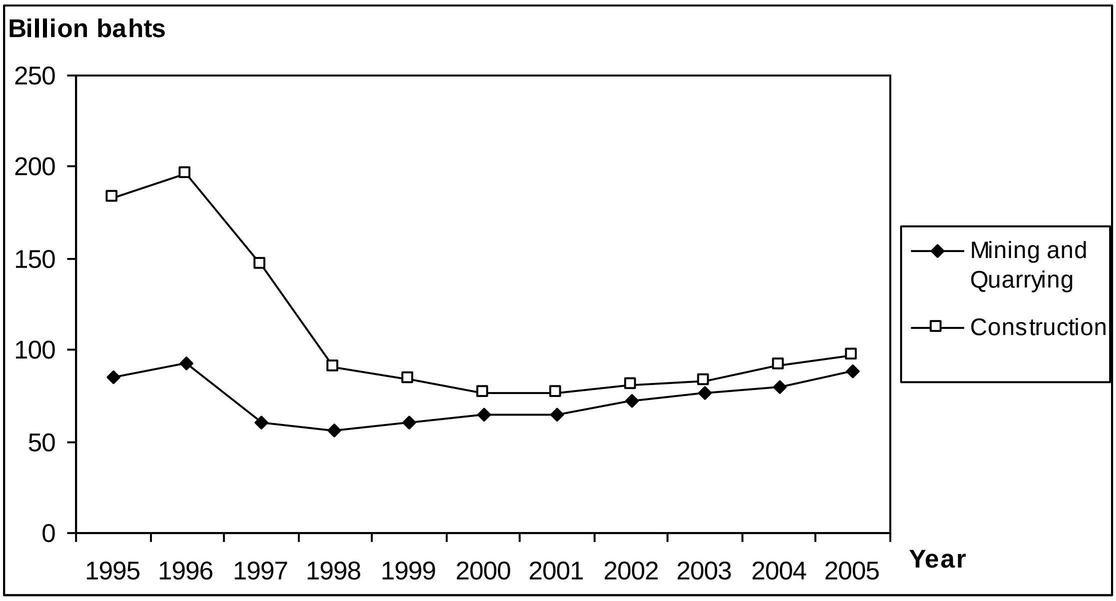

Figure 1.2 GNP by Industry from 1995 to 2005 at 1988 Prices

Source: Bank of Thailand (2006)

1.2.2 Portland Cement

As shown in Figure 1.3, after the economic crisis, the production statistics for Portland cement showed two distinctive patterns: one during the period from 1999 to 2002, another during the period from 2002 to 2005. Although it was affected by and barely survived after the economic crisis, the production of Portland cement for the former period increased at the average rate of 7.0% per annum, a better figure than the construction sector as a whole, because of the increasing export as a result of the depreciation of the Thai currency. During the latter period, the production of cement increased at the average rate of 3.8% per annum. Its production rose owing, in larger part, to the growth construction sector in the Thai economy, while the export declined significantly. In fact, during the latter period, the domestic consumption of cement grew at the average rate of 8.0% per annum. In 2005, the domestic consumption accounted for 67% of the country's total production, at 43.5 million metric tons, which reached 89% of the country's production capacity (Office of Industrial Economics, 2006).

As shown in Figure 1.4, the production of limestone and shale as raw materials for cement production, after the economic crisis, from 1999 to 2005, also grew in a similar pattern to that of the cement. As for gypsum, another raw material in producing Portland cement, the situation was less correlative with that of the cement. The unique situation of gypsum was due to the exportation of gypsum and its other significant domestic uses. Figure 1.5 shows the production, consumption, and export of gypsum from 1995 to 2005 (Department of Primary Industries and Mines, 2006). Details of the gypsum resources in Thailand will be presented in Chapter 5.

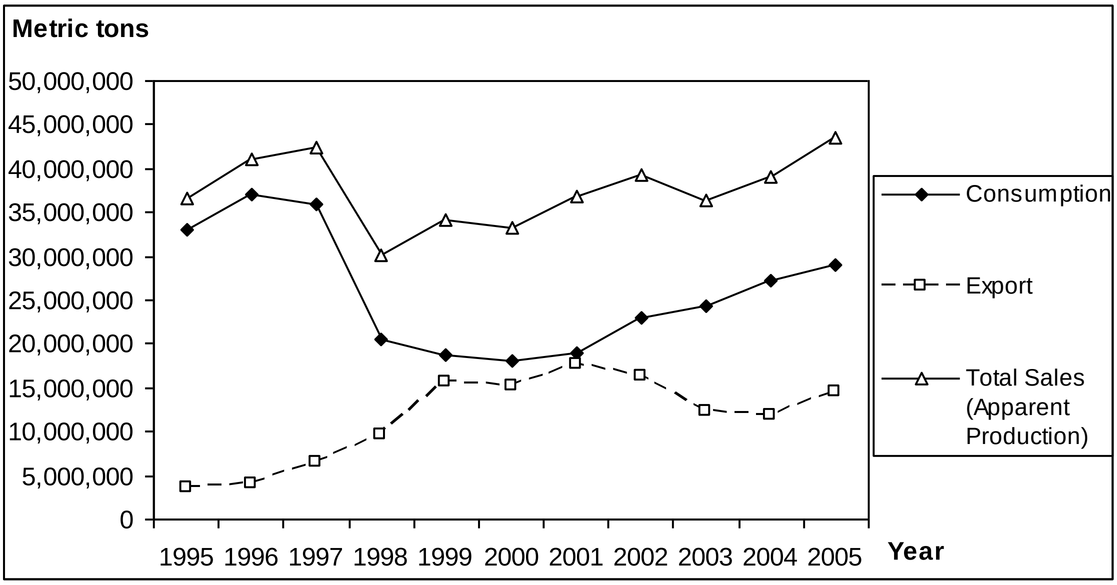

Figure 1.3 Total Cement Statistics from 1995 to 2005

Source: Office of Industrial Economics (2006)

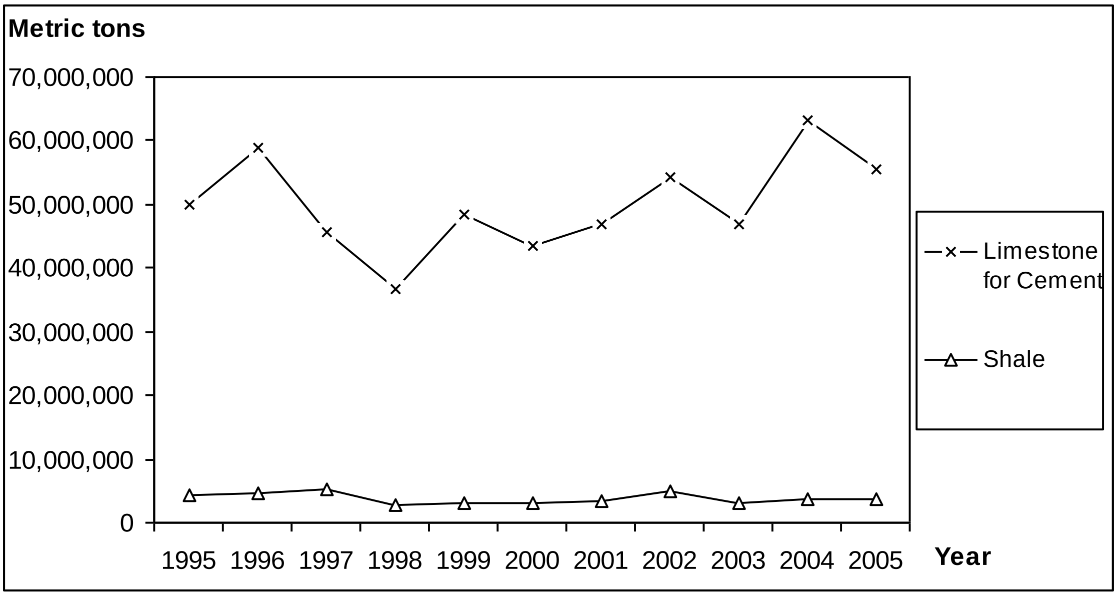

Figure 1.4 Production of Limestone for Cement and Shale from 1995 to 2005

Source: Department of Primary Industries and Mines (2006)

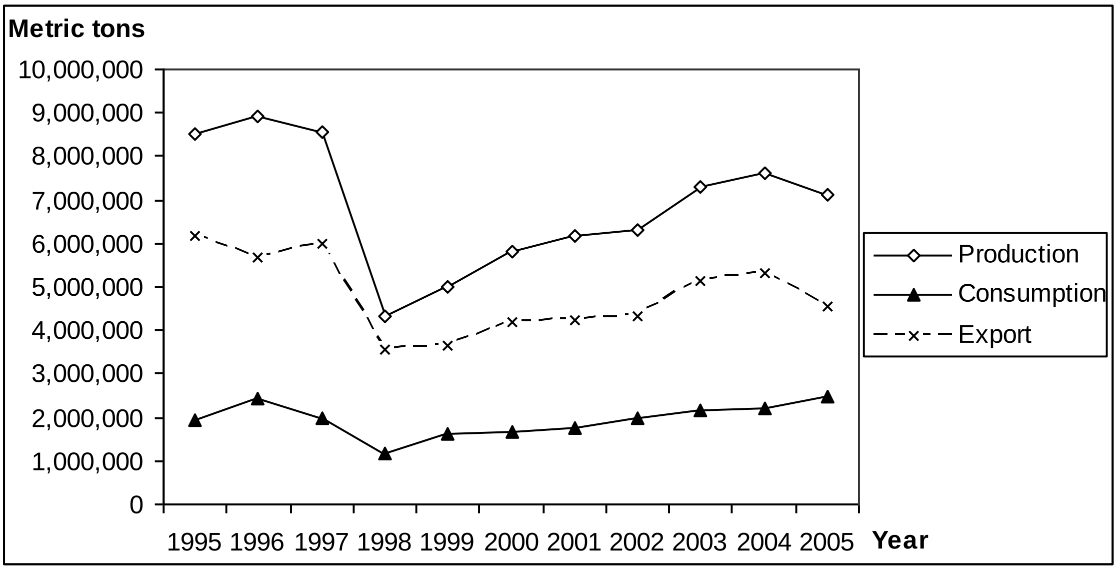

Figure 1.5 Production, Consumption, and Export of Gypsum from 1995 to 2005

Source: Department of Primary Industries and Mines (2006)

1.2.3 Crushed Stones

In Figure 1.6, after the economic crisis, the production of crushed stones, consisting of limestone, granite, basalt, and hard sandstone, as aggregates for the domestic construction industry, can be divided into two patterns: one during the period from 1997 to 1998, and another during the period from 1998 to 2005. The production during the former period decreased at the average rate of 36.1% per annum, while during the latter period it grew at the average rate of 26.4% per annum. In 2005, the domestic consumption accounted for 97% of the country's total production, at 97.4 million metric tons (Department of Primary Industries and Mines, 2006).

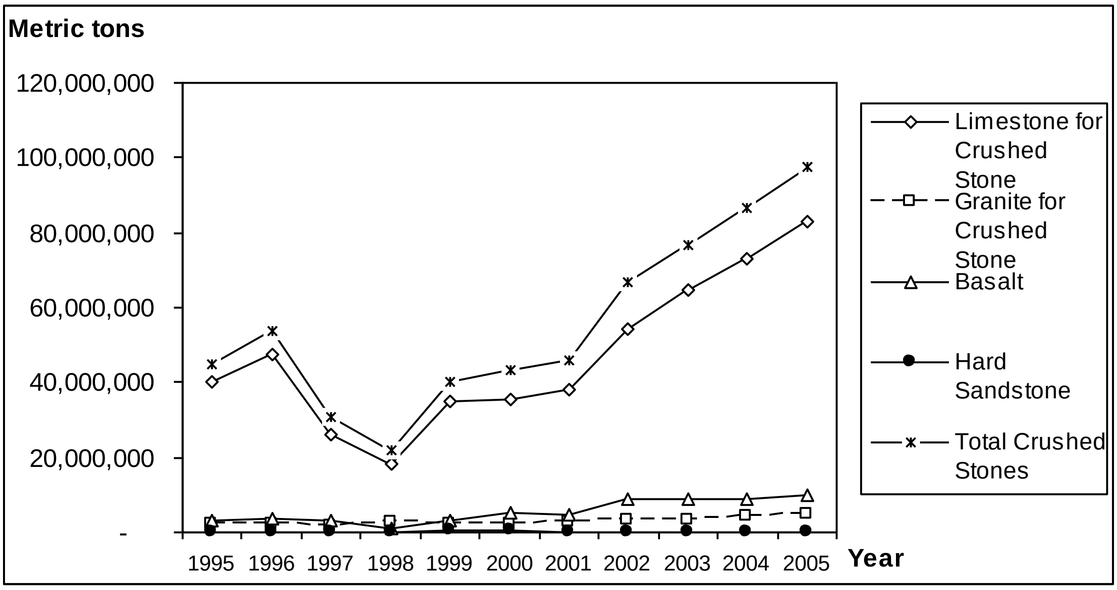

Figure 1.6 Production of Crushed Stones from 1995 to 2005

Source: Department of Primary Industries and Mines (2006)

1.2.4 Dimension Stones

The dimension stone industry in Thailand faced a bleak future even before Thailand encountered the economic crisis. In Figure 1.7, from 1995 to 1996, the total production of dimension stones decreased at an annual rate of 6.8%. After the economic crisis, the patterns of production of dimension stones can be divided into two periods; one from 1997 to 1999, and another from 1999 to 2005. Affected by the severe economic crisis, the total production during the former period declined sharply at the average rate of 50.7% per annum. The production during the latter period improved with an annual increasing rate of 12.1% due to the growth of the construction sector. However, the production numbers were below 40,000 cubic metres (Department of Primary Industries and Mines, 2006).

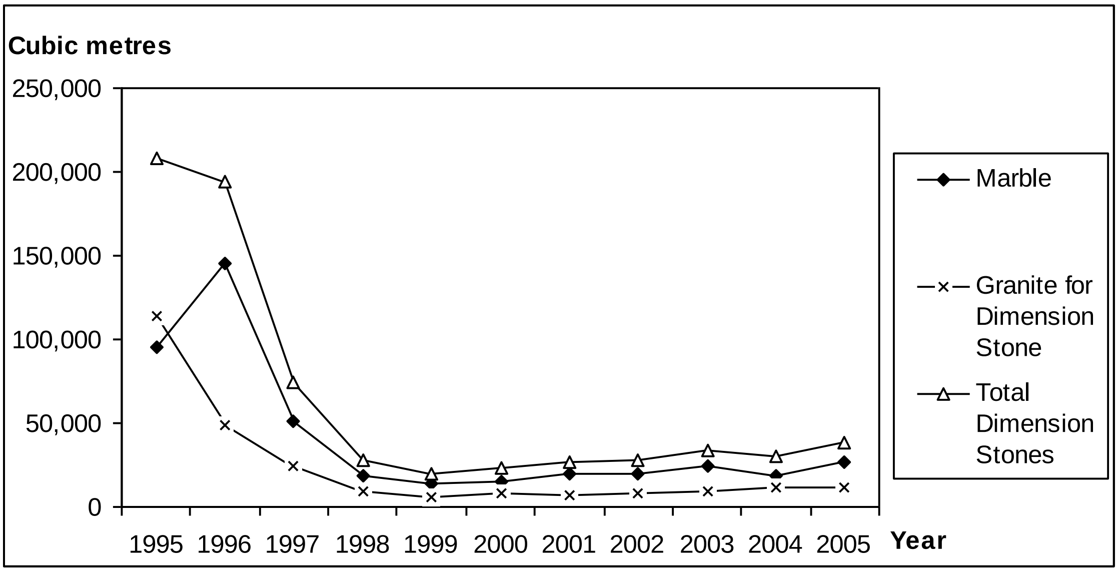

Figure 1.7 Production of Dimension Stones from 1995 to 2005

Source: Department of Primary Industries and Mines (2006)

1.3 The Construction Mineral Availability of Thailand

The availabilities of minerals for future exploitation are quoted as reserves and resources of the minerals. A general classification of reserves and resources of minerals is depicted by the McKelvey box of Figure 1.8. The total amount of material on earth is the ‘Base resource’ as represented by the outer box (= total resource). The undiscovered part of the base resource is the ‘Hypothetical resource’. The discovered base resource is divided into two parts: the part that cannot be economically or technically extracted is called ‘Conditional resources’, while the part that is economically and technically extractable is ‘Reserves’. Theoretically, the size of a reserve relative to the base resource can increase because of exploration, price rises, lifted restrictions, improved technology, etc. and decrease because of price falls or imposed restrictions (Gray, 2004). To reflect varying degrees of both geological and economic certainty, reserves can be subdivided into proven, probable and possible categories; frequently used synonyms are: measured, indicated, and inferred. Proven or measured reserves are stocks with reasonable certainty that can be recoverable under current prices and costs. Probable or indicated reserves are stocks partly explored with some certainty and representing the best approximation of extra stocks that can be recoverable under current prices and costs. Possible or inferred reserves are stocks whose approximations are based on broad geological character. Generally, reserves are not fixed. The more prices rise, the more stocks can be economically extracted (Perman *et al.*, 2003).

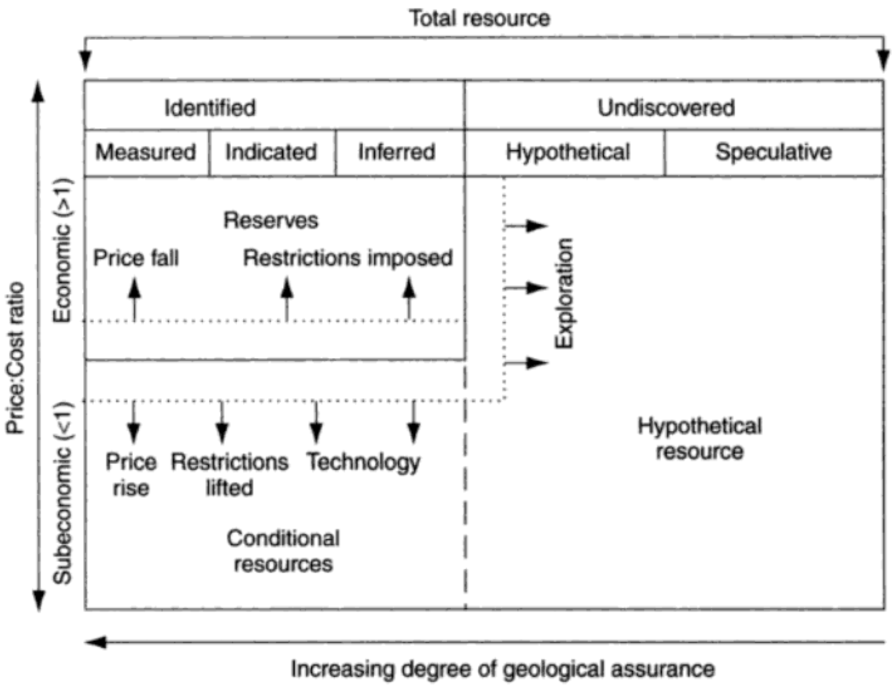

Figure 1.8 The McKelvey Box Showing the Relationship between Resources and Reserves

Source: Bennett and Doyle (1997)

However, as demonstrated in Figure 1.9, gypsum and other cheap sedimentary minerals--including limestone and shale--have very high geological continuity and high grades by nature. Therefore, their reserves can be identified and estimated without much effort. In fact, they are cheap simply because they are abundant and easy to be found, explored, excavated and processed. As a country having a fairly complete geological map, it is more likely that all major economic deposits of construction minerals in Thailand are known. Hence, the chance that price rises will spur discoveries of new significant deposits is slim. Furthermore, their stratified orebodies are physically clear-cut and massive. Therefore, the sizes and quantities of the already known reserves will not alter by changes in prices either. But a conditional resource can switch over to economic reserves by a sufficient increase in prices paying to producers. In fact, because of the relatively high transportation costs, distances from a deposit to the mineral users decide whether the deposit is an economic reserve or a conditional resource. An uninteresting hard-rock hill can become an economic reserve for crushed stone once a large town springs up or a big construction project is planned to be developed near by.

All the reserve figures for the construction minerals shown in topics 1.3.1 and 1.3.2, apart from those of gypsum, were the total proven reserves of each mineral in the areas of the present-day mining licenses as updated in 2006. The figures for gypsum were the total proven plus probable reserves in the areas of the present-day mining licenses, of the applications for mining licenses, and in a forest that primarily explored by the Department of Mineral Resources (DMR). Indeed, with the exception of gypsum, there are at least hundreds of million metric tons of reserves of each mineral that are located outside the areas of the present-day mining licenses. In other words, most construction mineral resources are physically sustainable since there are a lot of hard rock mountains all over the country providing vast reserves of rocks.

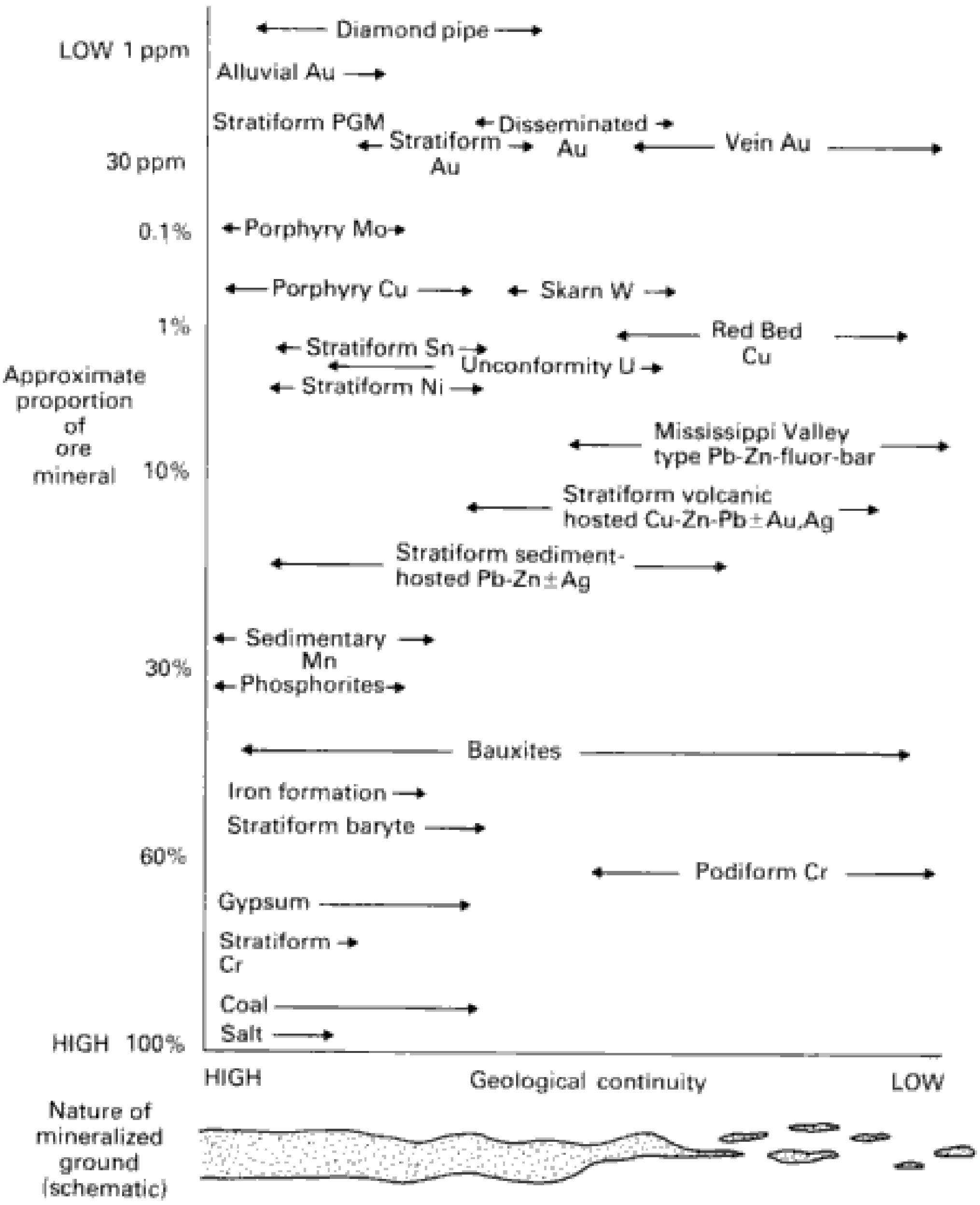

Figure 1.9 Diagrammatic Representation of the Continuity of Different Orebody Types and Approximate Grades.

Source: King *et al*. (1982)

1.3.1 Portland Cement Group

a) Limestone Suitable for Portland Cement Production

Limestone is very widespread and can be found throughout most parts of the country, except for the north-eastern Korat Plateau. However, the reserves of limestone that are suitable for Portland cement production are located in some areas in the central, northern, and southern parts of the country. The deposits of such limestone in the central part of country, especially in Saraburi, Nakhon Ratchasima, Ratchaburi, Phetchaburi, and Nakhon Sawan provinces, are the major sources of raw material of many cement plants supplying Portland cement to the city of Bangkok and its vicinity, the most important domestic market for construction materials.

In the northern part, the deposits in Lampang, Phrae, Chiang Rai, and Nan provinces support a cement plant in Chae Hom district, Lampang province. In the southern part, there are deposits in Nakhon Sithammarat province, in which a cement plant is located. Just the total proven reserves ***in the areas of the present-day mining licenses as updated in 2006*** were 7,520 million metric tons.

b) Shale

The reserves of shale are abundantly found all over the country. Just the total proven reserves ***in the areas of the present-day mining license as updated in 2006*** were 487.13 million metric tons, all of which are in Saraburi, Lampang, and Nakhon Sithammarat provinces, where cement plants are located.

c) Iron ore

Iron ore is a minor raw material in the production of Portland cement. There are six deposits of iron ore reserves in three provinces. In Loei Province, there are four deposits, namely, Phu Yang, Phu Ang, Phu Lek, and Phu Hia, and their total proven reserves ***in the areas of the present-day mining licenses as updated in 2006*** were 27.2 million metric tons of 52 per cent Fe. The Khao Uem Kreum deposit in Kanchanaburi province had the total proven reserves ***in the areas of the present-day mining licenses as updated in 2006*** of 4.8 million metric tons of 40 per cent Fe. Finally, in Lop Buri province, Khao Thab Kwai deposit had the total proven reserves ***in the areas of the present-day mining licenses as updated in 2006*** of 7.6 million metric tons of 44.4 per cent Fe.

d) Gypsum

Gypsum constitutes a very small part in Portland cement, but it is a crucial raw material. The reserves of gypsum are in Suratthani and Nakhon Sithammarat provinces in the southern part, Phichit and Nakhon Sawan provinces in the central part, and Loei province in the north-eastern part. Its total proven plus probable reserves in the areas of the present-day mining licenses, of the applications for mining licenses, and in a forest primarily explored by the Department of Mineral Resources (DMR), as updated in 2006, were 270.73 million metric tons. The locations of Thailand and its gypsum deposits are shown in Figure 1.10 and Figure 1.11, respectively.

Figure 1.10 Location of Thailand in South-East Asia

Source: National Statistical Office of Thailand (2000)

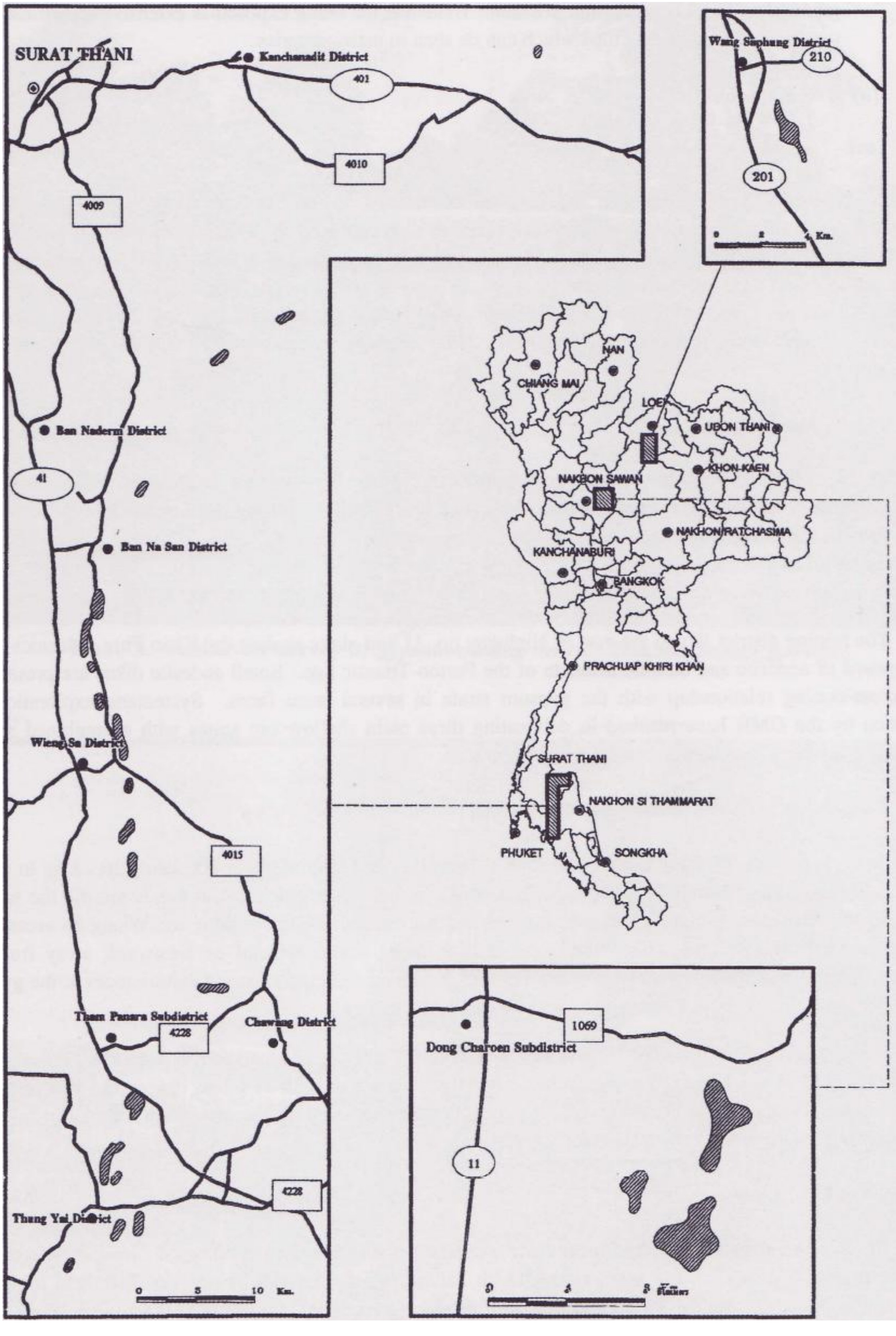

Figure 1.11 Location of Gypsum Deposits in Thailand

Source: Utha-aroon and Rattanajaruraks (1996)

1.3.2 Aggregate Group

a) Limestone

More than 80% of the total consumption of crushed stones comes from limestone because its outcrops are located all over the country and its quality is quite consistent. Just the total proven reserves ***in the areas of the present-day mining licenses as updated in 2006*** were 2,355 million metric tons.

The suppliers of crushed stones to the city of Bangkok and its vicinity are from 62 limestone quarry areas in 9 provinces: Saraburi, Lopburi, Pargeneburi, Sakweaw, Kanganaburi, Supanburi, Ratchaburi, Petchaburi, and Prajuabkerekan.

b) Granite

Granite is the second most important source for the production of crushed stones for construction after limestone, especially in the areas lacking limestone such as in Chonburi and Naratiwat provinces. Besides substituting for limestone, crushed granite is used as aggregate in concrete where high strength is a requirement. Granite mountains are located all over the country except for Korat plateau in the north-eastern part of Thailand. Just the total proven reserves ***in the areas of the present-day mining licenses as updated in 2006*** were 296 million metric tons.

c) Basalt

Basalt is the third important source for the production of crushed stones for construction, constituting about 10% of total consumption of crushed stones. Crushed basalt is produced only in the north-eastern part of the country, where basalt is widespread. Just the total proven reserves ***in the areas of the present-day mining licenses as updated in 2006*** were 156 million metric tons.

d) Hard Sandstone

Hard sandstone is located in many areas all over the country especially in the north-eastern part. Just the total proven reserves ***in the areas of the present-day mining licenses as updated in 2006*** were 31 million metric tons.

1.4 Government Policies on the Construction Mineral Industries of Thailand

At present the government policies on the construction mineral industries are not fully cohesive. The administration of the resources of construction minerals—namely, crushed stones for aggregate, dimension stones, sand, shale, and gypsum—in Thailand is under the direct jurisdiction of at least three departments in three ministries. While the Department of Mineral Resources, Ministry of Natural Resources and Environment, has a control over the declared lands of high mineral potential, the Department of Primary Industries and Mines, Ministry of Industry, is authorized to administer the mining industry which includes the producers of crushed stones for aggregate, limestone and shale for Portland cement, and the mineral gypsum. Excavation of construction sand is under the provincial authorities, which are supervised by the Ministry of Interior. In addition, before permission to mine is granted, a mining project has to submit its Environmental Impact Assessment (EIA) report to the Office of Natural Resources and Environmental Policy and Planning for approval. It is a system of checks and balances, but a result is red tape in the administration of the mineral resource industries.

1.4.1 Specific Policies on Gypsum

Thailand's gypsum is unique. The total proved ore reserves of gypsum in Thailand at present is large, at the level of hundreds million metric tons. Unlike in North America and in Europe, where gypsum production is dominated by a small number of big corporations, Thailand has more than twenty small producers. Thailand's production of natural gypsum in 2004 was about 8 million metric tons, ranking as the 5th largest natural gypsum producer in the world behind U.S.A, Iran, Canada and Spain (Founie, 2006). But, in terms of export, Thailand is the world's second largest supplier of natural gypsum behind only Canada. Thailand has become the dominant international supplier of gypsum in the Asia-Pacific region because it has almost no rivals in the region. As gypsum is a cheap and bulky commodity, transportation costs play a crucial role in competition. Note that, in U.S.A., freight and logistics costs can be 50% to 70% of delivered cost of the mineral to customer (Barker, 2007) and, as to be mentioned in some details in Chapter 5, from 1988 to 2004, the average Cost, Freight and Insurance (CIF) price of gypsum at Japan's ports, in constant dollars (year 2005=100), was 30.5 US$/metric ton. Such a price, which included transportation costs, was almost double the average Free on Board (FOB) price of gypsum at Thailand's ports, in constant dollars (year 2005=100), of 15.5 US$/metric ton, during the same period. The closest competitor of Thailand in the region is Australia, besides far away Mexico and Morocco. But the transportation costs from Australia to major gypsum consuming countries, such as Japan and South Korea, are higher than that from Thailand, because of the longer distances. But facing big powerful foreign gypsum users, Thai gypsum producers have almost never realized this advantage. Competition by price-cutting among Thai gypsum producers was intense from time to time. Once in a while, when the gypsum price had been so low, small gypsum miners would ask the Government to intervene. At present, the following measures are enforced by DPIM:

i) No new mining license to mine gypsum will be granted. This measure is not effective in reducing the supply of gypsum, because it does not affect the present capacities of the existing mines. But the measure eliminates new entrants to the industry.

ii) Export of gypsum is under government control, and non-marketable quotas for export were allocated to all gypsum mines depending on three factors: each mine production capacity, remaining gypsum reserve in each mine, and a share of each mine in the total export of the country in the previous year. However, facing strong opposition from miners, the Government was unable to cut down the export of each mine much. As a result, the country's total export quota has always exceeded the total demand from abroad. Therefore, this measure alone has not totally eliminated price-cutting competition.

iii) In conjunction to the export control measure mentioned above, the government allows the Mining Council of Thailand to divide the export markets into six zones, and only the mining company who used to export to a particular zone will be granted permission to export to that zone. After introduction of these measures five years ago, the gypsum price has improved, but not very much.

1.4.2 Problems with Present Policies on Gypsum

As mentioned above, the present government policy has not been very effective in its attempt at increasing the export price of gypsum. Another drawback of the present policy is that it does not address the future problems when the country's resources of natural gypsum are depleted in the near future.

1.5 Narrowing the Scope of the Construction Mineral Industries to be Studied

Of all the construction minerals and their industries, only gypsum will be focused on in this study. The reason is that the amounts of reserves of other construction minerals can be deemed as physically sustainable to a reasonable future. On the other hand, gypsum is only one mineral in this group having limited reserves of 270.73 million metric tons, ***as updated in 2006***, which is not very big in comparison with its annual production. Even though there are some chances that reserves may increase from exploration, technological progresses, price rises, etc., the expected increasing stock is unlikely to meet future domestic consumption and export demands. Besides being a raw material for producing domestic Portland cement, gypsum is one of the important mineral resources raising the country's revenues from exportation. The upward trend of gypsum production is opposite to the downward trend of its remaining reserves. Therefore, its critical situation deserves to be focused on in this study.

1.6 Main Questions to be Answered and Corresponding Contents

To achieve the main objective of developing long-term strategies and plans for the government of Thailand to manage its gypsum mineral resources, the thesis will try to answer the following questions:

i) How does Thailand manage its mineral resources in general as opposed to gypsum in particular? This is a question about background information that needs to be answered before any recommendations to the government of Thailand can be made. Chapter 2 of this thesis will brief the essence of the mining law, taxation and policy of Thailand together with those of Canada, Australia and Brazil for comparison.

ii) What are the implications of exploiting mineral resources for a country, and how well did Thailand fare when it encountered the so-called "resource curse"? It is important for an individual involving mineral resource management to understand the "resource curse" phenomenon. Chapter 3 of this thesis, explaining the notion of natural resource curse and analysing the past reactions of Thailand when it faced the curse, is aimed to answer this question.

iii) What is the connection between the concept of sustainable development and mineral resources, and is the development of Thailand sustainable? Since an important theme of the concept of sustainable development is a concern over the environmental degradation and the depletion of natural resources, this question needs to be answered in dealing with mineral resource management. Chapter 4 of this thesis, covering the discussions about the concept of sustainable development, the role of mineral resources, together with an analysis about indicators for sustainable development in Thailand, will respond to these questions.

iv) What are the gypsum consumption functions for Thailand and its clients? Answer to this question is very important in determining the optimal depletion path of the gypsum resource of Thailand, empirically. Chapter 5 will show a very simple model determining gypsum demand in Thailand and some countries that imported gypsum from Thailand.

v) What is the optimal extraction path of Thai gypsum resource? This question needs to be answered because policies and plans for managing the Thai gypsum resources should be based on numerical facts. An economic model determining the optimal depletion path of Thailand's gypsum resources will be presented in Chapter 6.

Empirical solutions of the model will be the bases for the discussion in Chapter 7 and a part of the recommendation to be presented in Chapter 8.

Chapter 2 Mining Laws, Taxation, and Policies of Thailand and Some Other Countries

Mining activities adversely affect the environment while providing benefits to the public in the form of employment, export earnings, government revenues, etc. As a result, in most countries, mining industries are tightly controlled by special legislation and are levied extra taxes--such as mineral royalty, special income tax, etc.--in addition to corporate income tax that is levied on all businesses. This chapter will summarize the essence of the mining law, taxation and policy of Thailand. Also those of Canada, Australia and Brazil will be presented to see their similarities and differences. Canada and Australia are chosen as they are rich in minerals and are the leading mineral export countries. The framework of mining management in Brazil is considered as it is one of the developing countries, similar to Thailand, that export a lot of minerals. The comparison of Thailand's policies with those of Canada, Australia, and Brazil will be presented here too.

2.1 Thailand's Mining Laws, Taxation and Policies

Thailand is a single state country. There are elected local administrations at the sub-district level, but they have very limited authority. With regard to mineral resources, a local administration has been authorized to give consent to mining projects and to monitor the compliance with environment protection measures of miners in its jurisdiction. Although it is not stated explicitly in laws, mineral resources are treated as owned by the State and administrated by a department of the central government. Thailand has a long history of mining for metals, especially tin and gold, and the Government of Thailand has always committed to developing the mineral industry through the private sector. To govern private mining ventures, a governmental agency has been established for more than a century. During its long history, this agency has evolved, adopted some different names, and come under various ministries. Its present name is the Department of Primary Industry and Mines (DPIM) under the Ministry of Industry. Apart from being the main administrative agency executing mining laws, regulations, etc. the DPIM has a duty to promote mining ventures. The DPIM encourages private investments from both domestic and foreign sources, by providing necessary facilities in terms of legal and regulatory aspects as well as various forms of technical assistance.

2.1.1 Mining Laws

Thailand had its first modern mining law in 1901, more than a century ago. The law was repealed and replaced twice. At present the principal law governing the mining sector is the Minerals Act of 1967, which was amended in 1973, 1979, 1991, and 2002. The Minerals Act of 1967 and its amendments regulate prospecting, mining, mine-out land reclamation, mineral dressing, smelting, and mineral transactions including transporting, selling, buying, import and export of minerals. The Act really revolves especially around the tight control on mining for and extraction of tin, which was the single most important mineral in Thailand up until about two decades ago, in order to collect tin royalty effectively. The unwritten concept of the law is that minerals are vested to the nation; therefore, the owner of the land is not automatically entitled to be the ownership of the minerals underneath. No one shall explore for or undertake mining in any place, regardless of the right over the area unless obtaining a prospecting license or a mining concession from the DPIM. According to the Minerals Act, doing mineral business in every stage in Thailand must first get permission, in the form of licenses, permits, or concessions, from the DPIM. Some of the licenses and permits under the Minerals Act are as follows (Department of Primary Industries and Mines, 2004b):

a) Licenses for Prospecting

There are three types of prospecting licenses as follows:

i) *Prospecting License (PL)*: It is a one-year permit allowing a person to conduct general prospecting and exploration for minerals within a specified district or province.

ii) *Exclusive Prospecting License (EPL)*: This type of license grants a person an exclusive right to conduct prospecting and exploration for minerals within a specified area. In an area of an EPL, no other persons can apply for another EPL, a Special Prospecting License, or a Mining Concession. An inland EPL is valid for 1 year and covers an area not exceeding 4 square kilometres, while an offshore EPL is valid for 2 years and covers an area not exceeding 800 square kilometres.

iii) *Special Prospecting License (SPL)*: It is a document granting exclusive right to conduct mineral prospecting and exploration within a specified area not exceeding 16 square kilometres and with a validity period of 5 years. In an area of an SPL, any other persons cannot apply for another SPL, an EPL, or a Mining Concession.

b) Mining Concessions

Mining concessions under the present Mineral Act can be categorized into three types as follows:

i) Mining Concession for a surface inland mine: It is a document granted to a mining investor for an exclusive right to extract minerals inland by a surface mining method within a specified maximum area of 48 hectares and with a valid life of up to

25 years. A concession area is rather small, but one can apply for several mining concessions in conjunction.

ii) Mining Concession for an offshore mine: It is a document granted to a mining investor for an exclusive right to extract minerals offshore within a specified maximum area of 80 square kilometres and with a valid life of up to 25 years.

iii) Mining Concession for underground mining: It is a document, with a valid life of up to 25 years, granted to a mining investor for an exclusive right to extract minerals underground. The maximum area of this type of Mining Concession is 16 square kilometres, which can cover lands legally held by others. If the underground mining activities are done deeper than 200 metres, the miner does not need to get permission from the surface land owners. However, to get a Mining Concession for underground mining, an investor must past several stringent requirements including one or more public hearings.

c) <u>Licenses for Mineral Processing, Metallurgical Processing, Mineral Transactions, and other Licenses</u>

i) Mineral Processing License: It is a license allowing a person to set up a mineral processing plant. It has a valid life of up to 3 years, which may be extended and re-extended for up to 3 years each time.

ii) Metallurgical Processing License: It is a license allowing a person to set up a smelter or metallurgical processing plant. It has a valid life of up to 25 years, which may be extended for up to 25 years.

iii) Mineral transaction licenses comprise Mineral Purchase License, Mineral Storage License, Mineral Possession License, Mineral Transport License, Mineral Import License, and Mineral Export License.

iv) Other licenses exist such as License for a Joint Mining Operation, License for Temporary Suspension of Mining Operation, License for Diverting Water, Artisan Mining License, and Ore Panning License.

According to the Enhancement and Conservation of the National Environmental Quality Act of 1992, an applicant for mining must submit an Environmental Impact Assessment (EIA) report to the Office of Natural Resources and Environmental Policy and Planning (ONEP) for reviewing. A Mining Concession will not be granted by the DPIM before the EIA report is approved by ONEP.

Besides the requirement to submit an EIA report, the Enhancement and Conservation of the National Environmental Quality Act of 1992 stipulates a number of issues affecting mining activities as follows (United Nations, 2001):

- Establishing environmental standards enforcing on all mining activities,
- Designating any pieces of lands as environmentally protected areas to control land uses, and
- Establishing an environmental fund. This fund can be loaned by miners for spending on pollution control activities and reclamation of mined-out areas.

According to the Minerals Act of 1967, for mined-out areas, a holder of a Mining Concession must either backfill the pits, sumps or shafts, or reclaim the area to the original form. Reclamation of mined-out areas must be done in accordance with the conditions proposed in the mining plan submitted to the DPIM. Before mine closure, all mine structures and facilities must be completely removed. Furthermore, any mine reclamation and rehabilitation must comply with the conditions set out in the approved EIA report.

Foreign investors must get a Business License to run a mining business from the Minister of Commerce, with the approval of the Cabinet, as stipulated by the Foreign

Business Act of 1999. In addition, under the Foreign Business Act, a foreign company—defined as a company whose majority shareholders are foreigners—may run mining businesses in Thailand only if Thai nationals or Thai juristic persons hold the shares of not less than 40 percent of the capital of that company. The minimum amount of shares needed to be held by Thai nationals may be reduced to the level of not less than 25 percent with the approval of the Cabinet, but two-fifths of the total number of the company's directors must be Thai nationals. An application for a Business License to run a mining business can be submitted at the Department of Business Development, Ministry of Commerce, in Bangkok, or at a Local Business Development Office located in every province. The Cabinet will approve the application within sixty days of the application submitting date (Department of Primary Industries and Mines, 2004c).

2.1.2 Mining Taxation

According to the Revenue Code, a company doing any business in Thailand has to pay corporate income tax at a rate of 30% of its net profit and Value Added Tax (VAT) at a rate of 7%. In the case that the company's products are exported, all the VAT will be refunded. In addition to the aforementioned taxes, a mining company is also required to pay Mineral Royalties as stipulated in the Mineral Royalty Rates Act of 1966 amended in 1977 and 1979. The Mineral Royalty is a kind of ad valorem tax, paid to the DPIM in percentages of the revenues from minerals. In relation to construction minerals, the Mineral Royalty rates of limestone and shale for cement industry, iron ore, gypsum, and rocks for crushed stones are 7, 4.5, 4, and 4 percent, respectively. Besides specifying mineral royalty rates, the Mineral Royalty Rates Act of 1966 also spell out how to determine the revenues from minerals that will be the basis for Mineral Royalty payments (Department of Primary Industries and Mines, 2004a).

Besides taxes and mineral royalties, a mining company must also pay some operational fees to the DPIM in accordance with the Minerals Act of 1967 as follows:

i) Application fees: 100 bahts[5] for a PL, 500 bahts for an EPL, 1,000 bahts for an SPL, and 1,000 bahts for a ML.

ii) Annual land use fees: 3,750 bahts per square kilometre for prospecting and exploration, and 12,500 bahts per square kilometre for mining.

iii) Special Benefits to the State: An applicant for a ML for all kinds of minerals except for industrial rocks[6] must offer a special benefit to the State for the amount of 0.1% of total value of mineral reserves over 50 million bahts. To receive a ML for an industrial rock, an applicant must offer a special benefit to the State at the rates as shown in Table 2.1.

Table 2.1 Special Benefit to the State for a ML for Industrial Rocks

Value of Rock Reserves in the Ranges of (million bahts)	**Rates (%)**
< 50	-
50-2,500	0.1
2,500-7,500	0.2
7,500-20,000	0.5
20,000-50,000	1.0
> 50,000	2.0

Source: Department of Primary Industries and Mines (2004)

iv) Special Subscriptions: As stated in the Minerals Act, a ML holder must pay a Special Subscription at a rate not exceeding ten percent of the royalty paid for minerals produced. This Special Subscription will be kept by the DPIM as an expense budget for the reclamation of mined-out areas, for the prevention and suppression of illegal mining activities, and for local development. At present only tin mines are required to pay these Special Subscriptions at the rate of 2.5 percent of the royalty paid.

[5] In 2005, 40.22 Bahts = 1 US$

[6] Industrial rocks are solid rocks in Portland cement group (limestone for cement and shale) and crushed stone group (limestone for crushed stone, granite, basalt, and sandstone).

v) Reclamation Guarantee Deposits: Before a ML is granted a miner must deposit a sum of money at the DPIM as a guarantee that he/she will reclaim the mined-out areas. If the ML holder fulfils his/her obligation, this deposit will be returned to him/her in full (Department of Primary Industries and Mines, 2004b).

2.1.3 Mining Promotion Policies

a) Investment Promotion by the Board of Investment

Businesses in all stages of the mineral industry, including mining, are also eligible to apply for Investment Promotion Privileges (IPP) prescribed under the Investment Promotion Act of 1977 amended in 1991 and 2001. The investment promotion privileges, which can be granted by the Board of Investment (BOI) established by the Investment Promotion Act, include tax incentives and non-tax incentives. Some of the non-tax incentives include permission to bring in foreign workers, to own land, and to take out foreign currencies. The really important incentives are the tax incentives, the details of which are as follows (Department of Primary Industries and Mines, 2004d).

i) Exemption or reduction of import duty on imported machinery and equipment;

ii) Exemption of corporate income tax for 3, 5 or 8 years for a project with capital investment exceeding 10 million bahts (excluding costs of land and working capital) and obtaining ISO 9000 or similar international standard certification within 2 years, otherwise the exemption of corporate income tax will be reduced by 1 year;

iii) Reduction of corporate income tax by 50% for 5 years after the end of corporate income tax holiday;

iv) Double deduction from taxable income for transportation, electricity and water costs for 10 years from the date of first revenue derived from promoted activities; and

v) Deduction can be made from net profit of 25 per cent of the project's infrastructure installation or construction costs for 10 years from the date of the first sales, and net profit for one or more years of any year can be chosen for such deduction. The deduction is in addition to normal depreciation.

b) Providing Geological Data

Besides offering fiscal and other incentives, Thailand has invested a lot in developing good geological information available for potential mining investors. A geological survey unit has been established in the Department of Mineral Resources since 1933. In Thailand, systematic prospecting and exploration for economic minerals done by the government has been guided by the consecutive National Economic and Social Development Plans (NESDPs) with the aim of supporting domestic downstream industries and strengthening the national economy. During 1962-1976 (NESDP Nos. 1-3), exploration focused on tin, iron ore, manganese, ceramic minerals, fluorspar, glass sand, and marl which were commodities produced mainly for export. During 1977-1981 (NESDP No. 4), there was continual exploration from the earlier NESDPs and new projects focused on potash/rock salt and energy minerals such as solid fuels and radioactive minerals. Since the early 1980s, the production of mineral commodities has shifted orientation from export towards domestic uses because of the domestic economic growth and the collapse of the world tin market in 1986. During 1982-1986 (NESDP No. 5), exploration focused on industrial minerals, solid fuels, hydrothermal energy and radioactive minerals.

During 1987-2006 (NESDP Nos. 6-9), large budgets were allocated to two consecutive mineral exploration projects: the Mineral Resources Development Project (MRDP), and the Accelerated Mineral Resources Exploration and Evaluation Project (AMREEP), with the aim firstly to accelerate the exploration for minerals of economic importance such as gold, potash, and raw materials for Portland cement and secondly, to promote mineral exploration investment by the private sector. The MRDP's objectives were to define mineral potential areas on a regional scale and to acquire geological data for resource management. As a result of the MRDP, 345 high mineral potential areas were located, and one-third of these potential areas showed good prospects for finding gold and base metals. Under the AMREEP, 60 high mineral potential areas, the results of the MRDP, covering 36,400 square kilometres, were selected for detailed investigation by farming out exploration contracts to private companies. It was expected that the mineral deposits thus discovered as a result of AMREEP would be released by bidding to the private mining investors. However, at present this policy has been unintentionally changed due to the bureaucratic reform of 2002. Before October 2002, the Department of Mineral Resources, Ministry of Industry, was the sole governmental authority responsible for gathering geological data, managing the country's mineral resources, and governing the mineral industries. Since the bureaucratic reform, the Department of Mineral Resources, has been come under the Ministry of Natural Resources and Environment, and is authorized to oversee only geological works and to manage the high mineral potential areas. At the same time, the DPIM has been established in the Ministry of Industry and authorized to administer the country's mineral industries. These two departments have not yet worked in tandem; therefore, the plan to release the discovered mineral deposits to private investors by bidding has not yet materialized (United Nations, 2001).

c) Inducing the Support of Local Communities

To reduce the conflicts between miners and local communities, DPIM has worked with other relevant government agencies and local authorities to minimize social and environmental problems from mining operations. Local authorities are delegated to be involved in decision-making about the exploitation of mineral resources in their responsible areas. Furthermore, 60 per cent of mineral royalties collected by DPIM will be allocated to local and provincial administrations for the well-being of the local people.

d) Promoting Good Practices

During 2005-2006, DPIM ran a project to rate the operational performance in the areas of engineering and environmental management of all mining, mineral processing, milling, and metallurgical entrepreneurs. Any companies rating highly on operational performance in both areas will be awarded certificates of recognition by the DPIM. This project had the key objective of encouraging entrepreneurs in the mineral industries to improve their performance for the benefit of neighbouring communities and the country as the whole.

2.1.4 Relevant Environmental Policies

a) On Pollution from Mining

In Thailand, at present, the biggest mineral businesses are quarrying and rock milling to produce crushed stones for aggregates and hence, affects environment the most. These industries are the major sources of dust pollution from the mineral sector. Because crushed stone is a bulky low-price commodity, the sources of production, which generate dust, are normally situated close to cities and this proximity is the major cause for concern by the public. The quarrying and rock milling industry is an old and important industry because its product—crushed stones—is a necessary material for construction of roads, buildings, and other structures. In Thailand, because of the rapid economic growth, the industry has grown very fast. The environmental problem from the quarrying and rock milling industry is exacerbated by the concentration of rock quarries and mills in a small area. In Thailand, metropolitan Bangkok and its surrounding cities and towns are the major consumers of aggregate. Therefore, quarries and rock mills are concentrated at limestone outcrops not too far from Bangkok, which has no stone resources of its own because of being situated on a flood plain. The largest concentration of quarrying and rock milling industry in Thailand is at Tha-pra-lan and adjacent districts in Saraburi Province which is the main crushed stone supplier for metropolitan Bangkok and its surrounding cities and towns: the major aggregate consumers of the country. In this area, there were 108 quarries, 50 rock mills, and 15 limestone-powder mills, with a total crushed stone production of about fifty million tons per annum, which was about one half of the total country's crushed stone production.

As the country's economy grew, dust pollution in the areas of concentrated crushed stone production had gotten worse year by year. In 1995, the Thai government took actions by placing the quarrying and rock milling industry under the supervision of the Department of Mineral Resources (now the DPIM). At its worst, in 1996, the total suspended particles in the air at the centre of the district town was measured at 1,721 micrograms per cubic metre, more than five times the acceptable air quality standard of 330 micrograms per cubic metre. To solve the problem, strict enforcement of the laws was not seen as an option because it would have disrupted the supply of aggregate. The DPIM had to start everything from scratch since all rock mills were used to emitting dust freely without penalty.

The project to mitigate dust pollution in the areas surrounding quarries and rock mills at Tha-pra-lan and adjacent districts in Saraburi province was initiated in 1997 and ran until 2000. The main objective of this project was to reduce dust pollution in the area to the acceptable safe standard by using dust prevention and suppression technology and environmental management. The project was intended as a pilot project for solving the dust pollution problem caused by quarries and aggregate mills in other concentrated areas of crushed stone production all over the country. The Faculty of Engineering, Chulalongkorn University, was hired as the project consultant. Altogether, the total budget was about $5 million. The project could be claimed to be moderately successful because the dust pollution gradually reduced. In 1999, around the middle of the project, the Total Suspended Particle (TSP) at the centre of the district town was reduced to 230 micrograms per cubic metre and 120 micrograms per cubic metre at the end of the project in 2001. The two figures are well below the acceptable standard of 300 micrograms per cubic metre.

b) On Recycling

In Thailand, construction and demolition waste has not been processed for reuse as aggregates. In Bangkok, this waste is used entirely as landfill, since Bangkok, situated on a flood plain, faces problems with subsidence.

2.1.5 Sustainable Development Policies

Thailand has given importance to sustainable development by putting the issue on its national agenda. The concept of sustainable development was first addressed in the 9th National Economic and Social Development Plan (2002-2006) and it was defined as a holistic development which involves six dimensions: economics, social, environment, politics, technology and knowledge, and mental and spiritual balance. In 2003, Thailand established the National Sustainable Development Council chaired by the Prime Minister. The council is responsible for formulating operational plans, implementing processes, and evaluating outcomes. The council's objective is to reach a balance between economics, social, natural resource and environment for the well being of people across generations (Office of the National Economic and Social Development Board, 2001).

The national strategies involving the concept of sustainable development are as follows:

a) The strategy on sustainable natural resource and environmental development: This strategy focuses on the conservation, the revival, and the sustainable utilization of natural resources. Projects under this strategy are:

i) the conservation and revival of forests and coastal lines,
ii) holistic water basins management,
iii) recovery of degraded natural resources,
iv) mitigation and protection of pollution problems, and
v) enhancement of the effectiveness of natural resource use and environment management by taking into account the opinions of the local population and other relevant parties

b) The strategy on sustainable economic development: This strategy focuses on the continuity of economic stability, economic growth benefiting the majority of Thai people, production and consumption improving quality of life without jeopardizing the environment or creating pollution.

c) The strategy on sustainable social development: This strategy focuses on reducing poverty and social inequality.

d) The strategy on the promotion of social participation for sustainable development: This strategy aims to allow people and all stakeholders to participate in development of natural resources, environment, economy and society in such a way that all relevant opinions are heard and balanced.

The concept of sustainable development is also employed in the mineral policy statements of the DPIM. It is stated in its vision that DPIM will manage, organize, and develop mineral deposits and primary industries by using appropriate technology and taking into account the environmental impact to ensure the sustainable development of the industry. The DPIM's mission is to improve the productivity and competitiveness of the mineral and primary industries, and to fulfil the demands for sustainable utilization of mineral resources while ensuring a safe and healthy environment. The DPIM's policies emphasize (1) physical sustainability of mineral production through mineral exploration and development, and (2) sustainability of ecosystems and the environment in mining areas through mine site rehabilitation.

2.2 Canadian Mining Laws, Taxation and Policies

2.2.1 Mining Laws

Canada is a federation of ten provinces and three territories. The ten provinces are Alberta (AB), British Columbia (BC), Manitoba (MB), New Brunswick (NB), Newfoundland and Labrador (NL), Nova Scotia (NS), Ontario (ON), Prince Edward Island (PE), Quebec (QC), and Saskatchewan (SK), while the three territories are Northwest Territories (NT), Nunavut (NU), and Yukon (YT). The government of each province and territory has its own mining legislation to regulate aspects of exploration, mining, and environmental management. Exceptions have been the Northwest and Nunavut Territories whose mineral resource management is under the control of the Canadian Federal Government. Names of laws relevant to mining and their fields of enforcement and application of each province and territory are presented in Table 2.2.

Table 2.2 Provincial/Territorial Mining Laws and Their Applications

Province/Territory	**Names of Laws**	**Fields of Enforcement and Application**
Alberta	Mines and Minerals Act	- exploration, mining activities, environmental management, reclamation, and mining taxation
British Columbia	Mines Act Mineral Tax Act	- exploration, mining activities, environmental management, and reclamation - mining taxation
Manitoba	Mines and Minerals Act Mining Tax Act	- exploration, mining activities, environmental management, and reclamation - mining taxation
New Brunswick	Mining Act Metallic Minerals Tax Act Quarriable Substances Act	- exploration, mining activities, environmental management, and reclamation of all mines except for quarries - mining taxation of all mines except for quarries - exploration, mining activities, environmental management, reclamation, and mining taxation for quarrying
Newfoundland and Labrador	Mining Act Mining and Mineral Rights Tax Act Quarry Materials Act	- exploration, mining activities, environmental management, and reclamation of all mines except for quarries - mining taxation of all mines except for quarries - exploration, mining activities, environmental management, reclamation, and mining taxation for quarrying
Nova Scotia	Mineral Resources Act	- exploration, mining activities, environmental management, reclamation, and mining taxation
Ontario	Mining Act Mining Tax Act	- exploration, mining activities, environmental management, and reclamation - mining taxation
Quebec	Mining Act Mining Duties Act	- exploration, mining activities, environmental management, and reclamation - mining taxation
Saskatchewan	Energy and Mines Act Mineral Taxation Act	- exploration, mining activities, environmental management, and reclamation - mining taxation
Northwest Territories	Territorial Lands Act	- exploration, mining activities, environmental management, reclamation, and mining taxation
Nunavut	Territorial Lands Act	- exploration, mining activities, environmental management, reclamation, and mining taxation
Yukon	Yukon Quartz Mining Act	- exploration, mining activities, environmental management, reclamation, and mining taxation of all mines except for coal and gold mines

Source: Natural Resources Canada (2006)

Besides being under the provincial and territorial environmental laws and regulations, any significant mining project may need to be reviewed by several relevant federal departments under the Canadian Environmental Assessment Act (CEAA).

2.2.2 Mining Taxation

Canadian mining taxation can be divided into three levels, the Federal Government, the Provincial and Territorial Governments, and the Municipalities. The Federal Government imposes corporate income taxes (corporate income tax and withholding tax), a capital tax, the GST (Goods and Services Tax), payroll levies (employment insurance and Canada Pension Plan), property taxes, sales taxes, excise taxes, and custom duties. The rates of some taxes are shown in Table 2.3. At the federal level, a special treatment includes the following tax provisions (Natural Resources Canada, 2006):

- Resource Allowance;
- Provincial/territorial mining taxes and royalties;
- Canadian Exploration Expenses (CEE);
- Flow-Through Shares (FTS) and the Investment Tax Credit for Exploration in Canada (ITCE);
- Foreign Resource Expenses (FRE) and Foreign Exploration and Development Expenses (FEDE);
- Canadian Development Expenses (CDE)
- Special class of Capital Cost Allowance (CCA);
- Accelerated Capital Cost Allowance (ACCA);
- Depletion Allowance;
- Treatment of foreign ores; and

- Deduction for mine reclamation trust fund contributions.

Table 2.3 Federal Tax Rates

Tax	**Tax Rate**
Federal Corporate Tax	21.57% of resource income
Capital Tax	0.125% of assets above $10 million
Goods and Services Tax	7% of purchases
Fuel Excise Tax	
- Gasoline	10 cents per litre
- Diesel	4 cents per litre

Source: Natural Resources Canada (2006)

The Provincial and Territorial Governments impose corporate income taxes in all provinces and territories. Capital taxes are imposed in SK, MB, ON, QC, NB, and NS. All provinces and territories collect mining and royalty taxes require mining companies to pay workers' compensation. Payroll levies--health and/or post-secondary education taxes--are applied in MB, ON, QC, NL, NU, and NWT. Value-added taxes are imposed in QC, NB, NS, and NL, and excise taxes (on fuel) and sales taxes are applied in PE, ON, MB, SK, and BC. The municipal taxation is property tax, licenses, and fees. The structures and rates of main taxes are shown in Table 2.4 and Table 2.5.

Table 2.4 Canadian Corporate Income Tax Rates Applicable to Mining

Province/Territory	Net federal tax rate on resource income (%) (1)	Prov./Terr. Statutory Income Tax Rate (%) (2)	Resource Allowance Reduction (%) (3)	Net Provincial Tax Rate on Resource Income (%) (4) = (2) + (3)	Net Combined Fed./Prov./Terr. Income Tax Rate (%) (5) = (1) + (4)
Alberta	21.57	11.5	-2.88	8.62	30.19
British Columbia	21.57	12.0	0	12.00	33.57
Manitoba	21.57	14.5	-1.27	13.23	34.80
New Brunswick	21.57	13.0	-1.14	11.86	33.43
Newfoundland and Labrador	21.57	14.0	-1.23	12.77	34.34
Nova Scotia	21.57	16.0	-1.40	14.60	36.17
Ontario	21.57	12.0	-3.00	9.00	30.57
Quebec	21.57	9.9	-2.48	7.42	28.99
Saskatchewan	21.57	17.0	-4.25	12.75	34.32
Northwest Territories	21.57	14.0	-1.23	12.77	34.34
Nunavut	21.57	12.0	-1.05	10.95	32.52
Yukon	21.57	15.0	-1.31	13.69	35.26

Source: Natural Resources Canada (2006)

Table 2.5 Canadian Provincial/Territorial Mining or Royalty Tax Rates

Province/Territory	**Mining or Royalty Tax Rate***	
	First Tier	**Second Tier**
Alberta	1 percent on revenue	12 percent on net profits
British Columbia	2 percent on net current proceeds	13 percent on net revenue
Manitoba	N/A	18 percent on profits
New Brunswick	2 percent on net revenue	16 percent on net profits over $100,000
Newfoundland and Labrador	N/A	15 percent on 80 percent of net profit, plus 20 percent on the remaining 20 percent of net profit
Nova Scotia	2 percent on net revenue	15 percent on net profits
Ontario	N/A	10 percent on net profits
Quebec	N/A	12 percent on profits
Saskatchewan	N/A	10 percent on net profits.
Northwest Territories	N/A	a variable tax rate (5-14%) that, on average, cannot exceed 13 percent of net income
Nunavut	N/A	a variable tax rate (5-14%) that, on average, cannot exceed 13 percent of net income
Yukon	A progressive tax rate varies according to amount of income. The starting tax rate is 3 percent and rises by 1 percentage point for every tranche of $5 million of taxable income. But the maximum tax rate shall not be higher than 18 percent.	

Source: Natural Resources Canada (2006)
Notes: *Some provinces impose a two-tier mining tax system and the greater one will be levied.
N/A = not applicable.

2.2.3 Mining Promotion Policies

From Gurmendi (2004), Canada is a world leading producer of potash, diamond, nickel, selenium, columbium (niobium), and zinc. The Federal, Provincial, and Territorial Governments ensure Canada remains a leading mineral producer by providing support and encouraging exploration and deposit appraisal activities by means of fiscal incentives, resolution of land access issues, and the provision of geoscientific data (Canadian Intergovernmental Working Group on the Mineral Industry, 2004). Some of the Federal and Provincial Governments' policies in promoting mining industry are as follows.

a) <u>Federal Government</u>

One of the fiscal incentives used to assist investors in mineral exploration is the programme of the super Flow-Through Shares (FTS), which grants 15% federal tax credits for mineral exploration. The credit is in addition to the existing 100% deduction of eligible exploration expenditures from the Federal portion of investors' income tax. This is equivalent to a 136.7% exploration expense deduction.

b) Provincial Governments

With the aim to encourage investment in mineral exploration, tax credits granted for mineral exploration are as follows: British Columbia offers a non-refundable tax credit at a rate of 20% from 2005-2008; Manitoba offers a non-refundable tax credit at a rate of 10% from 2002-2005; Ontario offers a refundable tax credit at a rate of 5% from 2000-2007; Yukon offers a refundable tax credit at a rate of 25% from 2003-2005; and Quebec allows a deduction of up to 150% of the cost of certain qualifying exploration expenses from 2002-2007 (Canadian Intergovernmental Working Group on the Mineral Industry, 2004).

To increase mineral supply and avoid land use conflict especially in crushed stone for the aggregate sector, the Government of Ontario Province introduced the Ontario Provincial Policy Statement and one of the policies in this statement was the Mineral Aggregate Resources Policy. This policy had a goal to protect mineral aggregate supply for long-term use. Its two main parts consisting of (1) developing mineral aggregate resources in deposits which are as close to markets as possible, and (2) protecting mineral aggregate operations from land use conflicts by restricting migration of people to mineral aggregate supply areas. The mining operation provides new infrastructure such as roads, power, and water supply system, with the result that people decide to migrate to areas adjacent to quarry. The resulting problem is land use conflict because mining companies cannot expand quarrying because there are communities around mining area. Therefore, restricting migration of people to mineral aggregate supply areas will provide long-term mineral aggregate supply and reduce water and land conflict (Ontario Aggregate Resources Corporation, 2005).

2.2.4 Relevant Environmental Policies

Some of the relevant environmental policies of the Canadian Federal and Provincial Governments are as follows.

a) Federal Government

The Prospectors and Developers Association of Canada (PDAC) was established by the Federal Government in 1932 to support mineral exploration and develop the mineral industry. The PDAC introduced the Total Landscape Management (TLM), a concept to balance between resource development and conservation objectives (Prospectors and Developers Association of Canada, 1998), which consists of:

(i) employing the overarching method of biodiversity conservation to manage complete landscapes;

(ii) planning a floating reserve system to successfully protect dynamically changed landscapes of mining areas

(iii) adaptive management of relevant data, ecosystems, and disturbances; and

(iv) co-management ensuring provision for local community input.

To conserve mineral resources, recycling is one action that helps. This is especially important in the case of construction mineral resource group. In 2001, the Natural Resources Canada, a Federal government agency supervising the natural resources sector, launched the five-year (April 2001-March 2006) Enhanced Recycling Programme to foster an increased use of recycled minerals and metals by seeking partners in the automobile, construction, electro-plating and electronics sectors (Natural Resources Canada, 2003).

b) Provincial Governments

In all provinces and territories, at the end of mining project, mining companies are required by law to reclaim, restore, or rehabilitate mined areas. But, in case that reclamation fails, the mining area is abandoned uselessly. To solve this problem, the Government of Ontario Province set up the Management of Abandoned Aggregate Properties (MAAP) Programme to restore abandoned aggregate quarries within Ontario under the Aggregate Resource Act. This programme is funded by money collected by deducting 0.5 cent of the annual six-cent per ton license levy. In 2005, MAAP restored over 75 hectares of aggregate mining areas at a total cost of C$548,272. These sites were rehabilitated to natural areas (40 hectares), agricultural land (28 hectares), and recreation areas (7 hectares) with the average cost of C$7,267 per hectare, decreasing from that of C$13,411 per hectare in 2004 (Ontario Aggregate Resources Corporation, 2005).

2.2.5 Sustainable Development Policies

In stating their mineral resource and mining policies, the Canadian Federal and Provincial Governments also used the popular term of "sustainable development". The differences between the Federal and Provincial policies are the scope of the concept of sustainable development. The mineral resource policies concerning "sustainable development" of the Federal government covered three-dimensional areas: economic, environmental, and social. However, those of the provincial governments focused only on (1) physical sustainability of mineral production through mineral exploration and development and (2) sustainability of ecosystems and the environment in mining areas through mine site rehabilitation.

a) Federal Government

In 1996 the Federal Government of Canada issued the Minerals and Metals Policy of the Government of Canada: Partnerships for Sustainable Development. The policy, which states the Federal Government's role, the objectives and the strategies for sustainable mineral and metal resources development, represented the first attempt by the Government to incorporate the concept of sustainable development into a comprehensive policy document in the natural resources area. The six-part policy stated its principal objectives as follows:

> "- to integrate the concept of sustainable development in federal decision-making affecting the minerals and metals industry;
>
> - to ensure the international competitiveness of Canada's minerals and metals industry in the context of an open and liberal global trade and investment framework
>
> - to advance the concept of the sustainable development of minerals and metals at the international level through partnerships with other countries, stakeholders, and multilateral institutions and organizations;
>
> - to establish Canada as a global leader in promoting the safe use of minerals and metals, and their related products;

> - to promote Aboriginal involvement in minerals and metals-related activities; and
> - to provide a framework for the development and application of science and technology to enhance the industry's competitiveness and environmental stewardship" (Natural Resources Canada, 1996).

In implementing the sustainable development approach, the Policy emphasized the need to integrate, fully and as early as possible, the environmental, economic and social considerations in the decision-making process concerning minerals and metals. In summation, this federal policy intended to promote minerals and metals industry of Canada by taking into account the environmental, economic and social aspects through good governance and under the open and liberal concepts of the free-market economics. The Policy also stressed the importance of science and technology (S&T) activities related to minerals and metals in supporting the objectives of sustainable development.

b) <u>Provincial Governments</u>

Alberta

According to Alberta Mineral Development Strategy 2002, the vision of the Albertan Government is to provide full opportunity for industry to explore and develop mineral resources for the greatest benefit of all Albertans while ensuring commitment to sustainable development. The goals of Alberta Mineral Development Strategy are as follows:

> " - To develop a comprehensive Geoscience Knowledge Initiative needed by government, industry and the public

for earth resources stewardship and sustainable development. Strategic partnerships (such as the Cooperative Mapping Strategies) and establishment of adequate base level funding will ensure attainment of acceptable levels of basic geological mapping, geoscience information and expertise;

- To establish a regulatory, environmental and fiscal framework for exploration and development that is effective, efficient and fair by designing policies and guidelines for integrated land management, ensuring available mineral tenure policies are proper for exploration and development, by developing the recommendations for improvements of mining regulation, environmental protection, and health and safety issues, and by ensuring Alberta's fiscal regimes are equitable, competitive, and stable;
- To implement innovative communication, consultation and community development processes by fostering participation of relevant sectors consisting of governments, indigenous people and society, educational institutes and mining industry; and
- To ensure that Alberta's infrastructure supports and facilitates responsible development of the mineral industry" (Government of Alberta, 2002).

British Columbia

According to the British Columbia Mining Plan 2005, there are four cornerstones of the mining industry: focusing on communities and indigenous people, protecting employees and environment, increasing competitiveness, and access to land. Strategies of each cornerstone are shown as follows:

> "Cornerstone 1: Focus on communities and indigenous people
>
> Strategy 1: encourage greater relationships with communities
>
> Strategy 2: encourage greater relationships with indigenous people
>
> Strategy 3: develop approaches to sustainable mining
>
> Cornerstone 2: Protecting employees and environment
>
> Strategy 4: lead in standards and practices of health and safety
>
> Strategy 5: lead in standards and practices of environment
>
> Strategy 6: work with other relevant sectors to solve environmental problems
>
> Cornerstone 3: Global competitiveness
>
> Strategy 7: ensure competitive taxation
>
> Strategy 8: streamline regulation
>
> Strategy 9: invest in geoscience
>
> Strategy 10: attract investment

Strategy 11: enhance excellent infrastructure

Strategy 12: invest in people development and technology

Cornerstone 4: Access to land

Strategy 13: define land available for exploration and mining

Strategy 14: cooperate with other land users”

(Government of British Columbia, 2005)

Manitoba

The purpose of Manitoba’s Sustainable Development Act 1997 is to create a framework through which sustainable development will be implemented in the provincial public sector and promoted in private industry and in society generally. The guidelines of sustainable development in this Act are composed of the followings:

> “ (1) Efficient use of resources by means of: encouraging and facilitating development and application of systems for proper resource pricing, demand management and resource allocation together with incentives to encourage efficient use of resources; and employing full-cost accounting to provide better information for decision makers.
>
> (2) Public participation by means of: establishing forums which encourage and provide opportunity for consultation and meaningful participation in decision making processes by Manitobans; endeavouring to

provide due process, prior notification and appropriate and timely redress for those adversely affected by decisions and actions; and striving to achieve consensus amongst citizens with regard to decisions affecting them.

(3) Access to information by means of: encouraging and facilitating the improvement and refinement of economic, environmental, human health and social information; and promoting the opportunity for equal and timely access to information by all Manitobans.

(4) Integrated decision making and planning by means of encouraging and facilitating decision making and planning processes that are efficient, timely, accountable and cross-sectoral and which incorporate an inter-generational perspective of future needs and consequences.

(5) Waste minimization and substitution by means of encouraging and promoting the development and use of substitutes for scarce resources where such substitutes are both environmentally sound and economically viable; and reducing, reusing, recycling and recovering the products of society.

(6) Research and Innovation by means encouraging and assisting the researching, development, application and sharing of knowledge and technologies which further our

> economic, environmental, human health and social well-being" (Government of Manitoba, 1997).

Newfoundland and Labrador

In 1997 the Government of Newfoundland and Labrador announced its intention to enact a Proposed Sustainable Development Act. At present, the proposed act has not been passed into an active law as yet. However, details of the proposed act are still posted on the web-site of the Government of Newfoundland and Labrador. In this proposed act, the Government of Newfoundland and Labrador has committed to introduce a Sustainable Development Act that will:

> " - Establish sustainable management of the province's natural environment as a central policy objective.
>
> - Recognize the full range of uses and values of natural resources, including resource industries, habitat for wildlife, parks and wilderness, tourism and recreation.
>
> - Safeguard the life supporting capacity of air, water, soil and ecosystems.
>
> - Provide for the sustainable development of renewable resources in a way that enables people to provide for their economic, social and cultural needs, while preserving the integrity of ecosystems and meeting the reasonably foreseeable needs of future generations.
>
> - Ensure nonrenewable resource developments benefit future as well as present generations by controlling the pace of development, promoting value-added product

> manufacturing and spending royalties in ways that have long-term benefits across generations.
>
> - Direct resource departments and related agencies to harmonize resource policies, which will make them more consistent and efficient in their pursuit of a healthy economy, environment and society for present and future generations.
>
> - Ensure that workers, environmentalists, industry, communities, aboriginal peoples and others have a say in how our resources are managed" (Government of Newfoundland and Labrador, 2006).

Ontario

The objectives of the Mineral Development Strategy, introduced in 2006, are to help Ontario remain one of the world's leading mining jurisdictions while, at the same time, supporting responsible and sustainable mineral development that benefit communities and all Ontarians. The four key strategies objectives are:

(1) Promoting long-term sustainability and global competitiveness by applying appropriate tax and fiscal regimes, improving geological database, and supporting research and development;

(2) Supporting modern, safe and environmentally sound exploration and mining by monitoring environmental performance of the mining industry, developing mining technology, and modernizing regulatory processes of mining issues;

(3) Clarifying and modernizing mineral resource stewardship by encouraging participation of indigenous people in mining industry and clarifying access to mineral resources; and

(4) Promoting community development and opportunities for all by supporting jobs for local people, and improving public infrastructure such as roads, hospitals, and schools (Government of Ontario, 2006)

Quebec

In 2004 the Government of Quebec announced Quebec's Sustainable Development Plan: Consultation Document, effective from 2004 to 2007. In the Plan fourteen principles were set to guide the Government of Quebec's actions with respect to sustainable development. The principles, which will serve to define their legal obligations and authority, are as follows:

> " (1) Health and quality of life: People, protection of their health and improvement of their quality of life are at the centre of concerns for sustainable development; people are entitled to a healthy and productive life in harmony with nature.
>
> (2) Social equity: Development must be undertaken in a spirit of intra- and inter-generational equity, taking the needs of everyone concerned into account.
>
> (3) Environmental protection: To achieve sustainable development, environmental protection must constitute an integral part of the development process.
>
> (4) Economic efficiency: The economy of Québec must be effective, geared toward innovation and economic prosperity that is conducive to social progress, and respectful of the environment.

(5) Involvement and commitment: Sustainable development is founded on a shared commitment; the involvement of citizens and a partnership among all groups in society are needed to ensure the social, economic and environmental sustainability of development.

(6) Access to knowledge: Educational measures and access to information must be encouraged in order to stimulate innovation, raise awareness and ensure effective public involvement in the implementation of sustainable development.

(7) Protection of cultural heritage: The property, sites and landscapes making up a society's cultural heritage are a source of identity, pride and solidarity. Through its cultural heritage, the traditions, customs, values and knowledge of a society are passed on from generation to generation and the preservation of this heritage fosters the economy of resources. Cultural heritage components must be identified, protected and enhanced, taking their intrinsic rarity and fragility into account.

(8) Prevention: In the presence of a known risk, preventive and corrective actions must be taken, with priority given to actions at the source, using the best techniques available at an economically acceptable cost.

(9) Precaution: Where there is a risk of serious or irreversible harm, the lack of absolute scientific certainty must not be used as an excuse for postponing the adoption of effective measures to prevent environmental degradation.

(10) Biodiversity preservation: Biological diversity offers incalculable advantages and must be preserved for the benefit of present and future generations; the protection of species, ecosystems and the natural processes that maintain life is essential if quality of human life is to be maintained.

(11) Respect for ecosystem support capacity: Human activities must be respectful of the support capacity of ecosystems, and must not exceed the threshold beyond which the functions and balance of the natural environment would be irreversibly altered.

(12) Responsible production and consumption: Production and consumption patterns must change in order to reduce their adverse social and environmental impact to a minimum and, in particular, avoid waste and the depletion of resources.

(13) Polluter/User-pay: Those who generate waste material or other forms of pollution should bear the cost of preventive, waste reduction and anti-pollution measures; goods and services should be priced so as to

reflect all the costs they generate, whether at the production or consumption stage.

(14) Inter-governmental partnership and cooperation: Governments must collaborate to ensure that development is sustainable from an environmental, social and economic standpoint; the external impact of actions in a given territory must be taken into consideration (Government of Quebec, 2004).

2.3 Australian Mining Laws, Taxation and Policies

2.3.1 Mining Laws

Australia is a Commonwealth of six states and one territory consisting of the states of New South Wales (NSW), Queensland (QLD), South Australia (SA), Tasmania (TAS), Victoria (VIC), and Western Australia (WA), and Northern Territory (NT). Mineral resources are under state or territorial ownership. The government of each state and territory has its own mining legislation to regulate aspects of exploration, mining activities, environmental management, reclamation of mining areas, and mining taxation. Names of laws relevant to mining and their fields of enforcement and application of each state and territory are presented in Table 2.6.

Table 2.6 State/Territorial Mining Laws and Applications

State/Territory	Names of Laws	Fields of Enforcement and Application
New South Wales	Mining Act 1992	- exploration, mining activities, environmental management, reclamation, and mining taxation
Queensland	Mineral Resources Act 1989	- exploration, mining activities, environmental management, reclamation, and mining taxation
South Australia	Mining Act 1971	- exploration, mining activities, environmental management, reclamation, and mining taxation
Tasmania	Mineral Resources Development Act 1995	- exploration, mining activities, environmental management, reclamation, and mining taxation
Victoria	Mineral Resources Development Act 1990	- exploration, mining activities, environmental management, reclamation, and mining taxation
Western Australia	Mining Act 1978	- exploration, mining activities, environmental management, reclamation, and mining taxation
Northern Territory	Mining Act 2005 Mineral Royalty Act 2006	- exploration, mining activities, environmental management, and reclamation - mining taxation

2.3.2 Mining Taxation

Mining companies must pay tax to two levels of government, Commonwealth and states. The Commonwealth Government imposes corporate income tax, Goods and Services Tax (GST) or VAT, Fringe Benefits Tax (FBT), capital gains tax, and fuel excise tax. The rate of corporate income tax is 30 percent of taxable income. Goods and Services Tax (GST) or VAT is levied at a rate of 10 percent of values added at each step in production and distribution of goods and services including importation. The Fringe Benefits Tax (FBT) is collected at a rate of 48.5 percent of the taxable values of certain fringe benefits they provide to their employees.

State governments impose land tax in all states except for Northern Territory, stamp duty in all states and territory, payroll tax in all states and territory at a rate between 4.75% and 6.85%, and mineral royalties are collected in all states and territory. The details of mineral royalty rates applied to construction minerals, which are the focuses of this study, are shown in Table 2.7.

Table 2.7 Royalty Rates for Construction Minerals in Australia

Commodity	**WA**	**NSW**	**VIC**	**QLD**	**SA**	**TAS**	**NT**
Aggregate	30c/t	35c/t	84c/t	25c/t	20c/t	A$1/t	18% NV[7]
Gypsum	30c/t	35c/t	24-84c/t	25c/t	20c/t	ad v + prof[8]	18% NV
Limestone	50c/t	35c/t	84c/t	30c/t	20c/t	60c-A$1.2/t	18% NV

Source: Government of Western Australia (1999)

2.3.3 Mining Promotion Policies

In Australia, the Commonwealth and State Governments have introduced their own policies in promoting mining industry. Their available mining promotion policies are shown as follows.

a) <u>Commonwealth Government</u>

From Lyday (2003), Australia is a world leading producer of lead, nickel, sands, tantalum, uranium, and zinc. To continue such status, the Commonwealth Government has a policy on encouraging investment in mineral exploration and mining activities. Under such policy, the Australian Resources Research Centre (ARRC) was established in 2001. The ARRC was a joint venture of the Commonwealth Scientific and Industrial Research Organization (CSIRO), Curtin University of Technology, and the Government of Western Australia. The ARRC's initial research on minerals and mining are focused on technologies that enable the discovery of new world-class, high quality mineral deposits and extraction method at the lowest possible cost with emphasis on safety and the environment (Australian Resources Research Centre, 2001).

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[7] NV means net value of mineral commodity sold in a royalty year.
[8] ad v + prof means ad valorem and profit-based combination.

b) State Governments

New South Wales

Besides ARRC, Cooperative Research Centre for Landscape Evolution and Mineral Exploration (CRCLEME) is another research centre that is a joint venture between New South Wales Geological Survey, Australian National University, University of Canberra, and CSIRO Division of Exploration and Mining. Its objective is to improve the understanding of the Australian landscape in terms of its geomorphology, regolith (soil cover), weathering, and alteration processes to aid in the search for new mineral resources (Government of New South Wales, 2006).

South Australia

The South Australian Government promotes mineral investment through various initiatives. The recent and presently active initiatives are South Australian Exploration Initiative (SAEI), Plan for Accelerating Exploration (PACE), Broken Hill Exploration Initiative (BHEI), and Targeted Exploration Initiative South Australia (TEISA) of 2020. The SAEI, implemented from 1992 to 1996 at a total state government budget of A$23.5 million, was tasked with gathering mineral geoscientific data by airborne geophysical surveys, bedrock drilling and compilation of geoscientific databases. The BHEI, started in 1994, is a joint program involving the South Australian, New South Wales and Commonwealth Governments with the aim of promoting mineral investment in the Broken Hill-Olary region in order to help secure the future of a port and a city in the region. Under the PACE, which was established in 2004, the State Government will co-fund up to 50% of approved drilling projects to enhance the level of mineral exploration in the State. The TEISA of 2020, a renewal exploration programme that targets key areas of South Australia, started in 1992, has been an approach to ensure that high quality pre-competitive geoscientific data continues to be supplied to mineral and petroleum explorers wishing to do business in South Australia (Government of South Australia, 2004).

Northern Territory

The mining promotion plan of the Northern Territory (NT) was stated in the Building the Territory's Resource Base (BTRB) initiative with the aim of informing potential explorers about the rich prospect of the NT. The presently active component in the initiative, launched in 2005, is called the Top End Secret campaign – Strategy for increased NT exploration (Government of Northern Territory, 2006)

Tasmania

Since the mineral industry has played and continues to play a substantial role in the Tasmanian economy, the State of Tasmania also supports the industry. With the cooperation of the Commonwealth Government and the mineral industry in Tasmania the Western Tasmanian Regional Minerals Programme was implemented in order to, amongst other tasks, to set up a regional development plan, for up to 15 years, to identify the infrastructure needed to support an expanded industrial base in Tasmania (Government of Tasmania, 2006).

Victoria

Victoria State devised a plan called "the Innovation Roadmap" with the aim of stimulating the innovation and strategic investment necessary for the sustainable development of Victoria's mineral and energy wealth. The aim of the roadmap was to identify priorities of research and development, and to define obstacles to investment in gold, mineral sands, coal, construction stone, natural gas and oil sectors.

As for construction minerals, in 1993, the Department of Primary Industries issued a Geological Survey of Victoria Technical Record designating Extractive Industry Interest Areas (EIIA). This geological survey report, which has been reviewed a number of times to include new information and changes in land use and zoning, designated lands containing stone resources of sufficient quantity and quality to support extractive industry operations. The EIIA is a guideline for both mining companies to find new stone deposits and local communities to realize and prepare long-term public land use plans at the mines end of life (Government of Victoria, 2006).

2.3.4 Relevant Environmental Policies

In Australia, the Commonwealth and State Governments have introduced their own policies for the mining industry. The available environmental policies related to the mineral industry are as follows.

a) Commonwealth Government

To support rehabilitation, the Australian Centre for Minesite Rehabilitation Research (ACMRR), a joint venture of the Commonwealth Scientific and Industrial Research Organization (CSIRO), University of Queensland, Curtin University of Technology and the Australian Mineral Industries Research Association, was established in 1994 with initial funding of A$600,000. The main objective of ACMRR was to conduct strategic research into mine-site rehabilitation, which would lead to significant improvements in rehabilitation processes for the mutual benefit of Australia and its mining industry (Lyday, 1994).

b) <u>State Governments</u>

Victoria

To preserve mineral resources, recycling is one method that helps, especially in construction mineral resource group. In 2002, the Government of Victoria State released the *Towards Zero Waste* strategy. This strategy has three objectives consisting of

(1) to reduce solid waste from three sources: commerce and industry, municipalities, and construction and demolition;

(2) to increase the amount of materials for reusing and recycling; and

(3) to decrease environmental damage resulting from these solid wastes.

For the solid waste from construction and demolition, the goal is a recovery rate of 80 percent by weight to be reused and recycled by 2014, while an interim goal is a recovery rate of 65 percent in years 2008-09. In years 2002-03, there was 3.75 million tons of solid waste from construction and demolition accounting for 40 percent of the total solid waste generated in Victoria. Approximately 0.9 million tons of demolished concrete was reprocessed into aggregate (Government of Victoria, 2005).

South Australia

The South Australian Government introduced ‘Waste Strategy 2005-10’ to ensure a healthy environment for South Australians across generations. The strategy identified three waste types consisting of municipal solid waste, commercial and industrial waste, and construction and demolition waste. For construction and demolition waste, the strategy sets targets to increase recovery and reuse of construction and demolition materials by 20, 35, and 50 percent within 2006, 2008, 2010, respectively (Government of South Australia, 2005).

New South Wales

The New South Wales Government has introducing the Waste Avoidance and Resource Recovery Strategy 2006 (Waste Strategy 2006), an update of the Waste Strategy 2003, with the aim of maximizing the conservation of natural resources and minimizing waste and disposal. Waste Strategy 2006 will provide guidance for actions to ensure efficient utilization of natural resources and to reduce the impact on the environment throughout the life cycle of goods and materials. The strategy's targets are, by 2014, to increase the recovery and use of the three waste types: municipal waste, commercial and industrial waste, and construction and demolition waste to 66%, 63%, and 76%, respectively.

In New South Wales State, abandoned mining areas where no accountable individual, company or organization can be found will be rehabilitated under the New South Wales Derelict Mines Programme. This programme has been administered by a joint agency committee (the Derelict Mines Committee) comprising senior representatives from the Department of Primary Industries, Department of Lands, Department of Environment and Conservation and the NSW Minerals Council. The programme aims to minimize risks, to remove environmental pollution sources, and to reduce land degradation for the health and safety of local communities (Government of New South Wales, 2006).

Queensland

In 2005 the Environmental Protection Agency of Queensland with the cooperation of the Queensland Resources Council started the process of setting up a policy framework to encourage the progressive rehabilitation of large mines. The proposed framework includes:

> “ - New provisions in the *Environmental Protection Act 1994* (EP Act) for certifying progressive rehabilitation, recording details of the areas certified and verifying this at final relinquishment of the mining tenement;
>
> - Changes to the current process for setting and recording the rehabilitation objectives for each mining and exploration project and how progress towards those objectives will be measured;
>
> - A Guideline on rehabilitation requirements and the criteria to assess the suitability of rehabilitation;
>
> - A mechanism to assess the residual risk of each rehabilitated area; and
>
> - Changes to the FA system in the EP Act and Guidelines.” (Queensland Resources Council, 2005)

2.3.5 Sustainable Development Policies

The concept of “sustainable development” is also employed in the policy statements of the Commonwealth and State Governments. However, the Commonwealth and State Governments approach the scope of sustainable development differently because the Commonwealth and states have different roles in administrating mineral resources. While the sustainable policies of the Commonwealth Government give general guidance, those of the provincial governments focus only on (1) physical sustainability of mineral production through mineral exploration and development and (2) sustainability of ecosystems and the environment in mining areas through mine site rehabilitation.

a) Commonwealth Government

The Commonwealth applies its policies on sustainable mineral development through the Ministerial Council for Mineral and Petroleum Resources (MCMPR), established in June 2001. The MCMRR consists of the Commonwealth Minister for Industry, Tourism and Resources and, State and Territory Ministers with responsibility for minerals and petroleum. It has adopted a long-term strategic vision, to be achieved in 2025, as "Australia is recognised as a world-class location for minerals and petroleum exploration and development, with a competitive resources industry valued for its contribution to the sustainable development of the nation and the world."

To achieve its vision the MCMPR identifies several key priorities, one of which is valuing community and contributing to sustainable development. Under this priority, the MCMPR believes that to attain a sustainable future, and thereby maintain *its licence to operate*, the industry must:

> "- Operate to accepted world's best environmental practices;
>
> - Demonstrate an overriding commitment to the health and safety of its employees and the communities in which it operates;
>
> - Undertake meaningful consultation with stakeholders regarding decisions that may affect them; and
>
> - Create economic benefits for shareholders, employees and local communities as well as the community at large (as owner of the resource)." (Ministerial Council for Mineral and Petroleum Resources, 2005)

b) State Governments

Western Australia

The Western Australian Government took the concept of sustainable development seriously. In September 2003, it released a very comprehensive sustainability strategy called "Hope for the Future: The Western Australian State Sustainability Strategy". The strategy explained the conceptual basis of sustainability and covered almost, if not, all aspects of sustainability. It seeks to resolve the tensions between economic, environmental and social goals through finding mutual benefits. The strategy attempts to show how the needs of current and future generations can be met through an integration of environmental protection, social advancement and economic prosperity.

Concerning mineral resources, the strategy discussed sustainable mining and petroleum production under the topic of Sustainable Natural Resource Management. It stated its objective as to ensure that minerals and petroleum production in Western Australia remains at world best practice and the industries help to establish the standard for sustainability. Besides the present requirement for the industry to conduct environmental impact assessments that helps establish environmental bottom lines and the State's royalty regime that helps ensure an economic return for communities from the development of mineral resources, its action plans comprise:

> " - Work towards sustainability assessment of complex or strategic mining and petroleum projects using sustainability criteria (consistent with the Keating Review).
>
> - With key stakeholders, develop a set of agreed sustainability operating principles for the mining and

petroleum sectors through a working group or groups managed through the Department of Industry and Resources and the Sustainability Roundtable.

- Foster local community involvement (particularly Aboriginal communities, pastoralists and local shires) as part of the sustainability assessment process.

- Establish transparent processes to enable community awareness of the day-to-day regulatory system for exploration, mining and minerals processing including through the web site of the Department of Industry and Resources.

- Work with industry on the development of voluntary accreditation for mining and petroleum industry sustainability.

- Implement strategies that support the use of local employment in mining ventures, particularly using regional centres as employment hubs, and encourage mining companies to maximise their purchasing of goods and services within regions." (Government of Western Australia, 2003)

New South Wales

The term sustainable development was mentioned in the Regulatory Impact Statement issued in the process of enacting Mining Regulation 2003 of the State of New South Wales. In the regulation, the Department of Mineral Resources is assigned to advance sustainable mineral development for the benefit of the community by providing custodianship of mineral resources and ensuring sound resources utilization. This is achieved by:

> “ - Encouraging and facilitating well planned, responsible mineral exploration and mining/minerals development;
>
> - Allocating and managing exploration and mining titles in an efficient and timely manner; and
>
> - Ensuring a fair and equitable royalty return to the community from development of its mineral resources.
>
> - Improving the safety and performance of the mining industry by providing an appropriate regulatory framework.
>
> - Ensuring that the exploration and mining industry meets outcomes expected by the community and Government for environmental management and rehabilitation” (Government of New South Wales, 2003)

Victoria

The Department of Primary Industries, Victoria, stated its purpose as “the sustainable development of primary industries for the benefit of all Victoria”. To attain its purpose the Department set five key strategies as follows:

- Allocating natural resources by managing and regulating natural resource use in the public interest;
- Working with industries by facilitating investment in the sustainable use of Victoria's natural resources;
- Using science to drive improvements in the productivity and sustainability of Victoria's primary industries;

- Securing market opportunities for Victoria by protecting and enhancing access to markets; and
- Assisting with change by strengthening the capacity of rural industries and communities to anticipate and respond to change. (Government of Victoria, 2006)

Tasmania

The State of Tasmania's policies and planning is administered under the Resource Management and Planning System (RMPS). The RMPS has the objective of furthering sustainable development by considering environmental, economic, cultural and social factors in decisions about planning and development. The RMPS is composed of a suite of Acts, principally:

- State Policies and Projects Act 1993
- Land Use Planning and Approvals Act 1993 (LUPA)
- Resource Management and Planning Appeal Tribunal Act 1993
- Public Land (Administration and Forests) Act 1991
- Environmental Management and Pollution Control Act 1994 (EMPCA)
- Historic Cultural Heritage Act (1995)
- The Resource Planning and Development Commission Act (1997)

The common objectives of the RMPS are as follows:

> "– promote sustainable development of natural and physical resources and to maintain ecological processes and genetic diversity
>
> – provide for fair, orderly and sustainable use and development of air, land and water

– encourage public involvement in resource management and planning

– encourage opportunities that promote sustainable development

– promote a shared responsibility for resource management and planning between the different spheres of government, the community and industry in Tasmania" (Government of Western Tasmania, 2005)

2.4 Brazilian Mining Laws, Taxation and Policies

2.4.1 Mining Laws

Brazil is a Federation consisting of twenty-six states and one federal district. Besides, within each state there are Municipalities, which are autonomous and hierarchically independent from both federal and state governments. Under the Federal Constitution, enacted on 5th October, 1988, mineral resources are owned by the Union. According to the Mining Code of 1967 (Executive Law No. 227 of 28th February, 1967), the National Department of Mineral Production (DNPM), Ministry of Mines and Energy, is responsible for supervising mineral exploration and exploitation in Brazil. The private sector can operate a mining business by means of a joint venture with the Federal, State, or Municipal Governments or by taking 100 percent privatization investment in the mining industry as stipulated in Constitutional Amendments Nos. 6 and 9 dated 15th August, 1995. Exploration and mining cannot take place without permits from the Government. An Exploration Authorization Permit is granted by the Director-General of the DNPM, while a Development Concession is issued by the Ministry of Mines and Energy in accordance to Article 7 of Executive Law No.9314 of

January 1997. For industrial minerals including those used for construction, the authorities who are empowered to grant licenses to mine and utilize the minerals are local governments (City halls) together with environmental agencies. The licenses are required to register with the DNPM.

With regard to environmental protection, the legislation that is applied to mining connects to the following environmental requirements: an environmental impact assessment (EIA), environmental licensing (LA), and a plan for recovery of degraded areas (PRAD). An EIA is required in every mining project. An LA is mandatory for the installation, expansion, and operation of any mining activities. The Resolution 010 of the National Council for the Environment (CONAMA) of December 6, 1990, stipulates that mineral rights can be granted by the DNPM only after LAs have already been obtained. Article 225 of the 1988 Brazilian Constitution dictates that mined-out areas that were environmentally damaged must be reclaimed, and a PRAD requires suitable technical solutions to rehabilitate the soil and other aspects of the environment degraded by mining activities

Laws and regulations that govern the mining sector with regard to environmental protection are as follows:

- Federal law No. 6938 of August 31, 1981, and its amendments (Acts Nos. 7804 of July 18, 1989, and 8028 of April 12, 1990) provide the purpose and mechanism for formulating the National Environmental Policy;
- Federal law No. 9605 of February 12, 1998, provides sanctions against activities harmful to the environment;
- Federal Decree No. 97632 of April 10, 1989, deals with rehabilitation of areas damaged by mining;
- Federal Decree No. 99274 of June 6, 1990, regulates law No. 6938;

- Resolution No 1 of the CONAMA of January 23, 1986, provides basic criteria and general guidelines for writing the Report on Environmental Impact (RIMA);
- Resolution No. 009 of the CONAMA of December 6, 1990, regulates environmental licenses for mineral extraction;
- Resolution No. 010 of the CONAMA of December 6, 1990, regulates environmental licenses for mineral extraction used in civil construction;
- Resolution No. 2 of the CONAMA of April 18, 1996, provides for compensation for environmental damages; and
- Resolution No. 237 of the CONAMA of December 19, 1997, provides the procedures and guidelines used in environmental licensing. (Gurmendi, 2004)

2.4.2 Mining Taxation

Mining companies must pay tax to three levels of government: federal, state, and municipal. Brief details of taxation at the Federal and state levels are show as follows.

a) Federal Government

i) Federal General Taxation

Corporate Income Tax: The corporate income tax is levied at the rate of 15 percent on net profit, plus an additional tax of 10% on any net profit exceeding R$ 240,000 (US$ 111,600)

ii) Federal General Levies

Social Contribution Tax on Net Income (CSLL): CSLL is levied at the rate 12 percent on the adjusted net profit, before income tax.

Social Integration Program (PIS): PIS is levied monthly at the rate of 0.65 percent on gross operating revenue. This tax, which is spent on financing an unemployment-insurance programme, is not collected on income from exports.

Contribution for Social Security Fund (COFINS): COFINS is levied monthly at the rate of 3 percent on earnings. Income from exports is exempt from this contribution.

Social Charges: There are some other social expenses to be paid by a company: *National Social Security Institute (INSS)* and *Employees' Indemnity Guarantee Fund (FGTS)*. INSS and FGTS are levied at rate of 20 and 8 percent on payroll, respectively.

iii) Mineral Royalties

In Brazil, mineral royalty is called Financial Compensation for Exploiting Mineral Resources (CFEM). The CFEM rates are 3 percent for bauxite, manganese ore, rock salt, and potassium; 2 percent for iron ore, fertilizers, coal, and other minerals; 1 percent for gold; and 0.2 percent for other precious minerals and precious stones. CFEM levied is distributed to three levels of government, municipality, state and federal, in proportion of 65, 23 and 12 percent, respectively.

b) State Governments

i) State General Taxation

Added Value Tax on Sales and Services of Interstate and Inter-municipal Transportation and Communication (ICMS): ICMS is due at all stages of selling a product, along the chain from producers to end-users. All minerals, produced in Brazil or imported, are liable for ICMS collection, with rates varying from state to state, but not exceeding the maximum rates as shown in Table 2.8.

Table 2.8 The Brazilian Maximum Rate of ICMS in each Operation

Operation	Maximum Rate
Interstate	18%
Interstate – Taxpayer	12%
Interstate – End-user	18%
Exportation	13%
Importation	18%

Source: Ministry of Mines and Energy (2000)

2.4.3 Mining Promotion Policies

From U.S. Geological Survey (2004), Brazil is a world leader in producing bauxite, columbium, graphite, iron ore, manganese, tantalum, and tin. To continue as a world leading mineral producer, the Federal Government has had a policy on encouraging mineral exploration by providing interested investors with up-to-date geological information. In 1994, the Government decided to resume public investments in basic geological mapping, by transferring the Company of Research on Mineral Resources (CPRM), which was set up in 1969 with a mixture of state and private ownership, to be entirely owned by the Federal government. The CPRM has been designated to carry out the functions of the Geological Survey of Brazil, under the auspices of the Ministry of Mines and Energy. At present, the Programme Geology of Brazil in the formulation of the Multi-Year Investment Plan 2004-2007 of the CPRM is tasked with gathering geological, economic and metallogenic information across the entire country and in the areas of high potential metallic mineralization. In 2005 and 2006, CPRM has given priority to studies that can help activities in: small scale mines; the increase of supply of industrial minerals used in agriculture and construction; and, the development of metallogenic studies. Specific projects have been carried out in three separate sub-programmes (Company of Research on Mineral Resources, 2006).

In addition, to assist the mining and mineral industry technologically, the Mineral Technology Centre for Mineral Technology (CETEM), an organization linked to the Ministry of Science and Technology, was established in 1979. The CETEM works to develop and propagate technologies in the areas of mining, metallurgy, and materials.

Besides providing geological information and technologies to the private sector, the Federal Government also grants income tax reduction to investors investing in the less economically and socially favoured regions of Brazil. Such regions are Northeast and Amazon regions, which are administered by the Northeast Development Agency (SUDENE) and Amazon Development Agency (SUDAM), respectively.

At state level, most Brazilian States stimulate foreign trade and development of the States by means of ICMS exemption or reduction authority, by reducing the calculation base of the tax or deferring its collection. Some states offer to convert the tax to be collected into a financing scheme at preferential rates (National Department of Mineral Production, 2006).

2.4.4 Relevant Environmental Policies

The environmental management of Brazil is rather complicated. The Environmental Policy of Brazil (BEP), which is coordinated and formulated under the responsibility of the Ministry of Environment (Ministrio de Meio Ambiente: MMA), is executed at three levels: federal, state, and municipal. The BEP included such instruments as a Permit System for Polluting Activities, compulsory performance of environmental impact assessments, environmental zoning, and environmental quality standards. Under the MMA is the National Counsel for the Environment (Conselho Nacional de Meio Ambiente), which has authority to grant the environmental licenses required for all mining activities in Brazil.

There is a National System for the Environment set by law in 1986, which comprises various agencies and entities of the Union, states, municipalities and foundations instituted by the government as follows:

> " (a) Government Council as the governing body;
>
> (b) National Counsel for the Environment (CONAMA) as the consulting and deliberating body;
>
> (c) SEMAN/PR (Secretariat for the Environment of the Presidency of the Republic) coordinated by the Environment Department of the Executive Branch as the central body;
>
> (d) The Brazilian Institute for the Environment and Renewable Resources (IBAMA) as the executive board responsible for policing and enforcement of all federal environmental laws, in which all information concerning fines or other environmental problems of a targeted company in its data banks can be accessed;
>
> (e) District Agencies; and
>
> (f) Local agencies
>
> Due to the many government agencies involved, it is not unusual for conflicts to arise that need to be settled in the courts." (Noronha Advogados, 2003)

Relating to the construction and demolition waste (CDW), which can be used as substitutes for construction minerals, Brazil has a policy to regulate its transportation and dumping. However, in a big city like São Paulo, such policy alone is not very effective in preventing illegal dumping of CDW. It has to be complemented by a network of transfer stations, which helps cut down the legal transportation costs, to make illegal dumping less attractive. However, a new policy, as presented by National Resolution 307 of the CONOMA requires all municipalities and building contractors to set up CDW management schemes. Recycling will be a very important tool for managing CDW in big cities like São Paulo (Angulo *et al*., 2002).

Besides policies on rules and regulations, Brazil uses various technologies to help manage the environment. CETEM also conducts research on reclamation and environmental damage abatement. Since 1998 CETEM has received the assistance in implementing the application of mined land reclamation of the Canadian Mining and Minerals Sciences Laboratories, under a sponsorship programme of Canadian International Development Agency (CIDA) (Natural Resources Canada, 2001).

2.4.5 Sustainable Development Policies

Brazil also employs the popular term of "sustainable development" in its policy statements. The current policy statements are in the Brazil's 2004-2007 Multi-Year Plan (Plano Plurianual: PPA). Brazil's 1988 Constitution requires that a four-year PPA be submitted by each newly elected government at the beginning of its four-year mandate to the national Congress for approval. PPA is to guide fiscal and public expenditure management. The notion of sustainability is firstly adopted in the macro-objectives of the PPA 2004-2007, which place emphasis on social issues such as land reform, gender and racial equality, and social inclusion of indigenous people. The three core “mega” objectives of the PPA 2004-2007 are:

(i) Social inclusion and reduction of inequality;

(ii) Growth with environmental sustainability and reduces regional inequalities; and

(iii) Promotion of citizenship and democracy.

Some of the macro objectives under the mega objective of Growth with Employment Generation, Environmental Sustainability and Reduced Regional Inequalities, are as follows:

> “ - Attain macroeconomic equilibrium and the recuperation of sustainable economic growth, with better income distribution and with employment generation;
>
> - Expand jobs, promoting professional development and the reduction of the informal sector;
>
> - Implement effective land reform, and promote sustainable rural agriculture and development;
>
> - Coordinate and promote productive investment and productivity, with emphasis on the reduction of external vulnerability;
>
> - Expand and strengthen scientific and technical knowledge regarding sustainable development, with emphasis on equity across regions;
>
> - Stimulate investment in infrastructure in a manner that is coordinate and sustainable;

- Reduce regional inequalities, using an approach that addresses development at the national, regional as well as local levels, stimulating participation of society in local development; and

- Promote environmental quality, as well as the conservation and sustainable use of natural resources, with emphasis on education regarding the environment." (World Bank, 2003)

With regard to technology that supports sustainable development, Brazil has also received assistance from the Federal Government of Canada. From 1995-1999, under the Canada-Brazil Cooperation Project for Sustainable Development in the Minerals Sector, the Natural Resources Canada, helped train Brazilian scientists from CETEM in the area of technical environmental management consisting of acid mine drainage, aquatic effects, life cycle assessment, and ISO 9000 accreditation (Natural Resources Canada, 1999).

2.5 The Comparisons of Thailand's Policies with Those of Canada, Australia, and Brazil

In comparisons of policies on mineral resources of Thailand and those of Canada, Australia, and Brazil, one should take into account of the differences in government structures between the four countries. Thailand is a single state country where local administrations are still in their infancy. At present, a local administration is authorized to give or refuse consent to mining in its jurisdiction, but the final say on the matter of mineral resources rests with central government. On the other hand, Canada, Australia and Brazil are governed by systems of federation with different degrees of state or provincial power. In Canada and Australia, states or provinces have full authority over mineral resources, but in Brazil, mineral resources are proclaimed by the nation's constitution as properties belonging to the Union.

Besides government structure, different geographies, environments, and population densities also affect countries' policies on mineral resources. Thailand and Brazil are tropical countries and parts of the countries are dense tropical forests. Canada and Australia are in temperate-to-cold climate zones and large parts of the countries are arid land. Among the four, Thailand's population density is the densest, while major parts of Australia and Canada are sparsely populated.

2.5.1 Mining Promotion Policies

a) <u>Exploration Investment Promotion</u>

Canada is a land of vast areas and rich natural resources. Its economy and its people have depended significantly on the exploitation of its natural resources, including mineral resources. Because of its abundant mineral resources and the extensive experience of its workforce, more than 60% of the world's mining companies are based in Canada. The importance of the mineral sector to their economies ensures the state and national governments support and encourage the country's mineral industry. Canada devised a fiscal incentive scheme to encourage mineral exploration, called Flow-Through Shares (FTS) programme, which grants 15% federal tax credits for mineral exploration activities. The FTS means that the federal government will share 15% of the cost of every successful exploration project in the private sector. With the FTS programme, Canada may be the most supportive, among the four countries, to the mineral industry as a whole.

Australia, another country that is rich in mineral resources and its economy depend somewhat on them, also treats the mineral industries favourably. Fiscal incentives to the private sector are not prevailed as much as in Canada for only the State of South Australia offered to co-fund the approved drilling projects under a plan for accelerating exploration. Governments of various states and the Commonwealth resort to the strategy of supplying potential investors with useful information. Such information involves geoscience data, regional development plans, guidelines for investors, innovation roadmaps identifying priorities for research and development in some important minerals, etc. Besides providing information, some states invested in initial exploration aiming to identify potential areas of mineral deposits for investors to conduct detailed exploration for mineral deposits, at less risk. Another strategy employed by the Commonwealth and states to encourage mineral exploration is the establishment of research centres. The Australian Resources Research Centre (ARRC) of the Commonwealth Government of Australia has been established with the focus on developing technologies to improve the probability of discovering high-quality mineral deposits. At the state level, the Cooperative Research Centre for Landscape Evolution and Mineral Exploration (CRCLEME) is another research centre that has been established by the New South Wales Government to assist the discovery of new resource areas, and to provide support in landscape mapping projects.

Developing countries such as Brazil and Thailand use similar methods to Australia in promoting their mineral industries by providing useful information to potential investors, and investing in geological surveys and initial exploration. In attempting to specify areas with potential deposits, Thailand sponsored two projects: the Mineral Resources Development Project (MRDP) and the Accelerated Mineral Resources Exploration and Evaluation Project (AMREEP). Thailand does not offer a fiscal incentive to an exploration project, but a mine investor can apply for income tax exemption from Thailand's Board of Investment similar to other business investors. In Thailand mineral investors may request technical assistances from the government, but no research centres specifically designed to perform research and development on minerals are established. In the case of Brazil, however, Federal Government has established the Company of Research on Mineral Resources (CPRM) to study potential mineral deposits and assist mining companies with geological information services.

b) Land Use Conflict Alleviation

Each country solves its land use conflicts differently. While developed countries such as Canada and Australia resort to preventive measures, the developing countries such as Brazil and Thailand have seldom anticipated problems in advance. Details how each country solved land use conflict are as follows:

Because of the cost of transportation, aggregate mines, for sands and crushed stones, are usually situated close to cities. In the case of Canada, as cities grow, available infrastructure and utilities at the sites of aggregate mines and mills entice new settlements near and around them. To solve the ensuing land-use conflict, the Government of Ontario Province introduced the Mineral Aggregate Resources Policy. Its two main parts consist of (1) developing mineral aggregate resources in deposits which are as close to markets as possible, and (2) protecting mineral aggregate operations from land use conflicts by restricting migration of people to mineral aggregate supply areas.

Unlike Canada that restricts settlements around mining areas, Australia attempts to solve land use conflict prior to the commencement of mining operation by inducing a compromise between mining companies and nearby communities. For example, the

Victoria Government introduces the Extractive Industry Interest Areas (EIIA) report aiming to increase stone supply for the vitality of Victoria's economy and, at the same time, to reduce land use conflicts between mining companies and communities. The EIIA report is a guideline for both mining companies to find new stone deposits and local communities to realize and prepare for long-term plans for public land use of the mined-out areas.

In Brazil, one cause of land use conflict with aggregate mine is dust pollution emitted by mines and mills. The Brazilian Federal and State Governments use command and control instruments to solve this environmental problem caused by aggregate production. Mining firms that do not comply with environmental regulations will be closed, while the others that manage to get dust emission below the required standard can continue to operate. A lack of long-term land use planning that designates aggregate supply areas and no guidelines for mining firms and communities to reach a compromise makes land use conflicts in Brazil a chronic problem.

In Thailand, in the case of aggregate minerals, the designation of rock resources all over the country that are suitable for crushed stone production and permitted to be mined has been achieved. A local administration is empowered to give a say before a mining concession in its jurisdiction is granted by the authority in Bangkok. The conflicts between miners and local communities are further alleviated by a scheme of tax-revenue sharing. Local and provincial authority administrations will get 60 per cent of mineral royalties collected by the Department of Primary Industries and Mines (DPIM) from mines in their jurisdiction. As a result of the aforementioned government policies and actions, land use conflicts between aggregate producers and local communities in Thailand are not so severe. The land use conflicts are more of a problem among governmental agencies overseeing environment and various land resources for example: national forests, national parks, wild life preservation areas, watershed areas, and agricultural areas.

2.5.2 Relevant Environmental Policies

a) Mine and Mill Pollution Alleviation

In Canada and Australia, pollution from aggregate mines and rock crushing mills rarely occurs because of the close supervision of Provincial/State Governments and the efficient environmental management of mining firms. On the other hand, Brazil is still plagued with the problems. Brazilian federal and state governments seem to use only command and control instruments, however, with insufficient manpower and budget.

In Thailand, besides command and control instruments, technological transfer is employed to solve environmental problems. In 1997, the DPIM established a project to mitigate dust pollution in the most concentrated crushed stone production area, Tha-pra-lan and adjacent districts in Saraburi province, under the consultancy of the Faculty of Engineering, Chulalongkorn University. The objectives of this project were (1) to reduce dust pollution in the area to the safe level by means of dust prevention and suppression technology and engineering and environmental management, and (2) to be a pilot project for solving the dust pollution problem caused by quarries and rock crushing mills in other areas. At the end of the project, the air quality in this area met the standard but not for so long because of a lack continuous enforcement by both the local and central authorities.

b) Abandoned Mined-Out Area Rehabilitation

In all four countries, after mining projects ceased, mining companies are required by law to reclaim, restore, or rehabilitate mined-out areas. But, in the cases that reclamation fails or mined-out areas are abandoned, each country has different way to solve this problem as follows:

In Canada, the Government of Ontario Province set up the Management of Abandoned Aggregate Properties (MAAP) Programme to restore abandoned aggregate quarries within Ontario under the Aggregate Resource Act. The abandoned mined-out areas were rehabilitated to appear natural or converted to agricultural lands or recreational areas.

Australia deals with the problem of abandoned mine-out areas through three approaches. The first approach, like those implemented by Canada, is to set-up a reclamation programme. For example, the New South Wales State created the New South Wales Derelict Mines Programme to reclaim abandoned mining areas where no individual, company or organization can be found responsible. The second approach is to implement progressive monitoring processes and to offer incentives for miners to provide progressive rehabilitation of mined-out areas. For example, in Queensland, the practice of performing land reclamation inspections by government officials only at the end of a mining project was replaced by a practice of intermittent scheduled visits by officials in accordance with the land reclamation programme, which should start long before the mining project ends. Queensland also developed a scheme of incentives to encourage progressive rehabilitation. The third approach is to assist miners through science and technology innovation. The Australian Centre for Minesite Rehabilitation Research (ACMRR) was established by Commonwealth Government to develop processes and evaluate indicators of ecosystem rehabilitation success.

Brazil, like many other developing countries, just recently took the environmental problems of abandoned mined-out areas seriously. The problems were so severe that it is even stated in the 1988 Brazilian Constitution that mined-out areas that were environmentally damaged must be reclaimed. Brazil also uses the Australia's third approach in dealing with problems. Through the Mineral Technology Centre for Mineral Technology (CETEM) of the Federal Government, with the assistance, under the Brazilian Mine Rehabilitation Project of the Natural Resource Canada, scientific and technological knowledge about reclamation is being developed and transferred to Brazilian miners.

In the case of Thailand, all Australia's three approaches have been used. However, Thailand has not established an institute for research and development on mining and related technology. In Thailand, universities are funded to transfer scientific and technological knowledge to miners. At present, DPIM runs a project to reclaim mining areas efficiently by hiring the Faculty of Forestry at Mahidol University to train miners in land rehabilitation and covering: area preparation, soil quality adjustment, tree selection, tree planting, and tree growth improvement.

c) Recycling

Solid waste from industries and communities has become a problem of most developed and developing countries. Therefore, most countries promote recycling as a means to reduce solid waste and to help preserve their mineral resources. In comparing the environmental policies on recycling of the four countries, one must understand that each country has different kinds and severity of problems and also face different difficulties in solving them. A fact is that richer countries normally generate more waste per capita than poorer countries. Richer countries have to set strong policies and measures to support recycling businesses. But in less developed and developing countries, because of high unemployment and lower income among labourers, useful and saleable wastes from household waste and city waste dumps are the lifelines of many of the poor. Hence, in a poorer country the problem of solid waste is comparative less severe and easier to induce recycling.

In the case of Canada, the richest among the four countries in terms of national income per capita, its Federal Government lay the scope of recycling to cover retrieval of metals and minerals that are the raw materials of industries. The Natural Resources Canada, a Federal government agency supervising natural resources sector of Canada, launched the Enhanced Recycling Programme to foster an increase in recycled minerals and metals by seeking partnerships with automobile, construction, electro-plating and electronics industries.

Australia however, stressed its recycling promotion policy on the sources of waste: commerce and industry, municipalities, and construction and demolition. The Government of Victoria State released the *Towards Zero Waste* strategy with the following objectives: to reduce solid waste from three sectors: commerce and industry, municipal, and construction and demolition; to increase the amount of materials reused and recycled; and to decrease environmental damage caused by these solid wastes. The South Australian Government also issued a waste strategy, while the New South Wales Government introduced the Waste Avoidance and Resource Recovery Strategy with the same objectives as those of the Victoria Government.

Brazil is a developing country; therefore, a major part of valuable household wastes, such as metals and plastic, are always collected and sold for recycling by some poor people. Its chief concern regarding solid wastes, however, is illegal dumping of waste from demolition. Therefore, Brazilian scope of recycling emphasizes on construction and demolition waste. The National Council for the Environment (CONAMA) of Brazil is now in the process of approving a management scheme of construction and demolition waste (CDW). The scheme requires all municipalities and building contractors to establish their own management plans to recycle CDW. Besides recycling CDW for use, the construction sector in Sao Paulo has started utilizing artificial sands produced by washing grainy residual by-products from crushed stone production as a substitute for natural sand.

Solid waste problems in Thailand, as a developing country, are partly solved by the poor in a similar way to that of Brazil, and by small recycling businesses that buy, separate, and sell sorted waste items as raw materials to industries. However, the poor and small recycling businesses have become less and less effective as the country has grown economically. The Thai Ministry of Industry took action by creating a Division in the DPIM to promote recycling in industry. With regard to the illegal dumping of construction and demolition waste, Thailand, especially the great metropolitan of Bangkok, has not faced the same problem as has Brazil. Bangkok, which is situated on a soft flood plain with an elevation of just a few meters above sea level, demands a lot of landfill materials to elevate the ground before buildings and other structures can be erected. All construction and demolition wastes are, therefore, used as landfill.

2.5.3 Sustainable Development Policies

Canada and Australia adopted the concept of sustainable development using similar strategies. The Canadian Federal Government issues the Minerals and Metals Policy of the Government of Canada stating its aim to be Partnerships for Sustainable Development. The Australian Commonwealth Government has adopted a long term strategic vision for sustainable development of minerals and the petroleum industry.

The main objective of both governments is to provide a framework for the country's sustainable mineral development on three-dimensions: economic, environmental, and social. But in the viewpoints of Provincial/State Governments of both countries, sustainable development is focused on (1) physical sustainability of mineral production through mineral exploration and development and (2) sustainability of ecosystems and the environment in mining areas through mine site rehabilitation because of their need to earn revenue for developing their own provinces/states.

Both Brazil and Thailand adopted the concept of sustainable mineral development by stating their aims to realize it in their national plans: the Federal Government Multiyear Plan (PPA) for Brazil, and the National Economic and Social Development Plan for Thailand. Both countries accept that the sustainable development has to be achieved through the balance of three-dimensions: economic, environmental, and social. But indeed, at the departmental level, the policies of both the National Department of Mineral Production of Brazil and the Department of Primary Industry and Mines of Thailand still insist on only one dimension: the sustainability of minerals revenues. This is because both are developing countries and revenues from mining industries still play an important role to their own country's development.

Chapter 3 The Notion of the Natural Resource Curse

3.1 Introduction

Natural resources all over the world are non-uniform in nature: arable lands, rivers and seas have differing yields; forests have different timber densities; mineral deposits have differing grades; etc. Producers of a commodity will have different production costs, depending upon how good the endowments of the natural resources employed in their production are. Since the global aggregate supply of a commodity is the sum of the outputs of all producers, according to economic theories, the price of a commodity is driven by the marginal production cost of the highest-cost producer. As a result, the marginal production costs for a commodity borne by the majority of the producers are, in general, less than the market price of the commodity. Hence, extraction of natural resources normally generates economic rents. It is logical for most economists and policy makers to believe that, for a country, revenues in term of foreign exchanges accruing these economic rents should generate wealth for an economy, promote economic progress and reduce poverty. However, the past couple of decades have witnessed the emergence of a new and far less benevolent view of the contribution of natural resources, especially nonrenewable ones, to economic development, particularly in the developing world. Based on empirical studies, many scholars have reported that resource rich countries appear to have experienced a worse economic performance than resource poor countries (Auty, 2001; Sachs and Warner, 1995; Bravo-Ortega, and De Gregorio, 2001; and Leite, and Weidmann, 1999). Though some argued against this conclusion (Maloney, 2002; Gylfason, 2001; Wright & Czelusta, 2002; Stijns, 2001), there appears to be a broad agreement that natural resource wealth may not really be a blessing for a developing country. This phenomenon has become known as the “resource curse”. The term was first used in formal economics literature in 1993 (Auty, 1993). However, it should be noted that not all countries appeared to suffer a “curse” as a result of the influx of large natural resource revenues (Sachs and Warner, 1997). Thus the “resource curse” phenomenon is not exactly unavoidable. We should, therefore, learn the causes of this phenomenon in order to prevent its strong recurrent tendency occurring in a country.

3.1.1 Why do Economic Rents Become a Resource Curse?

There seems to be no single explanation why a country with good revenue from natural resources tends to suffer a “curse”. However, all explanations base upon the simple notion that the curse occurs when a country’s abundance in natural resources causes a distortion in the country’s economy that becomes difficult to manage and results in resources being used less efficiently than they would be otherwise. Compiled and derived from various literature, the causes of resource curse comprise: long term decline in terms of trade, revenue volatility, structural economic change, and socio-cultural and political impacts.

a) Long Term Decline in Terms of Trade

Countries whose foreign exchanges depend on export of the primary products of natural resources face long term decline in “terms of trade”, statistically defined as the ratio of the average price of exports to the average price of imports. Several empirical works, including those on Thailand, from my unpublished research paper to be mentioned later (Arnonkitpanich, unpublished), and Jamaica (Atkins, 2000), demonstrated that, in the long term, the prices of primary commodities decline relative to the prices of manufactured goods (Brohman, 1996). Continuing progression in technology may play an important role in this tendency. Technological improvements mean higher capacities of commodity production with lower costs of production and, at the same time, production of manufactured goods uses fewer raw materials than before (Prebisch 1950, 1964; Singer, 1950). Except in the cases of some specific commodities, such as petroleum oil and diamond, whose producers have formed cartels, commodities markets are generally competitive; therefore, any reductions of production costs are passed on to consumers in the form of lower prices. On the other hand, the producers of manufactured products have greater market power, which allows them to maintain the prices and pass the benefits of falling costs to workers and shareholders. Decline of export revenue, in itself, is negative to economic growth. Furthermore, over time, a resource rich country would be able to buy less and less imports of capital goods thereby inhibiting development-creating investment in an economy.

b) Revenue Volatility

Revenue volatility of a resource rich country is clearly evident. It was found that during 1972-92, regions with high primary export shares experienced terms of trade volatility two to three times greater than industrial countries in the same period (Mikesell, 1997). Because the demand for a commodity, a product from natural resources, is a derived demand, which has rather low elasticity by nature; therefore, the commodity price is very sensitive to change in the demand for the commodity. When the world economy is booming the commodity prices are more likely to shoot up. Conversely, when the world economy is in recession the commodity prices tend to be depressed severely. This means that, for the resource rich country, export earnings and tax revenue are particularly volatile. This volatility could cause a variety of problems. Fluctuating revenue profiles make it very difficult for a government to pursue a prudent fiscal policy and macro-economic management. This creates problems in the economy ranging from aggravating investor uncertainty to "stop go" spending policies. Because markets are far from fluid, there exists a significant asymmetry between the economic impacts of excess aggregate demand versus deficient aggregate demand likely to arise from fluctuating government spending. Thus, excess leads to inflation and a high propensity to import while deficient demand causes falling real output, unemployment and falling real income. Hence the economic benefits from a mineral boom might be more than offset by the adjustment costs during any following recession (Gelb and Associates, 1988).

c) Structural Economic Change

The undesirable structural economic change that deindustrializes a nation's economy as the result of the discovery and exploitation of natural resources is known as "Dutch Disease". The phenomenon was first observed in the Netherlands in the 1960s, when large reserves of oil and natural gas in the North Sea were discovered and exploited. It was found later that the manufacturing sector in the Netherlands declined during the period. Total exports from the Netherlands decreased markedly relative to Gross Domestic Product (GDP) during the 1960s. The expansion of petroleum exports in the 1960s reduced other exports disproportionately (Gylfason, 2006). The mechanism of the Dutch Disease is that the rapid increase in oil and gas exports leads to a surplus in international trade that causes the domestic currency to appreciate. The rise of the real exchange rate of the domestic currency makes the domestic manufacturing sector vulnerable to import goods. Furthermore, the increasing volatility of exchange rate as the result of the oil price fluctuation also hurts foreign trade in manufacturing goods. In addition, the boom in the oil and gas industries pushes up the domestic wage rate since other sectors have to compete for labour with the booming oil and gas sector, which enjoys high profit from economic rent. These bias effects make the other domestic sectors, especially the manufacturing one, less competitive and decline (Fardmanesh, 1991; McKinnon, 1976; Van Wijnbergen, 1984). As a result, domestic investment in the sectors other than the oil and gas industries will stagnate or shrink. A study found that the level of domestic investment was inversely related to dependence on primary product exports (Gylfason *et al*., 1999).

d) Socio-cultural and Political Impacts

There is an argument that natural resource rents, particularly those that are easily exploited, create tendencies for rulers to do badly. Initially, the easy revenues remove the budget constraint, which encourages spending in wasteful but politically important projects. A study, for example argues that in the case of Venezuela it was bad government management that caused the problems rather than direct distortions from the export booms of the 1970s and 1980s (Mikesell, 1997). In many resource rich countries, this imprudent spending leads to a budget deficit. Besides, resource rich countries tend to have big governments that are normally bureaucratically inefficient. Easy money induces corruption. High resource rents, particularly those from oil and mineral resources, lure people to seek the easy rents. An example was the case of Ghana where corruption could be seen as rent seeking behaviour (Mbaku, 1992). More often, rush for rents causes over investment in the sectors that render rents. This is especially true in the cases of gold rush and the discoveries of the deposits of other high-price minerals. Because of the Dutch Disease resource rich governments tend to adopt protectionism policies on other domestic industries, which encourage inefficiency. A study found a positive correlation between dependency on primary products and a closed trade regime (Sachs and Warner, 1995).

3.1.2 How Can Resource Curse Be Avoided?

Because of the resource curse phenomenon, the possession of wealthy natural resources, especially mineral deposits, alone is not a guarantee of economic development. However, it seems that few scholars, if any, refute the significant contribution to the economic development of a country. There is widespread consensus that:

i) Mineral deposits that can be extracted profitably are (natural) capital assets. If they are converted into human or physical capital, they can promote economic growth; and if they are consumed, they can lower current poverty. In either case, they can enhance economic development. In short, mineral resources provide developing countries with opportunities that they would not otherwise enjoy.

ii) Some countries have taken advantage of these opportunities, and used their mineral wealth to promote economic development. Historically, Britain, the United States, and Germany are often cited as successful examples. In more recent times, it is generally agreed that mineral resources have promoted economic development in Australia, Botswana, Canada, Chile, Malaysia, the Netherlands, and Norway. It should be noted that Botswana, the world's leading producer of diamond by value, is the only country ever to graduate from the United Nations' least developed country grouping, and it holds the world record for per capita economic growth since 1965 (Gylfason, 2001).

iii) Similarly, it is widely recognized that in other countries, such as Zambia and Sierra Leone, mining has increased poverty and impeded long-term economic development through many of the avenues described earlier (Davis and Tilton 2002).

Since the performances of all resource rich countries are varied, the extent to which most of the potential benefits of natural resources are realised entirely depends on the quality of the developing country's administrative, judicial and legislative institutions. These governmental institutes have the power to support or hinder economic development in the developing world. The ultimate question should be: Which are the appropriate measures and policies to be implemented in the developing world in order to ensure economic development? Recommendations by scholars in the literature have a number of different analytical strands as follows:

a) Gradual Exploitation

The extreme option under this recommendation is to leave natural resources, especially oil and minerals, in the ground as suggested by the Oxfam study (Ross, 2001). This study essentially stated that: "Oil and mineral dependence produce a type of economic growth that offers few direct benefits for the poor; moreover, oil and mineral dependence make pro-poor forms of growth more difficult, due to the Dutch Disease." This suggestion, which was contrary to Davis and Tilton's conclusions mentioned above, is considered to be flawed by some critics. However, while this cannot be regarded as a serious option, it does raise issues about the speed with which a natural resource project, especially the oil, gas or mineral one, is undertaken and hence the consequent production/revenue profile.

If a country is in danger of the resource curse because it is about to develop a new mineral deposit, the slower the development of the project, the greater the chance the economy and society has to adjust to the inflow of revenue. Furthermore, slow development is likely to allow the development of a service industry based on the project whereas swift development must be based upon imported services. The difficulty of this solution is how to persuade the investors to slow development.

A variant on the theme of slowing development is the nature of the revenue flow from the projects. Differing forms of extractive agreements – concession based on royalty and taxes, joint ventures, production sharing agreements, service agreement etc. – will create differing patterns of revenue flow. For example, in the case of Botswana, the agreement with De Beers on diamond sales effectively smoothes the revenue flow to the government (Stevens, 2003).

Though the agreement governing the revenue distribution between Government and De Beers is confidential, some analysts estimate that the Botswana Government takes about 75% of the profits from diamond mining through taxes, royalties and dividends. The Sales Marketing Agreements, typically for a 5 year period, and Mining Agreements for 25 years, provide a stable framework for both the investor and the Government (Modise, 2000).

b) Diversification

Many scholars recommended this solution (Ross, 2001; Auty, 1994). However, this is a solution that is difficult to achieve, if not an illusive one. The performances of resource rich countries, in general, have been very poor for huge amounts of public money being poured into inefficient and uncompetitive industries (Stevens, 2003). The reasons might be because of the consequence of Dutch disease and crowding out effects, which depressed other non-natural resource sectors. Furthermore, the diversification policy has consisted of governments trying to pick industries to be promoted. Notwithstanding wrong choices, it is more likely that they will attract subsidies and protection that will eventually inhibit their development, and if they are monopoly public enterprises, such enterprises tend to be high cost and inefficient.

However, the experience of the Asian tigers shows that the only really effective diversification comes from private sector investment, although governments can play a supporting role in this process (World Bank, 1993). To strengthen this avenue, it might be a good suggestion for a government to leave a good portion of resource rent in the hand of the private sector rather than the public sector. However, this affects the issue of income distribution. Another way to encourage successful diversification is to liberate trade policy. It was quite noticeable that the "usual suspects" who avoided the curse – Botswana, Chile, Indonesia and Malaysia - all pursued a policy of trade openness with the rest of the world coupled with a deliberate policy of exchange rate depreciation to ensure the competitiveness of non-natural resource industries (Stevens, 2003).

c) Sterilization of Revenue

This solution recommended the resource rich countries to neutralize the impact of the large windfall revenue inflow on the rest of the economy. Fiscal prudence is needed to prevent the revenues from translating immediately into greater aggregate demand and inflation. Ideally, a government should resist spending pressures and either to accumulate budget surpluses or to channel the revenues into some form of fund to be spent appropriately later. A country that has attempted to follow this recommendation is Norway, the third largest oil exporter in the world. Norway is a country that can avoid the resource curse. In 1990, Norway, considered a developed country, established the Government Pension Fund (formerly, Norwegian Petroleum Fund), to which all revenues from petroleum have accrued. The Fund has been designed to ensure that petroleum revenues are used not only by the current generation but also by future generations (Gylfason, 2006). The Norwegian Government Pension Fund will be discussed further in the next section.

However, for most resource rich developing countries, total sterilization of the revenue from natural resources is not practicable because of its size in comparison with the total government revenue. (Of course if the revenue from natural resources is small, which means the share of natural resource sector in the economy is small, the effect of resource curse should not be a matter of concern to a government.) In the real world, countries have mostly opted to cautiously spend the revenue and make great attempts to stabilize rather than to sterilize it. Stabilization of revenue from natural resources by way of setting revenue funds will be mentioned in the next section.

Using the promises of expected revenue from natural resources to increase borrowing should be avoided at all costs for it increases revenue fluctuation even more. Increased foreign borrowing also has a further disadvantage of helping appreciate the exchange rate thus directly contributing to the Dutch disease effect. Very often in the case studies, the experience of Indonesia who did not borrow is compared to the experience of Mexico who did (Usui, 1997).

Another important recommendation under this solution is for a government to avoid exchange rate appreciation. A fixed exchange rate policy should be discarded when domestic inflation of any magnitude exists. Currency devaluation is even encouraged. One option is for the central bank to purchase foreign exchange to hold down the nominal rate (Mikesell, 1997). One common factor in the case of those who recently avoided the resource curse, i.e. Botswana, Chile, Indonesia and Malaysia, is that all four experienced significant depreciation of the real exchange rate as a result of explicit policy choices (Stevens, 2003).

d) Setting up Revenue Funds

Another mechanism to stabilize spending is to establish a fund or funds, financed by a good portion of the revenues from natural resources. To insulate the domestic economy from large revenue windfalls the funds have to invest outside the country. Such funds can be used as a mechanism to put assets aside for future generations. Only the earned income from the funds should be allowed to be spent at present, while the accumulated capital sum of the funds should be left intact to allow future generations to share the benefit from the depletable natural resources. However, during the down turn when the revenue from natural resources falls below a certain level the funds may be withdrawn to top up the government budget. But integrating the funds into the overall fiscal policy "has proven problematical, and despite the operation of a fund, the stabilization of expenditure has remained elusive…" (Davis *et al.*, 2001).

Anyway, it can be argued that even if conditions are not ideal, the creation of such funds can make some contribution to avoiding the worst excesses of the resource curse because of the role of the funds in dampening spending expectations. The success story of Norway is owed in part to the establishment of the Government Pension Fund. Besides putting off money for future generations, the Norwegian Government Pension Fund also aims to serve as a buffer between current petroleum revenues and the use of these revenues in the Norwegian economy. Thus the domestic economy is shielded from fluctuations in prices and extraction rates in the petroleum sector. By law, the capital from the fund can only be used over the central government budget, which is capped by a Norwegian parliament's guideline not to exceed 4 per cent of the fund or the expected real return on the fund. As in 2006, the Norwegian Government Pension Fund reached the amount of about USD 300 billion (Gylfason, 2006). Besides Norway, Chile and Indonesia have also established successful revenue funds (Mikesell, 1997; Usui, 1997). At a state or provincial level, the Alaska Permanent Fund of the Alaska State Government, U.S.A., and the Alberta Heritage Fund of the Alberta Provincial Government, Canada, can be considered as successful funds accrued from natural resource revenues (Hanneson, 2001).

e) Political Reforms to Carry Out the Corrective Politics

To avoid the risk of suffering a resource curse, a country need to be a developmental rather than a predatory state whose rulers prey on their subjects rather than promoting development. However, recent research suggests that mineral wealth may actively promote a predatory style of government (Fridthof Nansen, 2000; Birdsall and Subramaniam, 2004). Part of the reason is that revenues from natural resources, especially oil and minerals, reduce the need to impose taxes on the general population. At first this seems like a blessing, but it is not. States that tax their citizens need to seek their consent, or at least their acquiescence, and this involves a process of political bargaining—typically through elections. Resource-rich governments that are already inclined towards authoritarianism are likely to choose a different option. They can use rich revenue to buy off political opponents, strengthen their personal praetorian guards and suppress dissent.

There is an argument for a country to develop democracy. However, while this may well be highly desirable for many reasons, the successful stories of authoritarian states, such as South Korea, Taiwan, Indonesia, Singapore, Chile, Botswana, etc. during their early development, show that democracy is not a necessary condition for successful economic performance. The more important avenues are for a regime to contain corruption and to reduce rent seeking. A clean-up campaign must start with an agreement on a common standard of morality (Gillespie and Okrhlik, 1991).

Incorporation of corruption controls in legal codes, setting up independent and fearless enquiries, and practicing transparency or good governance are ways to reduce corruption. Reducing rent-seeking opportunities can be done by de-politicizing resource allocation, through deregulation and privatization allowing free markets to take politicians and bureaucrats out of the resource allocation process (Mbaku, 1992). The competition will squeeze out illicit margins, as demonstrated by an empirical study (Gregoire, 1992)[9].

Developmental state is defined as a state aiming at an improved standard of living for the majority. To become one requires two components: the strong elite whose interests are aligned with the population, and the institutional capacity to implement the necessary policies without being captured by narrow private interests. Securing an alignment of interests is crucial and, of course, one route to achieve it is democracy where the government must satisfy public interests or be voted out. However, it seems not to be the only route. For example, Chile under Pinochet together with Malaysia, Indonesia and indeed Botswana as a one party democracy managed the alignment quite well (Stevens, 2003). It is fortunate for some countries, such as Thailand, Indonesia, and Malaysia, that they long have possessed both two components—that are the strong elite and the necessary institutional capacity. That was the reason why those countries could avoid the effects of the resource curse. For some other countries, outside help may be need. Clearly international organizations, such as UNDP, the international financial institutes, such as the World Bank and Asia Development Bank, and the investing companies have roles to play. Help can be in the

[9] Gregoire, Emanuel (1992), in his book titled "The Alhazi of Maradi: Traditional Hausa merchants in a changing Sahelian city", studied the rise of a merchant class of the Hausa ethnic groups who live across the border between Northern Nigeria and Niger. The border was hardly patrolled or not patrolled at all. The local merchants have often benefited from the caprices of the national governments on either side of the Niger-Nigeria border. Gregoire found that the cross-border illicit trade in cigarettes rendered minimal profit margin of about 4 to 6 percent as the result of competition among large groups of smugglers and local merchants.

forms of seconding expertise to governments and training up those elements of the bureaucracy who could play a key role in policy making (Stevens, 2003).

3.2 The Case of Thailand[10]

Thailand can be considered a resource-rich developing country for it is endowed with a variety of mineral resources and fertile arable lands. At the early stage of its development, the well being of Thai people depended much upon resource base economy. During the 1960's, agricultural and mineral commodities, derived from forest, marine and land resources, accounted for more than eighty per cent of the total export of the country, and their sectors accounted for about one-third to forty per cent of the annual gross national product (GNP).

3.2.1 Encountering the Resource Curse

a) Experiencing Export Revenue Fluctuation

As shown in Figure 3.1 and Figure 3.2, between years 1960 and 1985, when the exports from Thailand were dominated by commodities, the annual export revenues of Thailand declined in several years. The maximum change of export revenue from year to year during the mentioned period was 54%, which could be considered huge, but not so severe when taking into account the average annual growth during the period of 13.2%. The reason that Thailand had exported varieties of commodities might help because the declines in prices of some commodities were often offset by the increases in prices of other commodities. Today commodities still play an important role in generating foreign exchange for Thailand. However, after 1985, when the values of

[10] An excerpt from my unpublished research paper done to fulfil a course at Colorado School of Mines

exports from manufacturing sector surpassed those of the commodities, Thailand has never again faced a negative growth in export revenue.

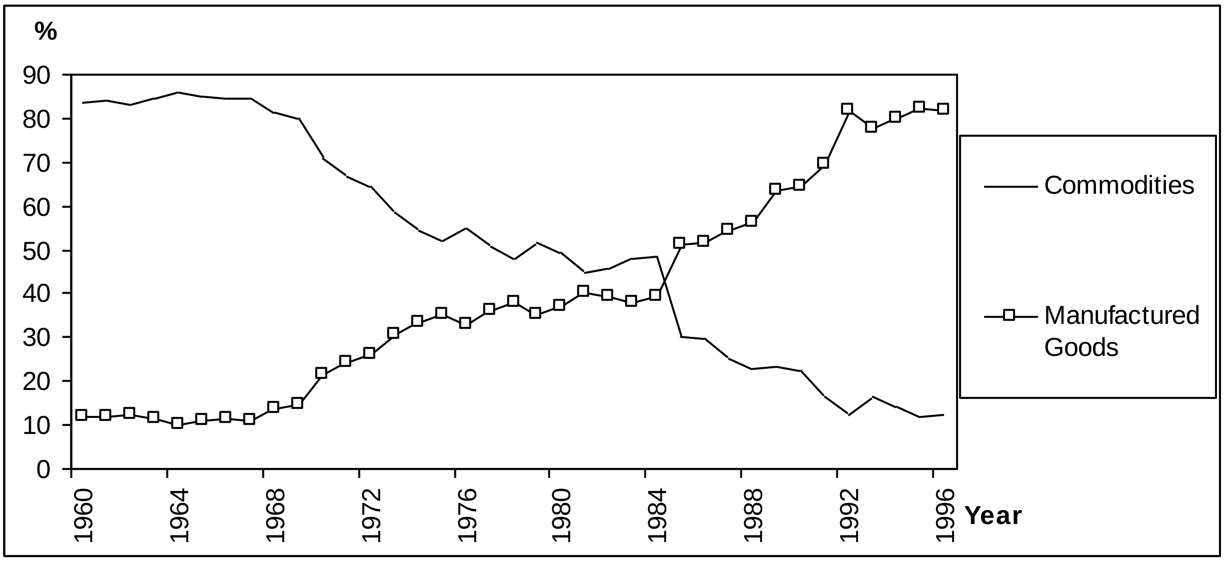

Figure 3.1 Shares of Commodities and Manufactured Goods as a Percentage of Total Exports, 1960 – 1996

Source: Department of Customs (2000)

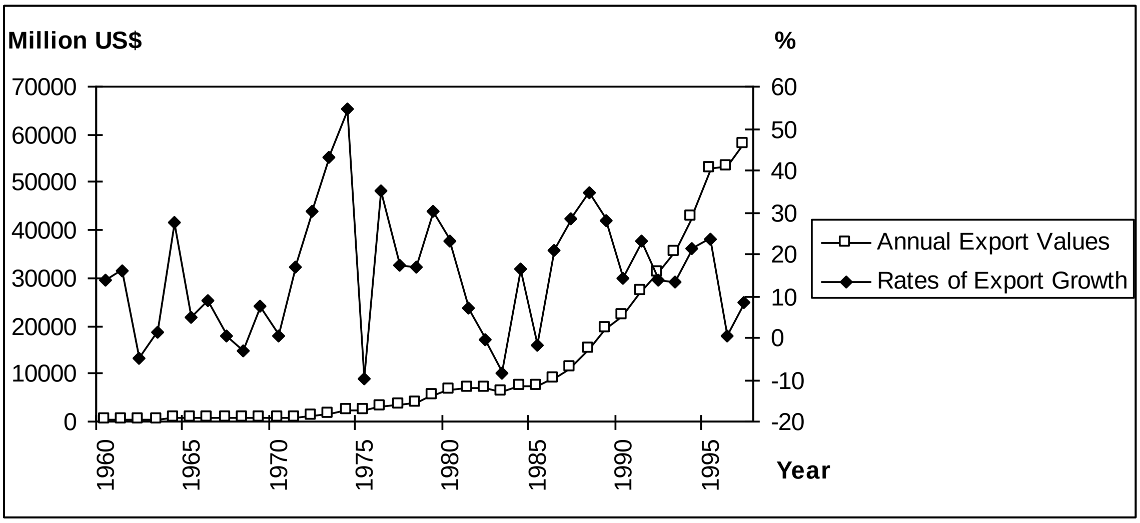

Figure 3.2 Annual Export Values in Current-Dollar and Rates of Export Growth of Thailand, 1960-1997

Source: Department of Customs (2000)

b) Facing Decline in Terms of Trade

As shown in Figure 3.3, Thailand has experienced long term decline in terms of trade, matching the theory nicely. At a period of time before 1985, when agricultural and mineral commodities played major roles in Thailand's total export, the decline in terms of trade deteriorated fast, especially during the early part of the 1980's. The World Development Report 1986 by the World Bank, found that, during the 5-year period from 1980 to 1984, out of its 125 member countries, both developed and developing countries, Thailand was among the group of ten countries that faced the most severe decline in terms of trade. The worst decline in terms of trade occurred after the "Commodity Boom" of the period from 1970 to 1979, during which Thailand benefited greatly. The decline in terms of trade for Thailand has been mild since 1988, when manufactured products became the major source of export earnings for the country.

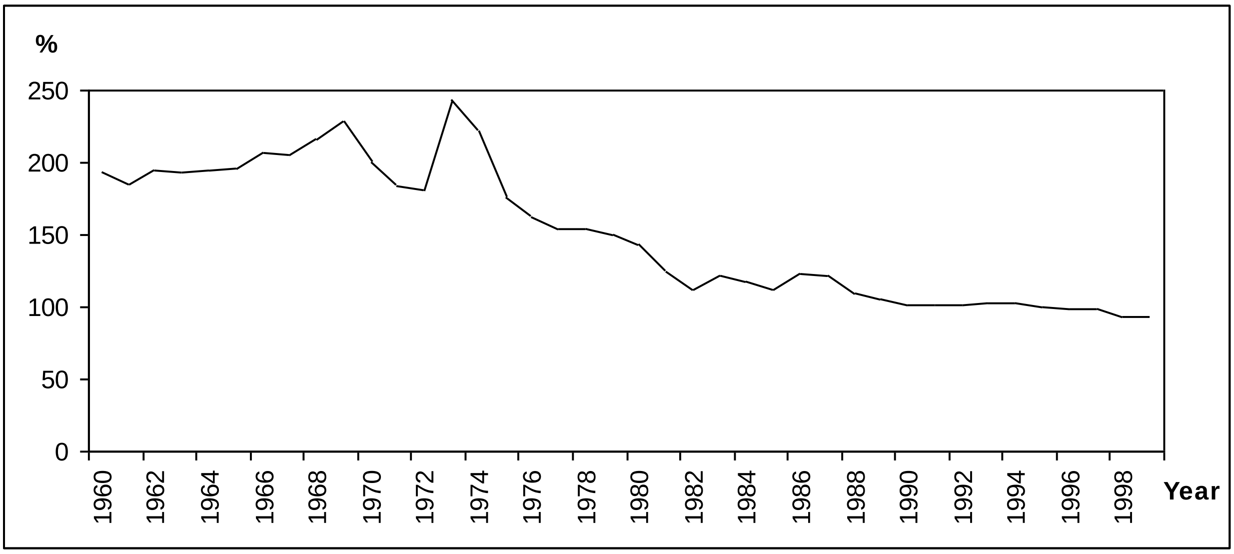

Figure 3.3 Terms of Trade of Thailand, 1960-1999

Source: Department of Customs (2000)

c) Catching No Symptom of the Dutch Disease

Since modern times, Thailand's currency has never faced the pressure to appreciate. On the contrary, before the economic and financial crisis of 1997, the opposite was true for Thailand which long faced chronic trade deficit. In the 1960's and 1970's, even after the end of the Brenton Woods Agreement, the Thai Baht moved in a narrow band between 20.35 and 20.965 Baht per US$. During the first half of 1980's, the long persistent deficit of the Balance of Payment forced Thailand to depreciate its currency twice—from 20.775 Baht per US$ to 23 Baht per US$ in July 1981, and from 23 Baht per US$ to 27 Baht per US$ in November 1984. Indeed export revenue from natural resources had never overwhelmed the balance of trade of Thailand. The reason may be that Thailand has never suddenly discovered a deposit of mineral resources with comparatively high value. Both important land and mineral resources have been exploited for export since more than a century ago. It is safe to say that Thailand has not caught the Dutch disease.

d) Socio-cultural and Political Impacts from Exploiting Natural Resources

When commodities dominated the country's economy, easy profits were in the business of trading agricultural commodities, besides mining. A major part of valuable domestic capital was locked in stockpiling agricultural commodities with the intention of profiting from the seasonally fluctuating prices. As a result, industrialization of the country was slow at the beginning, even though the government implemented industrial promotion and protectionism policies. The manufacturing sector flourished later only after the flux of foreign investments.

At that time also, export duties from agricultural commodities and mineral royalties were major sources of total tax revenue of the government because of the ease of their collections. In 1960, export duties plus mineral royalties accounted for about 22 per cent of the total tax revenue of the Thai government. (By comparison, in 2003, export duties plus revenues from mineral and petroleum resources was only 6.5 per cent of the total tax revenue.) During that period of time, it is not difficult to understand why the wealthy class was almost exclusively people engaging in trading and the poorest were farmers who were, indirectly, heavily taxed.

Like many other developing and under-developing countries such as the Philippines and Indonesia, Thailand has been plagued with corruption. According to Transparency International (TI) who compiles the TI Corruption Perceptions Index (CPI) Scores[11] of countries, the average score for Thailand between 1995 and 2006 was very low, only 3.3 points out of maximum 10 points compared with an average of 9.2 and 5.1 points, for those of Singapore and Malaysia, respectively (see Figure 3.4). But, because tax revenue from natural resources plus foreign aid had never surged to overwhelm the economy, misspending on bad projects by the Thai government was not so obvious at the time when Thailand depended on commodities.

[11] CPI Score, compiled by Transparency International, relates to perceptions of the degree of corruption as seen by business people and country analysts, and ranges between 10 (highly clean) and 0 (highly corrupt).

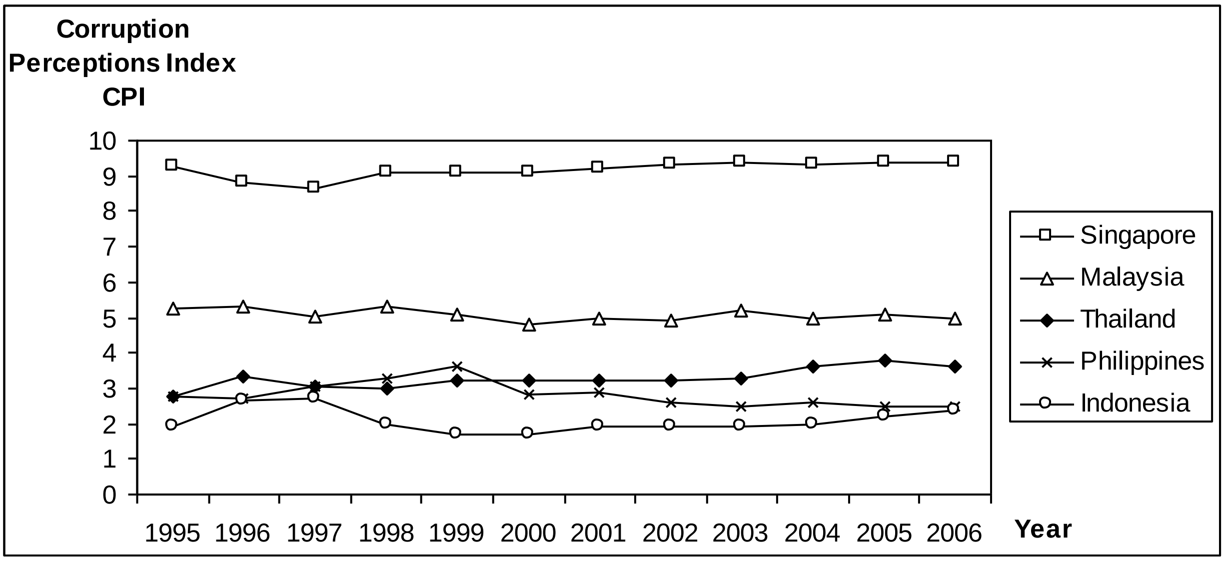

Figure 3.4 Corruption Perceptions Index (CPI) Scores for some Countries (1995 – 2006)

Source: Transparency International (2006)

3.2.2 How Thailand is Fighting Back

Before 1997, Thailand always managed economic woes by prudent and rather conservative economic policies. An example case was the implementation of economic policies during years 1981-85, the period after the "Commodity Boom", when Thailand's terms of trade declined by about twenty per cent from the previous five-year period. As a result, the average annual GDP growth during the period was down to 5.2 % from the figure of 7.4 % of the last five-year period. The country faced heavy deficits in both the country's balance of payment and the government budget. Inflation in 1980 and 1981 reached two-digit levels.

To cope with the above-mentioned economic problems, the Thai government resorted to restrictive economic policies. Regarding monetary policy, interest rates were pushed to remain high to entice foreign investment, while commercial bank loans were kept tight. In 1981 and 1984 the domestic currency – the Baht – was devaluated twice: 9.7 % and 14.8 %, respectively. Regarding financial policy, the Thai government adopted zero growth budgeting and the tax rates were increased to fight budget deficits. This, so called restrictive domestic demand management policy, helped reduce the balance of payment deficit from the average rate of 5.6 % of GDP for the preceding five-year period to the average rate of 5.2 % of GDP. This achievement came at the price of high unemployment that came together with slow economic growth. It demonstrated that the Government of Thailand was not afraid to implement painful economic policies.

Another indicator that proves the good deeds of the Thai Government was its improvement in the ability to collect direct taxes (income taxes). In the 1960's, tax revenues depended much upon import duties at an average of 32 % and, taxes derived from natural resources (export duties collected from commodities plus mineral and petroleum royalties and taxes) at an average of 17 %. During that period of time income taxes accounted for an average of only 10 %. In 1996, the share of income taxes improved to become 35 % of the total tax revenues, while that of import duties reduced to become only 16 % of the total tax revenues and the taxes derived from natural resources become almost negligible (only 1 % of the total tax revenues). However, we do not need to go into every detail to prove that the Government of Thailand, in general, acted responsibly. The overall economic performance over the whole period may give a better summary.

During 1960-1996, the GNP per capita of Thailand, in current dollars, grew at an average rate of 9.7 %, from $101 in 1960 to reach $2,836 in 1996. This rather impressive growth was the result of the country's high economic growth together with the reduction in population growth rate. Thailand was lauded as a special case among developing countries, with not very high GNP per capita, that effectively implemented family planning, for it has reduced its population growth from the rate of about 4 % in

1960 to a level of about 0.6 - 0.7 % at present. From 1961 to 1996, Thailand faced an average inflation rate (rate of growth of consumer price index) of 5.4 %, which was a moderate figure in comparison with other developing countries. Only in two two-year periods: 1973 - 1974, and 1980 – 1981, when Thailand and the world encountered oil crises, did the country have two-digit rates of inflation.

The strongest indicator that refuted the bias effects of the resource curse on other economic sectors was the impressive growth of the country's manufacturing industry. The manufacturing sector in Thailand, in current dollars, grew at an average rate of 14.6 %, from $419 million in 1960 to $49.274 billion in 1996, and the share in the country's GDP of the total value of the manufacturing products, in current dollars, increased from 14.5 % in 1960 to 34.5 % in 2004.

From the above-mentioned economic evidence, it can be concluded that Thailand's economy, which once depended very much upon natural resources, has been developing very well. Though it felt certain effects of the resource curse, the Thai Government has been quite successful in industrializing the country, and made the people of Thailand a lot better off.

3.2.3 Explaining the Tame Impact of the Resource Curse Faced by Thailand

The tame impact of the resource curse on the Thai economy may be contributed to by the following factors:

a) Strong Elite Bureaucrats

The ability of Thailand to weather through the resource curse was partly due to the successive implementation of appropriate economic measures by the Thai government. This economic success was contrary to the fact that, on the surface, Thailand had not been stable politically. During the period 1960 to 1996 Thailand had thirteen Prime Ministers and fifteen governments, an average of about 2.4 years per government. Even worse, some transfers of power from government to government were undemocratic—by three bloody events of civil strife and by three bloodless coups (not to mention two failed coup attempts)—during the period. However, the backbone of every Thai Government was the highly educated civil servants, especially in the field of economics. Because of the complexity of economics, Thai Prime Ministers and coup leaders always appointed elite economists to oversee the Finance Ministry and left the Bank of Thailand to work almost without political interference.

Another factor that has constrained the abuse of power of Thai politicians is the unique nature of Thailand's social and political norms. The political stability of Thailand, which is a kingdom, was not as bad as it seemed to be. For more than half a century, above all politics is the present constitutional monarch, King Bhumibol Adulyadej who is revered by all Thai people. Even the communist insurgents did not dare to criticize him. All coup leaders paid homage to the King, and governed the country under his name, though he seldom intervened in politics. The beloved King, who has been accepted by all concerned as the supreme political arbitrator, might be the reason that Thai politics seldom went to extremes.

b) Cultural Homogeneity

Except for the Malay minority in the four southernmost provinces, most people in Thailand are rather culturally homogenous—speaking Thai, adopting Buddhism, and revering the King. Thailand is so successful in implementing its assimilation policy that descendants of Chinese, the biggest minority, adopt Thai names. To the outside there are no Thai Chinese, but Thai. This cultural homogeneity removes racial conflicts and helps the Thai Government to reach appropriate political consensus, including economic matters, easier.

c) Orthodox and Conservative Economic Policies

As already explained in other parts of this study, Thailand managed its economy prudently. Orthodox and conservative economic policies, especially on controlling inflation and keeping foreign and domestic loans of the Government under limits, was the reason why Thailand has never faced hyperinflation like many Latin American countries did. The economic and financial crisis of 1997 was not caused by the size of the Government's foreign loans but by the burden of the large foreign loans of the private sector, which was the result of the Government's mistaken policy in partially opening the country's financial system[12].

Since 1961, Thailand has managed its economic policies as guided by a five-year Economic and Social Plan. The First Economic and Social Plan, 1961-66, and the Second Economic and Social Plan, 1967-71, were set up with the assistance of the World Bank, while the latter plans were organized mainly by Thai bureaucrats. During the early stages, the plans pinpointed specific targets for the Government to follow. However, since the latter plans did not link directly with annual government's budgets, the latter plans looked more like good guidelines than true plans.

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[12] With an ambition to establish Bangkok as a leading offshore financial centre in the region, in 1993, a few years before the crisis, the Government of Thailand liberalized the capital control, however, without floating the foreign exchange market. Because of relatively high interest rates in Thailand during that time period, such financial liberalization led to a great influx of foreign capital. With a long history of rigid foreign exchange rates, few investors saw the perilous risk associated with the cheap foreign capitals. Therefore, in late 1997, when the Bank of Thailand had not been able to defend the over-valued Baht, the sudden drop of the Thai currency caused a large number of investors who had resorted to foreign loans to be suddenly overwhelmed by debts and bankrupted. As a result, Thailand's 1997 economic and financial crisis was ensured.

d) Geo-Politics and Regional Events

Thailand's economy was also strongly shaped by external factors as follows.

i) Vietnam War: Considered by the U.S.A. as a frontline state in fighting against communists, Thailand was strongly affected, both good and bad, by the Vietnam War of the 1960's and the first half of the 1970's. During the War, Thailand was a close ally of the U.S.A. and allowed the U.S.A. to use its lands as air bases to bomb Vietnam. Thailand even sent some troop to fight in South Vietnam along side the U.S. soldiers. As a result, Thailand received financial aid from the U.S.A. The total foreign aid was substantial in some years, such as in 1968 when the total foreign aid was almost equivalent to 10 % of the value of Thailand's exports for that year. But some authors (Harford and Klein, 2005) equate foreign aid with a curse similar to that of the resources. Certainly, during that period of time, the Thai Government enjoyed receiving foreign aid because it helped support its currency during a time of persistent trade deficit. But, as shown in Figure 3.5, foreign aid that Thailand received from 1961 to 1991, fluctuated widely. With its fluctuation, foreign aid was no different than volatile revenue from natural resources; therefore, it might also have contributed to adverse effects on Thailand's economy during the period.

The indirect effect of the war might be more important than the grants from the U.S. Government. The U.S. expenditure on war supply stimulated the economies of many countries in the region. The war period coincided with a period of high growth rates in the manufacturing sector in Thailand. Therefore Thailand might owe the beginning of its industrialization partly to the war.

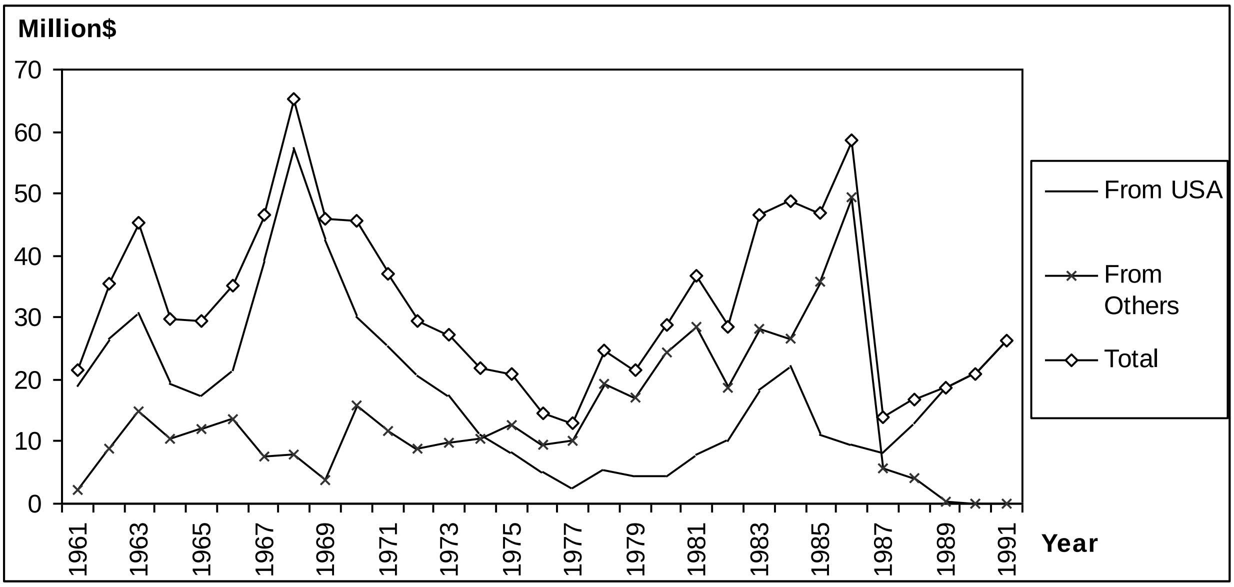

Figure 3.5 Foreign Aid Received by Thailand, in Current Dollars, 1961 - 1991

Source: Bank of Thailand (2007)

ii) Economic Spillover from the Success of Japan: The economic success of Japan after the Second World War was phenomenal. During the 1980's, the high labour cost in Japan together with the low cost of foreign capital, as a result of the Yen appreciation, induced Japanese investors to look outside their country for investment. Thailand was one of the countries most favoured by Japanese investors. The share of foreign direct investment (FDI) from Japan in the total FDI from 1970 to 2006, averaging 32.5 %, is shown in Figure 3.6. The hefty foreign investment, led by Japan, after 1988, as shown in Figure 3.7, coincided with the rapid increase in Thailand's GNP per capita. Indeed, foreign direct investment has been the most important factor in the economic success of Thailand.

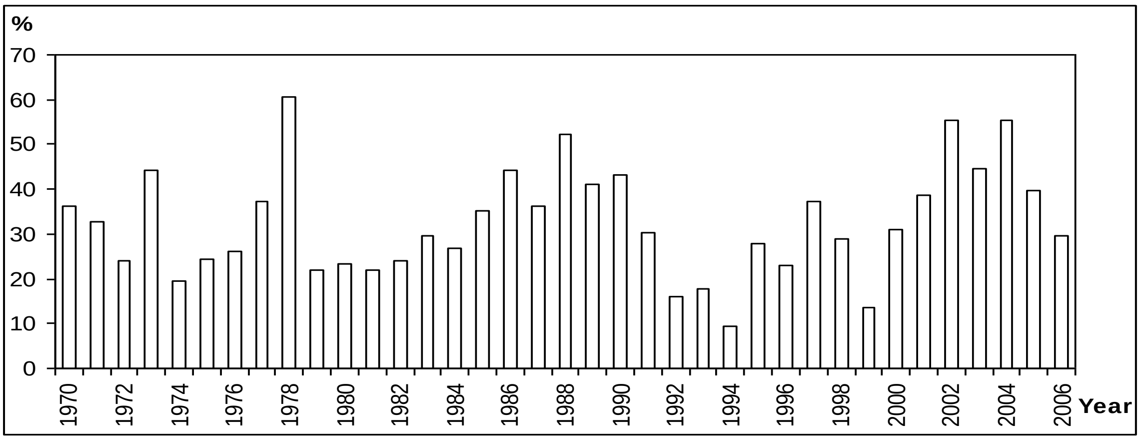

Figure 3.6 The Percentage Share of Foreign Direct Investment from Japan, 1970-2006

Source: Bank of Thailand (2007)

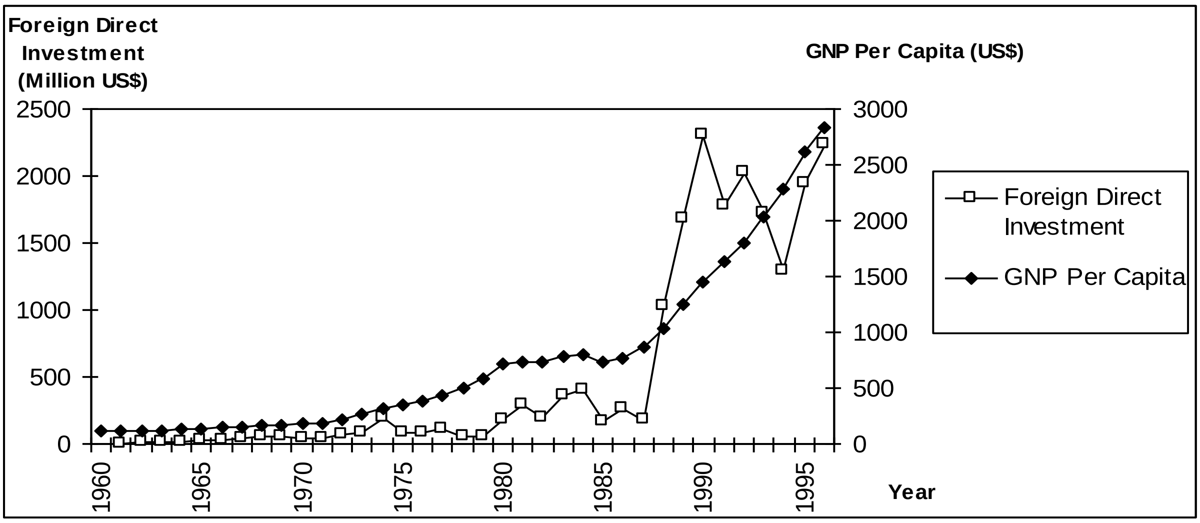

Figure 3.7 Foreign Direct Investment and Thailand's GNP Per Capita, in Current Dollars, 1960 - 1996

Source: Bank of Thailand (2007)

iii) The Nature of Thailand's Natural Resources: In the 1960's, the resource base economy that Thailand depended upon was dominated by agriculture and accounted for an average of 35% of GDP, while the mineral sector contributed less than 2% of GDP. During that period of time, agricultural commodities were also the dominant exports from Thailand, while minerals accounted for only 9% of the total export value. Some authors argued that exploitation of agricultural resources, which involve a lot of peasant farmers, renders less curse effect than that of mineral or petroleum resources, the so-called “point” resources.

Even exploitation of “point” resources in Thailand might have less curse effect than normal. Tin, the main mineral produced in Thailand during the 1960’s, was dominated by small mines and employed mining methods developed in the region that used more local made tools and equipment. Tin mining costs in Thailand were low in comparison to those in Bolivia. Thus, tin mining in Thailand rendered high resource rent. However, the Thai Government levied very high rates of tin royalty, a kind of ad valorem taxes. The rates of tin royalty in Thailand have been progressively varied with tin prices. It has been applied under the concept that the state should get higher share of the economic rent when the price gets higher and the miners should pay royalties at the lesser rates when the price is down. Until late 1985, the effective ad valorem rate was always in the range above 20 % of tin price, and it reached the level above 30 % of tin price around late 1970’s. As a result, economic rent from mining in Thailand was widely distributed to people, through both upstream and downstream private investment related to tin mining and through government expenditure, than those in many other developing countries.

Another important fact about the exploitation of Thailand’s natural resources was that it had been done long before the time period of study. There was not a sudden surge of economic rent to overwhelm the national economy from new agricultural crops or from the new discovery of large mineral or petroleum deposits. The country was already accustomed to the unavoidable effects of the curse, and found ways to live with them.

3.2.4 An Index of the Resource Curse for Thailand

From resource curse literature, some authors used the non-negative genuine saving as the index to decide whether or not a country faces the resource curse. Matsen and Torvik (2005) stated that Thailand is one of the countries that have claimed to have escaped the resource curse because the average genuine saving rate of Thailand between 1972 and 2000 was 20% of its gross national income. Costantini and Monni (2006) stated that the countries that have managed to escape the resource curse (Malaysia and Thailand, as only developing country examples) have higher genuine savings rates than those that have not escaped (Congo, Nigeria, and United Arab Emirates, among others). Appropriate policy was claimed to be the main reason Thailand avoided the resource curse. For example, Esanov, Raiser and Buiter (2003) stated that Botswana, Chile, Malaysia and Thailand were a small number of countries having actually made the policy choices to turn natural resources into a blessing rather than a curse. Furthermore, Gylfason (2001) stated that, of 65 resource rich developing countries only four managed to achieve long-term investment exceeding 25 percent of GDP and an average GDP growth exceeding 4 per cent, namely Botswana, Indonesia, Malaysia and Thailand. The three resource rich Asian countries have managed to do this by economic diversification and industrialisation.

3.3 Conclusion

The case of Thailand confirms the existence of some effects of the resource curse. At the time when Thailand depended upon a resource-based economy, it was plagued with revenue volatility and long term decline in terms of trade. However, the present outcome of the economic and social development of Thailand demonstrated that it could steer itself through the resource curse successfully. Of course, its achievement was arrived at by the help of some external factors, notably the flux of foreign direct investment. However, one should not downplay the importance of the implementation of the right economic policies, the amiable Thai people, and the rarely violent politics, which have made Thailand inducive to foreign investors.

The results of this study, together with the conclusions of other literature, indicate that the resource curse is a real issue. But the curse is just a factor among many others that affect a county's development. In the South-East Asia region, not only Thailand, but also Indonesia and Malaysia (Rosser, 2004; Sachs and Warner, 1997), which are also resource rich countries, have been successful in avoiding the curse. Maybe the studies that postulate the existence of the curse might look at only one side of the story. There are also benefits from the exploitation of natural resources. The easy money can be used as a springboard for development. It is difficult to see how a poor country with little natural resources like Bangladesh can easily take off from poverty. Looking back long enough (a century or longer), we could see that nearly all developed countries, including the U.S.A. and Japan, used to depend more or less on a resource-based economy. Therefore, the question for a country is not whether or not to exploit the country's rich natural resources, but how to mitigate the effect of the resource curse.

The next chapter will talk about sustainable development, which is a broader picture concerning the future wellbeing of mankind under limited natural resources. Among other things, it will present rules and conditions proposed by economists that are necessary to achieve non-declining consumption, one of the economic interpretations of the sustainable development. Avoiding resource curse and sustainable development are related. Indeed, avoiding resource curse and pursuing sustainable development have the same objective, that is, to maintain the wellbeing of people into the future. However, the next chapter will cover a broader subject ranging from theoretical discussion about intergeneration equity to methods measuring performances of countries with regard to sustainable development, while this chapter talks about ways to avoid pitfalls from being a resource rich country. Anyway, they will form the bases for some of the recommendations in Chapter 8 of this thesis to the Thai government on how to appropriately manage the resource rents derived from the exploitation of its mineral resources.

Chapter 4 The Principle of Sustainable Development

Exploitation of natural resources for its well-being is the hallmark of humanity. However, exploitation of natural resources affects the environment, especially the nonrenewable resources whose extractions result in depletion. As a result, it is logical to perceive that heavy exploitation of some natural resources at present will compromise the well-being of future generations. In the last few decades, there were several scholars proposing some concepts, theories and observations pertaining to the natural resources and the effects of their exploitation. This research will briefly present some relevant concepts, theories and observations as follows.

4.1 A Brief History of the Sustainable Development Principle

Human development involves exploitation of natural resources, both renewable and nonrenewable. There has been fear that the present wellbeing of humanity, which is associated with the fast rate of natural resource exploitation, is gained at the expense of the future. As a result of this fear the concept of sustainable development was slowly developed. Its brief history in chronological order is shown below.

In 1972 the Club of Rome, an informal international association, with a membership of about seventy individuals from twenty-five nations, published its major report – *Limits to Growth*, being the results of a study, in which a computer model, World3, was used to simulate the world's future. The conclusions of the report are as follows:

> "1. If the present growth trends in world population, industrialisation, pollution, food production and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the

next 100 years. The most probable result will be a sudden and uncontrollable decline in both population and industrial capacity.

2. It is possible to alter these trends and to establish a condition of ecological and economic stability that is sustainable far into the future. The state of global equilibrium could be designed so that the basic material needs of each person on earth are satisfied and each person has an equal opportunity to realise his or her individual human potential.

3. If the world's people decide to strive for this second outcome rather than the first, the sooner they begin working to attain it, the greater will be their chances of success." (Meadows *et al*., 1972)

It should be noted that the term "Limits to Growth" in this report does not mean limits to "economic growth", which includes the consumption of not only the output of the agricultural and industrial sectors but also that of the service sector. In fact, the conclusions quoted above indicate that there were limits to the growth of material throughputs for the world economic system. Although these conclusions overstated the speed with which the world was exhausting many natural resources, the report was an important precursor of modern debates (IISD, 2002).

The *Limits to Growth* also caught the interest of economists. Among the early responses from the mainstream economists to the *Limits to Growth* were those of Dasgupta and Heal (1974), Solow (1974), Stiglitz (1974), and Hartwick (1977, 1978). Their works will be briefly discussed in the next section.

In 1980, a significant document, jointly proposed by the UN Environment Programme, the World Wildlife Fund, and the International Union for Conservation of Nature and Natural Resources, entitled the World Conservation Strategy was published by the World Conservation Union. The most important goal of the document was "to persuade the nations of the world to adopt ecologically sound development practices". It also argued that “For development to be sustainable, it must take account of social and ecological factors, as well as economic ones; of the living and non-living resource base; and of the long-term as well as the short-term advantages and disadvantages of alternative actions” (UNEP/WWF/ IUCNNR, 1980).

In 1987, the UN Commission on the Environment and Development was created by the United Nations. The Commission’s members comprised both conservationists and important figures in international development. The report of this commission entitled "Our Common Future", which has also been known as the Brundtland Report, created a globally accepted general definition for Sustainable Development--"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

In 1992, the UN Conference on the Environment and Development (UNCED) in Rio de Janeiro developed Agenda 21, a complete solution to succeed in sustainable development. This plan compiled economic, social and environmental factors for decision-makers and established a global foundation for sustainable development. However, Agenda 21 did not go far enough to effectively convert the principles of sustainable development into action.

The commitment to work towards sustainable development was reaffirmed by world leaders at the 2002 UN World Summit on Sustainable Development, at which the new goals, schedules, and commitments to take action were set. All nations were urged to urgently push forward their national sustainable development strategies and to start putting them into action by 2005.

With regard to mineral resources, an important part of the whole natural resources, the widely publicized concept of sustainable development received the attention of the world mining sector. In response to the planned 2002 World Summit on Sustainable Development, nine of the world's largest mining firms launched a project to study the sustainable development in the minerals sector. Through the World Business Council for Sustainable Development, they, together with the support of the Rockefeller Foundation, contracted with the International Institute for Environment and Development to undertake the Mining, Minerals and Sustainable Development Project (MMSD). Under this project the terms of sustainable mineral development and mineral sustainability were studied and defined (IIED, 2002).

4.2 The Concept of Sustainable Development

Secrett (1995) breaks down the original Brundtland definition of sustainable development into four conditions as follows:

- Material and other needs for a better quality of life have to be fulfilled for people of this generation,
- Distribution of the benefits from development has to be done as equitably as possible,
- Ecosystem limits have to be respected, and
- A basis on which future generations can meet their needs has to be built.

However, since its inception more than two decades ago, the concept of sustainable development has been further refined and augmented by several scholars. Because the definition given by the Brundtland Report is short and vague, and the concept deals with the future, different authors with different backgrounds, interests and motivations have interpreted the concept differently. According to Holmberg and

Sandbrook (1994), by 1994 there were more than 80 different definitions and interpretations that fundamentally shared the core concept of the Brundtland Report's definition. Nevertheless, one of the versions describing the lately-developed concept of sustainable development is that of MMSD's study. The study provides a set of guiding principles for each of the four dimensions of sustainable development consisting of economic, social, environmental, and governance spheres shown below.

"**Economic Sphere**

• Maximize human well-being;

• Ensure efficient use of all resources, natural and otherwise, by maximizing rents;

• Seek to identify and internalize environmental and social costs; and

• Maintain and enhance the conditions for viable enterprise.

Social Sphere

• Ensure a fair distribution of the costs and benefits of development for all those alive today;

• Respect and reinforce the fundamental rights of human beings, including civil and political liberties, cultural autonomy, social and economic freedoms, and personal security; and

• Seek to sustain improvements over time; ensure that depletion of natural resources will not deprive future generations through replacement with other forms of capital.

Environmental Sphere

• Promote responsible stewardship of natural resources and the environment, including remediation of past damage;

• Minimize waste and environmental damage along the whole of the supply chain;

• Exercise prudence where impacts are unknown or uncertain; and

• Operate within ecological limits and protect critical natural capital.

Governance Sphere

• Support representative democracy, including participatory decision-making;

• Encourage free enterprise within a system of clear and fair rules and incentives;

• Avoid excessive concentration of power through appropriate checks and balances;

• Ensure transparency through providing all stakeholders with access to relevant and accurate information;

• Ensure accountability for decisions and actions, which are based on comprehensive and reliable analysis;

• Encourage cooperation in order to build trust and shared goals and values; and

• Ensure that decisions are made at the appropriate level, adhering to the principle of subsidiarity where possible" (IIED, 2002).

Nevertheless, the MMSD's study does not specify a clear time frame for the principle to maximize human well-being in the economic sphere. It is not certain that the study purposely means to maximize human well-being over time across generations. Another ambiguity of that study is the principle to ensure efficient use of all resources, natural and otherwise, by "maximizing rents". Efficient use also involves time in future. The report did not explicate whether the rents obtained from the exploitation of a natural resource at different times are weighted by a discount rate. If the concept of discounting future values was adopted, to attain the maximum present value of rents, the exploitation or production rates of a natural resource will decline over time in accordance with the famous Hotelling models, which will be discussed in Chapter 6. Since a natural resource is exploited either as a necessary raw material for the production of final goods for consumers or for direct consumers' consumption, the less the resource extracted, the less the consumption. Apparently, the declining rate of consumption suggested by the Hotelling model is contrary to another standing principle of sustainable development that requires non-declining consumption over time.

However, scholars in the field of economics focus on sustainability in a context of concern for intergenerational equity over several generations. Pezzey (1992) classified the economic definitions of sustainable development into two approaches as follows:

i) The definitions based directly on the welfare of people, such as the one that consumption (or utility) is non-declining through time.

ii) The definitions based on the means to provide people with welfare, such as the one that the total capital stock is non-declining through time.

Discussion about the non-declining consumption through time under the finite non-renewable resources, the first approach of the economic definitions of sustainable development, by economists took place not long after the publication of the *Limits to Growth*. Among the early works were those of Dasgupta and Heal (1974), Solow (1974), and Stiglitz (1974). Their models of studies were based on the assumptions that natural resources are finite, non- renewable, and essential to production and that human-made capital is indefinitely substitutable for resources via a Cobb–Douglas production function. Dasgupta and Heal (1974) suggested that if the objective of society is to maximize the present value (PV) of the representative agent's instantaneous utility using a constant positive discount rate with no technological progress the level of consumption and utility approach zero in the very long run. However, Stiglitz (1974) pointed out that the PV-optimal path can have sustained increases in per capita consumption as a result of ongoing technical progress. In his model, the technical progress rate is assumed to be large enough to offset the resource depletion effects.

Solow (1974) showed that, with Cobb-Douglas production function, zero population growth, and no technical progress, the constant consumption could be sustained over time by a suitable path of capital accumulation. Sequels to Solow's 1974 work were those of Hartwick (1977, 1978), from which the Hartwick rule was proposed. The rule states that a constant level of consumption can be sustained if all the rents on non-renewable resources extracted at each point in time are totally invested in reproducible capital. Since the net investment in all the economy's productive stocks is the capital investment minus resource rents, the rule can simply be rewritten as "Zero net investment forever results in constant consumption forever" (Pezzey and Toman, 2002b). However, later works pointed out that Hartwick rule is just a necessary but not sufficient condition. To attain non-declining consumption through time other three conditions have to be met: 1) an economy has to be already on a sustainable path, 2) the resource extraction path must be efficient in a competitive economy, and 3) the conditions of the economy's production technology are right. The second condition pertains to Hotelling rule, while the possible production functions that satisfy the third condition are those of the Cobb-Douglas and the Constant Elasticity of Substitution with some conditions, or any production functions if a backstop technology is permanently available. The details of such possible production functions are shown as follows (Perman *et al*., 2003):

Case I: Under fully competitive conditions through a Cobb-Douglas production function with constant returns to scale and two inputs consisting of a non-renewable resource, R, and manufactured capital, K, then the output,

$$Q = K^{\alpha} R^{1-\alpha}$$

where α is the distribution parameter indicating the relative share of manufactured capital in the product.

In the case that there is no technological progress and population growth is zero, constant consumption over time is possible if the share of total output going to capital is greater than the share going to the natural resource (that is, if $\alpha > 1 - \alpha$). However, if the population growth is positive, the ratio of the rate of technological progress to the rate of population growth must be greater than or equal to the share of output going to the resource to maintain the constant consumption over time (Stiglitz, 1974).

Case II: Under fully competitive conditions through a Constant Elasticity of Substitution production function with constant returns to scale, the output

$$Q = A[\alpha K^{-\theta} + (1-\alpha) R^{-\theta}]^{-1/\theta}$$

where θ is the substitution parameter determining the value of the elasticity of substitution, σ, and $\sigma = 1/(1 + \theta)$.

In the case that there is no technological progress and population growth is zero, constant consumption over time is possible if the elasticity of substitution, σ, is greater than or equal to one. In the case that the elasticity of substitution is less than one and the population growth is zero, to maintain the constant consumption over time the technological progress on production must be continual (Dasgupta and Heal, 1979).

Case III: Under the permanent existence of backstop technology, the constant consumption over time is possible disregarding the depletion of a non-renewable resource. For example, in the energy sector, under the assumption of this case, the backstop technology can deliver an unlimited amount of energy from another renewable resource like wind or solar power (Nordhaus, 1973). Conclusively, the constant consumption over time is possible under the permanent existence of backstop technology, but the level of consumption may be limited, depending on the potential of the backstop technology.

For a specific example of the second approach of the definitions of sustainable development--the non-declining through time of the total capital stock--it is classified as weak sustainability, as opposed to the strong sustainability that does not accept perfect capital substitution. In this sense, the capital, which is defined as a necessary tool for a human-being to have a good quality of life (Willett, 2002), consists of the following:

- *Natural capital*, such as biological diversity, scenic areas, clean air and water, forest, and mineral resources, which provide ecosystem benefits to human beings ranging from the enjoyment of its intrinsic value and good health to necessary basic materials;

- *Manufactured capital*, such as machinery, buildings, and infrastructure, which provide human beings with cheap goods;
- *Human capital*, in the form of knowledge, skills, health, and cultural endowment, which are the most important assets in the development of mankind;
- *Social capital*, the institutions and structures that allow individuals and groups to develop collaboratively; and
- *Financial capital*, which can be invested to receive financial returns.

The above five capitals may be grouped into two parts: the natural capital and the human-made capitals comprising manufactured, human, social, and financial capitals. The latter is sometimes referred to as reproducible capital. Indeed, the difference between weak and strong sustainability is the extent of the possibilities of substitution between the natural and the human-made capitals.

The assumption of perfect substitution between natural and human-made capitals is the core of 'weak sustainability', and to attain sustainability requires the total capital stock, the sum of natural and human-made capitals, to be non-declining. Historic evidence supporting this assumption was the role of lead as the raw material used for covering electric cables for insulation and for general protective purposes, during the 1960s and 1970s. But technological innovations have caused this role of lead to disappear (IIED, 2002). This event has shown the potential of human-made capital (technology) to perfectly substitute for natural capital (lead) in the role of raw material.

'Strong sustainability' is based on the concept that there are constraints on substitution between natural and human-made capitals, and to attain sustainability requires not only the non-declining total capital stock but also the non-declining natural capital stock (Neumayer, 1999). Proponents of strong sustainability argued that, like natural capital, the human-made capital can provide the necessary life-support services such as temperature control, breathable air, etc., but only on a small scale. In regard to amenity services, some take the view that a lack of contact with the natural environment is dehumanising, and would argue that we should regard the substitution possibilities of human-made capital for natural capital substitution as limited. In fact the argument some people make is that natural capital and man-made capital are complements rather than substitutes. These academics, whose thought is dubbed the 'thermodynamic' school, argue that while substitution within each of the two types of capital may be highly possible (e.g. coal for charcoal, plastics for metals, or modern machines for old machines, computers for labour, machines for labour), substitution between the two types are seldom feasible (Christensen, 1989; Daly, 1990). Complements mean that, to increase consumption, both types of capital have to be utilized in increasing quantities together.

In conclusion, the weak versus strong sustainability question is multi-faceted, and has no exact answers to the general question: how far is human-made capital substitutable for natural capital? In some circumstances, the answer is as much a matter of taste and/or ethics as it is a matter of science and technology (Perman *et al*., 2003).

4.3 Sustainable Development and Mineral Resources

4.3.1 Roles of Mineral Resources

Mineral resources certainly play critical and controversial roles in sustainable development. Besides being natural capital, the exploitation of mineral resources provides humans with goods and services: the materials of human well-being. With the present size of the world population, all humans on the earth cannot totally survive without mining, let alone maintain their standard of living. Currently only recycling can partly substitute for mining in supplying such necessary materials to humans. But mineral resources are nonrenewable, though their depletion is not as crucial to the survival of mankind as that of ozone layer. As a result, exploitation of mineral resources or mining remains to be a central topic for hot debate with regard to sustainable development.

However, a scholar concluded that mining production can be physically sustainable because of the following three factors (Eggert, 2000). First, mining companies replace depleted reserve by investing in mineral exploration and development. Second, using technological innovation, miners can now extract mineral resources that were previously either technically difficult or commercially unfeasible to be mined. Third, recycling adds mining production to markets which helps it be more sustainable, especially metals and many nonmetallic materials, such as cement and construction aggregate.

Scholars who adopted the narrow “or strong” concept of sustainable development require very tough protection of the natural environment. In the case of mineral resources, they tend to be pessimistic about the capacity of new discoveries and technological advances to continue to keep pace with rising demand for mineral commodities. Therefore, their minimum requirement is that depletion through mining must be fully offset by replenishment of known economic resources through exploration and technological advances, so that there is no rise in real prices in the long-term. A stricter interpretation would require that this applies to each mineral commodity. A government that adopts the narrow concept of sustainable development will interfere with an efficient allocation of resources because that concept effectively places an infinite price on environmental resources at the limit, leaving no room for trade-offs that are in the interests of society. As a result investment and operational decisions will be interfered with to an extent greater than necessary to ensure social costs of adverse environmental effects are fully accounted for or internalised. These distortions will cause economic waste (Willett, 2002).

In the views of the proponents of the broad "or weak" concept of sustainable development, intergenerational equity will be satisfied as long as exploration and technological progress offset the depletion and degradation of mineral resources. Acceptance of the broad concept means substantially less intervention by governments than the narrow concept. However, governments still have a responsibility to ensure that the ecological processes on which life depends are maintained or restored; and that the mining sector and governments are fully accountable for the social costs of adverse environmental and other effects of their activities (Willett, 2002).

4.4 Sustainable Development Indicators

In recent years, considerable effort has been made to implement the concept of sustainable development. The foremost effort was the creation of macroeconomic indicators to measure and monitor the sustainable development of a country. In the same manner as that of the concept of sustainable development itself, consensus has not yet been reached on which indicator is the best one. Based on their popularities and modernity, six proposed indicators for sustainable development will be briefed here: Genuine Savings, Green Net National Product, Augmented Genuine Savings, Augmented Green Net National Product, UN Commission on Sustainable Development (CSD) Indicators of Sustainable Development, and World Bank World Development Indicators.

4.4.1 Genuine Savings and Green Net National Product (GNNP)

Genuine Savings and Green Net National Product are the results of an attempt to incorporate the effects of the exploitation of natural resources into the existing indicators that we use to measure our well being and development. These two indicators and their "augmented" versions, together with their linkage, will be discussed separately below.

a) Genuine Savings (GS)

Genuine Saving (GS) is a more comprehensive concept of saving than that used in conventional national accounts. It was developed and introduced as the World Development Indicators, by the World Bank in 1998 to measure whether one country's saving rate is large enough to overcome the total depreciation of natural and man-made capitals (World Bank, 2006).

i) Brief Theoretical Concept

The formal model of Genuine Saving was presented by Hamilton (2000), an economist working in the World Bank. He started with a theoretical assumption of a simple closed economy with a single resource used as an input to the production of a composite good, denoted F, that may be consumed, invested in produced assets or human capital, or used to abate pollution, so that

$$F(K,R,N) = C + \dot{K} + a + m$$

where K is physical capital,

R is resource use,

N is human capital,

C is consumption,

$\dot{K}$ is investment in physical capital,

a is pollution abatement expenditures, and

m is current education expenditures.

The education expenditures are transformed into human capital by the equation: $\dot{N} = q(m)$

Pollution emissions are a function of production and abatement, $e = e(F, a)$

The pollutants accumulate in a stock X such that $\dot{X} = e - d(X)$, where d is the quantity of natural dissipation of the pollution stock.

Resource stocks S grow by an amount g and are depleted by extraction R, so that $\dot{S} = -R + g(S)$.

The utility of consumers is assumed to be a function of consumption and environmental services, $U = U(C, B)$. The flow of environmental services B is negatively related to the size of the pollution stock. Wealth, W, is defined to be the present value of utility on the optimal path. Then we can maximize wealth by using a fixed pure rate of time preference r as follows:

$$\max W = \int_t^{\infty} U(C,B)e^{-rs}ds$$

subject to: $\dot{K} = F - C - a - m$

$$\dot{X} = e - d$$

$$\dot{S} = -R + g$$

$$\dot{N} = q(m)$$

The Hamiltonian function can be written as,

$$H = U(C,B) + U_C\left[\dot{K} - (1 - be_F)F_R(R-g) - b(e-d) + q/q'\right] \qquad (4.1)$$

where b is the marginal cost of pollution abatement.

The parenthesized expression in the second term of the right side of equation 4.1 is equal to the change in the real value of all assets in the economy; therefore, it may serve as the definition of genuine saving, G, in equation 4.2.

$$G \equiv \dot{K} - (1 - be_F)F_R(R-g) - b(e-d) + q/q' \qquad (4.2)$$

In words, the genuine savings are composed of the investment in produced assets and human capital, less the values of depletion of natural resources and accumulated pollutants.

NNP, the maximum amount of produced output that could be consumed while leaving total wealth instantaneously constant, of a closed economy is as follows:

$$NNP = C + \dot{K} - (1 - be_F)F_R(R-g) - b(e-d) + q/q' \qquad (4.3)$$

NNP for an open economy that includes foreign and depreciation of produced assets is given as,

$$NNP = C + \dot{K} - \delta K + E - M + iA - (1 - be_F)F_R(R-g) - b(e-d) + q/q' \qquad (4.4)$$

where δ is the depreciation rate of produced capital,

A is net foreign assets,

E is exports, M is imports, and

i is a fixed international rate of return.

The first six terms in equation 4.4 are the standard measure of *NNP*. The whole equation 4.4 implies that, to get a truthful *NNP*, the standard *NNP* should be adjusted by deducting net depletion of natural resources and the marginal damages from net pollution accumulation, and by adding investments in human capital.

If the net marginal resource rents is defined as: $n \equiv (1 - be_F)F_R$, *NNP* can be written as follows:

$$
\begin{aligned}
NNP &= GNP - \delta K - a - m - n(R-g) - b(e-d) + q/q' \\
&= GNP - \delta K - a - n(R-g) - b(e-d) + \left(\frac{1/q'}{m/q} - 1\right)m
\end{aligned}
\qquad (4.5)
$$

where $1/q'$ is the marginal cost of creating a unit of human capital, and

m/q is the average cost.

Equation 4.5 shows that the value of investments in human capital should be greater than current education expenditures and the current expenditures are a lower-bound estimate of the investment in human capital. Furthermore, equation 4.5 expresses that pollution abatement expenditures, *a*, should be deducted in measuring genuine saving. But, in practice, most current abatement expenditures are already treated as intermediate inputs in standard national accounting. Therefore, we can calculate genuine saving from real data by the following equation 4.6:

$$G = GNP - C - \delta K - n(R - g) - \sigma(e - d) + m \qquad (4.6)$$

where δK is produced asset depreciation,

n is net resource rental rate,

R is resource extraction,

g is amount of growing resource stock

σ is marginal social cost of pollution

e is pollution emissions

d is quantity of natural dissipation of the pollution stock

m is current education expenditures

GNP - C is traditional gross saving, which includes foreign savings, while GNP - C - δK is traditional net saving (Hamilton, 2000).

ii) Practical Solutions

In 2002, the World Bank published "Manual for Calculating Adjusted Net Savings" written by Katharine Bolt, Mampite Matete, and Michael Clemens to help nations to come up with their Genuine Saving figures. The publication rewrites the above equation 4.6 in the following form:

$$G = GNS - Depr + EE - ED - MD - NFD - CO_2D - PM_{10}D$$

where G = Genuine Saving

GNS = Gross National Saving,

$Depr$ = Depreciation of fixed capital,

EE = Educational expenditure,

ED = Rent from Energy depletion,

MD = Rent from Mineral depletion,

NFD = Rent from Net forest depletion,

CO_2D = Damages from carbon dioxide emissions, and

$PM_{10}D$ = Damages from PM_{10} emissions.

Please note as follows:

GNS, Gross National Saving, is the terms ($GNP - C$) of the equation 4.6. Gross National Saving is calculated as the difference between Gross National Income (GNI) and public and private consumption plus net current transfer. It can be calculated by the following expression:

GNS = GNI – public consumption - private consumption + net current transfer, where GNI is the Gross National Income. According to the 1993 System of National Accounts, GNI in current (nominal) prices is equal to Gross National Product (GNP), while GNI in constant (real) prices is equivalent to GNP plus the terms of trade adjustment.

Depr, Depreciation, is the term δK of the equation 4.6. Depreciation of fixed capital is the replacement value of capital used up in the process of production.

EE, educational expenditure, is the term *m* of the equation 4.6. Educational expenditure is defined as the public current operating expenditure in education, including wages and salaries and excluding capital investments in buildings and equipment.

(*ED* + *MD* + *NFD*), the total determinable natural resource depletion, is equivalent to the terms *n(R-g)* of the equation 4.6.

Energy depletion, *ED*, is asset depreciation measured as the "user cost" – the change in asset value associated with extraction of the energy over the accounting period. It covers coal, crude oil, and natural gas. It is estimated as the product of the unit resource rents and the physical quantities of energy extracted. *ED* can be calculated by the following expression:

ED = production volume (international market price – average unit production cost)

Mineral depletion, *MD*, is asset depreciation measured as the "user cost" – the change in asset value associated with extraction of the mineral over the accounting period. It covers tin, gold, lead, zinc, iron, copper, nickel, silver, bauxite, and phosphate. It is estimated as the product of the unit resource rents and the physical quantities of mineral extracted. *MD* can be calculated as follows:

MD = production volume (international market price – average unit production cost)

NFD, net forest depletion, is the estimate of the rent on the amount of forest extraction that exceeded the natural increment in wood volume. *NFD* can be calculated as follows:

NFD = (roundwood production – increment) * average price * rental rate, where rental rate = (price – average cost) / price

(CO_2D + $PM_{10}D$), the total determinable damages from pollution (CO_2 and PM_{10}), is equivalent to the term $\sigma(e - d)$ of the equation 4.6.

CO_2D is the product of carbon dioxide emissions (tons) and the marginal global damages per ton of carbon emitted, which is assumed to be $20 in 1995 (Fankhauser, 1994). As the emissions data is for CO_2 and the damage estimate per ton is for carbon, the emissions data is transformed by the following expression:

CO_2D = emissions (tons) * $20*(12/44)

$PM_{10}D$, damages from PM_{10} emissions, is determined by the willingness to pay (WTP) to avoid mortality and morbidity attributable to particulate emissions. $PM_{10}D$ can be calculated by the following expression:

$PM_{10}D$ = disability adjusted life years lost due to PM emissions * WTP

With regard to the estimation of energy and mineral depletions, in 2007, Atkinson and Hamilton published an article investigating and compiling the estimating methods to calculate the "user cost" of exploiting non-renewable resources. Among the five discussed methods, the article favours the quasi-optimal approach as proposed by Vincent (1997). The approach assumes that the extraction cost function is isoelastic with increasing marginal cost, the prices of minerals and mineral fuels are constant, and the Hotelling rule is applied. As a result,

ED and *MD* = production volume (international market price – average unit production cost) × $[\varepsilon/\{1+(\varepsilon\text{-}1)(1+r)^N\}]$

where: ε is the elasticity of the isoelastic extraction cost function,

r is the discount rate, and

N is the reserves-to-production ratio.

Details of the methods will be briefed in Appendix A.

In summary, Genuine Saving can be calculated by making adjustments to the Gross National Saving of the conventional national account. There are four adjustments. First, depreciation of fixed capital is deducted from Gross National Saving to become Net National Saving. Second, the education expenditures, which are treated as investments in human capital, are added to the figure (in the conventional national accounting, education expenditures are treated as consumption). Third, the depreciation of natural resources is deducted from summation of Net National Saving and education expenditures. The depreciation of natural resources is based on resource rents calculated from the difference between world prices and the average extraction costs of such natural resources. Energy, mineral and forest depletion are included. Finally, the pollution damages, including carbon dioxide emissions and air pollution, are deducted from the resulting figures to become the Genuine Saving, as shown in Figure 4.1.

Since no special conditions are placed on the level of natural capital, the Genuine Saving indicator is of the broad concept of sustainable development, i.e. weak sustainable development. It is assumed that man-made and natural capitals have the same ability to produce welfare; therefore, this concept allows investment in reproducible capital to compensate natural resource degradation and depletion.

The non-negative Genuine Saving is the key to sustainable development, because it ensures that total wealth is at least intact over time. On the other hand, negative Genuine Saving means decline in total wealth. The persistent decline in total wealth will certainly lead to the decline in welfare of people; therefore, such development is unsustainable. The Genuine Saving has some advantages as a policy indicator because it presents resource and environmental issues within a framework that politicians who set government policies can easily understand. However, there are several criticisms of 'Genuine Savings'. First, measurement of depreciation of natural capital (for instance biodiversity) is very difficult. Second, it is not convincing how investments in man-made capital can always be substituted for some natural capital such as photosynthesis, etc.

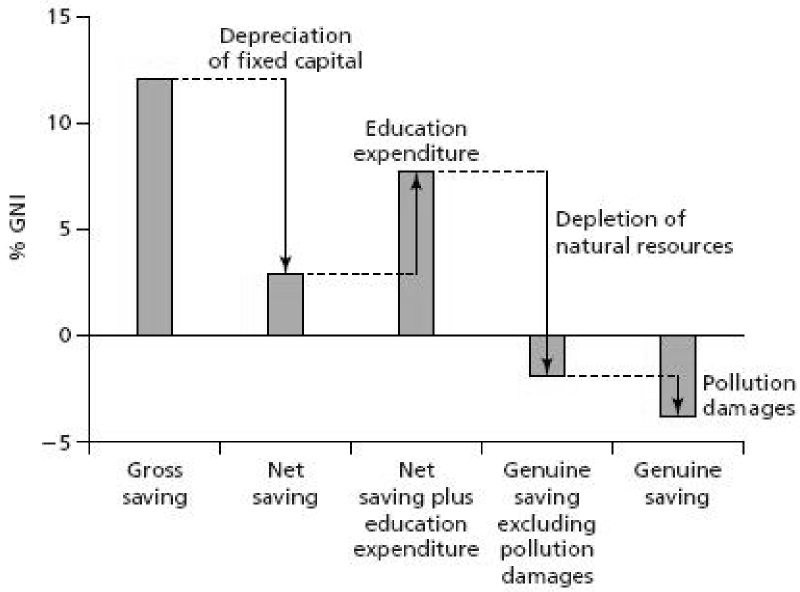

Figure 4.1 Calculation of Genuine Saving

Source: World Bank (2006)

b) Green Net National Product (GNNP)

In a perfectly competitive economy, Net National Product (NNP), which is derived from the conventional System of National Accounting (SNA), represents the value of the flow of goods and services that are produced by the productive assets of an economy. It is the popular yardstick for the measurement of a country's economic performance. But NNP does not take account of the deterioration of environment as a result of economic activities. An attempt has been made to transform NNP and other national accounts into the measurements of welfare of a country and whether such country is on a sustainable path, given that economic activity and the environment are inter-linked. Correctly adjusted NNP, i.e. the Environmentally Adjusted National Product (EANP) or the Green Net National Product (GNNP) is an outcome of such an attempt. To derive GNNP, the conventional NNP is to be adjusted by three groups of adjustments for: the depletion of non-renewable resources, the exploitation of renewable resources, and the effects of pollution (Pezzey, 1992).

i) Adjustments for the Depletion of Non-renewable Resources

In determining the adjustments for the depletion of non-renewable resources, we begin with an optimal growth model with a single produced good, *Q*, which may be consumed or added to the stock of reproducible capital. The production of the good requires the capital, *K*, and a non-renewable resource, *R*, which has a fixed quantity of resource stock, *S*. The resource extraction is costly and there is exploration activity. *N* is new discoveries brought about by exploration activity with a cost function, *F*(*N*, *S*), such that costs rise with the level of exploration activity, $F_N = \partial F_t / \partial N_t > 0$, and as the stock of resources is depleted, $F_S = \partial F_t / \partial S_t < 0$. The costs of extraction are given by *G*(*R*, *S*), such that costs rise with the level of extraction,

$G_R = \partial G_t / \partial R_t > 0$, and as the stock of resources is depleted, $G_S = \partial G_t / \partial S_t < 0$. The optimization problem is to maximize the present value of utility for a single agent over an infinite time horizon. Utility is a function of consumption *C* only and the utility discount rate ρ is constant. The optimal growth problem is thus:

$$Max \int_0^\infty U(C_t) e^{-\rho t} dt$$

subject to $\dot{S}_t = -R_t + N_t$, and $\dot{K}_t = Q(K_t, R_t) - C_t - G(R_t, S_t) - F(N_t, S_t)$

The current-value Hamiltonian is

$$H_t = U(C_t) + P_t(-R_t + N_t) + w_t[Q(K_t, R_t) - C_t - G(R_t, S_t) - F(N_t, S_t)].$$

By maximization, and further mathematical processing we get:

$$GNNP_t = C_t + \dot{K}_t - (Q_R - G_R)(R_t - N_t) \tag{4.7}$$

From the first derivative equations, necessary conditions of maximization, we can come up with the following equation: $Q_R - G_R = F_N$; therefore, the equation 4.7 can be rearranged as:

$$GNNP_t = C_t + \dot{K}_t - (Q_R - G_R)R_t + F_N N_t \tag{4.8}$$

In words, if taking into account only the depletion of non-renewable resources, then $GNNP_t$ for this economy is NNP_t ($C_t + \dot{K}_t$) less the depreciation of the non-renewable resource stock, which is the total Hotelling rent—that is, marginal rent, ($Q_R - G_R$), multiplied by extraction net of new discovery, ($R_t - N_t$).

ii) Adjustments for the Exploitation of Renewable Resources

In this analysis, renewable resources are exploited for three alternative uses: one totally for raw materials or inputs of the production of the consumption/capital goods; another totally for direct human consumption, which is an argument in the utility function, the other is the mix of the first two. These three kinds of exploitation give different effects on the GNNP as discussed below.

Renewable Resource as an Input of Production

The same optimal growth model of the above non-renewable resources is assumed, however, with R as a renewable resource in production instead. Therefore, the current value Hamiltonian is

$$H_t = U(C_t) + P_t[F(S_t) - R_t] + w_t[(Q(K_t, R_t) - C_t - G(R_t, S_t)]$$

where R_t is a renewable resource and $F(S_t)$ is the intrinsic growth function. Note that the harvest cost depends on the size of the harvest and the stock size, $G(R_t, S_t)$. Following the same mathematical processing as above, we obtain the following expression:

$$GNNP_t = NNP_t - (Q_R - G_R)(R_t - F(S_t)) \tag{4.9}$$

So that, if considering only the exploitation of a renewable resource as an input of production, then $GNNP_t$ for this economy is NNP_t less the product of the marginal rent, $(Q_R - G_R)$, and the harvest net of intrinsic growth, $(R_t - F(S_t))$. We can see that equation 4.9 has similar structure as equation 4.7.

Renewable Resource as a Direct Consumer Good

In the case that a renewable resource, such as fish and other sea food, is harvested for direct human consumption, which is an argument in the utility function, the current value Hamiltonian will be:

$$H_t = U(C_t, R_t) + P_t[F(S_t) - R_t] + w_t[(Q(K_t) - C_t - G(R_t, S_t)].$$

By maximization, and further mathematical processing we get:

$$GNNP_t = NNP_t - [(U_R / U_C) - G_R](R_t - F(S_t)) \qquad (4.10)$$

This has the same structure as equation 4.9 in that $GNNP_t$ is NNP_t less depreciation, but note that the term ($(U_R / U_C) - G_R$), used to value the change in stock size, is different in this case.

Renewable Resource as Both an Input of Production and a Direct Consumer Good

An example of this case is the harvested timber that may be used in production, while standing timber is a source of aesthetic pleasure and recreation. In such a case, the Hamiltonian is

$$H_t = U(C_t, S_t) + P_t[F(S_t) - R_t] + w_t[(Q(K_t, R_t) - C_t - G(R_t, S_t)]$$

With the same previous mathematical processing we get:

$$GNNP_t = NNP_t + (U_S / U_C)S_t - (Q_R - G_R)(R_t - F(S_t)) \qquad (4.11)$$

As compared with equation 4.9 there is a structural difference here. As well as subtracting depreciation from NNP_t, it is now necessary to add the value of the stock of the renewable resource, where the value uses U_S/U_C.

iii) Adjustments for Pollution

To illustrate the effect of pollution, consider a model that has an index of environmental quality, E, affecting both utility and production, where that index has a negative effect upon utility. Thus the utility function is $U = U(C, E)$ in which, by assumption, $U_C > 0$ and $U_E < 0$. Furthermore, the index E depends on the rate of resource use, R, and on the accumulated stock of pollutant in the relevant environmental medium, A. So we have $E = E(R, A)$, in which $E_R > 0$ and $E_A > 0$. The way in which the accumulated stock of pollution, A, changes over time is modelled by the following expression:

$$\dot{A}_t = M(R_t) - \alpha A_t - F(V_t).$$

The above expression says that the pollution stock is increased by the emissions arising from resource use, $M(R_t)$, and is decreased by natural decay, αA_t (with an assumption that a constant proportion α of the ambient pollutant stock decays at each point in time), and by the effect of defensive expenditure, $F(V_t)$. The term F describes the reduction in the pollution stock brought about by some level of defensive expenditure V.

The optimization problem in this case is:

$$Max\int_0^\infty U(C_t, E(R_t, A_t))e^{-\rho t}dt$$

subject to $\dot{S}_t = -R_t$

$$\dot{K}_t = Q(K_t, R_t, E(R_t, A_t)) - C_t - G(R_t, S_t) - V_t$$

$$\dot{A}_t = M(R_t) - \alpha A_t - F(V_t)$$

Here $G(\cdot)$ is the extraction cost of resource. The current value Hamiltonian is

$$H_t = U(C_t, E(R_t, A_t)) + P_t(-R_t) + w_t[Q(K_t, R_t, E(R_t, A_t)) - C_t - G(R_t, S_t) - V_t]$$
$$+ \lambda_t[M(R_t) - \alpha A_t - F(V_t)]$$

With $U(\cdot) = U_C C_t + U_E E_t$, thus

$$GNNP_t = NNP_t + (U_E/U_C)E_t - (Q_R - G_R)R_t - R_t[E_R(Q_E + (U_E/U_C)) - M_R/F_V]$$
$$-(1/F_V)[M(R_t) - \alpha A_t - F(V_t)] \tag{4.12}$$

Therefore, from the expression 4.12 above, if we just take account of the effect of pollution, going from NNP to GNNP now involves four adjustments. While the first two: the value of the environmental quality index, $(U_E/U_C)E_t$, and the depreciation of the resource stock, $(Q_R - G_R)R_t$, are easy to interpret, an intuitive interpretation of the latter two is complicated. Anyway, an important fact is that implementing these adjustments would require non-market valuation. This certainly makes global standardization of GNNP more difficult, and may require the world's political arena to settle differences. Without conformity that makes comparison meaningful, an index is almost useless.

Note that GNNP is derived from the concept not far from that of the adjusted NNP used in determining the above-mentioned Genuine Saving. Both kinds of indicators incorporate the negative effects of the exploitation of natural resources and of the pollution created by economic activities. The major difference between the two is that the Genuine Saving gives extra importance to educational expenditures.

Nevertheless, GNNP is far from being the perfect indicator of sustainable development. Besides difficulties and problems in determining parameters for calculation, GNNP can only be a good welfare indicator in a convex economy (Maler, 1991) (see Appendix B). Rising GNNP might tell us that welfare was increasing over the accounting period, but it does not tell us whether this trend is going to continue. Falling GNNP would be a sign of unsustainable development, but again it does not tell us whether such a situation will continue (Mulalic and Olsen, 2004).

c) Augmented Green Net National Product (GNNP) and Augmented Genuine Saving (GS)

Based on Genuine Saving (GS) and Green Net National Product (GNNP), Pezzey and Toman (2002a) have derived two fairly general, one-sided tests for the unsustainability of an economy with constant population and constant production possibilities. If the value of GS is momentarily zero or negative, or if GNNP is momentarily constant or falling, then at that moment the economy is unsustainable, meaning that its current level of utility cannot be sustained forever. They are one-sided tests because they show only unsustainability, not sustainability. An economy that will encounter an unsustainable peak of development must go through a period before the peak. Thus, there are possibilities that the changes of ordinary net investment and GNNP may send a false message, by being strictly positive when the economy is in fact unsustainable.

In the real world, population growth and the changes in production as the result of technological progress and/or changes in terms of trade are the norm. The production possibilities of a real economy certainly have direct dependence on time from at least three sources: technological progress; changes in world prices that face a trading country; and population growth. An upward movement of the production possibilities, which represent an increase in economic opportunities, alone may cause an increase in the GNNP and the GS. Because of this fact, an economy may have positive GNNP and GS when it is actually unsustainable. Therefore, in order to apply the above-mentioned tests to economies where production possibilities change exogenously over time, both GS and GNNP have to be 'augmented' to include a term called here the 'value of time', which measures the value of future exogenous changes to production possibilities. Referring to Pezzey *et al*. (2006), the methods of calculating augmented GNNP and GS are as follows:

$$AugmentedGNNP = NNP - e \cdot E + bB - J + (Q^R - f_R) \cdot \dot{S} + Q^t$$

$$AugmentedGS = NNP - C - J + (Q^R - f_R) \cdot \dot{S} + Q^t$$

where: NNP	is the conventional Net National Product
$e \cdot E$	is the (dis-)amenity costs of emissions
$bB - J$	is the net benefit of agri-environmental schemes
$(Q^R - f_R) \cdot \dot{S}$	is the negative value of rents from resource stock depletion

C	is consumption
J	is government spending on agri-environmental improvement schemes, and
Q^t	is the value of time that can be derived by the following expression: $Q^t(t) = \int_t^\infty [F_s + \dot{Q}^R \cdot (R^X - R^M)(s) e^{-r(s-t)} ds$

where

F_s	is the exogenous technological change
$\dot{Q}^R$	is the resource price changes, and
$(R^X - R^M)$	is the net resource exports.

d) Linkage between Genuine Saving and Green Net National Product

Initially, the GS and GNNP were developed separately as indicators of sustainable development. However, if the same accounting data are used the relation of the two is as follows:

GNNP = Consumption Expenditure + Net Investment

Since in an equilibrium economy, Net Investment is equal to GS. Therefore,

GNNP = Consumption Expenditure + GS

Asheim and Weitzman (2001) have found the linkage between the GNNP and the GS. The two authors have theoretically proven that, in a present value-maximising economy, the time derivative of the real GNNP is equal to the GS multiplied by the real interest rate. This can be mathematically expressed as follows:

$$dGNNP/dt = GS \times i \qquad (4.13)$$

where i is the real interest rate.

Pezzey and Toman (2002a), who developed one-sided tests for the unsustainability of an economy, refined the concept further by using 'augmented GNNP' and 'augmented GS' instead of the regular GNNP and GS. That is:

Augmented GNNP = Consumption + Augmented GS, and

The time derivative of augmented GNNP is always the interest rate times augmented GS, or

$$d(\textit{augmented GNNP})/dt = (\textit{augmented GS})\times i \tag{4.14}$$

The above expression looks plausible and very logical, for an additional national income (defined as its time derivative) should come as the result of the return on the augmented net investment (or the interest of the augmented GS). However, the empirical work of Pezzey *et al.* (2006), which used Scotland's economic data to compute the change in augmented Green Net National Product (GNNP) and the interest on augmented Genuine Savings (GS) as shown in Table 4.1, found a mismatch of the figures. Shown by the last two rows of the first part of Table 4.1, the change in augmented GNNP of every year is very much bigger than the interest on augmented GS. The discrepancies between these two sets of figures are still huge even using a higher interest rate of 6%, the UK Treasury's discount rate for public sector investments during 1992–1999 instead of the UK's real consumption discount rate of 2%, and making an ad hoc allowance for the Scottish business cycle. The finding certainly cannot be claimed as the proof of the theory of Asheim and Weitzman (2001).

Pezzey *et al*. (2006) proposed some explanations to this mismatch, but could not conclusively identify a real heavyweight culprit. In this regard, this thesis wishes to offer additional explanatory hypotheses as well as some views, which might have been overlooked, as follows:

Table 4.1 Totals and Constituent Parts of Change in Augmented GNNP and Interest on Augmented GS for Scotland, 1992–1999

	1992	1993	1994	1995	1996	1997	1998	1999
Main calculation using 2% real interest rate								
Conventional GNP	47946	48982	51685	54221	54592	54637	56533	56897
δK (depreciation of man-made capital)	8340	9301	9460	8385	7568	7496	6934	6863
NNP=GNP $-\delta K$	39606	39680	42225	45836	47024	47140	49599	50034
$\boldsymbol{e} \cdot \boldsymbol{E}$=pollution damage	3096	2906	2615	2444	2290	2097	2108	1712
$bB-J$=net benefit of agri-environmental schemes	1	1	2	3	3	2	4	4
$(\boldsymbol{Q}^R-\boldsymbol{f_R}) \cdot \dot{\boldsymbol{S}}$=negative resource rents	− 293	− 184	− 87	− 233	− 199	− 164	− 81	109
Q_t=value of time	716	682	690	609	609	621	675	752
Augmented GNNP=NNP $-\boldsymbol{e} \cdot \boldsymbol{E}+bB-J+(\boldsymbol{Q}^R-\boldsymbol{f_R}) \cdot \dot{\boldsymbol{S}}+Q^t$	36934	37273	40214	43771	45146	45502	48089	49186
Augmented GNNP/NNP	93%	94%	95%	95%	96%	97%	97%	98%
Augmented genuine savings (GS)	1943	1651	2155	2507	2492	2791	3625	3664
Change in augmented GNNP	–	339	2942	3557	1375	356	2587	1098
Interest rate $r \times$ augmented GS	39	33	43	50	50	56	73	73
Sensitivity testing by using 6% real interest rate; then adding educational expenditure								
Q^t=value of time	519	488	498	419	418	429	482	561
Change in augmented GNNP	–	342	2944	3559	1374	355	2586	1099
Interest rate $r \times$ augmented GS	105	87	118	139	138	156	206	208
Estimated educational expenditure	2579	2646	2776	2899	2908	2903	2991	3010
Interest rate $r \times$ augmented GS including educational expenditure	259	246	284	313	313	330	385	389

All values except % are £ million in constant 1999 prices.

Source: Pezzey *et al*. (2006)

i) It is too inaccurate to use a real consumption discount rate as the rate of return on a net investment of an economy. The real consumption discount rate, which might be close to a bank deposit interest rate, could only be considered as the rate of return on household savings. In addition, the UK Treasury's discount rate for public sector investments, which was used to determine the interest from the augmented GS, is certainly not the same figure as that of the rate of return on the augmented net investment of the UK because, the net investment of the economy of UK includes private investments. For private investors in the whole economy, whether they are corporate bodies or wealthy individuals, a rate of return on investment depends on their business opportunities, not the utility or consumption discount rate. The private rate of return on investment indirectly relates to the consumption discount rate only via the bank's lending interest rate, which moves in harmony with the bank deposit interest rate. This is because it is normal practice for an investor to loan money from banks and financial institutes to partly finance his/her investment. Another result of this normal practice is that an expected rate of return on such an investment is certainly higher than the lending interest rate. (If the rate of return on an investment is lower than the interest rate on a loan, an investor will lose money because of the loan.) Furthermore, corporate income taxes paid by business entities are parts of the return on investments. Therefore, the value of i in equations 4.13 and 4.14 should be the before-tax rate of return on investment of the whole economy.

ii) A real economy is not composed of only a single individual. In a nation, an addition earning of an individual will generate and regenerate incomes for others through spending and re-spending, as well as saving and re-saving. Thus, to determine the full affect accrued to the national income by an additional income generated from an investment, we have to take account of the Keynesian multiplier effect into the calculation.

Since the aggregate expenditure, AE, = $C+I+G$;

where C is the consumption,

I is the investment, and

G is the government spending.

Let M be the spending multiplier. Therefore, $M = dNNP/dAE$

Thus, $dNNP = MdAE$

$= Md(C+I+G)$

$= M(dC+dI+dG)$

Assume G is constant, then,

$$dNNP = M(dC+dI)$$

Since in an equilibrium economy $I = S$, the saving; therefore,

$$dNNP = M(dC+dS) \tag{4.15}$$

Let R be the return on the investment, I, and r be the before-tax rate of return on investment.

Therefore, $dR = Irdt$.

Replacing I by S, then, $dR = Srdt$

Since dR will be consumed and/or saved, then

$$dR = dC+dS$$

Therefore, $dC+dS = Srdt$

Thus the equation 4.15 can be rewritten as follows:

$$dNNP = M\,Srdt$$

Replacing the terms *NNP* and *S* by the terms *augmented GNNP* and *augmented GS*, the above equation can be rewritten as follows:

$$d(\textit{augmented GNNP}) = M \times (\textit{augmented GS}) \times r\ dt$$

Thus $$d(\textit{augmented GNNP})/dt = (\textit{augmented GS}) \times r \times M \tag{4.16}$$

The equation 4.16 can be quoted in words as follows:

"In a present value-maximising economy, the time derivative of the augmented GNNP is equal to the augmented GS multiplied by the before-tax rate of return on investments and the spending multiplier."

By conjecture, taking the above two hypotheses into account might increase the sizes of the figures of the last row in Table 4.1, by at least few folds and make them closer to the corresponding figures of the change in augmented GNNP. However, it is not the objective of this thesis to research for the appropriate discount rate and the spending multiplier. Therefore, whether the gaps between these two sets of figures is small enough to prove the Asheim and Weitzman's proposition remains unanswered.

4.4.2 UN Commission on Sustainable Development (CSD) Indicators of Sustainable Development

Following the 1992 Earth Summit in Rio de Janeiro, Brazil, the UN Environment Programme (UNEP), later the UN Commission on Sustainable Development (CSD), developed a series of indicators designed to determine governmental progress towards sustainable development goals. The selection of Sustainability Indicators is based broadly on the sections of the Agenda 21 document (United Nations, 1992) and falls into four categories: social, economic, environmental, and institutional, with a total of 132 indicators given in 16 subdivisions. A revision was made in 2001 when the total number of core indicators was reduced by the CSD to 58, grouped in 15 themes and 38 sub-themes under the same four categories. The third and last revised CSD indicator set was finalized in 2006 by an expert group of indicator experts. The set consists of 98 indicators, of which 50 are core indicators. At this juncture, their detailed methodology sheets, as references for all countries to develop national indicators of sustainable development, are not yet available. The latest indicators are no longer explicitly categorized into four pillars of sustainable development. They continue to be placed in a framework of themes and sub-themes. As shown in Table 4.2, the framework contains 14 themes, which are slightly modified from the previous edition. The indicators are an attempt to reflect common priorities among national and international issues.

The main objective of the CSD in developing the indicators was to make the indicators of sustainable development for the use of a government in decision-making processes at the national level. Within the framework of 58 core indicators, a government can select and use a suitable set of indicators to measure progress towards sustainable development of its nation in accordance with its own distinctive concerns. The CSD stresses that its framework and core set of indicators provide just a good starting point for such a national programme to monitor its sustainable development. Therefore, this mode of sustainable development indicators, though matching the name and concept exactly, could not be used to compare degrees of sustainable development of two or more countries.

Table 4.2 CSD Theme Indicator Framework

Social		
Theme	**Sub-theme**	**Indicator**
Equity	Poverty (3)	Percent of population living below poverty line
		Gini index of income inequality
		Unemployment rate
	Gender equity (24)	Ratio of average female wage to male wage
Health (6)	Nutritional status	Nutritional status of children
	Mortality	Mortality rate under 5 years old
		Life expectancy at birth
	Sanitation	Percent of population with adequate sewage disposal facilities
	Drinking water	Population with access to safe drinking water
	Healthcare delivery	Percent of population with access to primary health care facilities
		Immunization against infections childhood diseases
		Contraceptive prevalence rate
Education (36)	Education level	Children reaching grade 5 of primary education
		Adult secondary education achievement level
	Literacy	Adult literacy rate
Housing (7)	Living conditions	Floor area per person
Security	Crime (36, 24)	Number of recorded crimes per 100,000 population
Population (5)	Population change	Population growth rate
		Population of urban formal and informal settlements
Environmental		
Theme	**Sub-theme**	**Indicator**
Atmosphere (9)	Climate change	Emissions of greenhouse gases
	Ozone layer depletion	Consumption of ozone depleting substances
	Air quality	Ambient concentration of air pollutants in urban areas
Land (10)	Agriculture (14)	Arable and permanent crop land area
		Use of fertilizers
		Use of agricultural pesticides
	Forests (11)	Forest area as a percent of land area
		Wood harvesting intensity
	Desertification (12)	Land affected by desertification
	Urbanization (7)	Area of urban formal and informal settlements
Oceans, seas and coasts (17)	Coastal zone	Algae concentration in coastal waters
		Percent of total population living in coastal areas
	Fisheries	Annual catch by major species
Fresh water (18)	Water quantity	Annual withdrawal of ground and surface water as a percent of total available water
	Water quality	BOD in water bodies
		Concentration of faecal coliform in freshwater
Biodiversity (15)	Ecosystem	Area of selected key ecosystems
		Protected area as a % of total area
	Species	Abundance of selected key species

Note: Numbers in brackets indicate relevant Agenda 21 chapters.

Source: UN Division for Sustainable Development (2001)

Table 4.2 CSD Theme Indicator Framework (Continued)

Economic		
Theme	**Sub-theme**	**Indicator**
Economic structure (2)	Economic performance	GDP per capita
		Investment share in GDP
	Trade	Balance of trade in goods and services
	Financial status (33)	Debt to GNP ratio
		Total ODA given or received as a percent of GNP
Consumption and production patterns (4)	Material consumption	Intensity of material use
	Energy use	Annual energy consumption per capita
		Share of consumption of renewable energy resources
		Intensity of energy use
	Waste generation and management (19-22)	Generation of industrial and municipal solid waste
		Generation of hazardous waste
		Generation of radioactive waste
		Waste recycling and reuse
	Transportation	Distance traveled per capita by mode of transport
Institutional		
Theme	**Sub-theme**	**Indicator**
Institutional framework (38, 39)	Strategic implementation of sustainable development (8)	National sustainable development strategy
	International cooperation	Implementation of ratified global agreements
Institutional capacity (37)	Information access (40)	Number of internet subscribers per 1000 inhabitants
	Communication Infrastructure (40)	Main telephone lines per 1000 inhabitants
	Science and technology (35)	Expenditure on research and development as a percent of GDP
	Disaster preparedness and response	Economic and human loss due to natural disasters

Note: Numbers in brackets indicate relevant Agenda 21 chapters.

Source: UN Division for Sustainable Development (2001)

4.4.3 World Bank World Development Indicators

Unlike the above five indicators, the World Bank World Development Indicators are the non-national account ones. As suggested by their names, these indicators were actually created to track progress towards the international goals of development, which focus on reducing poverty; achieving universal primary education, gender equality in enrolments in primary and secondary education and drastic cuts in infant and child mortality rates. Their aim is also to reverse environmental degradation. Since all of these are aspects of the wider aims of sustainability and sustainable development, we can classify these indicators as sustainable development indicators.

The concept of the World Development Indicators was initiated by the Development Assistance Committee (DAC) of the OECD in 1996 when it chose 7 international development goals from resolutions of UN conferences. In 1998 a joint meeting was held between the UN, OECD and World Bank that led to a proposal of 21 indicators to track progress towards the goals. Subsequently annual reports have been produced, i.e. "World Development Indicators 2000" (Warhurst, 2002). Its latest version "World Development Indicators 2006" including more than 900 indicators in over 80 tables organized in six sections: World View, People, Environment, Economy, States and Markets, and Global Links (World Bank, 2006).

4.5 Indicators for Sustainable Development in Thailand

Since Thailand has a long history of benefiting from its rich natural resources, its people have been well aware of the environmental damage caused by such exploitation. As a result, the concept of sustainable development has been quickly adopted by both the Government and its people. Thailand was among the UN member countries that ratified multilateral agreement on the Earth Master Plan "Agenda 21" of the UN Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil in 1982. Since then, Thailand has adopted Sustainable Development and Agenda 21 as a framework for the national development plan. Sustainable development has been put on the national agenda and was first addressed in the 9th National Economic and Social Development Plan (2002-2006). It was defined as a holistic development which involves six dimensions: economics, social, environment, politics, technology and knowledge, and mental and spiritual balance. Furthermore, in 2003, Thailand established the National Sustainable Development Council chaired by the Prime Minister. The council is responsible for formulating operational plans, implementing processes, and evaluating outcomes. The council's objective is to arrive at a balanced state of economics, social, natural resource and environment for the well being of people across generations.

4.5.1 The Genuine Saving of Thailand

Since introducing the Genuine Saving in 1998, the World Bank has calculated and published the Genuine Savings of most countries, including Thailand. The latest version revealed the Genuine Savings of countries from 1990 to 2004, calculated in accordance to the 2002 World Bank's Manual for Calculating Adjusted Net Savings (Bolt *et al.*, 2002). Hence, the rents from energy and mineral depletion, two adjustments in defining the Genuine Savings, were estimated by the following expression:

Rent = production volume (international market price – average unit production cost)

As mentioned in a previous section, there are new proposals to calculate the user costs or the rents from natural resource depletion as investigated and compiled by Atkinson and Hamilton (2007), and among five approaches mentioned, the authors suggested the quasi-optimal approach as the most appropriate method. For comparison, this study recalculates the rents from energy and mineral depletion by the quasi-optimal approach. Current dollar (world) price and extraction data of energy and mineral resources were derived from the World Bank's Genuine Saving database, as published in World Development Indicators 2005 (World Bank, 2005), while energy reserves data were taken from The BP Statistical Review of World Energy 2007 (British Petroleum, 2007). Mineral reserves data were taken from the Department of Mineral Resources, Ministry of Natural Resources and Environment, Thailand. The social discount rate, *r*, is assumed to be 5% following Atkinson and Hamilton (2007), and the elasticity of the extraction cost function, ε, is 1.15 following Vincent (1997).

Note that the rents from the energy and mineral depletions, calculated by the quasi-optimal approach, are slightly lower than those posted by World Bank (2004). As a result, the figures of the recalculated Genuine Savings of Thailand are slightly higher than those of World Bank (2004) as shown in Figure 4.2. From the figure, the Genuine Savings of Thailand, from 1990 to 2004, is positive which means that the Thai economy was on the sustainable development path. Therefore, if Genuine Saving is used to measure sustainability of development, Thailand could claim to be successful.

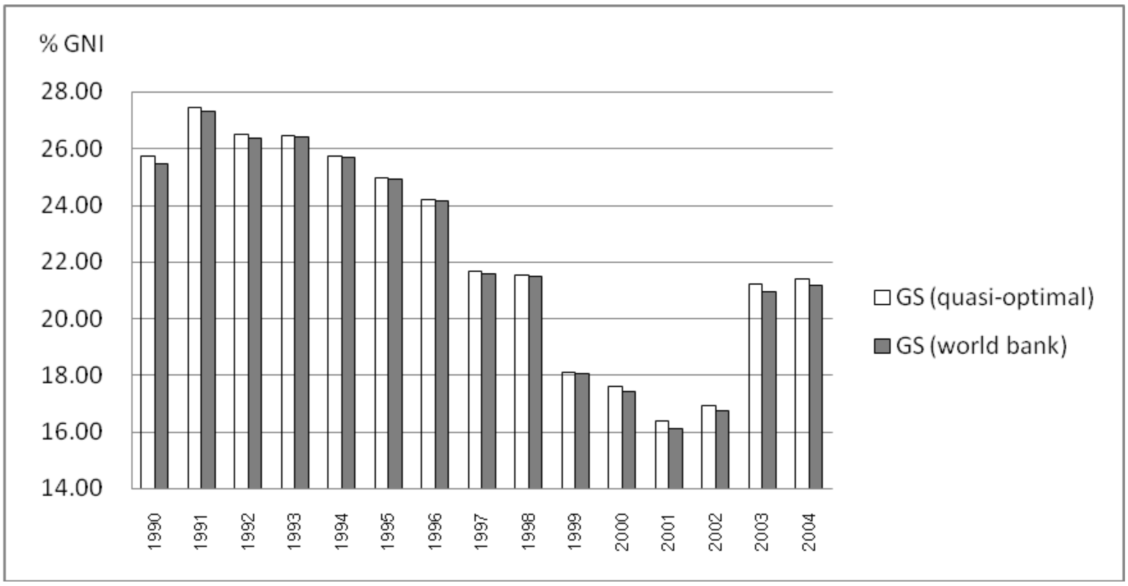

Figure 4.2 Genuine Savings (GS) of Thailand as a Percentage of Gross National Income (GNI) from 1990 to 2004

4.5.2 The Green Net National Product (GNNP) of Thailand

In 2006, the National Economic and Social Development Board (NESDB) of Thailand launched a five-year project to develop a "road map" for establishing environmental accounting to create “Green GDP” as a part of the national income accounts. The project is an attempt to implement the guidelines set by the SEEA. Its two aims are to provide the Thai Government with the following (Koomsup, 2006):

a) Details of the satellite accounts designed for natural resources and environment in Thailand comprising:

  i) Classification of the activities related to natural resources and environment,

  ii) Establishment of supply and use accounts for natural resources and environment in physical and monetary terms,

  iii) Establishment of environmental assets accounts,

  iv) Establishment of environmental protection expenditure accounts,

  v) Establishment of the “green GDP” national income account reflecting the impacts on natural resources and the environment with adjustments for depletion, defensive expenditures, and degradation.

b) A road map of the establishment of environmental accounts comprising the following phases:

  i) Revision of the classification of activities in the national account by adding those related to natural resources and the environment in accordance with the SEEA,

  ii) Development of the supply and use accounts and environmental asset accounts for natural resources and environment,

  iii) Establishment of expenditure accounts on protection and management of natural resources and environment,

iv) Integration of phase b) and c) to come up with at least the Extraction Adjusted Domestic Product and the Depletion Adjusted Domestic Product. This account should compare with the adjusted GDP in other countries, and

v) Recommendation for governmental agencies to make use of the results from phases a) to d) in setting policies and measures for dealing with natural resources and environment.

In order to make some contribution to the above-mentioned work, this thesis attempts to calculate the GNNP figures of Thailand, from 1993 to 2004. In doing so, the conventional NNP is to be adjusted for depletion of natural resources and pollution damage. The natural resources depletions in this calculation comprise depletions of energy (oil, natural gas, and coal), minerals (lead, tin, zinc, and iron), fish, and forest.

The *energy* and *mineral* depletions of Thailand are calculated by using the quasi-optimal approach (Atkinson and Hamilton, 2007). Current dollar (world) price and extraction data of energy and mineral resources are derived from the World Bank's Genuine Saving database, as described in World Bank (2005). Energy reserves data are taken from British Petroleum (2007), while mineral reserves data are taken from the Department of Mineral Resources, Ministry of Natural Resources and Environment, Thailand. The social discount rate, r, is assumed to be 5% following Atkinson and Hamilton (2007), and the elasticity, ε, is 1.15 following Vincent (1997).

Fisheries data are obtained from the Department of Fisheries, Thailand. For *forestry*, productions, increments and unit rent are derived from the World Bank's Genuine Saving database, as described in World Bank (2005).

The air pollutions considered in this calculation comprise CO_2, CO, NO_x, SO_2, and SPM (Suspended Particulate Matter). The CO_2 emissions are derived from World Bank (2005) and the conservative figure of $20 marginal global damage per ton of carbon emitted is from Fankhauser (1994).

For calculating the social costs of CO, NO_x, SO_2, and SPM emissions, two kinds of data are required; the energy consumption for all economic sectors and the emission factors of energy consumption, defined as kiloton of pollution per kiloton of oil equivalent (KTOE) consumed, of each economic sector. The energy consumption of five sectors, transportation, electricity generation, industry, residence, and agriculture, was estimated by the Energy Research Institute (ERI), Chulalongkorn University. The emission factors of each economic sector are shown in Table 4.3 (ERI, 2006). The costs of pollution abatement for CO, NO_x, SO_2, and SPM are derived from Guenno and Tiezzi (1998) and their values per ton, in 2006 $, are 2, 192, 499 and 28, respectively.

Table 4.3 Emission Factors of Energy Consumption by Economic Sector

Sector	**Emission Factor (kiloton of pollution per kiloton of oil equivalent (KTOE))**			
	CO	**NO_x**	**SO_2**	**SPM**
Transportation	0.11	0.03	0.01	0.001
Electricity generation	0.0009	0.01	0.06	0.07
Industry	0.03	0.01	0.02	0.0005
Residence	0.65	0.007	0.0004	0
Agriculture	0.03	0.04	0.02	0.004

Source: ERI (2006)

The calculated figures of the GNNP together with those of the conventional NNP of Thailand are shown in Figure 4.3. All figures of GNNP are a bit smaller, less than 6 per cent, than those of the NNP, and the two sets of figures move in harmony. It can be said that Thailand's GNNP is sensitive to conventional NNP. During the period of study, the GNNP and NNP of Thailand decreased in 1997 and 1998 and again in 2000 and 2001. The decreases were attributed to the 1997 Asian economic and financial crisis. If the one-sided tests for the unsustainability, proposed by Pezzey and Toman (2002a), is used, it can be said that Thailand's development was briefly unsustainable during the years 1997, 1998, 2000, and 2001. This is not in agreement with the conclusion from the GS indicator of subsection 5.1. However, since 2002, Thailand's economy has fully recovered with no sign of unsustainability. Another point is that during the period of study, there was another bad sign of sustainable development for the adjustments for resources depletion and pollution damages were increasing over the period of time studied.

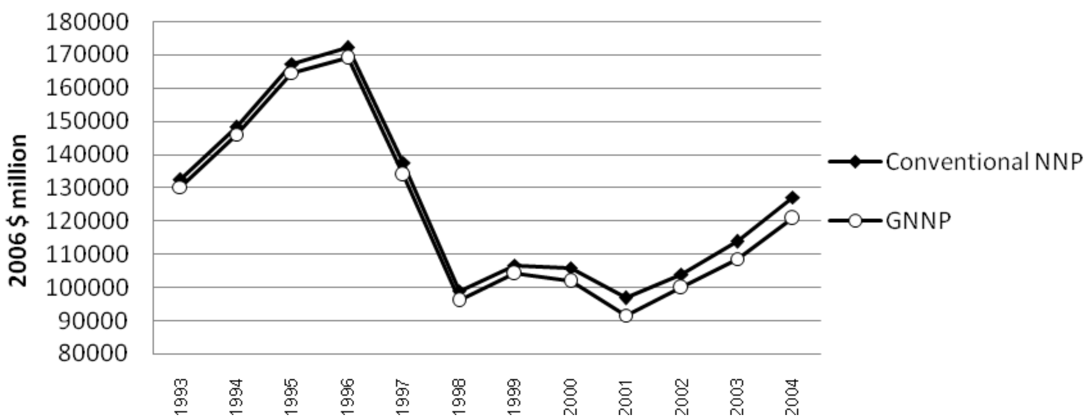

Figure 4.3 Green Net National Product of Thailand from 1993 to 2004

4.5.3 Augmented Green Net National Product (GNNP) and Augmented Genuine Saving (GS) of Thailand

This thesis will follow in the footsteps of Pezzey, Hanley, Turner, and Tinch (2006) by trying to determine the Augmented Green Net National Product (GNNP) and Augmented Genuine Saving (GS) of Thailand and to see whether they are also mismatched. The results, which are shown in Table 4.4, are based on the sources of data and assumptions explained below. Note that, due to different sources of basic and intermediate data and variant forms of calculation, the figures of GNNP and GS here are close to but not exactly the same as those in subsections 5.1 and 5.2, though they basically have the same meanings.

a) Sources of Data and Assumptions

GNP, NNP, and capital depreciation were available from the National Economic and Social Development Board of Thailand. Two values of real interest rate (r), 5% and 10% are used in calculation. The 5% rate was the mean value of real interest rate of Thailand from 1977 to 2000 (Holmes and Maghrebi, 2003). The alternative rate of 10% is chosen because it was the discount rate used by the World Bank for project evaluation in developing countries (Hayes and Smith, 1993), and because it was close to the rate of 11.7 %, which was the average before-tax rate of return of all companies traded on the Thailand's Stock Exchange from 1993 to 2004. (11.7 % was derived from the average price per earning (P/E) of 12.20 and the 30 % corporate income tax rate.) Due to lack of data, the proposal of this thesis, in subsection 4.1.4, to apply the before-tax rate of return on investments of the whole economy instead of the real interest rate and to take into account the spending multiplier effect of income, is disregarded here.

The natural resource depletion, consisting of energy, minerals, forest, fish, and pollution damages from CO_2, CO, NO_x, SO_2, and SPM are the same as those in topic 5.2. For the agri-environmental spending of Thailand, the details of the cost and area of take-up for the schemes for improving quality of soil from acid, alkaline, and infertile soil problems were from the Land Development Department, while the value of benefits per square kilometre came from the study of Israngkul (2006).

In computing the value of time, the estimates of total factor productivity (TFP) and TFP growth rate from Bank of Thailand (2006) are used as the estimates of F_t/F, which are projected forward to 2024. Differing from the approach of Vincent *et al*. (1997), changing terms of trade in fishery products (shrimp, fish, and cuttlefish), is used instead of changing terms of trade in oil and minerals because Thailand is an important fishery product-exporting country while export of minerals is small. The data of the price change of fishery products (shrimp, fish, and cuttlefish), their imports, and exports come from the Bank of Thailand. Actual price data (up to 2006) and its predictions (2006 onwards) are used to calculate changes in prices, and the future fishery product exports from Thailand is assumed to be constant at the average level of actual exports during 1993–2006.

b) Results

The calculated results are shown in Table 4.4. As also shown in Figure 4.4, during the study period, the augmented GNNP moved down in some years, but the augmented GS is always positive. According to the one-sided tests developed by Pezzey and Toman (2002a), this means that the augmented GNNP suggested unsustainable development in Thailand in some years, while the augmented GS did not suggest unsustainable development in Thailand at all during the period. The contrasts between augmented GS and augmented GNNP are in the same pattern as those between the GS in subsection 5.1 and the GNNP in subsection 5.2.

Note that the figures of augmented GNNP are about 6-1% less than those of NNP. The green and augmentation terms have a small effect on NNP. Therefore, the sustainable development of Thailand depends mostly on NNP. Thailand's NNP dropped by 20 per cent in 1997, a strong sign of unsustainable development, as the result of the economic crisis near the end of 1996 and NNP has increased continuously since 2002. It can be said that in the case of Thailand, a medium economy, the GNNP and augmented GNNP can be greatly affected by the severe business cycles of the country. On the other hand, in the case of GS, the economic crisis did not cause the values of net saving to go negative. Furthermore, they greatly outweighed the sums of resource depletion and pollution damage. In the same way, the augmented GS were all positive because the figures of NNP were much higher than the sums of consumption, government spending on agri-environmental improvement schemes, and resource depletion values. Because the economic crisis of late 1996 was an unusual event, the GS and augmented GS might be better indicators of sustainable development in Thailand.

If the theory developed by Asheim and Weitzman (2001) is true, the annual change in augmented GNNP of Thailand should be equal to the interest on augmented GS. But, from Table 4.4, the absolute values of the changes in the augmented GNNP of all years were a lot (from 2 to 28 times) bigger than the values of interest on the augmented GS. This "mismatch" is similar to those of Scotland calculated by Pezzey *et al*. (2006). The details are also shown in Figure 4.5.

To check how robust the mismatch problem is, sensitivity tests are done as reported in the second part of Table 4.4. The first sensitivity test examines the effect of using a higher interest rate of 10%. The results are shown in Table 4.4 and demonstrated as the lower and middle graphs in Figure 4.6. The higher discount rate decreases the absolute value of the value of time by about 49%, so the value of augmented GS is lower. But this reduction is outweighed by the doubled interest rate and the falling user cost of resource depletion as the quasi-optimal approach which is used in this calculation ($UC_t = \frac{\varepsilon(pq - c)}{1 + (\varepsilon - 1)(1 + r)^N}$ $UC_t = \frac{\varepsilon(pq-c)}{1+(\varepsilon-1)(1+r)^N}$). The interest on augmented GS increases when using the higher interest rate while the augmented GNNP is barely changed, so its results are not shown.

Following Hamilton and Clemens (1999), the second sensitivity test is performed by reclassifying educational expenditure as investment in human capital in the national accounting calculation. Reclassifying educational expenditure from consumption to investment increases augmented GS but augmented GNNP (the total) is not affected. Figure 4.6 shows that adding educational expenditure to augmented GS makes the graph of the interest on augmented GS move from the middle to upper positions. Although the higher interest rate and the change of the educational expenditure accounting decrease the difference between the change in augmented GNNP and interest on augmented GS, the mismatch remains strong. The causes of this problem could be the difficulties of valuing environmental resource depletion and degradation, lack of some specific data of Thailand, and the effect of business cycles. As discussed in sub-section 4.1.4, the huge mismatch might be because the rate of return on the net investment that is used is much smaller than the actual one and because we disregard the spending multiplier effect of income.

Table 4.4 Totals and Constituent Parts of Change in Augmented GNNP and Interest on Augmented GS for Thailand, 1993–2004

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Main calculation using 5% real interest rate												
Conventional GNP	171879	193289	218640	228597	184543	133526	144244	141257	129340	139869	153352	168848
δK (depreciation of man-made capital)	39481	45056	51402	56527	46905	34540	37601	35290	32596	35958	39603	41610
NNP = GNP - δK	132397	148233	167238	172069	137638	98986	106643	105968	96745	103911	113748	127238
$e \cdot E$ = pollution damage	1526	1673	1878	2037	2071	1834	1905	1898	1983	2094	2193	2489
$bB - J$ = net benefit of agri-environmental schemes	6	7	7	7	5	4	4	3	4	3	4	5
$(Q^R - f_R) \cdot \dot{S}$ = negative resource rents	-708	-588	-645	-917	-1741	-1147	-653	-2290	-3254	-1977	-3002	-4034
Q^t = value of time	1028	1194	-879	-1085	-4468	338	659	-627	74	-173	1954	1667
Augmented GNNP = NNP - $e \cdot E + bB - J + (Q^R - f_R) \cdot \dot{S} + Q^t$	131198	147173	163843	168037	129363	96346	104749	101156	91586	99671	110511	122388
Augmented GNNP/NNP	99%	99%	98%	98%	94%	97%	98%	95%	95%	96%	97%	96%
Augmented genuine savings (GS)	37335	42867	47514	44317	27830	23261	23640	22484	18192	20356	23257	26428
Change in augmented GNNP		15976	16670	4194	-38675	-33016	8402	-3593	-9570	8085	10840	11876
Interest rate r x augmented GS	1867	2143	2376	2216	1391	1163	1182	1124	910	1018	1163	1321
Sensitivity testing by using 10% interest rate; then adding educational expenditure												
$(Q^R - f_R) \cdot \dot{S}$ = negative resource rents	-654	-563	-596	-827	-1643	-1089	-613	-1930	-2823	-1694	-2448	-3540
Q^t = value of time	530	615	-420	-522	-2220	176	341	-303	46	-75	990	849
Change in augmented GNNP		15866	17732	4339	-36981	-35466	8227	-2630	-9851	8063	10050	11961
Interest rate r x augmented GS	3689	4231	4802	4497	3018	2316	2336	2317	1860	2074	2285	2610
Estimated educational expenditure	3952	4014	4686	5734	6475	8750	9210	8508	6079	6595	6546	5996
Interest rate r x augmented GS including educational expenditure	4084	4633	5271	5070	3665	3191	3257	3168	2467	2733	2939	3210

All values except % are US$ million in constant 2006 prices.

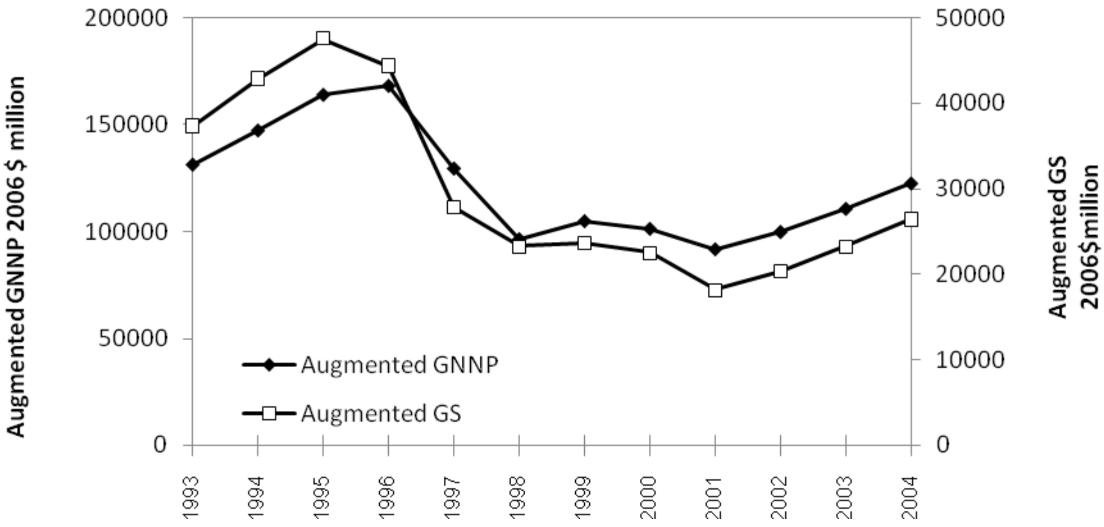

Figure 4.4 Augmented Green NNP and Augmented Genuine Savings for Thailand from 1993 to 2004

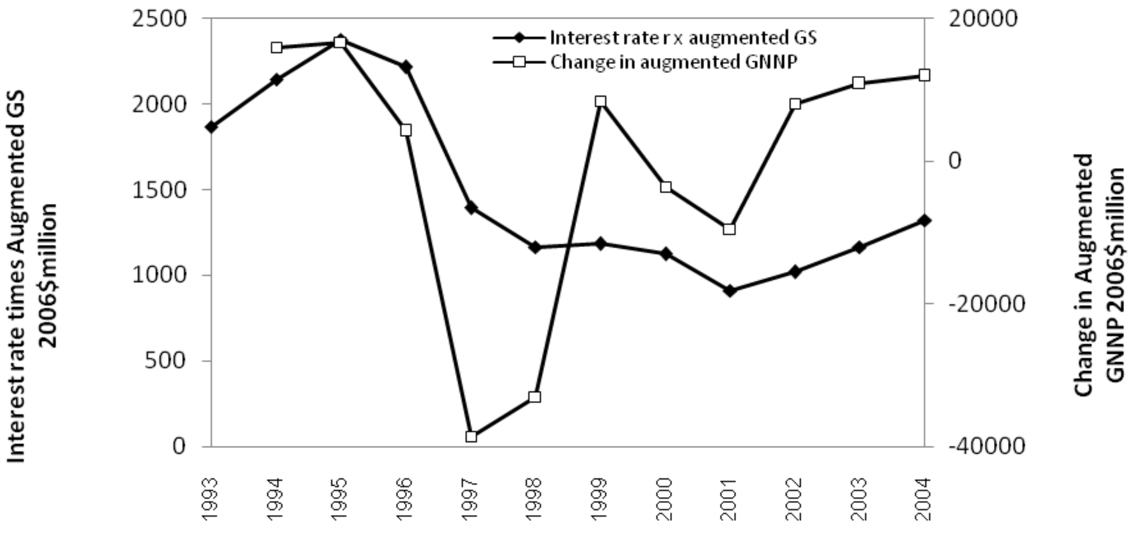

Figure 4.5 Change in Augmented Green NNP and Interest on Augmented Genuine Savings for Thailand from 1993 to 2004

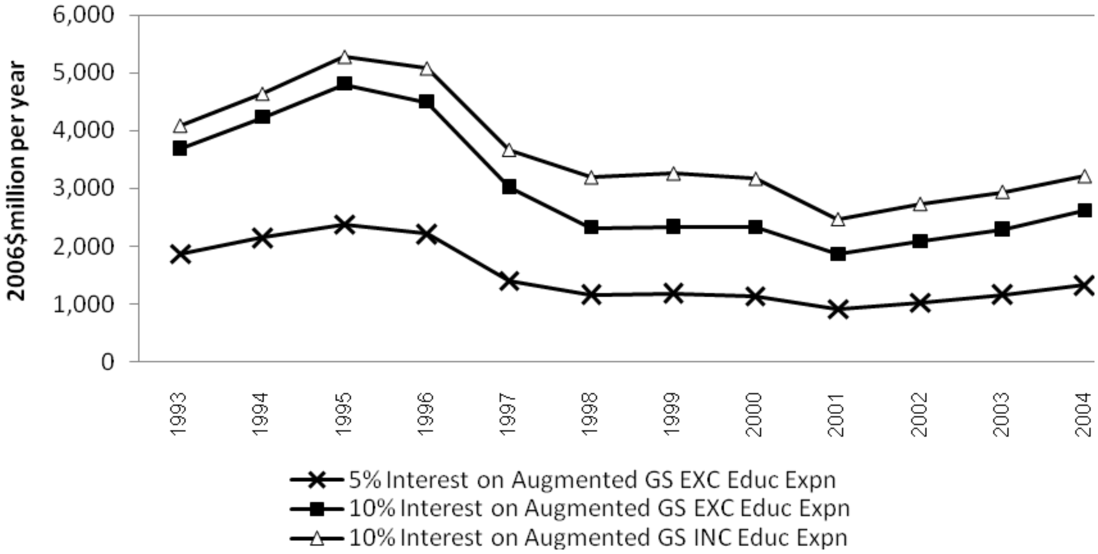

Figure 4.6 Sensitivity Tests on Interest on Augmented Genuine Savings for Thailand from 1993 to 2004

4.5.4 The Sustainable Development Indicators and the Sustainable Development Composite Index of Thailand

a) Sustainable Development Indicators

Chapter 40 of Agenda 21, which was ratified by Thailand, calls on countries at the national level, as well as international, governmental and non-governmental organizations to develop and identify indicators of sustainable development that can provide a solid basis for decision-making at all levels. However, up until 2004, Thailand had not had indicators that could officially evaluate the level of sustainable development, or the balance of economic, social and environment, of the nation. To amend this inadequacy, in 2003, the NESDB of Thailand sponsored Thailand's Environment Institute and Kenan Institute of Asia to implement a one-year project with the main objectives being to develop an evaluation framework for Thailand's sustainable development, and to develop Sustainable Development Indicators (SDI) and a composite index as evaluation tools to monitor and assess Thailand's sustainable development.

The outcome of the project defined a total of 37 indicators, as shown in Table 4.5, comprising: 13 environmental indicators, 12 economic indicators and 12 social indicators. The indicators were developed under some guidelines of the CSD's *Indicators of Sustainable Development: Framework and Methodologies* (2001), but did not follow all of the CSD Theme Indicator Framework. However, of the 37 indicators developed, 17 indicators are consistent with the CSD Theme in 2001 and 3 indicators are similar with a slight difference in calculation process of those of the CSD Theme in 2001. It should also be noted that Thailand considered only the original three pillars of sustainable development—the economic, environmental, and social dimensions; it has not taken the institutional dimension into account.

Table 4.5 Sustainable Development Indicators of Thailand[1]

No.	Indicators	Unit	Status[3]	Completeness level of data[4]
	Economic dimension			
1	Total Factor Productivity (TFP)	Percentage	DF	1
2	Ratio of energy consumption to GDP	Percentage	S	1
3	Consumption of renewable energy	Percentage	S	1
4	Rate of waste recycling in all communities	Percentage	R	2
5	Total unemployment rate	Percentage	DF	1
6	Ratio of public debt to GDP	Percentage	DF	1
7	Ratio of current account to GDP	Percentage	S	1
8	Gini coefficient of income distribution	0 to 1	S	1
9	Achievement in poverty reduction	Percentage	DF	1
10	Index of Sustainable Economic Welfare (ISEW)	Baht	S	2
11	Ratio of imported goods	Percentage	DF	1
12	Ratio of short-term foreign debt to foreign reserve	Percentage	DF	1
	Social dimension			
13	Average years of education	Year	S	1
14	Test results of 4 major subjects	Percentage	R	2
15	Ratio of research and development investment to GDP	Percentage	S	2
16	Life expectancy at birth	Year	S	1
17	Rate of sickness and number of population who have health insurance	Sickness/capita/year and Percentage	R	1
18	Ratio of crime and drug cases to number of population	Cases/1000 persons	S	2
19	Corruption index	Percentage	S	1
20	Proportion of female to male members in local council	Female to 100 male	S	2
21	Loss of life and property to disaster	Persons, baht	R	2
22	Cultural indicator[2]	No indicator at the present	S	3
23	Violation of human rights by the government	Cases/100,000 persons	S	3
24	Accessibility to safe drinking water	Percentage	S	2
	Environmental dimension			
25	Proportion of forest area to nation's area	Percentage	S	1
26	Proportion of the current mangrove forest area to the 1961 mangrove forest area	Percentage	DF	2
27	Abundance of coastal marine life	Percentage	DF	2
28	Surface water and ground water used per water consumption	Percentage	S	3 (surface water) 2 (ground water)
29	Proportion of good quality water resources to all water resources	Percentage	S	1
30	Air quality in major urban areas that is below standard	Percentage	DF	1
31	Properly treated hazardous waste	Percentage	R	3
32	Chemical used in agriculture	Metric ton/year	S	2
33	Important settlement	Number	S	3
34	Lands unsuitable for agriculture	Percentage (sq. km.)	S	1
35	Public projects that have public participation	Percentage	R	3
36	Emission of green house gases	Giga-gram/GDP Giga-gram/capita	DF	3
37	Consumption of ozone depleting substances	Ton/year	DF	1

Note: [1] Have 17 indicators that are consistent with the United Nations in 2001 and 3 indicators that are similar with a slight difference in calculation process.

[2] In process of selecting proper indicators.

[3] DF means Driving Force
S means State
R means Response

[4] Level 1 means data are fully complete and ready for evaluation
Level 2 means data are moderately complete and usable for trend estimation
Level 3 means data are incomplete or unavailable and needs to be collected

Source: National Economic and Social Development Board (2004)

b) Composite Index

Besides developing sustainable indicators, the NESDB's project also attempted to quantify each indicator and to combine all the grades (called index, in percentage) of the indicators into a single composite index. However, it was found that of the 37 indicators, some have limitations in their data, either lacking collection processes or being not up to date. At the end of the project in 2004, there were 23 indicators that could be used to make the composite index, comprising 9 indicators in the economic dimension, 7 indicators in the social dimension and 7 indicators in the environmental dimension. At this preliminary stage, the research team of the project gave each dimension an equal weight, and also gave all indicators equal weight within a dimension. Table 4.6 shows the calculation methodology of the index for each indicator of the three dimensions of sustainable development. The indicators and the indices, the calculated results of Table 4.6, of the three dimensions in comparison with the levels of Thailand's development are shown in Table 4.7. Figure 4.7 shows the graph of the Sustainable Development Indices of the three dimensions, while Figure 4.8 shows the graph of the Sustainable Development Composite Index of Thailand (1999-2003).

Table 4.6 The Calculation of the Index for each Indicator of Three Dimensions of Sustainable Development

No.	Dimension of Sustainable Development Indicators	Calculating criteria
	Economic dimension	
	- Quality development	
1	Total Factor Productivity (TFP)	Compare with the changing rate of the TFP in the past, the minimum point is 0 percent and the maximum point is 5.0 percent. If the development results in a 5.0 expansion rate this indicator will receive 100 points. If the expansion rate is 0 percent this indicator will receive 60 points.
2	Ratio of energy consumption to GDP	The ratio of energy consumption to GDP of the year 1994 which was at the lowest at 0.01515 is set to be the maximum target. The ratio of energy consumption to GDP of the year 1990 which was at the highest at 0.01751 is set to be the minimum target. If the ratio is 0.01515 or lower, this indicator will receive 100 points. If the ratio is 0.01751 or higher, this indicator will receive 0 point.
3	Consumption of renewable energy	The goal of renewable energy is set at 28 percent of total energy. The points received in each year are calculated from the achievement of this goal.
4	Rate of waste recycling in all communities	The goal of recycling waste is set at 30 percent of all waste generated. The points received in each year are calculated from the achievement of this goal.
	- Stable development	
5	Total unemployment rate	The suitable unemployment rate is 2 percent. If the unemployment rate is 2 percent or below this indicator will receive 100 points.
6	Ratio of public debt to GDP	Target of public debt to GDP of 30 percent. The lowest point of 70 percent is considered having no sustainability. The score is varied between the highest and the lowest points. If the score is beyond the set level, the highest and the lowest points will be used instead.
7	Ratio of current account to GDP	A good ratio of current account to GDP is between 4 to -4 percent of the GDP. If the current account is -4 percent or lower, or the current account is 4 percent or higher, this indicator will receive 60 points. If the current account is equal to 0 percent, this indicator will receive 100 points.
	- Wealth distribution	
8	Gini coefficient of income distribution	Good Gini coefficient of income distribution is 0.40. If the Gini coefficient is at the goal, the indicator will receive 100 points.
9	Achievement in poverty reduction	The Eighth National Social and Economic Development Plan set the goal of poverty reduction to 10 percent. The indicator will receive 100 points if the poverty rate reaches this goal.

Source: National Economic and Social Development Board (2004)

Table 4.6 The Calculation of the Index for each Indicator of Three Dimensions of Sustainable Development (Continued)

No.	Dimension of Sustainable Development Indicators	Calculating criteria
	Social dimension	
	- Capacity building	
10	Average years of education	The Ninth National Social and Economic Development Plan set the minimum years of education at 9 years. The points received are calculated from the achievement of such goal.
11	Achievement in education	Transform the test result of 100 point base to the achievement of the development using 75 points as goal.
	- Improvement of quality of life	
12	Life expectancy at birth	The expected average age is 80 years and the lowest tolerable average age is 25 years. If the average age of Thai people is 80, this indicator will receive 100 points.
13	Human health	Calculated from healthy (non-sick) population from the total population with the goal of 100 percent healthy.
14	Life security	Calculated from the average ratio of cases reported per year per 1,000 persons compared with the lowest ratio of cases reported as the goal. The lowest ratio of crime cases is 1.2 cases per 1,000 persons and the lowest ratio of drug cases is 1.8 per 1,000 persons.
	- Creating equality and participation	
15	Participation index	Calculated from the rate of people using their rights to vote with the goal set at 100 percent.
16	Corruption index	Calculated from the Belief in Corruption Ranking result by Transparency International (TI) with the highest point =10 and the lowest point = 1.
	Environmental dimension	
	- Conservation	
17	Proportion of forest area to nation's area	At least 40 percent of the land area must be forest to maintain the balance in ecosystem. If the forest area is 40 percent of the nation's area, it will receive 100 points.
18	Proportion of the current mangrove forest area to the 1961 mangrove forest area	The goal is 80 percent of the mangrove forest area in the past (1961) which was abundant at 3,680 square kilometres. If the area is 2,944 square kilometres, it will receive 100 points.
19	Amount of economic marine livestock caught within 3 kilometers of the Thai coast	The goal of catching economic marine livestock is 10 kilograms in 1 hour. If the marine livestock is abundant to the catching limit, it will receive 100 points.
20	The use of ground water to the available amount	The goal of the amount of useable ground water is between 20-160 percent. If the ground water is used less than 20 percent, the score received is 100 but if it is used to more than 160 percent, the score is 60.
	- Good environmental quality	
21	Proportion of good quality water resources to all water resources	Calculate the proportion of good quality water resources to the total water resources with the goal of 100 percent.
22	Air quality in major urban areas that is below standard	Percentage of the air quality monitoring stations that reports low air quality (measure for particles smaller than 10 microns) with the goal set at 100 percent report good air quality.
23	Properly treated hazardous waste	The goal of properly treated hazardous waste is 50 percent of all hazardous waste in year 2006.

Source: National Economic and Social Development Board (2004)

Table 4.7 The Sustainable Development Indicators and the Indices of the Three Dimensions of Thailand (1999-2003)

Dimension of Sustainable Development Indicators	***Index (%)***				
	The Eighth National Social and Economic Development Plan			***The Ninth National Social and Economic Development Plan***	
	1999	***2000***	***2001***	***2002***	***2003***
Economic dimension	**70.23**	**69.84**	**66.65**	**76.44**	**79.05**
Quality development	***69.95***	***68.39***	***58.64***	***67.35***	***68.05***
Total Factor Productivity (TFP)	75.53	64.29	71.11	76.13	78.91
Ratio of energy consumption to GDP	99.01	100.00	53.48	75.19	75.19
Consumption of renewable energy	61.77	61.32	57.95	57.49	57.49
Rate of waste recycling in all communities	43.48	47.96	52.01	60.61	60.61
Stable development	***71.46***	***69.45***	***69.51***	***80.04***	***86.96***
Total unemployment rate	47.73	55.71	61.92	89.29	98.69
Ratio of public debt to GDP	71.23	63.76	63.12	65.84	78.43
Ratio of current account to GDP	95.42	88.87	83.50	85.00	83.75
Wealth distribution	***68.97***	***73.31***	***78.38***	***89.20***	***89.20***
Gini coefficient of income distribution	75.05	76.19	79.84	78.40	78.40
Achievement in poverty reduction	62.89	70.42	76.92	100.00	100.00
Social dimension	**61.90**	**61.11**	**62.51**	**62.80**	**65.37**
Capacity building	***64.43***	***63.06***	***62.69***	***64.37***	***65.48***
Average years of education	78.89	80.00	82.22	84.40	86.67
Achievement in education	49.97	46.11	43.16	44.29	44.29
Improvement of quality of life	***76.13***	***75.19***	***75.17***	***74.73***	***79.61***
Life expectancy at birth	82.00	83.50	83.50	83.50	83.50
Human health	85.80	85.80	84.90	84.90	81.30
Life security	60.58	56.22	57.07	55.75	73.99
Creating equality and participation	***38.05***	***38.05***	***43.35***	***43.35***	***43.90***
Participation index	51.70	51.65	62.25	62.25	62.25
Corruption index	24.44	24.44	24.44	24.44	25.56
Environmental dimension	**40.85**	**39.14**	**44.33**	**48.57**	**48.57**
Conservation	***53.05***	***53.20***	***59.20***	***61.20***	***61.20***
Proportion of forest area to nation's area	63.20	63.20	63.20	63.20	63.20
Proportion of the current mangrove forest area to the 1961 mangrove forest area	56.92	56.92	56.92	56.92	56.92
Amount of economic marine livestock caught within 3 kilometers of the Thai coast	40.10	32.00	42.70	42.70	42.70
The use of ground water to the available amount	52.00	60.67	74.00	82.00	82.00
Good environmental quality	***24.57***	***20.40***	***24.49***	***31.71***	***31.71***
Proportion of good quality water resources to all water resources	25.00	18.00	18.00	40.00	40.00
Air quality in major urban areas that is below standard	18.18	9.09	28.00	28.00	28.00
Properly treated hazardous waste	30.52	34.10	27.48	27.14	27.14
Total Sustainable Development Index of Thailand	**57.66**	**56.70**	**57.83**	**62.60**	**64.33**

Source: National Economic and Social Development Board (2004)

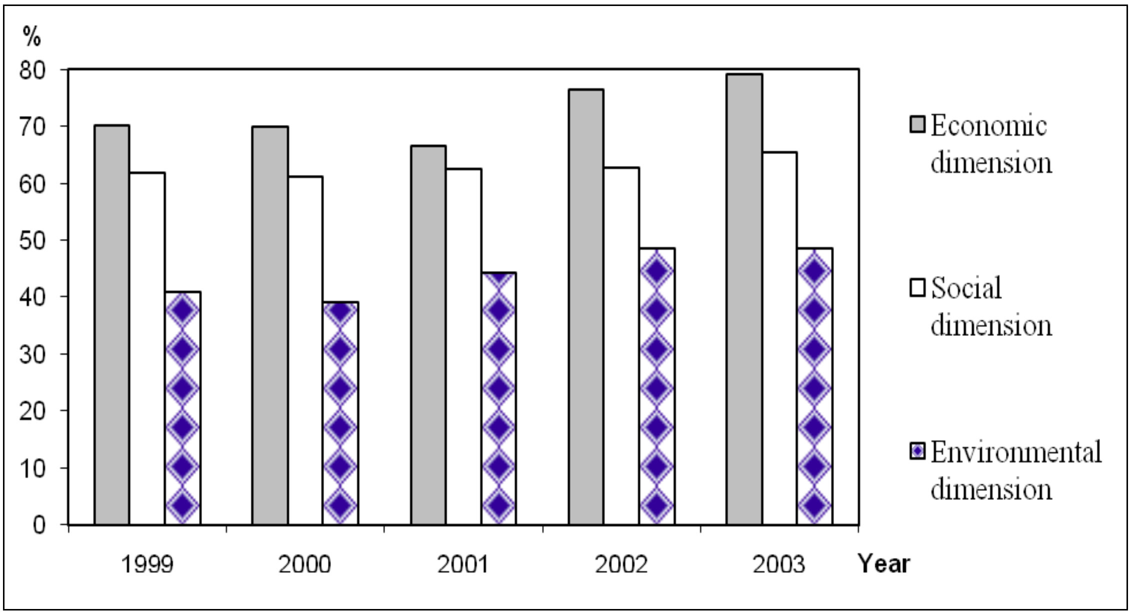

Figure 4.7 The Sustainable Development Indices of the Three Dimensions

Source: National Economic and Social Development Board (2004)

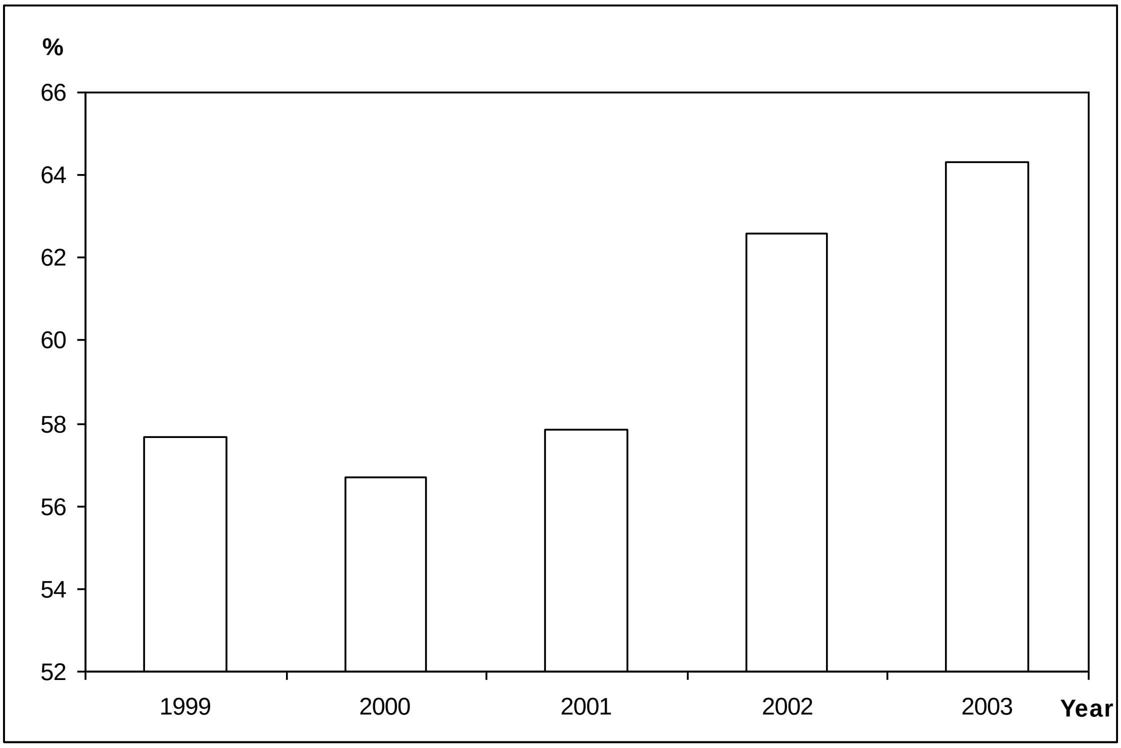

Figure 4.8 The Sustainable Development Composite Index of Thailand (1999-2003)

Source: National Economic and Social Development Board (2004)

c) Interpretation of the Results

Observing Table 4.7 and Figure 4.7, Thailand's sustainable development of the economic and social dimensions during the period from 1999 to 2003 were relatively good, but its sustainable development index of the environmental dimension failed because it fell below the 50 % mark. However, the indices of all three dimensions showed improving trends during the period. The results of the Sustainable Development Indicators and the composite indices during the period were conclusively interpreted by NESDB as follows:

> "The economic development at the macro level has better stability but the quality of economic growth and the distribution of wealth and development to all sectors remain poor. The disparity in income distribution and social inequality still affects the sustainable development of Thailand, though the living quality of Thai people is improving, especially the accessibility to healthcare, drinking water, information and better environment. However, when compared to other countries with the same level of economic development, the living quality of Thai people is still below par. People still suffer insecurity in life and property and also lack the opportunity to participate in decision-making processes of national development policies. People still overly consume goods and services and lack capacity to adapt to being a learning society.
>
> One positive sign concerning environmental dimension is that the destruction of natural resources, the reserve capital of the future generations, has been reduced, and they show trend to be

> recovered, though, over the long future. This demonstrates that the management of natural resources and environment of Thailand has been more efficient. However, the government must place greater importance on strengthening economic and social development at the grassroots level, supporting the system of monitoring natural resources by communities, building protection systems for all sectors, introducing mechanisms enabling public participation of all sectors in pushing for the sustainable development, and reforming the attitudes and the consumption and production patterns of Thai people." (NESDB, 2004)

d) Critique

The research team of this project admitted that the indicators developed in this project do not cover all factors of sustainable development. Therefore, they recommended that both the indicators and the calculation of the composite index need further improvement in order to better evaluate Thailand's sustainable development.

As mentioned previously, Thailand's approach partly deviated from the CSD Theme Indicator Framework from 2001, the most up-to-date version at the time when Thailand implemented this SDI project. It did so to suit the circumstances and conditions of the country, for many CSD's theme indicators are less applicable to Thailand. Though it did not set any indicators under the institutional dimension, two of the six CSD's indicators under the institutional dimension—Expenditure on R & D as a percent of GDP and Economic and Human Loss due to Natural Disasters—were included in its SDI's. Some of its invented indicators—Total Factor Productivity and Index of Sustainable Economic Welfare—are geared towards measuring the sustainability of its rapid economic growth, while some—Ratio of Import Goods and Ratio of Short-term Foreign Debt to Foreign Reserve—are indicators created to forewarn the government of the possible recurrence of economic crisis of 1997. It seems that Thailand gives a little more importance to social development and good governance as some of its invented indicators outside CSD's theme indicators are in the social realm. Certainly Thailand's SDI's were specially designed to be monitoring tools facilitating the Thai government in its decision-making, which is the main aim of the CSD Theme Indicator Framework.

With regard to the Sustainable Development Composite Index, it was a good attempt. However, since the chosen set of SDI's is not yet officially settled, and a set of social parameters changes through time, the created Sustainable Development Composite Index will certainly change in the future. In addition, without some perusal of Thailand's SDI's development and their methodology, the composite index, itself, tells us very little about the status of sustainable development of Thailand. At best, the high score of more than fifty per cent of the Index just points to an average achievement of the goals of Thai government development policies. The world has not set and endorsed the standard set of SDI's and the suitable weight of each indicator in the composite index is not thoroughly studied. As countries choose and create their own SDI's, the resultant composition indices of a country have not the same meaning; therefore, they cannot be meaningfully compared.

Indeed, the research team of this project admitted that the indicators developed in this project do not cover all factors of sustainable development. Therefore, they recommended that both the indicators and the calculation of the composite index need further improvement in order to better evaluate Thailand's development in a sustainability context.

4.5.5 Conclusions

When applying GS, augmented GS, GNNP, augmented GNNP and the sustainable development composite index to Thailand, the different indicators provide different answers. This is because each indicator is derived from different fundamental concepts and methods. GS and augmented GS show that the development of Thailand during the period of study, between 1993 and 2004, was sustainable because both sets of figures were all positive. On the other hand, the development of Thailand was unsustainable sometime during the period when GNNP, augmented GNNP, or the sustainable development composite index were used as indicators. A conclusion from this study is that, in the case of Thailand, the green and augmentation terms have a small effect on NNP; therefore, sustainable development of the country depends almost entirely on the conventional NNP. As Thailand faced the economic crisis in 1997, which dropped the country's NNP by 20 per cent, the sign of unsustainable development in Thailand appeared. But such a negative sign has disappeared since the NNP started to increase continuously in 2002, when the economy showed sign of recovery. Similarly, the drop of the value of sustainable development composite index in 2000 indicated that the development of Thailand was unsustainable in that year. However, the index rose again from 2001 to 2003. If we take all these five sustainable development indicators into consideration it is still unclear whether the development of Thailand is sustainable or not.

A factor that can explain the conflicting outcomes of these indicators was the severity of the Thailand's economic and financial crisis of 1997. Several other Asian countries also stumbled from the ripple effect of economic crisis. Though the crisis was the result of an indigenous mismanagement, Thailand was resilient enough to recover quickly. Thailand's resilience is certainly considered as a good sign of sustainable development. Every country in the world, developed or not, once in a while experiences an economic recession—a decline in a country's gross domestic product or negative real economic growth. We certainly cannot say that there are not countries with sustainable development in the world. Therefore, the declination of GNNP and the augmented GNNP in a short period of time might only be treated as warning indicators of unsustainable development. To make GNNP and augmented GNNP more useful as indicators of long-term sustainable development, we at least may need to incorporate the effect of business cycles into them.

With regard to the sustainable development indicators and the composite index, developed by the NESDB of Thailand, it can be said that they are useful monitoring tools as these specific micro-level indicators can help the government to mend each problem directly. Therefore, we may say that all indicators, especially genuine saving, GNNP, and sustainable development composite index, are useful policy tools for guiding Thailand to attain long-term sustainable development.

4.6 A Remark

Disregarding its sectional numbering, this chapter can be roughly divided into two parts. The first part covers a broad subject of sustainable development in general, including its history, its conceptual meanings in the views of economists, the roles of mineral resources, and its indicators. In this part the Hartwick rule, which is a necessary condition to maintain non-declining consumption per capita through time, and other necessary conditions are presented. In the second parts, the performance of Thailand with regard to such indicators of sustainable development was demonstrated. The Hartwick rule and the past performance of Thailand in sustainable development will be the bases for some of the recommendations in Chapter 8 to the Thai government on how to deal with the resource rents obtained from the exploitation of its non-renewable resources.

Chapter 5 Gypsum Resource of Thailand

5.1 Introduction

For understanding its background, problems, opportunities, and constraints in formulating policy, this chapter will firstly provide the general information about gypsum, particularly with respect to Thailand. In the latter part of the chapter, attempt is made to develop a model determining gypsum demands in Thailand and some countries that imported gypsum from Thailand. Because of the very small and incomplete data, the demand equations of the model derived from the Ordinary Least Squares technique will be very simple and should be treated as a very rough method of approximation of the demands for gypsum that is better than a guesstimate. Notwithstanding, it is not really an intended objective of this thesis to do a thorough econometric research on the demands for gypsum. However, future demands for gypsum are necessary inputs in determining the empirical solutions of the models on optimal extraction paths of gypsum resource in Thailand, the most important aim of this thesis, which will be presented in Chapter 6.

5.1.1 The Nature of Gypsum

Gypsum is a soft mineral composed of calcium sulfate dihydrate, $CaSO_4.2H_2O$. Its colour is white to grey. It has a hardness of 2 on the Mohs scale and a specific gravity of 2.2 – 2.4. By origin, gypsum can be divided into two groups: natural and synthetic gypsum. Natural gypsum is mainly found in marine evaporite, an inorganic chemical sediment that precipitates when the salty water in which it had dissolved evaporates. Synthetic gypsum is produced as a by-product of various industrial processes. It can be used as a substitute for natural gypsum, principally for plasterboard manufacturing, Portland cement production, and soil conditioning for agriculture. The major source of synthetic gypsum is Flue Gas Desulfurization (FGD) to reduce sulfur dioxide emissions from coal-fired electricity power plants. Smaller amounts of synthetic gypsum are derived as a by-product of various acid-neutralization processes.

5.1.2 Uses of Gypsum

Gypsum is utilized in two forms: raw gypsum and calcined gypsum. The major use of raw gypsum is in the production of Portland cement, where it acts as a retarder to prolong the setting time of the Portland cement. Raw gypsum is also used in manufacturing sulfuric acid, blackboard chalk, and coloured pencil. Furthermore, it is utilized in agriculture as a fertilizer and soil and water conditioner. The calcined gypsum, which is a ground gypsum roasted at 150-165°C to reduce water content from 2 molecules ($CaSO_4.2H_2O$) to ½ molecule ($CaSO_4.½H_2O$), is mainly used in manufacturing gypsum wallboard and ceramics. In developed countries, gypsum is predominantly used for wallboard, while in developing countries its major use is in the production of Portland cement. In the case of Thailand, gypsum is mainly used in the industrial sector comprising the cement industry (65 %), gypsum wallboard industry (26 %), plaster industry (5 %), and others (4 %) (Department of Primary Industries and Mines, 2006).

5.1.3 Substitutes

There are not any materials that can directly substitute gypsum in all uses. In such uses as stucco and plaster, Portland cement and lime may be substituted. Brick, glass, metallic or plastic panels, and wood are alternatives to gypsum wallboard. However, in the manufacturing of Portland cement, gypsum has no practical substitute. Synthetic gypsum is very important as a substitute for mined gypsum in wallboard manufacturing, Portland cement production, and agricultural applications (in descending tonnage order). In the U.S.A., in 2007, synthetic gypsum accounted for 22% of the total domestic gypsum supply (USGS, 2008).

5.2 Gypsum Availability in Thailand

In Thailand, the natural gypsum deposits are found in Suratthani, Nakhon Sithammarat, Phichit, Nakhon Sawan, and Loei provinces, with the estimated amounts of proven plus probable reserves as in 2006 in each province of 58, 27, 18, 132, and 36 million metric tons, respectively. The figures of Suratthani, Nakhon Sithammarat, Phichit, and Nakhon Sawan, can be classified as proven reserves for they were gathered from data of present-day mining licenses and applications for mining licenses, while that of Loei is close to be probable reserves. The gypsum deposits in Loei can be classified as marginally sub-economic deposits since they cannot compete, on price, with the deposits in the Phichit and Nakhon Sawan that are closer to industrial users of gypsum near Bangkok than them. In total, the estimated gypsum reserves (proven + probable) of Thailand as ***in 2006*** were 271 million metric tons.

As for synthetic gypsum, it is produced by two entities: the Electricity Generating Authority of Thailand (EGAT), a government enterprise that generates and distributes electricity all over the country, at its lignite-combustion power plants in Lampang province; and NFC Fertilizer Public Limited Company (NFC), a private company producing fertilizer located in Rayong province.

5.3 Gypsum Production, Export, and Domestic Consumption of Thailand

5.3.1 Natural Gypsum

In Thailand, natural gypsum is produced in 4 provinces, Suratthani, Nakhon Sithammarat, Phichit, and Nakhon Sawan and the productions from each province from 1966 to 2005 are shown in Figure 5.1. The total production increased from 27 thousand metric tons in 1966 to 7.113 million metric tons in 2005. During 1966 – 1996, before the Asian economic crisis in 1997, production increased to 8.899 million metric tons with an average annual growth rate of 26 per cent. During the period from 1997 onwards, the production decreased to 4.334 million metric tons in 1998 as a result of the Asian economic crisis, but the production increased again in 1999 after the economy recovered.

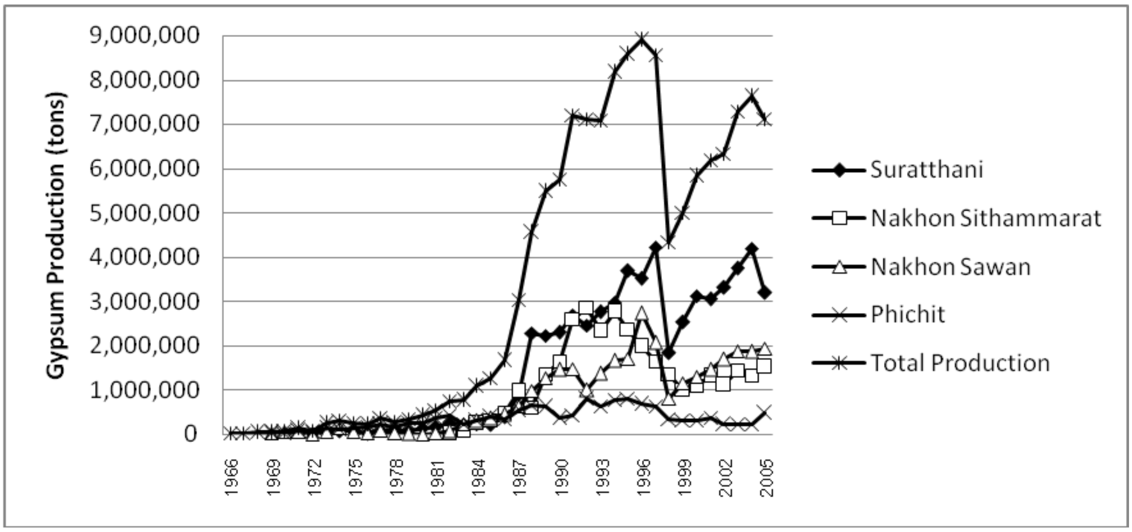

Figure 5.1 Natural Gypsum Production in Thailand by Province, 1966 – 2005

Source: Department of Primary Industries and Mines (2007)

Thailand's export and domestic consumption of natural gypsum increased from 467 and 26,545 metric tons in 1966 to 4,569,331 and 2,527,871 metric tons in 2005, respectively (see Figure 5.2). During 1966 – 1996, before the Asian economic crisis in 1997, export and domestic consumption increased to 5,977,284 and 2,410,352 metric tons, respectively, an average annual growth rate of 20.1 and 16.1 per cent, respectively. During the period from 1997 onwards, the export and domestic consumption decreased to 3,561,425 and 1,152,802 metric tons in 1998, respectively, as a result of the Asian economic crisis, but the export and domestic consumption increased again in 1999.

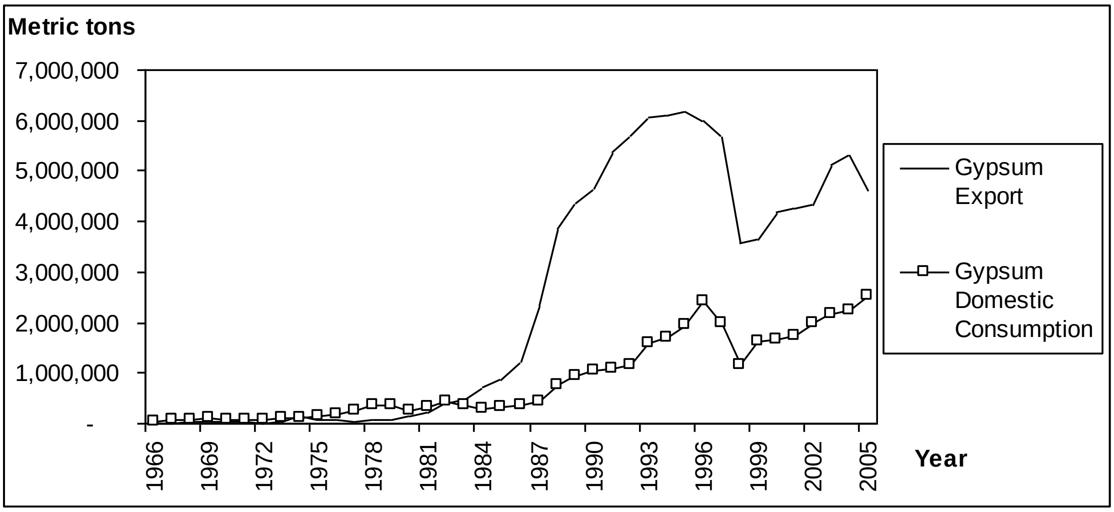

Figure 5.2 Natural Gypsum Export and Consumption in Thailand 1966 – 2005

Source: Department of Primary Industries and Mines (2007)

5.3.2 Synthetic Gypsum

a) Synthetic Gypsum Produced by EGAT

EGAT has produced synthetic gypsum since 1995 since it installed and started running the first Flue Gas Desulfurization equipment at its thirteenth electricity power plant in Lampang province, which utilizes lignite—the poorest class of coal—as its fuel. The high sulfur content in the fuel lignite, which causes a severe air pollution problem, makes Flue Gas Desulfurization necessary after EGAT enormously increased electricity production capacity at this power plant complex. At present, EGAT produces synthetic gypsum at a rate of around 3 million metric tons per annum, which is higher than the country's total consumption of gypsum. However, only a very small portion of the production has been dispatched and utilized. As a result, an estimated several hundred million metric tons of synthetic gypsum is stockpiled uselessly at the power plant complex.

The drawbacks of synthetic gypsum produced by EGAT are the same as that produced by others--its inconsistent grade, ranging from 85% to 95% $CaSO_4.1/2H_2O$; and its very high moisture content, 14 – 20% H_2O. In some uses the consistency of grade is more important than degree of purity because consistent gypsum is more convenient for blending. Furthermore, EGAT synthetic gypsum is complicated by high traces of salt (0.1% NaCl), which makes it unsuitable for plasterboard production. At present only a Portland cement plant in Lampang province, situated about 60 kilometres from the power plant complex, uses EGAT synthetic gypsum, about 30,000 – 50,000 metric tons annually. The Portland cement plant controls quality by blending synthetic gypsum with mineral gypsum, which is hauled a greater distance than EGAT synthetic gypsum. For more distant Portland cement plants, the cheap price of EGAT synthetic gypsum cannot yet compensate for the hauling cost and the burdensome blending to adjust the quality. To sum up, the distance from users is the paramount drawback of the EGAT synthetic gypsum.

b) Synthetic Gypsum Produced by NFC

Since 1997, the NFC Fertilizer Public Limited Company (NFC) has been the second source of synthetic gypsum in Thailand. It produces about 800,000 – 1,000,000 metric tons of synthetic gypsum annually as a by-product in producing phosphoric acid. The NFC controls its synthetic gypsum quality and sells it as soil conditioner for agriculture under the company brand name, Soil-Man®. NFC also sells it as a raw material for construction to other users.

5.4 World Production and Trade

The top five world rankings of gypsum producers are the United States, Iran, Canada, Spain, and China, respectively. Almost half (48 %) of the total world production in 2006 came from these five countries: United States (17.3 %), Iran (10.2 %), Canada (7.5 %), Spain (6.5 %), and China (6.1 %). Thailand ranked seventh with its share of total world production of about 5.9 %. Figure 5.3 represents the gypsum productions of the top five producing countries from 1990 – 2007. The top five world rankings of gypsum importers are the United States, Japan, Malaysia, Belgium, and Indonesia, respectively (see Figure 5.4). As for gypsum exporters, the top five world rankings are Canada, Thailand, Spain, Mexico, and Australia (see Figure 5.5). Canada, Mexico and Spain are the main sources of the United States' imported gypsum, while Thailand is the major gypsum supplier of Malaysia and Indonesia. Australia has Japan as its main client.

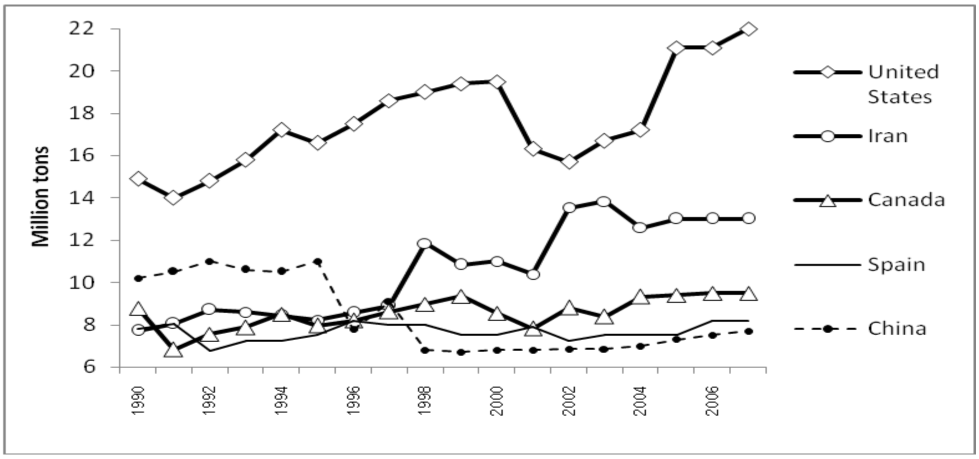

Figure 5.3 Top Five World Gypsum Productions by Country, 1990 - 2007

Source: USGS (2008)

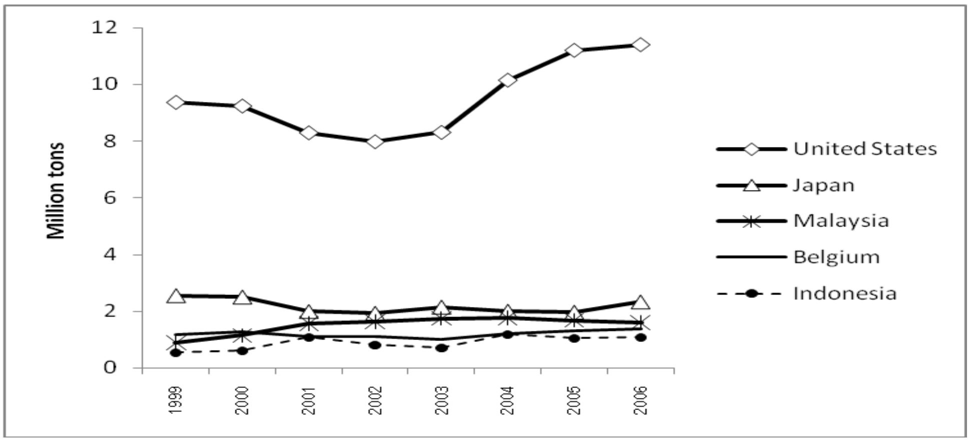

Figure 5.4 Top Five World Gypsum Imports by Country, 1999 – 2006

Source: Global Trade Information Services (2007)

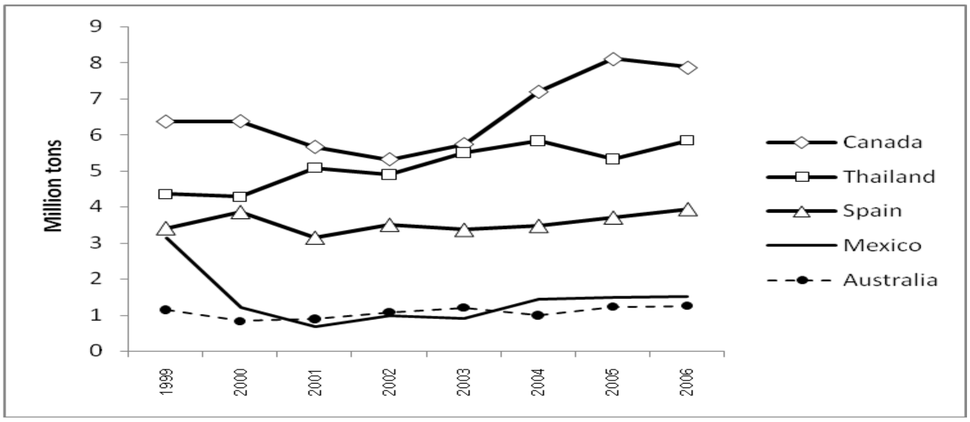

Figure 5.5 Top Five World Gypsum Exports by Country, 1999 – 2006

Source: Global Trade Information Services (2007)

5.5 Prices of Natural Gypsum in Some Important Markets

Because gypsum's deposits are normally large, close to the surface, and easily mined, gypsum production cost, in general, is low. As a result, gypsum is a low price commodity and transportation costs are an important share in the price paid by users. Freight and logistics costs can be 50% to 70% of delivered cost of mineral to customer (Barker, 2007). In other words, some faraway customers have to pay for gypsum up to 100/(100 – 70) = 3.333 times the price at a gypsum mine. For a user, distance will dictate which mine is the source of its gypsum supply. Though gypsum reserves are ample, deposits are not distributed evenly around the world. Therefore, international trade of gypsum is regional in nature. The gypsum prices paid by users in all regions are not the same all over the world and mostly not interrelated because of the huge transportation cost relative to price.

With regard to the grades of gypsum, it should be noted that gypsum is a commodity that is utilized because of its physical property. Except in some special uses, chemical grade plays no role in price determination. In most applications, users value uniformity of the mineral as the most important property. Users mostly dislike bulks of mineral with small amounts of foreign contaminants, such as pieces of shoes, sandals, wood, equipment spare parts, etc because these materials interrupt their production processes. In this study, import and Cost, Insurance and Freight (CIF)[13] prices in the U.S.A. and Japan, the two biggest gypsum consuming countries, and Free On Board (FOB)[14] prices in Thailand and Australia, which are relevant to this study, together with that of the U.S.A. are demonstrated.

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[13] Cost, Insurance and Freight (CIF) price is the selling price of the goods at a port of the buyer's country (arrival port). It includes the cost of the goods, the freight or transportation costs and the cost of marine insurance. In other words, it is the Free On Board (FOB) price at a departure port plus the freight and insurance costs from the departure port to the arrival port.

[14] Free On Board (FOB) price is the selling price of the goods put on a ship at a port of the seller's country (departure port).

5.5.1 Import and Cost, Insurance and Freight (CIF) Prices

a) United States Market

The United States has imported gypsum from three main gypsum producing countries: Canada, Mexico, and Spain. From 1993 to 2004, the average imports of gypsum into the U.S.A. from Canada, Mexico, and Spain were 5.813, 1.956, and 0.631 million metric tons, respectively. During this period, the average Cost, Insurance and Freight (CIF) prices of gypsum in constant dollars (year 2005=100) at U.S.A. ports from Canada, Mexico, and Spain were 10.48, 8.43, and 10.47 US$/metric ton, respectively. Imports of gypsum into the U.S.A. and the corresponding Cost, Insurance and Freight (CIF) prices from some countries from 1993 to 2004 are shown in Figure 5.6 and Figure 5.7.

It should be noted that Figure 5.7 confirms the apparent independence of gypsum prices in different regions of the U.S.A. that are far apart. However, when taking the huge freight and logistics costs into account, this behavior of gypsum prices may not contradict the law of one price. Most imports from Canada went to east coast plants, and Mexican sources chiefly served the west coast (USGS, 2006). The prices of gypsum at ports on the west coast of the U.S.A., which is imported from Baja California Sur and from Colima, Mexico, were mostly cheaper and fluctuated less than those at ports on the east coast, which are imported from Nova Scotia, Canada, and Spain. The prices of the imports from Canada and Spain serving the same region were nearly identical and moved mostly in the same direction. The higher cost of production at Nova Scotia, Canada, because gypsum ore there has to be processed through a heavy media plant, may be the cause of the higher prices on the east coast. This might also be the reason why gypsum from far away Spain was more or less competitive and could seep into the U.S.A. in small amounts as shown in Figure 5.6.

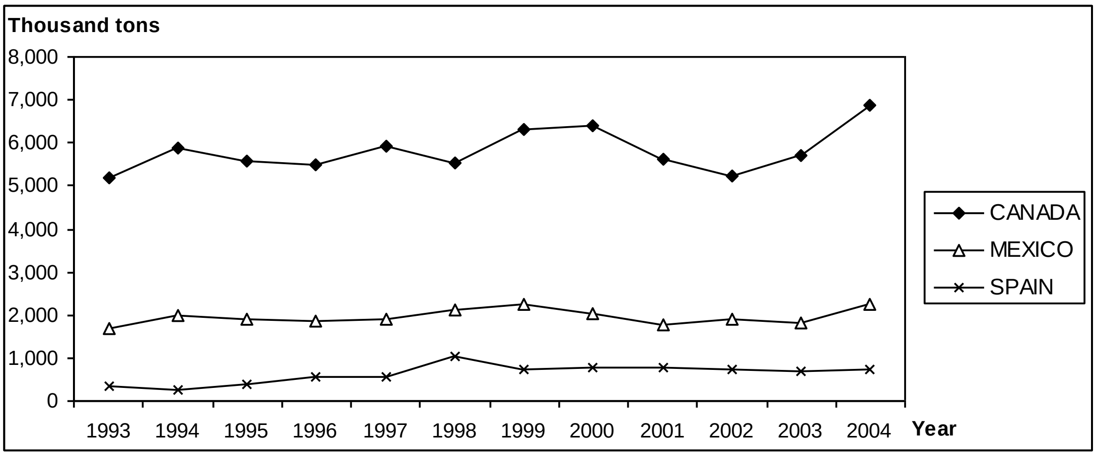

Figure 5.6 Imports of Gypsum into the U.S.A. by Country, from 1993 to 2004

Source: USGS (2006)

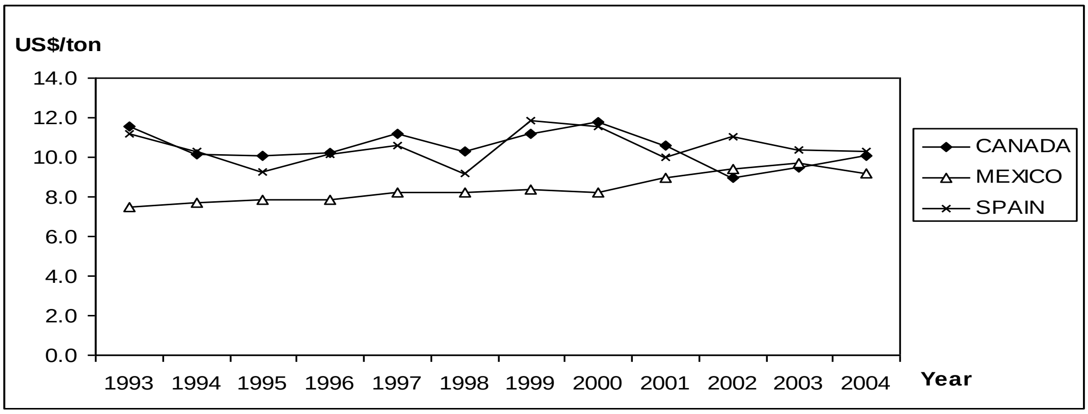

Figure 5.7 The CIF Prices of Gypsum in Constant Dollars (year 2005=100) at U.S.A. Ports by Country, from 1993 to 2004

Source: USGS (2006)

b) Japanese Market

Japan has imported gypsum mainly from Thailand and Australia. Figure 5.8 and Figure 5.9 show the imports of gypsum into Japan and the corresponding Cost, Insurance and Freight (CIF) prices from Thailand and Australia, from 1988 to 2005. In

Figure 5.8, the gypsum import statistics into Japan demonstrated two sharp contrast periods: the first period from 1988 to 1997 and the second period from 1998 to 2005. During the first period, when the Thai gypsum was noticeably cheaper than that of Australian as shown in Figure 5.9, imports from Thailand were high while those from Australia were very low. The reason that the imports from Australia, with a price disadvantage, did not cease may be due to the commercial strategy of gypsum users in Japan to keep an alternative source of the vital raw material open. However, during the second period, when prices from the two exporting countries were roughly on par, the imports from Thailand decreased sharply while that from Australia increased considerably. The cause of this phenomenon was that, Yoshino Gypsum Co., Ltd., the largest plasterboard producer in Japan with the market share of 78% of the total plasterboard sales in Japan, concluded an agreement with Dampier Salt, Western Australia, Australia's largest natural crude gypsum producer, in 1995. After Dampier Salt started production and supplied gypsum to Yoshino Gypsum Co., Ltd., the company stopped imports from Thailand. As a result, the imports of gypsum from Thailand into Japan dropped from an average annual tonnage of 3,093,428 metric tons during the first period to only 994,639 metric tons during the second period. In contrast, the imports of gypsum from Australia into Japan increased substantially from an average annual tonnage of 54,933 metric tons during the first period to 928,771 metric tons during the second period. After Yoshino Gypsum Co., Ltd., shifted its gypsum supply source from Thailand to Australia, the advantage of Cost, Insurance and Freight (CIF) prices of gypsum from Thailand disappeared. The roughly on par Australian and Thai Cost, Insurance and Freight (CIF) prices of gypsum in Japan during the second period might be the result of the agreement between the two trading partners.

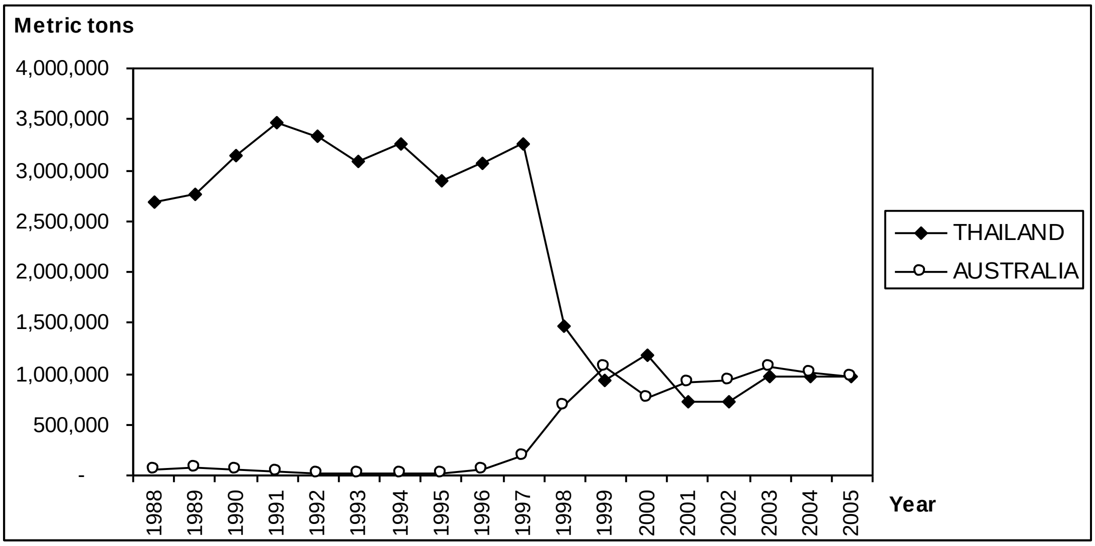

Figure 5.8 The Imports of Gypsum into Japan from Thailand and Australia, from 1988 to 2005

Source: Ministry of Finance, Japan (2006)

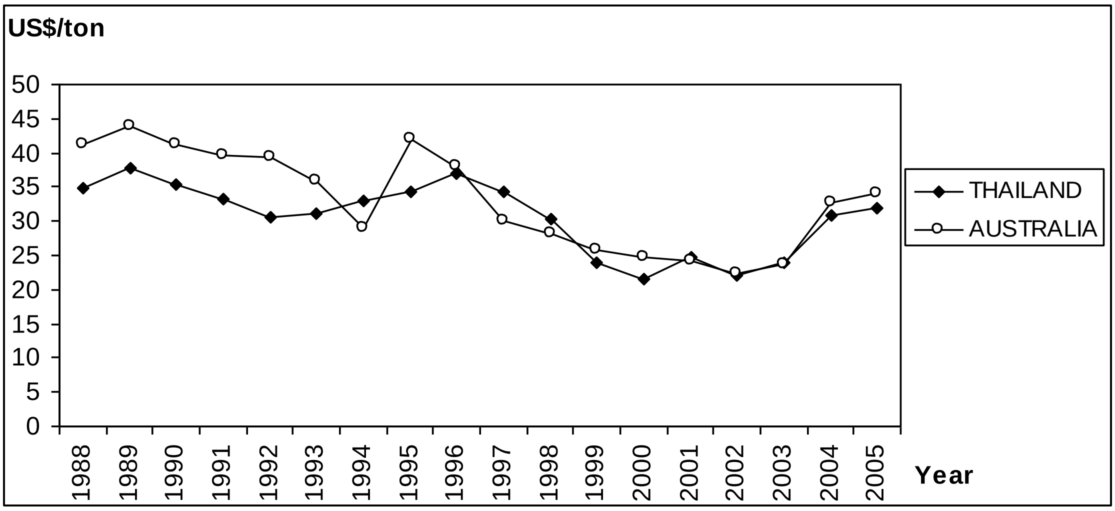

Figure 5.9 The CIF Prices of Gypsum in Constant Dollars (year 2005=100) at Japanese Ports from Thailand and Australia, from 1988 to 2005

Source: Ministry of Finance, Japan (2006)

5.5.2 Free On Board (FOB) Prices

Due to its vast area and the proximity of gypsum users in its neighbour, the U.S.A. also exports some of its gypsum. That is the reason why the U.S.A. has Free On Board (FOB) prices of gypsum, (FOB price is the price of export at the port of seller's country or departure port). The FOB prices of gypsum in three gypsum-producing countries: Thailand, Australia and U.S.A., from 1988 to 2004 are shown in Figure 5.10. During the period, the average annual FOB prices in constant dollars (year 2005=100) in the U.S.A., Australia, and Thailand are 8.9, 14.3, and 15.5 US$/metric ton, respectively. We can see that FOB prices in Thailand and Australia were closely correlated, and the average FOB price per metric ton in Thailand was 1.2 US$ higher than that in Australia. The FOB price in the U.S.A. was significantly lower and less volatile than those in Thailand and Australia. The different trends and movements of the FOB prices in the two regions, Thailand and Australia versus U.S.A., confirm that international trade of gypsum is regional in nature.

The costs of freight and insurance for transporting crude gypsum from Thailand to Japan and from Australia to Japan during that period are shown in Figure 5.11. The costs are really the differences between the import (CIF) prices into Japan and the FOB prices in the two countries. The average freight and insurance costs[17] in constant dollars (year 2005=100) for transporting gypsum to Japan from Australia and Thailand during the period from 1988 to 2004 were 18.7 and 15.0 US$/metric ton, respectively. The 3.7 US$/metric ton advantage of the average freight and insurance cost to Japan from Thailand over that from Australia was due to shorter hauling distance. The location of Thailand, which is close to the busy shipping lane from the West to the Far East, may also contribute to the lower freight cost from Thailand. We can see that the average freight and insurance costs to Japan from Thailand and Australia were even a little bit higher than the average FOB prices in Thailand and Australia. This means that distance plays an important role in determining the CIF prices of gypsum to the consumers in the Far East, and Thailand has this distance advantage over Australia.

[17] Freight and insurance costs are difference between Cost, Insurance and Freight (CIF) and Free On Board (FOB) prices.

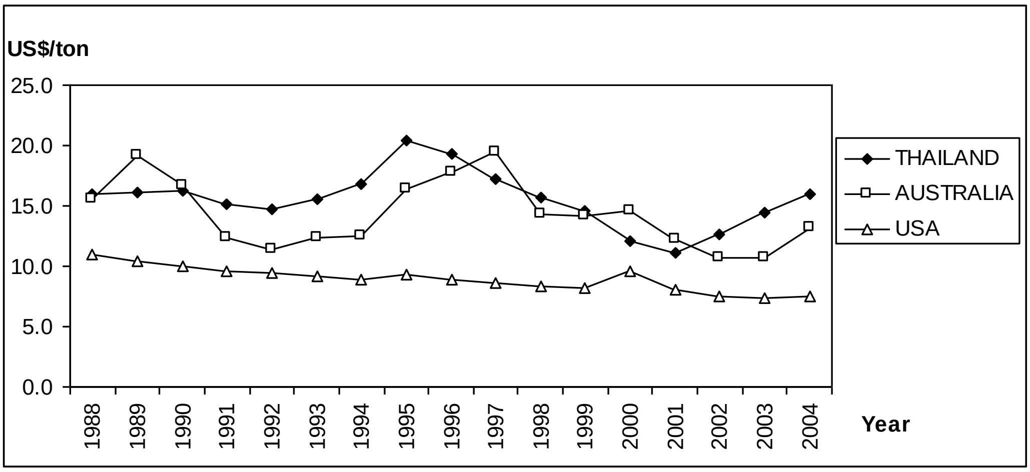

Figure 5.10 The FOB Prices of Gypsum in Constant Dollars (year 2005=100) in Thailand, Australia and U.S.A., from 1988 to 2004

Sources: ABARE (2006); USGS (2006); and Department of Primary Industries and Mines (2007)

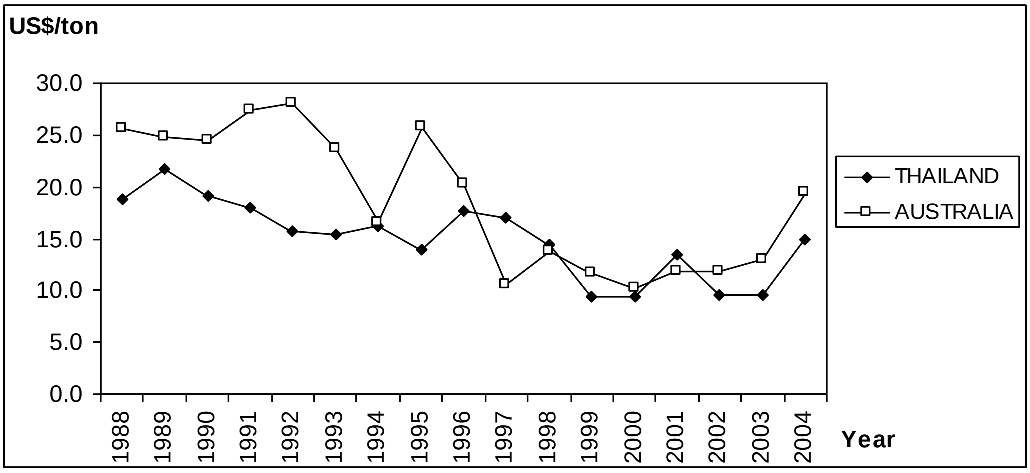

Figure 5.11 The Costs of Freight and Insurance in Constant Dollars (year 2005=100) for Transporting Crude Gypsum to Japan from Thailand and Australia, from 1988 to 2004

Sources: ABARE (2006); Ministry of Finance, Japan (2006); and Department of Primary Industries and Mines (2007)

5.6 A Gypsum Demand Model for Thailand and Its Client Countries

The main purpose of the thesis is to use economic theories to set long-term strategies and plans for the government of Thailand to manage its gypsum mineral resources. An economic model determining the optimal depletion path of Thailand's gypsum resources will be developed in the next chapter. In such a model, the demand for Thailand's gypsum resources needs to be known in defining the optimal path of extraction or depletion of the gypsum resources. Therefore, a gypsum demand estimate for Thailand and the countries buying Thai gypsum will be defined below. ***However, as stated in section 5.1 'Introduction' that becauseof the very small and incomplete data, the demand equations to be determined will be very simple and should be treated as a very rough method of approximation of the demands for gypsum that is better than a guesstimate. The approximate gypsum demand forecast obtained from this chapter will be used for determining the optimal extraction paths of gypsum in Chapter 6 later.***

5.6.1 A Review of Empirical Studies on Demands for Minerals and Metals

Journals were searched back to year 1990 to find empirical studies on demands for minerals and metals. Only eleven papers were discovered attempting to determine the consumption or demand functions of some metals, while ***similar studies on industrial minerals or ball park estimates of parameters concerning future consumption or demand of gypsum have not been found***. Methodologies used in these eleven papers can be divided into two categories: 1) An econometric model called 'Intensity of Use (IU) Model or Technique' and 2) Models with double-log demand functions.

a) Intensity of Use (IU) Model

There were six papers of five main authors employing IU models: Roberts (1990) on steel consumption in U.S.A.; Valdes (1990) on steel consumption in Australia; Roberts (1996) on world consumption of aluminium, copper, lead, and zinc; Crompton (2000) on steel consumption in Japan; Guzman *et al*. (2005) on copper consumption in Japan; and Rebiasz (2006) on steel consumption in Poland. The model was developed from the intensity of use hypothesis firstly suggested by W. Malenbaum (Valdes, 1990). The most critical point of this model is that it outright discarded price factors while GDP was weighted heavily in forecasting future consumption of a metal. Note that all five main authors of the papers in this category have sufficient knowledge of economics since they either were teaching at relevant departments in universities or were mineral economists by profession.

In the IU model, the metal requirements of the final products purchased by consumers need to be determined. The metal consumption is disaggregated by end-use industries. Assumed there are *n* metal consuming industries, a basic model can be formulated as follows.

$$M_t = \sum_{i=1}^{n} \left(\frac{M_{it}}{P_{it}} \times \frac{P_{it}}{GDP_t} \times GDP_t \right) \tag{5.1}$$

or $$M_t = \sum_{i=1}^{n} \left(MCP_{it} \times PCI_{it} \times GDP_t \right)$$

or $$M_t = IU_t \times GDP_t$$

where M_{it} = metal quantity consumed by industry *i* at time *t*;

M_t = metal consumed across all *n* metal consuming industries at time *t*;

P_{it} = total value of production in industry *i* at time *t*;

GDP_t = Gross Domestic Product at time *t*;

$MCP_{it} = M_{it}/P_{it}$ = material composition of product for industry *i* at time *t*,

$PCI_{it} = P_{it}/GDP_t$ = product composition of income for industry i at time t, and

$IU_t = M_t/GDP_t$ = an average intensity of metal use across n metal consuming industries at time t.

b) Models with Double-Log Demand Functions

Five papers included prices into their constructed double-log demand functions together with some additional parameters. The authors invented a model that utilized the Divisia index approach with only two variables, own prices and quantities in his study on world demands on aluminium, copper, lead, nickel, tin, zinc, and steel (Tcha and Takashina, 2002). Others—Suslick and Harris (1990) on Brazil's demand for aluminium; Vial (1992) on U.S.A.'s demand for copper; Batchelor and Gulley (1995) on the demand for steel in high-income countries; and Pei and Tilton (1999) on the demands for aluminium, copper, lead, nickel, and tin in the both groups of high-income and low-income countries—put some other parameters into their unique double-log demand functions. Table 5.1 summarizes the parameters or variables employed by various authors.

Table 5.1 The Relevant Variables in the Metal Demand Functions Constructed by Various Authors

Author	GDP	Own price	Substitute price	Previous year consumption	Energy price	Time as a proxy for technical change	Industrial production using the metal
Suslick and Harris (1990)	✓	✓				✓	
Vial (1992)		✓	✓		✓		✓
Batchelor and Gulley (1995)	✓	✓					
Pei and Tilton (1999)	✓	✓	✓	✓		✓	
Tcha and Takashina (2002)		✓		✓			

i) Divisia Index Approach

Tcha and Takashina (2002) used Divisia index approach to analyze demand patterns of major metals. The Divisia index approach was an attempt to address the problem arisen from the move of a demand curve through time as a result of change in consumers' incomes. A demand function under the Divisia index approach is as follows.

Let p_{it} be the price of metal i ($i = 1, \ldots, n$) in year t, and q_{it} be the quantity consumed per capita of metal i in year t. $\sum_{i=1}^{n} p_{it}q_{it}$ is the total expenditure or income and $w_{it} = p_{it}q_{it} / \sum_{i=1}^{n} p_{it}q_{it}$ is the budget share of metal i in year t. Then the arithmetic average of the budget share of metal i over the years t-1 and t is $\overline{w}_{it} = \frac{1}{2}(w_{it} + w_{i,t-1})$.

The log-change in the price of metal i from years t-1 to t is $Dp_{it} = \ln p_{it} - \ln p_{i,t-1}$ and the log-change in the quantity of metal i from years t-1 to t is $Dq_{it} = \ln q_{it} - \ln q_{i,t-1}$.

The Divisia price index is a budget-share-weighted average of the n price log-changes, $DP_t = \sum_{i=1}^{n} \overline{w}_{it} Dp_{it}$, and the Divisia volume index is $DQ_t = \sum_{i=1}^{n} \overline{w}_{it} Dq_{it}$. A double-log demand equation for metal i is as follows:

$$Dq_{it} = \alpha_i + \eta_i DQ_t + \gamma_i Dp_{it}^{*} + \sum_{j=1}^{k} \beta_{ij} d_{ij} + \varepsilon_{it} \tag{5.2}$$

where α_i = a constant term representing an autonomous trend of metal i,

η_i = the income elasticity of demand for metal i,

γ_i = the own-price elasticity of demand for metal i,

d_{ij} = the dummy variable of metal i in year j,

β_{ij} = the coefficient of the dummy variable of metal i in year j,

ε_{it} = a disturbance term of metal i in year t, and

$Dp_{it}^{*} = Dp_{it} - DP_{t} =$ the log-changes in the relative price of metal *i* defined as the nominal change deflated by the Divisia index.

The empirical results of this paper were summarized by the authors as follows:

> "The consumption pattern of seven major metals--steel, aluminum, copper, lead, nickel, tin and zinc--has frequently violated the law of demand in the late 20th century. ….. Divisia price–quantity covariance indexes report that the price and quantity consumed moved frequently in the same direction, and the elasticity approach shows that the own-price elasticities are extremely small and insignificant, while income elasticities are significant."

Disregarding their poor levels of statistical significance, the results of this study show the own-price elasticities of the world demand for those metals were between -0.004 for aluminum to -0.064 for tin. By comparison, the paper found that the income elasticities of the world demand for those metals were about +1, ranging from +0.674 for lead to +1.286 for nickel, with all passing the 1 % level of statistical significance. The results were even worse when the world was partitioned into regions, for many figures of own-price elasticities of demand for some metals in some regions had positive values that contradict economic theory of normal demand. The complete price elasticities of demand for aluminium, copper, lead, nickel, tin, zinc, and iron obtained from this study are shown in Table 5.2.

Table 5.2 Income and Price Elasticities of Demands for Metals

Metal	Income elasticity		Price elasticity	
	With a constant term in the function	Without a constant term in the function	With a constant term in the function	Without a constant term in the function
Aluminium	0.848	0.971	0.004	-0.009
Copper	0.846	0.867	-0.025	-0.025
Lead	0.674	0.615	-0.006	0.001
Nickel	1.286	1.321	-0.047	-0.049
Tin	0.911	0.833	-0.064	-0.053
Zinc	0.945	0.952	-0.020	-0.020
Steel	1.030	1.024	-0.012	-0.013

Source: Tcha and Takashina (2002)

ii) Other Double-Log Demand Models

Suslick and Harris (1990) ran a regression on aluminium demand in Brazil from 1950 to 1987, in the double-log form, as follows:

$$D_t = 4.5277\,\mathrm{x}10^{-6} Y_t^{1.3587} Pw_t^{-0.0824} \tau_t^{0.3359} \tag{5.3}$$

where D_t = aluminium demand,

Y_t = gross domestic product (billion 1980 US$),

τ_t = time as a proxy for technical change, and

Pw_t = constructed price obtained through the following equation:

$$\ln Pw_t = -7.6227 + \ln Pal_t(2.0472.x_{1t} + 2.1057.x_{2t}) - \ln Pal_t.\ln Pcu_t(0.1365.x_{1t} + 0.1442.x_{2t})$$

where Pal_t = aluminium price at London Metal Exchange,;

Pcu_t = copper price at London Metal Exchange, as a substitute price; and

x_{1t} and x_{2t} are dummy variables defined in the following way:

$x_{1t} = 1,\ 1950 \le t \le 1979$ and $x_{1t} = 0,\ 1979 < t \le 1987$

$x_{2t} = 0,\ 1950 \le t \le 1979$ and $x_{2t} = 1,\ 1979 < t \le 1987$

The authors used constructed prices because price regulation was imposed from year 1979 onwards. A result shows that ***the constructed price elasticity of demand was***

-0.0824, while the income elasticity of demand was 1.3587, and the elasticity of demand with regard to technical change is 0.3359.

Vial (1992) ran a regression on copper demand in the U.S.A. from 1967 to 1989 as follows:

$$\ln CU_t = \alpha_0 + (\alpha_1 + \alpha_2 t)\ln Q_t + \sum_{i=0}^{N}\alpha_{3i}\ln PCU_{t-i} + \sum_{i=0}^{S}\alpha_{4i}\ln PSUS_{t-i} + \sum_{i=0}^{T}\alpha_{5i}\ln PE_{t-i} + U_t \qquad (5.4)$$

where CU_t = the demand for refined copper in year t,

Q_t = an appropriate index of industrial production in year t,

PCU_t = the price of copper in year t,

$PSUS_t$ = the price of materials that compete with copper in the uses of this particular industry in year t,

PE_t = the price of energy in year t, and

U_t = an error term in year t.

The author divided industrial sectors into five main end-uses of refined copper: electrical products, transportation equipment, industrial equipment, construction, and general products. The elasticities of demands with regard to various variables of all five sectors and the aggregate are shown in Table 5.3. The results show that the elasticities of demand with respect to industrial production were in the range of 0.646 to 2.072. ***Except for the transportation equipment sector, the own price elasticities of demand were inelastic*** while cross-price and energy price elasticities of demand were in the range of 0.088 to 1.232 and -0.111 to -1.238, respectively.

Table 5.3 Elasticities of Demand for Copper in the U.S.A. with Respect to Various Variables

Sector	Elasticity with respect to industrial production using copper	Price elasticities		
		Own	Substitute	Energy
Electrical products	1.464	-0.103	0.787	-0.323
Transportation equipment	1.212	-1.050	0.647	-1.202
Industrial equipment	1.384	-0.607	1.232	-1.238
Construction	1.092	-0.843	1.102	-0.389
General products	0.646	-0.416	0.521	-0.572
Aggregate	2.072	-0.188	0.088	-0.111

Source: Vial (1992)

Batchelor and Gulley (1995) ran regressions on gold jewellery demand in high-income countries from 1978 to 1993 as follows:

$$\ln(D_{it}) = \beta_{0i} + \beta_{1i}\ln(Y_{it}) + \beta_{2i}\ln(G_{it}/P_{it}) + u_{it} \tag{5.5}$$

$$\ln(D_{it}) = \beta_{0i} + \beta_{1i}\ln(Y_{it}) + \beta_{2i}\ln(G_{it}/P_{it}) + \beta_{3i}\ln(D_{it-1}) + \beta_{4it}$$
$$+ \beta_{5i}\ln(G_{it+1}/G_{it}) + \beta_{6i}\ln(G_{it}/G_{it-1}) + u_{it} \tag{5.6}$$

where D_{it} = the quantity of gold jewellery demand,

Y_{it} = the total income or expenditure of consumers,

G_{it} = the price of gold jewellery,

P_{it} = an index of the general price level,

β_{4it} = time trend,

G_{it+1}/G_{it} = future change of gold price,

G_{it}/G_{it-1} = past change of gold price, and

u_{it} = an error term, with the subscripts indicating that variables refer to country i and year t.

Equation 5.5 was estimated by Ordinary Least Squares (OLS) but the problem that cov (u_{it}, u_{jt}) ≠ 0, for $(i,t) \neq (j,t)$, occurred. The authors used Zellner's Seemingly Unrelated Regression, SURE (Zellner, 1962), technique to eliminate the problem.

SURE were used to solve the equations 5.5 and 5.6. The addition of several variables—lagged dependent variable (previous year consumption), taste trend, future and past changes of gold price—improved the fit of the estimated equations. The price elasticities of demands with respect to various variables obtained from equation 5.6 are shown in Table 5.4. Table 5.4 shows that the income elasticities of demand were highly elastic for all countries while ***the price elasticities of demand were inelastic***. ***This paper considers both cross-section and time-series data and the resulted price elasticities of demand for the metals correspond to those from other papers.***

Table 5.4 Elasticities of Demands for Gold Jewellery with Respect to Various Variables

Variable	USA	Japan	Germany	France	Italy	UK
Consumer income or expenditure	3.24	6.74	1.15	2.24	3.89	4.32
Price of gold	-0.58	-0.71	-0.64	-0.20	-0.88	-0.89
Previous year consumption				0.28		
Time trend	-0.06	-0.19	-0.03		-0.09	-0.12
Future change of gold price	0.07			0.48		
Past change of gold price		-0.12	0.27			

Source: Batchelor and Gulley (1995)

Pei and Tilton (1999) ran regressions on metal demands by using a partial adjustment model. The partial adjustment model assumes that long-run price and income elasticities of demand are larger than those for short-run. It attempts to distinguish between the actual demand over a given time period t (Q_t) and the long-run equilibrium, toward which demand is moving during the same period (Q_t^*).

The long-run equilibrium demand is as follows:

$$\ln Q_t^* = \alpha_0 + \alpha_1 \ln P_t + \alpha_2 \ln SP_t + \alpha_3 \ln Y_t + \varepsilon_t \tag{5.7}$$

where Q_t^* = long-run equilibrium demand in period t,

P_t = the commodity's own price in period t,

SP_t = the price of a substitute in period t,

Y_t = income in period t, and

ε_t = an error term in period t.

The partial adjustment model assumes that the change in actual demand between any two periods, t-1 and t, is only some fraction (λ) of the difference between the logarithm of actual demand in period t-1 and the logarithm of the long-run equilibrium demand in period t. That is,

$$\ln Q_t - \ln Q_{t-1} = \lambda(\ln Q_t^* - \ln Q_{t-1}) \qquad \text{where } 0 < \lambda < 1 \tag{5.8}$$

Substituting equation 5.7 into equation 5.8 gives,

$$\ln Q_t = \beta_0 + \beta_1 \ln P_t + \beta_2 \ln SP_t + \beta_3 \ln Y_t + \beta_4 \ln Q_{t-1} + \varepsilon_t \tag{5.9}$$

The time variable is included into equation 5.9, to capture the combined effect on metal demand of technological change and consumer preferences, as follows.

$$\ln Q_t = \beta_0 + \beta_1 \ln P_t + \beta_2 \ln SP_t + \beta_3 \ln Y_t + \beta_4 \ln Q_{t-1} + \beta_5 T + \varepsilon_t \tag{5.10}$$

where Q_t = actual demand in period t,

P_t = the commodity's own price in period t,

SP_t = the price of a substitute in period t,

Y_t = income in period t,

T = time variable, and

ε_t = an error term in period t.

Both equations 5.9 and 5.10 were run by the method of Ordinary Least Squares and when serial correlation occurred the method of Generalized Least Squares was used. The resulted income, own price, and cross-price elasticities of demands for aluminium, copper, lead, nickel, tin, and zinc for high and low-income countries obtained from equations 5.9 and 5.10 are shown in Table 5.5. For high-income countries, the average income elasticities of demand were underestimated when the time trend was omitted. On the other hand, for low-income countries, except for tin, the average income elasticities of demand were overestimated when the time trend was omitted. We can see that, from Table 5.5, ***the income elasticities of demands were substantial but some were inelastic, while the own price and cross-price elasticities of demands for some metals were very small (highly inelastic) and others were abnormally positive. The resulted price elasticities of demand for metals in this paper correspond to those from other papers.***

Table 5.5 Average Short-Run Income, Own Price, and Cross-Price Elasticities of Demands for Metals

Metal	Income Elasticity of Demand				Own Price Elasticity of Demand				Cross-Price Elasticity of Demand			
	High-income countries		Low-income countries		High-income countries		Low-income countries		High-income countries		Low-income countries	
	Without time variable	With time variable	Without time variable	With time variable	Without time variable	With time variable	Without time variable	With time variable	Without time variable	With time variable	Without time variable	With time variable
Aluminum	1.026	2.210	3.264	0.878	0.00	-0.02	0.019	0.317	0.10	0.05	0.401	0.373
Copper	0.232	1.450	2.009	-0.008	0.11	0.02	-0.025	0.188	-0.09	-0.09	-0.011	0.142
Lead	0.134	0.680	1.578	0.465	0.08	0.06	-0.056	-0.023	0.00	0.00	0.000	0.000
Nickel	0.662	1.923	1.156	-0.587	-0.06	-0.03	-0.313	-0.313	0.14	0.07	0.718	0.718
Tin	-0.204	1.086	-0.635	0.548	-0.01	-0.03	-0.283	-0.151	0.04	-0.04	0.137	0.282
Zinc	0.386	1.922	1.772	-0.995	0.01	0.01	0.158	0.318	0.02	-0.01	-0.025	0.256

Source: Pei and Tilton (1999)

5.6.2 An Assumption and a General Model

A general demand model for Thailand and its client countries will be based on the representative agent assumption, which treats the behaviour of a typical individual as that of the aggregate. For the representative individual, a demand function for a good can be written as:

$$q_t = \mathrm{F}(I_t, P_t, Os_t) \qquad (5.11)$$

where q_t denotes the quantity of the good consumed at time t,

P_t denotes the price of the good at time t,

I_t denotes the income of the individual at time t, and

Os_t denotes the other factors.

If the good is mineral gypsum, therefore, under the representative agent assumption we have:

$$q_t = \frac{Q_t}{POP_t}, \text{ and}$$

$$I_t = y_t$$

where Q_t is the aggregate quantity of mineral gypsum consumed in the nation at time t,

POP_t is the population of the nation at time t, and

y_t is the Gross Domestic Product (or Income) per capita of the nation at time t.

Hence the demand function (equation 5.11) for gypsum in a nation is as follows:

$$q_t = \frac{Q_t}{POP_t} = F(y_t, P_t, Os_t) \qquad (5.12)$$

P_t in this gypsum demand model should be the gypsum price in an individual nation. In other countries, besides Thailand, such prices should directly correlate to the gypsum price in Thailand and Australia, the sources of imported gypsum. Therefore, P_t^{TH}, the gypsum price in Thailand at time t and P_t^{A}, the gypsum price in Australia at time t, may replace P_t in the model. Note that P_t^{TH} and P_t^{A} are the prices of the same commodity demanded in total by the representative individual; therefore, neither one is the price of a substitute.

With regard to the other factors, Os_t, there are the following four possible relevant factors that need to be considered:

1) P_t^S = the price of synthetic gypsum, a substitute for mineral gypsum, at time *t*;
2) *t* = time, representing the changes in technology and consumer taste;
3) x_t = the construction expenditure of the representative individual at time *t*, which is represented by the country's GDP of the construction industry per capita; and
4) m_t = the cement consumption of the representative individual at time *t*, which is represented by the country's cement production per capita = $\frac{CM_t}{POP_t}$, where CM_t is the total national cement production at time *t*.

Therefore, equation 5.12 can be rewritten as follows:

$$q_t = \frac{Q_t}{POP_t} = F(y_t, t, P_t^{TH}, P_t^A, P_t^S, x_t, m_t) \qquad (5.13)$$

Equation 5.13 states that gypsum consumption per capita is a function of GDP per capita, time, gypsum price at Thai ports, gypsum price at Australian ports, the price of domestic synthetic gypsum, construction expenditure per capita, and cement production per capita. However, in running the model, the variable P_t^S , the price of synthetic gypsum at time *t*, has to be excluded because of the lack of data. Its elimination is not really critical since synthetic gypsum has a rather high purifying cost that makes it less competitive with mineral gypsum. Furthermore, synthetic gypsum is not technologically a complete substitute for the mineral gypsum in the wallboard production.

Finally, there are seven relevant variables to be considered in the following three possible demand equations:

$$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_3 P_t^{TH} + \beta_4 P_t^A + \beta_5 x_t + \beta_6 m_t \quad (5.14)$$

$$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_7 \frac{P_t^{TH}}{P_t^A} + \beta_5 x_t + \beta_6 m_t \quad (5.15)$$

$$\ln q_t = \gamma_0 + \gamma_1 \ln y_t + \gamma_2 t + \gamma_3 \ln P_t^{TH} + \gamma_4 \ln P_t^A + \gamma_5 \ln x_t + \gamma_6 \ln m_t \quad (5.16)$$

If mineral gypsum is a normal good, β_1 and γ_1 are expected to be positive since gypsum demand should increase when the income of the representative agent increases. The expected signs of β_2 and γ_2 can be either positive or negative since gypsum demand may react to technological improvement and change in taste either way. Based on the law of demand, when P_t or its representatives, P_t^{TH} and P_t^A, increase q_t should decrease, and vice versa. Therefore, the expected signs of β_3, β_4, γ_3, and γ_4 should be negative. With regard to β_5, β_6, γ_5, and γ_6, they are expected to be positive because when construction expenditure and/or cement consumption of the representative individual increases, the gypsum consumption would increase too. Of the relative price factor, β_7, the expected sign, in the equation 5.15, is ambiguous.

5.6.3 Testing the Model

Equations 5.14, 5.15, and 5.16 are estimated by putting in the 1990 - 2006 data from Thailand and the other seven countries mainly importing gypsum from Thailand: Indonesia, Japan, Korea, Malaysia, the Philippines, Taiwan, and Vietnam. The GDP and GDPPC figures are provided by the International Monetary Fund (IMF). The data of domestic consumption of gypsum of Thailand are from the Department of Primary Industries and Mines. For other countries the consumption figures are calculated from the following equation, consumption = domestic production + import – export.

The source of gypsum domestic production data is the US Geological Survey (USGS), while the gypsum imports and exports are provided by Global Trade Information Services.

After running Ordinary Least Squares regression of the equations 5.14, 5.15, and 5.16 of all seven countries, there is no equation of any countries that all of its coefficients have the right signs and the t-statistics significance at the 95 per cent level of confidence. Therefore, some variables will be eliminated. At this stage there is no obvious reason for choosing between the linear function and logarithmic forms. But the aim of this chapter is to have reasonable demand functions for solving mathematically complex models in the next chapter that requires integral calculus. Therefore, the linear function form of equations 5.14 or 5.15 is adopted because of its easiness to be performed by integral calculus. The results of the nonlinear equation 5.16 are to be discussed just a little bit here, with respect to the elasticities of demand, q_t, but the equation will not be further processed and adopted.

a) An Analysis of the Logarithmic Demand Function

The t-statistics and the values of all coefficients of equation 5.16 of the seven countries importing gypsum from Thailand are shown in Tables C.40 and C.41. We can see that the coefficients of P_t^A and x_t of all countries, which are the elasticities of q_t with respect to P_t^A and x_t, are not statistically different from zero. This means that, while holding other variables constant, changes in gypsum price in Australia and construction expenditure of people did not affect individual gypsum consumption in all countries statistically. The reasons behind these results were that these countries imported just small amounts of gypsum from Australia, and the country's GDP of construction industry per capita might include a huge government expenditure per capita on highway and other infrastructure construction that did not use Portland cement much.

The coefficients of equation 5.16 whose t-statistics are significant at the 95 per cent level of confidence can be divided into two groups, having right and wrong signs as shown in Table 5.6. They can be interpreted as follows:

Table 5.6 Significant Coefficients of Variables in the Equation 5.16

Having the right sign			Having the wrong sign		
Coefficient	Country	Value	Coefficient	Country	Value
γ_1	Malaysia Vietnam	0.786 1.058	γ_1	Japan	-0.789
γ_2*	Indonesia Korea Philippines	0.052 0.176 0.062	γ_3	Japan	0.336
γ_6	Japan Taiwan	1.117 1.321			

Note: * The sign of γ_2 can either be positive or negative for gypsum consumption may react to technological improvement and change in taste either way.

(i) For the values of γ_1 of the variable y_t, which are the income elasticities of demand:

- If the income per capita of Malaysia and Vietnam increased by 1 per cent, the individual gypsum consumption in those countries would increase by 0.786 and 1.058 per cent, respectively.

- Any changes in income per capita of Indonesian, Korean, Filipino, and Taiwanese people did not affect their individual gypsum consumption, statistically.

- If the income per capita of Japan increased by 1 per cent, the individual gypsum consumption there would decrease by 0.789 per cent. This means that for Japanese people, gypsum was an inferior good as the consumption declined when income increased, or $\partial q_t / \partial y_t < 0$. But, in all other countries, gypsum was considered to be a normal good as the consumption in those countries increased or was maintained when income increased, or $\partial q_t / \partial y_t \geq 0$ (Nicholson, 2005).

(ii) For the values of γ_2 of the variable t:

- If time increased by one year while other variables were kept constant, the individual gypsum consumption in Indonesia, Korea, and the Philippines would increase by 5.2, 17.6, and 6.2 per cent, respectively.

- The changes in the individual gypsum consumption in Japan, Malaysia, Taiwan, and Vietnam were statistically insignificant over time if other variables were fixed.

(iii) For the values of γ_3 of the variable P_t^{TH}, which are the price elasticities of demand:

- The change in gypsum price in Thailand did not statistically affect individual gypsum consumption in all countries except Japan. In other words, the elasticities of q_t with respect to P_t^{TH} were not statistically different from zero.

- If the price of gypsum in Thailand increased by 1 per cent, while holding other variables constant, the individual gypsum consumption in Japan would increase by 0.336 per cent. This means that the gypsum demand curve of Japan was upward sloping. This abnormality would possibly be true for gypsum which was probably an inferior good for Japanese as mentioned in (i) above. The demand curve for an inferior good will have an upward slope if the income effect on the demand outweighed the substitution effect (Binger and Hoffman, 1998).

(iv) For the values of γ_6 of the variable m_t, which are the elasticities of demand with respect to cement production per capita:

- Any changes in cement production per capita in Indonesia, Korea, Malaysia, the Philippines, and Vietnam did not seem to affect the individual gypsum consumption in those countries, statistically.

- If cement production per capita in Japan and Taiwan increased by 1 per cent, the individual gypsum consumption in those countries would increase by 1.117 and 1.321 per cent, respectively.

b) Determining the Best Suitable Linear Form of the Demand Function

The best suitable form of the demand function should be the one that all of its coefficients have the right signs and the t-statistics significance at the 95 per cent level of confidence. To find it, the variables with wrong signs or insignificance in equations 5.14 and 5.15 are alternatively dropped, each one or two or three at a time. All equation forms are shown in Table 5.7 and their t-statistics and values of all coefficients in all equation forms of all eight countries are shown in Appendix C.

Table 5.7 The Possible Equation Forms for the Gypsum Demand of a Representative Individual

No.	Equation Form
1.1	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_3 P_t^{TH} + \beta_4 P_t^A + \beta_5 x_t + \beta_6 m_t$
1.2	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_3 P_t^{TH} + \beta_4 P_t^A + \beta_5 x_t$
1.3	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_3 P_t^{TH} + \beta_4 P_t^A + \beta_6 m_t$
1.4	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_3 P_t^{TH} + \beta_5 x_t + \beta_6 m_t$
1.5	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_4 P_t^A + \beta_5 x_t + \beta_6 m_t$
1.6	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_3 P_t^{TH} + \beta_4 P_t^A$
1.7	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_3 P_t^{TH} + \beta_5 x_t$
1.8	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_3 P_t^{TH} + \beta_6 m_t$
1.9	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_4 P_t^A + \beta_5 x_t$
1.10	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_4 P_t^A + \beta_6 m_t$
1.11	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_5 x_t + \beta_6 m_t$
1.12	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_3 P_t^{TH}$
1.13	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_4 P_t^A$
1.14	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_5 x_t$
1.15	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_6 m_t$
2.1	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_7 \frac{P_t^{TH}}{P_t^A} + \beta_5 x_t + \beta_6 m_t$
2.2	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_7 \frac{P_t^{TH}}{P_t^A} + \beta_5 x_t$
2.3	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_7 \frac{P_t^{TH}}{P_t^A} + \beta_6 m_t$
2.4	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t + \beta_7 \frac{P_t^{TH}}{P_t^A}$
2.5	$q_t = \beta_0 + \beta_1 y_t + \beta_2 t$

It is found that coefficients β_4, β_5, and β_7 of the variables P_t^A, x_t, and P_t^{TH}/P_t^A, respectively, in the equation forms nos. 1.3, 1.1, 1.4, 1.5, 1.11, 2.1, 2.2, 2.3, and 2.4, of all eight countries have the t-statistics insignificance at the 95 per cent level of confidence. Therefore, these equation forms are discarded.

With regard to the variable P_t^A in the equation forms nos. 1.2, 1.6, 1.9, 1.10, and 1.13, its coefficients, β_4's, have the t-statistics insignificance at the 95 per cent level of confidence for all countries except the Philippines. But the coefficient β_4 for the Philippines has the wrong sign. If the statistics were correct it would mean that gypsum consumption in the Philippines increased when gypsum price in Australia had increased and vice versa. The fact is that the Philippines imported a negligible amount of gypsum from Australia. In other words, during the study period, the gypsum consumption in the Philippines had no known connection to the gypsum price in Australia. Besides, gypsum could be classified as a normal good in the Philippines for its consumption increased when the Philippines's income per capita increased. By the law of demand, a normal good must have a downward-sloping demand curve (Binger and Hoffman, 1998), and it does not make sense for the Philippines to consume more gypsum when its price elsewhere increased or vice versa. Therefore, the statistical significance of the β_4 for the Philippines was deemed to happen by chance. Hence, all those equation forms are dropped.

As for the variable P_t^{TH} in the equation forms nos. 1.7, 1.8, and 1.12, its coefficients, β_3's, have the t-statistics insignificance at the 95 per cent level of confidence for all countries except Taiwan in the equation form no. 1.7; the Philippines, Taiwan, and Japan in the equation form no. 1.8; and the Philippines and Taiwan in the equation form no. 1.12. But these coefficients have the wrong signs. The statistical interpretation would mean that when gypsum price in Thailand had increased gypsum consumption in the Philippines, Japan, and Taiwan increased and vice versa. This means that their demand curves were upward-sloping. But, for Filipino and Taiwanese people, gypsum was a normal good since their gypsum consumption increased when their income per capita increased. Therefore, the statistical significances of β_3's for the Philippines and Taiwan could be coincidental because a normal good must have a downward-sloping demand curve. As for Japan, the upward-sloping demand curve might be attributed to gypsum being possibly an inferior good there. But Japan produces and consumes a lot of synthetic gypsum, which is a substitute for mineral gypsum in many uses. The omission of synthetic gypsum in this thesis, which is due to lack of data, might result in some positive bias. By these reasons, this thesis will treat the statistically positive sign of β_3 for Japan as positive bias caused by omitting the price of synthetic gypsum. Therefore, the equation forms nos. 1.7, 1.8, and 1.12 are eliminated.

At this stage, all the price variables: P_t^{TH}, P_t^{A}, and P_t^{TH}/P_t^{A}, in all the equation forms have been discarded. This means that the analysis of this thesis found that at least in the short run either gypsum price does not affect consumption or the price elasticity of demand for gypsum is too low to be defined. Therefore, the consumption model of this thesis will be done without price variables or, in other words, consumption of gypsum is considered highly price inelastic in this thesis. Indeed the exclusion of prices from empirical models forecasting consumption of minerals, especially the low-price ones, is the norm as demonstrated by other empirical studies (Intensity of Use), such as those of Roberts, 1990; Valdes, 1990; Roberts, 1996; Crompton, 2000; Guzman *et al*., 2005; and Rebiasz, 2006. (All the cited articles are from a single journal: Resources Policy, which is specifically devoted for mineral policy and economics. No other article dealing with this subject in other journals has been found. Unfortunately, knowledge about minerals is a specific, small and narrow field of study.) The rationale behind the irrelevance of price in the actual consumption will be further discussed in the subsection 5.6.4: Discussion.

Looking into the variable x_t in the equation form no. 1.14, we find that its coefficients, β_5's, have the t-statistics insignificance at the 95 per cent level of confidence for all countries except Indonesia. For Indonesia, the coefficient β_5 has the t-statistics significance at the 95 per cent level of confidence but a wrong sign. The simple correlation coefficient between variables x_t and y_t for Indonesia is 0.972. If the variable x_t for Indonesia in the equation form no. 1.14 is dropped to become the equation form no. 2.5, the t-statistics of the coefficients β_1 and β_2 decrease from 4.203 and 12.227 to 1.78 and 8.57 (see Table 5.8), respectively. But β_1 and β_2 in the equation form no. 2.5 are still statistically significant and have the right signs. This statistical result means that both the equation forms nos. 1.14 and 2.5 can be used to determine the gypsum consumption of Indonesia. If this statistical analysis was correct it would mean that, for other countries, the construction expenditures of the representative individual have no effect on individual gypsum consumption, while Indonesian people would consume less gypsum when they paid more construction expenditure and vice versa. The result is unexpected. Since gypsum is a mineral used mainly in construction, x_t's should have a positive correlation with the gypsum consumption of the representative individual of every country. The causes of this abnormality may lie on the fact that the country's GDP of construction industry per capita, representing x_t, includes a huge government expenditure per capita on highway and other construction that does not use Portland cement much. Therefore, the equation form no. 1.14 is eliminated.

Table 5.8 The t-statistics and Values of Coefficients in the Equation Forms Nos. 1.14 and 2.5 for Indonesia

	Equation form no. 1.14		Equation form no. 2.5	
Variable	Coefficient	t-statisitc	Coefficient	t-statisitc
y_t	5.666814	4.203	0.918154	1.78
t	301.0209	12.227	285.6207	8.57
x_t	-56.73860	-3.666	-	-

Investigating the variable m_t in the equation forms nos. 1.8 and 1.15, we find that its coefficients, β_6's, for Philippines and Vietnam are statistically significant at the 95 per cent level of confidence but have wrong signs and very small values, while those for Korea and Malaysia are statistically insignificant. Therefore, the variable m_t in the two equations for Korea, Malaysia, Philippines and Vietnam can be dropped. But those for Indonesia, Japan, Taiwan, and Thailand have the t-statistics significance at the 95 per cent level of confidence and the right signs. However, we also find that the simple correlation coefficients between variables m_t and t for Indonesia, Japan, Taiwan, and Thailand are 0.936, -0.877, -0.680, and 0.725, respectively, which are strong. When we drop m_t from the two equation forms to become the equation form no. 2.5, the coefficients β_2's of variable t, are more statistically significant for all four countries (see Table 5.9). This is a problem of multicollinearity; therefore, the variable m_t in the two equation forms for Indonesia, Japan, Taiwan, and Thailand can be dropped. Another reason to support the elimination of the variable m_t is that its data was not so accurate. A country's cement production per capita is not exactly the same as the cement consumption of the representative individual because Portland cement is a commodity traded worldwide. If countries produce more cement than they consume, the surplus can be exported. Other countries may produce less than they need and supplement their deficits by importing. Furthermore, the cement production of a country may also be influenced by the movement of huge government expenditure on infrastructure and government policies. The examples are: in 2004, the Indonesian Government, after economic recovery, invested in infrastructure, including roads and ports, for more than \$150 billion resulting in the increase in cement production (the USGS Minerals Yearbook, 2004); in 2004 cement production in Japan decreased because of the cutbacks in public works spending (the USGS Minerals Yearbook, 2004); and in 2006 cement production in Taiwan decreased slightly because China restricted the export of sand and gravel (the USGS Minerals Yearbook, 2006). Therefore, the equation forms nos. 1.8 and 1.15 are eliminated.

Table 5.9 The t-statistics of the Coefficients of Variable *t* in the Equation Forms Nos. 1.8, 1.15, and 2.5 for Indonesia, Japan, Taiwan, and Thailand

	t-statistics of β_2		
Country	Equation form no. 1.8	Equation form no. 1.15	Equation form no. 2.5
Indonesia	0.800	0.838	8.57
Japan	1.057	-0.927	-4.35
Taiwan	-0.767	-0.819	-4.68
Thailand	3.250	3.309	3.51

The values and t-statistics of the coefficients β_0, β_1 and β_2 for all eight countries of the remaining equation form no. 2.5, consisting of only variables y_t and t, are shown in Table 5.10. We can see that almost all of the coefficients are statistically significant at the 95 per cent level of confidence. Therefore, finally, the equation form no. 2.5 is adopted as the consumption model for all eight countries.

Note that, of the equation form no 2.5, the values of t-statistics of the coefficient β_1 of all countries, except for Japan and Korea, are significant. However, for Japan the values of both the coefficient β_1 and its t-statistics are low. This means that, in Japan, people's incomes have insignificant influence on their mineral gypsum consumptions. Income may also not affect mineral gypsum consumption in Korea. But in Thailand, Indonesia, Malaysia, Philippines, Taiwan, and Vietnam when people's incomes increase mineral gypsum consumption will rise.

With regard to the values of the coefficient β_2 for all countries, except for Japan and Taiwan, are positive. This means that the consumption of mineral gypsum of Japan and Taiwan will have negative trends if their populations and GDPs remain constant, while the other six countries have the trends to consume more mineral gypsum. The trend may reflect the possible change in the taste of the people in these two countries. However, this thesis will not investigate further on this matter for it is not the main objective of this thesis to go in depth on the demand for gypsum.

According to the equation form no. 2.5, it can be rewritten as follows:

$$q_t = \frac{Q_t}{POP_t} = \beta_0 + \beta_1 \frac{GDP_t}{POP_t} + \beta_2 t$$

Therefore,

$$Q_t = \beta_1 GDP_t + \beta_0 POP_t + \beta_2 tPOP_t \qquad (5.17)$$

The equation 5.17 will be utilized to estimate future national gypsum consumptions of all the eight countries in the models of the next chapter. The comparisons between the actual mineral gypsum consumptions and the estimates from the models of the eight countries from 1990 to 2006 are shown in Figure 5.12 - Figure 5.19.

Noted that equation 5.17 can be summarized as follows:

$$Q_t = \mathrm{F}(GDP_t, POP_t, t \cdot POP_t)$$

In words, a national aggregate consumption of gypsum is in the function of *GDP*, population, and the interaction of time and population. The interaction of population and time, or the term “time *t* times *POP* at time *t*” is the result of the representative agent assumption. It simply means that the effect of the changes in technology and the taste of the representative agent on his/her gypsum consumption multiplied by the total population becomes the aggregate effect of the changes in technology and taste of the nation on the national gypsum consumption.

Table 5.10 Ordinary Least Squares Regression of Equation Form 2.5

Country	Coefficient							
	β_0		β_1		β_2		R^2	F-statistic
Indonesia	-568497.9	(-8.53)	0.918	(1.78)	285.621	(8.57)	0.87	45.60
Japan	2268538	(4.42)	0.181	(0.75)	-1104.577	(-4.35)	0.74	19.71
Korea	-7214542	(-9.96)	1.006	(1.34)	3620.388	(9.90)	0.90	63.60
Malaysia	-900731.2	(-4.74)	5.433	(7.31)	451.575	(4.72)	0.63	11.84
Philippines	-334353.6	(-11.70)	1.472	(2.77)	168.171	(11.78)	0.91	75.00
Taiwan	1969560	(4.71)	2.496	(3.17)	-992.767	(-4.68)	0.62	11.44
Vietnam	-1545571	(-3.51)	20.494	(3.15)	777.901	(3.51)	0.54	8.33
Thailand	-2243722	(-8.87)	9.162	(6.59)	1124.918	(8.91)	0.86	42.73

Note: Figures in parentheses are t-statistics and critical t-value is 1.761.

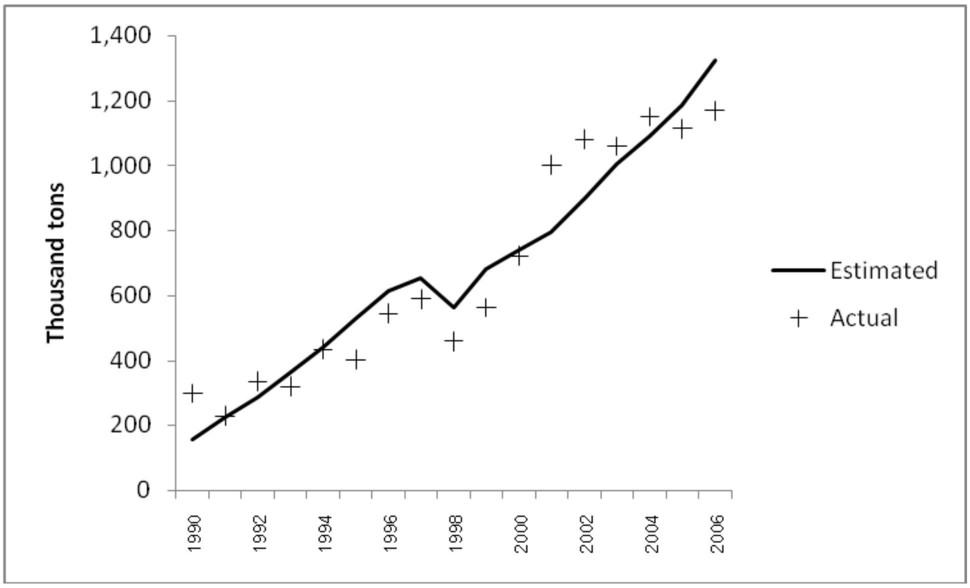

Figure 5.12 Actual and Estimated Gypsum Domestic Consumption of Indonesia, 1990 – 2006

Sources: USGS (2006) and Global Trade Information Services (2007)

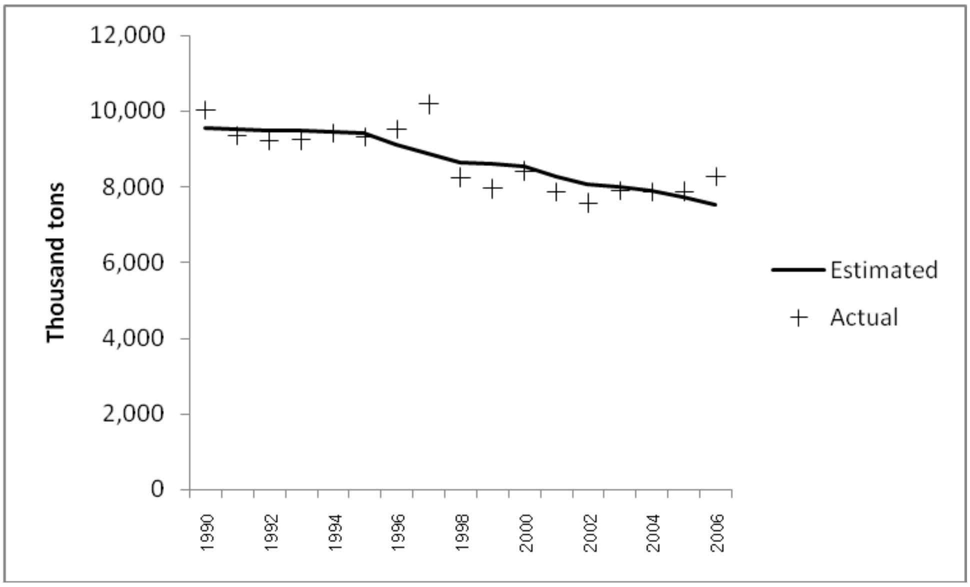

Figure 5.13 Actual and Estimated Gypsum Domestic Consumption of Japan, 1990 – 2006

Sources: USGS (2006) and Global Trade Information Services (2007)

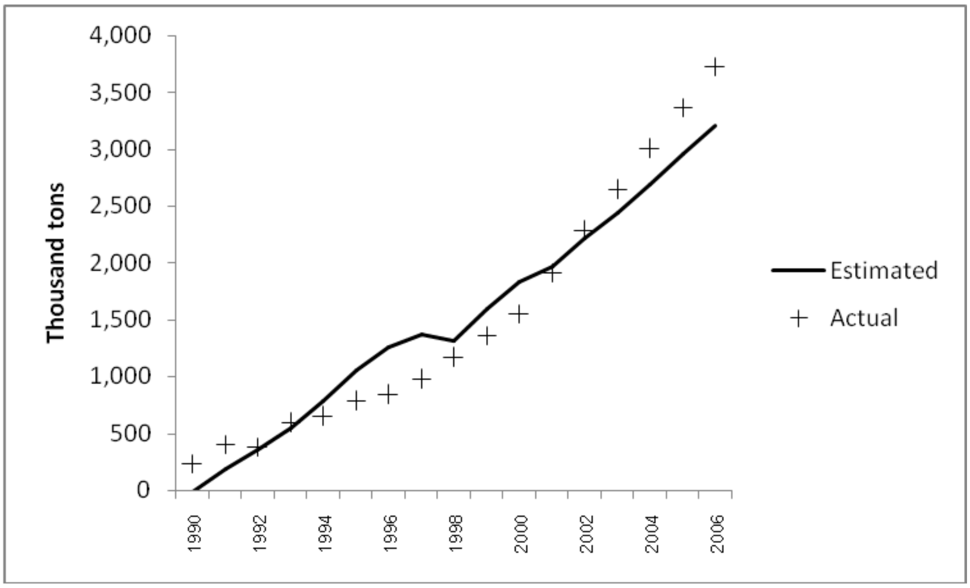

Figure 5.14 Actual and Estimated Gypsum Domestic Consumption of Korea, 1990 – 2006

Sources: USGS (2006) and Global Trade Information Services (2007)

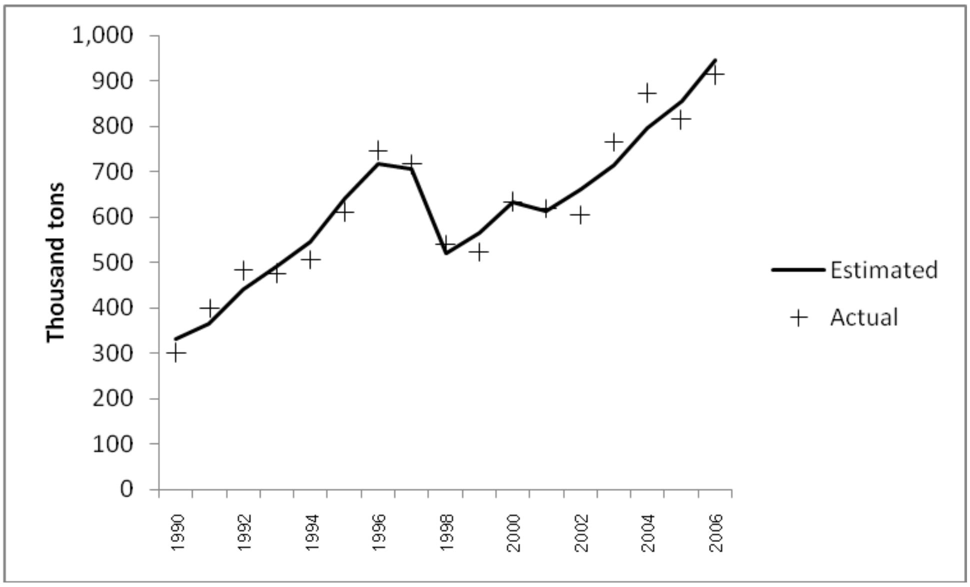

Figure 5.15 Actual and Estimated Gypsum Domestic Consumption of Malaysia, 1990 – 2006

Sources: USGS (2006) and Global Trade Information Services (2007)

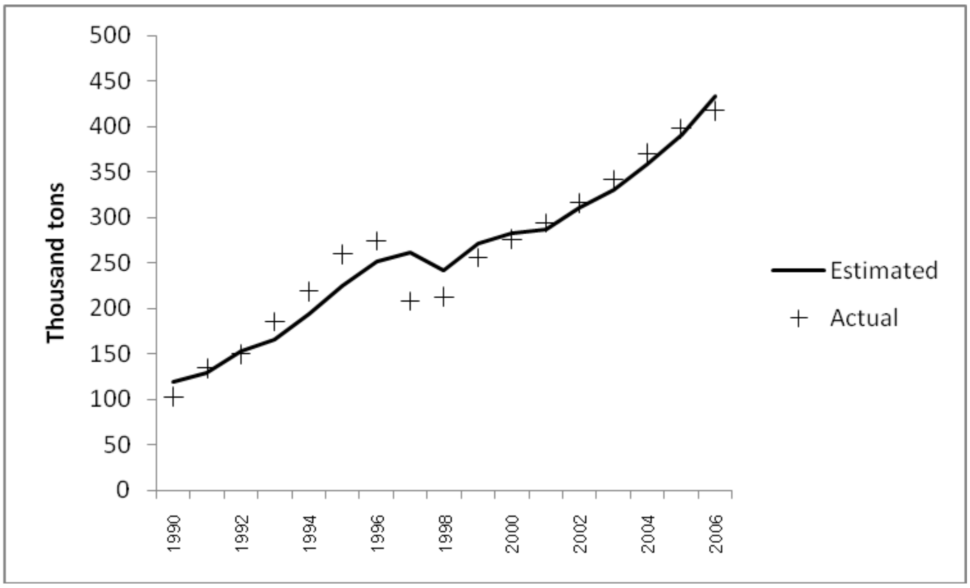

Figure 5.16 Actual and Estimated Gypsum Domestic Consumption of Philippines, 1990 – 2006

Sources: USGS (2006) and Global Trade Information Services (2007)

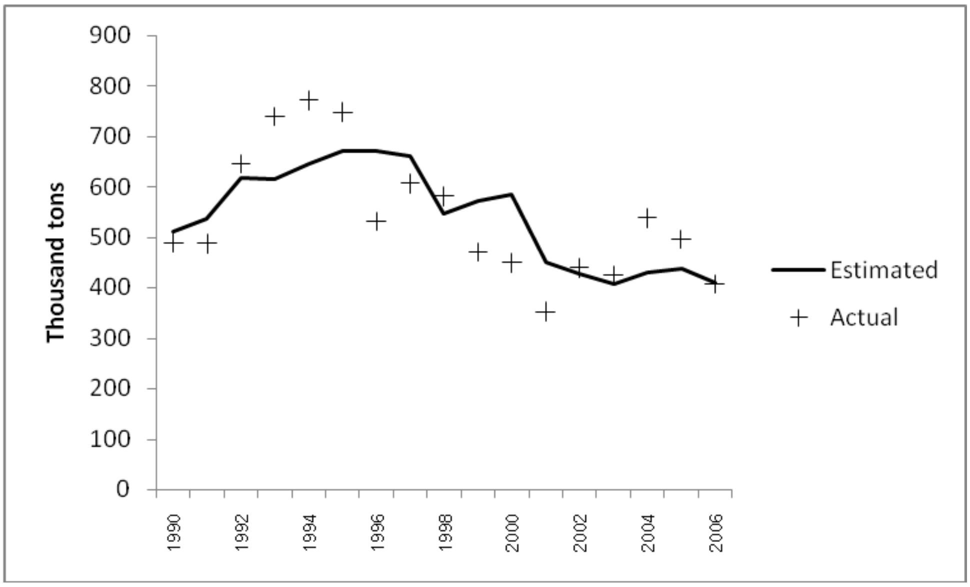

Figure 5.17 Actual and Estimated Gypsum Domestic Consumption of Taiwan, 1990 – 2006

Sources: USGS (2006) and Global Trade Information Services (2007)

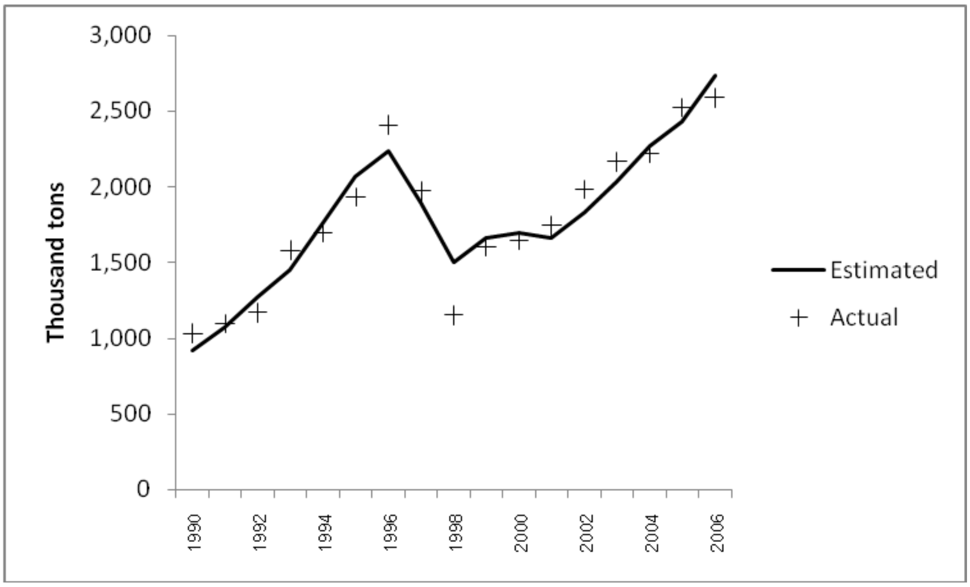

Figure 5.18 Actual and Estimated Gypsum Domestic Consumption of Thailand, 1990 – 2006

Sources: USGS (2006) and Global Trade Information Services (2007)

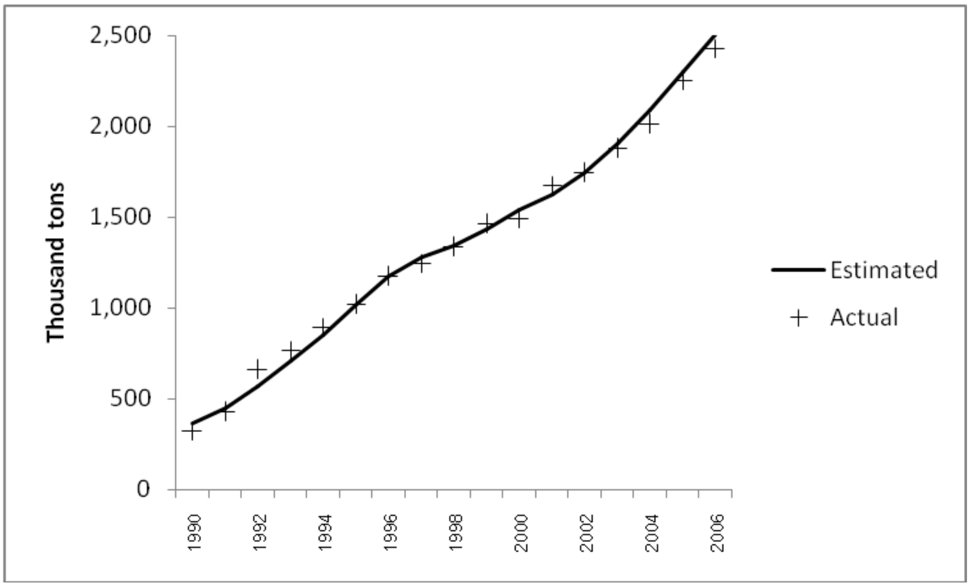

Figure 5.19 Actual and Estimated Gypsum Domestic Consumption of Vietnam, 1990 – 2006

Sources: USGS (2006) and Global Trade Information Services (2007)

5.6.4 Discussion

As already mentioned in the literature review of this chapter, the analytic result of this chapter, demonstrating the strong influence of people's income over and the insignificant effect of prices on mineral demand, reaffirms many previous studies in the field of mineral economics.

It should be noted that the low price elasticity of demand for a mineral conforms to the nature of the derived demand for most primary goods in general. Almost all minerals and their derivatives, metals, are produced as raw materials for the production of consumer goods. Hence, the costs (or prices) of mineral raw materials, especially the bulky low price ones, comprise just a fraction of the prices of consumer goods. With regard to some metals, Tcha and Takashina (2002) summarized their literature review to support their findings as follows:

> "…. Seo (1995) found that, based on 1990 data for Korea, input coefficients for steel for most industries that used steel intensively, were extremely low. His study showed that the value of steel used to produce US$1 value of each product was US$0.11 for general machinery, US$0.07 for automobiles, US$0.05 for construction and US$0.02 for electric and electronic appliances. In their comprehensive input–output analysis of the Western Australian economy, Clements and Qiang (1995) also showed that the portion of metals was extremely small across all 43 industries they considered, including those industries which used metals relatively intensively such as construction, road transport and general mechanics and equipment. Becker (1976) considered the case in the UK and found that the direct steel component of the value of motor vehicles was 0.10 in 1968, which recently would have dropped much further. Tin may be regarded as the most important input of cans, however, Demler (1984) reported that total cost of tin accounted for only 2.3% of the total production cost of one can. Another study by Tilton (1983), concerned with tin consumption, showed that tin constitutes between 18 and 35% of the final cost of producing organotin stabilizer, while, at later stages of production, tin's portion of the total cost becomes increasingly smaller, accounting for 1% or less of the final price of PVC plastic pipe."

In the case of gypsum as a raw material in the production of Portland cement, the major use (58 % in 2002) of gypsum mineral produced in Thailand and other developing countries, the price accounts for less than 0.5 % of the Portland cement's price (Department of Primary Industries and Mines, 2004). Mineral price movement, within a reasonable range, affects the prices of consumer goods very little; therefore, the consumption of consumer goods and its mineral raw materials will not change much.

Another reason that makes the demand for minerals highly price inelastic, especially in the short run, is that in some uses they are necessary raw materials, and people are slow to change their behaviour and taste. Moreover, it costs somewhat and takes time for industrial plants that use minerals to change their processes of production and to reinstall new equipment and machines to suit new substitute raw materials. As in the case of gypsum wallboard, another important use of mineral gypsum, no other materials can be wholly substituted for mineral gypsum in its production. Consumers may switch from gypsum wallboard to plywood or other kinds of partitions at will. However, gypsum wallboard producers have no choice but to be faithful to gypsum in their production, or else they have to shut their plants or to make heavy reinvestment to produce other products instead. Furthermore, in fighting to maintain or to increase its market share, an industry using mineral raw materials would tend to refrain from passing the burden of higher mineral costs, a very small portion in the price of its final product, on to consumers. Therefore, the demand for the product will not decrease, and as a result the demand for minerals used in the production of such a product will not be affected.

It should also be noted that for high price mineral commodities--such as gold, silver, tin, copper, zinc, etc--extra demand or extra supply of middlemen for their speculative investment and disinvestment in markets make the price elasticity of demand for such a commodity less inelastic. Since it is impractical to hoard low price bulky minerals, which require huge space for stockpiling, for profit, the inelastic demand for low priced minerals is rather vivid.

It is conceivable that substitution demand of a mineral is not highly inelastic in the long run. But, by the reasons mentioned above, the short run low price elasticity of demand for a mineral stays effective for quite a while. Hence, no mineral producers discern and take account of the long run behaviour of mineral consumers. As a result, in a competitive market, an individual mineral producer would never consider the long run price elasticity of demand in their production planning. The highly inelastic demand for minerals together with the continual technological progress may be a critical factor that fails the Hotelling model's prediction that mineral production should decline through time.

Because of highly inelastic demand of a mineral, the relation between the price and consumption of a low priced mineral cannot usually be determined from historical data, while the correlation between GDP per capita and mineral consumption is prominent. This means that the change in mineral consumption is the result of the shift in demand function due to, among others, the change in consumers' incomes, technology and taste.

Chapter 6 An Economic Model Determining the Optimal Depletion Path of Thailand's Gypsum Resources

6.1 Introduction

Exploitation of mineral resources basically transforms the resource rent of the natural capital into financial capital. If we accept the assumption of weak sustainability, then financial capital gained from the exploitation of mineral resources is more relevant to the people's welfare than the unexploited mineral resources, themselves. Normally, the capitals, especially the financial one, which can generate returns through business activities, will grow over time if parts or all of the capitals are reinvested properly. Under these assumptions, therefore, the mineral resources should be optimally exploited in such a way that renders maximum economic rents, through time.

The concept to maximize the present value through time of the economic rents (from now on shall be called "Resource Rents") obtained from the extraction of mineral resources was firstly introduced in a renowned article "The Economics of Exhaustible Resources", written by Harold Hotelling in 1931. This article and its extensions by other authors will be reviewed in a later section. Hotelling's article did not talk about sustainability since it was published long before the inception of the concept of sustainable development. However, Hotelling's model has become the basic of many later works that involve the optimal mineral resources exploitation. In 1977, J. M. Hartwick postulated in his article that the resource rents from an efficient extraction path can be reinvested in reproducible capital to maintain non-decreasing consumption over time. This postulation is called Hartwick rule, which was briefly explained and discussed in Section 4.3.2 of Chapter 4.

However, exploitation of mineral resources renders not only resource rents, which is, in other words, “producer surplus”, to mineral producers but also “consumer surplus” to consumers consuming minerals. An economic model determining the optimal depletion path of Thailand’s gypsum resources to be developed in the later part of this chapter will follow the Hotelling’s model, but it will also take into account the benefit of consuming gypsum by Thai people in the form of “consumer surplus”. In the model the concept of discounting future values shall be accommodated as a way to weight the total economic welfare accrued to Thai people at different time. The model will be presented in details from Section 6.3 of this chapter onwards.

6.2 Literature Review

6.2.1 The Hotelling Model

a) Hotelling Model as a Method to Determine the Rates of Extraction of Mineral Resources

In addition to treating a mineral resource as a known, finite stock, Hotelling simplified his economic models by making six assumptions as follows (Tilton, 2002):

i) The goal of mining is to maximize the present value of the stream of net benefits from extraction,

ii) The mining industry is perfectly competitive,

iii) The quantity of mineral stock, current and future costs of extraction and market price of the mineral are known,

iv) The mine has unlimited production capacity,

v) The resource stock of mine is homogeneous, and

vi) There is no technological advance.

The objective of his model is to select a time path for efficient mineral extraction, denoted *q(t)*, that maximizes the present value of the stream of net benefits from extraction, subject to the constraint that cumulative extraction is no greater than the initial resource stock, denoted S_0. If total benefits from mineral extraction are denoted by *B(q(t))*, and extraction costs are denoted by *C(q(t))*, where *S(t)* denotes the remaining stock, then mining company should determine *q(t)* by maximizing:

$$\int_0^T e^{-\mu t}[B(q(t)) - C(q(t))]dt \qquad (6.1)$$

subject to:

$$\dot{S}(t) = -q(t), \qquad S(t) \geq 0, q(t) \geq 0, S(0) = S_0, S(T) = 0 \qquad (6.2)$$

where μ denotes the rate of discount ($\mu > 0$), and

T denotes the time of final extraction

Letting $\lambda(t)$ denote the co-state variable for the resource stock, the current value Hamiltonian, *H*, for this problem is:

$$H(q(t), \lambda(t)) = B(q(t)) - C(q(t)) - \lambda(t)q(t) \qquad (6.3)$$

The co-state variable, $\lambda(t)$, can be interpreted as the current-value shadow price of the resource stock – its in situ value or net price – at time *t*. The first order necessary conditions include both the static and dynamic efficiencies.

The static efficiency condition is:

$$\frac{\partial H}{\partial q} = \frac{\partial B}{\partial q} - \frac{\partial C}{\partial q} - \lambda = 0, \qquad p(t) = mc(t) + \lambda(t) \qquad (6.4)$$

This condition requires that at each point in time, the marginal benefit from extracting the resource (or market price of resource, denoted *p*(*t*)) equals the sum of the marginal cost of extraction, denoted *mc*(t), and the net price of depleting the resource stock, $\lambda(t)$.

Letting $\dot{\lambda}(t)$ denote the time derivative of net price, the dynamic efficiency condition is:

$$\dot{\lambda} = \mu\lambda - \frac{\partial H}{\partial S} = \mu\lambda\,, \quad \frac{\dot{\lambda}}{\lambda} = \mu \tag{6.5}$$

In words, the equation 6.5 means that the shadow price of the resource stock should increase at the rate of discount, $\dot{\lambda}/\lambda = \mu$, which is the Hotelling rule.

The equation 6.5 can be rewritten in the new form as follows:

$$\dot{\lambda}(t) = \mu\lambda(t) \tag{6.6}$$

By integration of equation 6.6, we obtain:

$$\lambda(t) = \lambda(0)e^{\mu t}\,, \qquad \lambda(t)e^{-\mu t} = \lambda(0) = \text{constant} \tag{6.7}$$

The meaning of equation 6.7, another form of the Hotelling rule, is that the discounted net price of the natural resource is constant along an efficient resource extraction path.

While a resource is extracted more and more, its stock is depleting over time. We now define the efficient extraction path when the marginal extraction cost is increasing with the depletion of stock. The assumption is logical because the mine extraction progressively needs deeper and deeper mining operation that requires higher marginal extraction cost.

Give $\qquad \dfrac{dmc(t)}{dS} = -f$, where f is positive constant.

From equation 6.2, we get $\qquad \dfrac{dS}{dt} = -q(t)$

Then $\qquad$ $$\frac{dmc(t)}{dS}\frac{dS}{dt} = \frac{dmc(t)}{dt} = fq(t) \tag{6.8}$$

Assuming the demand curve is linear,

$$p(t) = a - bq(t), \text{where } a \text{ and } b \text{ are positive constants} \tag{6.9}$$

Differentiate equation 6.9 with respect to time, *t*, yielding:

$$\dot{p}(t) = -b\dot{q}(t) \tag{6.10}$$

In the same way, differentiate equation 6.4 with respect to time, *t*, yielding:

$$\dot{p}(t) = \dot{m}c(t) + \dot{\lambda}(t) \tag{6.11}$$

Substituting equations 6.8 and 6.10 into 6.11, we obtain:

$$-b\dot{q}(t) = fq(t) + \mu\lambda(0)e^{\mu t}$$

Then $$q(t) = \frac{[\mu\lambda(0) + fq(0) + b\mu q(0)]e^{-ft/b} - \mu\lambda(0)e^{\mu t}}{f + b\mu} \tag{6.12}$$

The equation 6.12 shows that the efficient extraction path is decreasing over time. This result, on the surface, is rather contrary to the aim of the most accepted concept of sustainable development, which requires a non-decreasing consumption level over time. Indeed, Hotelling rule is not a sustainability rule. Further conditions, under Hartwick rule, have to be met before the efficient extraction path under Hotelling rule shall be deemed sustainable.

In summary, the Hotelling model is an economic theory to explore the optimal output over time for a mine with a given amount of known resources under a number of strong assumptions. The Hotelling rule can be interpreted as the intertemporal efficiency conditions which must be satisfied by any efficient process of resource extraction. The static efficiency condition requires that at each point in time, the market price of a resource shall equal the marginal cost of extraction, including the net price, and the dynamic efficiency requires that the net price should increase at the rate of discount. The drawbacks of the Hotelling model and its validity will be discussed in the next section.

b) Some Further Extensions of Hotelling Model

Attempts have been made to generalise Hotelling Model by incorporating real conditions, such as technological change and external costs, into it. Technological change alters the extraction cost of resource stocks, and the extraction of a nonrenewable resource involves external costs. Some extensions of the Hotelling model are as follows.

i) Perfect Competition with Zero Extraction Cost and a Backstop Resource

It is an extension of the original Hotelling model. The model will take account of a backstop resource, which is defined as a perfect substitute for the nonrenewable resource that will come into the market at a higher price. Such a price is called the backstop price, at which the demand for the nonrenewable is supposed to be nil. The backstop resource may be the same nonrenewable resource stocked in a sub-marginal deposit, another natural resource, or a man-made product, and its price at present is higher than the nonrenewable resource's price. The following equations for the optimal extraction path model in a perfect competition market without extraction cost and with a backstop resource are adapted from Hanley *et al*. (2007).

Under the Hotelling rule and zero extraction cost, the growth rate of the price of the nonrenewable resource is equal to the discount rate. Therefore;

$$\frac{\dot{p}}{p} = r \tag{6.13}$$

where

p = the price of nonrenewable resource,

$\dot{p}$ = the rate of price change, and

r = the discount rate.

The demand switches altogether from the resource to the backstop technology at time, $t = T^c$. Let p^b be the price of the backstop technology. Then the price of the resource at time T^c is the price of the backstop technology. Therefore,

$$p(T^c) = p^b.$$

From equation 6.13, we obtain

$$p(t) = p^b e^{-r(T^c - t)} \tag{6.14}$$

Assume that the demand curve is a straight line, and its inverse curve cuts the vertical axis at price, $p = p^b$. Therefore, the inverse demand curve can be written as follows:

$$p = p^b - \beta q \tag{6.15}$$

where β is a positive constant and q is the quantity of resource extraction.

By substituting equation 6.14 into equation 6.15, we get

$$p^b e^{-r(T^c - t)} = p^b - \beta q(t)$$

Therefore,
$$q(t) = \frac{p^b}{\beta}\left(1 - e^{-r(T^c - t)}\right) \tag{6.16}$$

Differentiating equation 6.16 with respect to time we get:

$$\dot{q}(t) = -\frac{r p^b e^{-rT^c}}{\beta} e^{rt} \tag{6.17}$$

Therefore, based on equations 6.16 and 6.17, we can conclude that, for the perfect competition market with a backstop resource and zero extraction cost, the optimal extraction path declines through time and the rate of the decline in quantity extracted increases through time.

ii) Taking Account of Scarcity

Scarcity is the problem of insufficient productive resources to fulfill human wants and needs. Resource scarcity is related to the resource price and its extraction costs. In general, it is economic to extract a resource when the price is higher than the marginal cost. Based on the analysis in section 6.2.1, an economic resource stock has a positive shadow price. It can be inferred that $p = \mu + c_x$. That is, the price equals the shadow price (μ) plus the marginal cost, c_x. The shadow price of a stock is also termed 'scarcity rent'. While the shadow price or scarcity rent is the correct measure of its scarcity, the resource price and the marginal cost are a lot more readily available. As a result, price and marginal cost, or average cost, have often been used as measures of resource scarcity (Hanley *et al*., 2007). The model below, taken from Farzin (1992), summarizes the effects of costs on the optimal time path of scarcity rent, $\dot{\mu}$.

The cost function is in the form of $c(x_t, X_t, z_t)$, where x_t is the extraction rate at time t, z_t is an index measuring technological stage at time t, X_t is cumulative extraction up to time t, and $X_t = \int_0^t x_\tau \, d\tau$. The assumptions for the cost curve are $c_x > 0$, $c_X > 0$, $c_z < 0$, $c_{xx} > 0$, $c_{xX} > 0$, and $c_{xz} < 0$. Hence the cost curve is convex in x and X. Therefore, with no technical change, an optimal solution will be obtained.

The problem is to find the optimal time path of the shadow price or the scarcity rent by maximizing the present value of net benefit. In a competitive resource market, the resource is extracted at the rate determined by:

$$\text{Maximizing} \int_0^\infty e^{-rt}[px - c(x, X, z)]dt$$

subject to $\dot{X} = x; X(0) = 0$

The current-value Hamiltonian is

$$H = px - c(x, X, z) + \lambda x$$

where the co-state variable λ is the marginal cost of cumulative extraction instead of the scarcity rent of stock, μ, and they are related as μ = -λ. The necessary conditions are

$$p - c_x + \lambda = 0 \tag{6.18}$$

$$\dot{\lambda} - r\lambda = c_X \tag{6.19}$$

The transversality condition is

$$\lim_{t \to \infty} = e^{-rt}\lambda = \lim_{t \to \infty} e^{-rt}(-\mu) = 0$$

Solving the co-state condition in equation 6.19 on the basis of no technical change $\left(\dot{z} = 0\right)$ as

$$\mu = -\lambda = \int_t^\infty e^{-r(\tau - t)} c_X \, d\tau \tag{6.20}$$

Substituting equation 6.20 into equation 6.19, we obtain:

$$\frac{\dot{\mu}}{\mu} = r - \frac{c_X}{\int_t^\infty e^{-r(\tau - t)} c_X \, d\tau} \tag{6.21}$$

Using equation 6.20 and L′Hospital's rule to assess the scarcity rent as $t \to \infty$,we obtain:

$$\lim_{t \to \infty} \mu = \bar{\mu} = \lim_{t \to \infty} e^{rt} \int_t^\infty e^{-r\tau} c_X \, d\tau = \frac{1}{r} \lim_{t \to \infty} c_X \tag{6.22}$$

This implies that $\lim_{t \to \infty} c_X = c_X(0, \bar{X}, 0)$, where $\bar{X}$ is the maximum cumulative extraction from economic reserves and may be less than the total stock. To analyze the time path of scarcity rent, substitute equation 6.20 into equation 6.19 and integrate by parts to give:

$$\dot{\mu} = \int_t^\infty e^{-r(\tau - t)} \frac{d}{d\tau} c_X \, d\tau$$

Noting that $x = \dot{X}$, then by the function of a functional rule

$$\frac{d}{d\tau} c_X = c_{Xx} \dot{x} + c_{XX} x + c_{Xz} \dot{z} \tag{6.23}$$

Equation 6.23 defines the slope of the time path for the scarcity rent of the resource stock. If there is no technological change, $\left(\dot{z}=0\right)$, and the extraction rate is constant, $\left(\dot{x}=0\right)$, the scarcity rent rises monotonically as the path *a* in Figure 6.1. But, under other conditions, paths *b*, *c*, *d*, and *e* are also possible.

From the time derivative of equation 6.18, which is $\dot{p}=\dot{\mu}+\frac{d}{dt}c_x$, we can see that if the changes in the marginal cost and the scarcity rent are of opposite sign, it is quite possible that the direction of change in price is opposite to that of the scarcity rent. Therefore, the change in the resource price does not necessary mean a change in the scarcity rent of stock, though price, marginal cost, and shadow price (or scarcity rent) of stock are all used to measure scarcity.

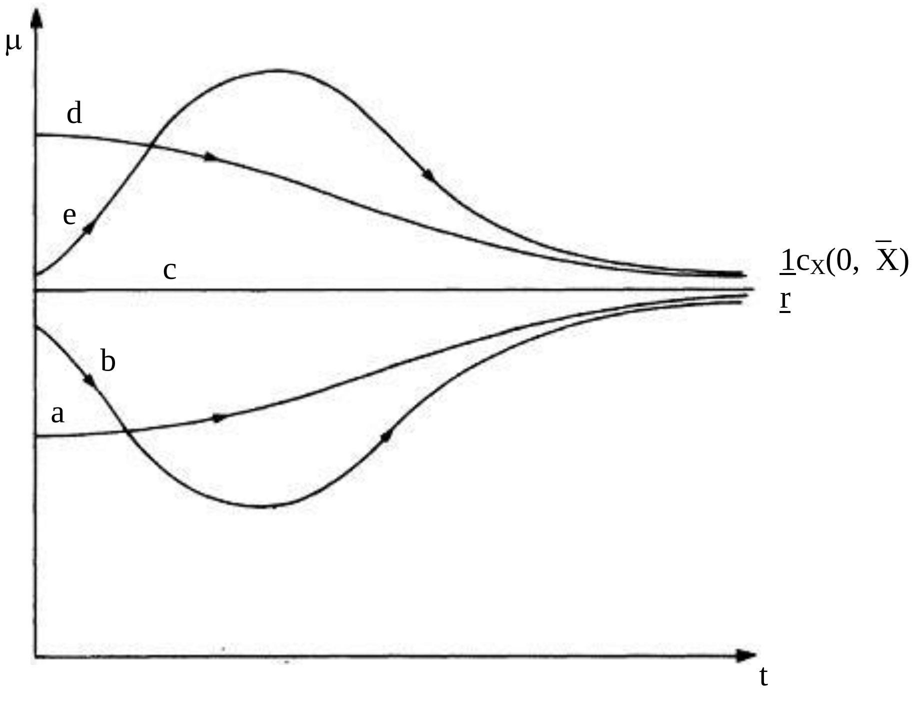

Figure 6.1 Time Paths for the Scarcity Rent of a Resource

Source: Farzin (1992)

iii) The Effects of Technological Change on Scarcity

It can be inferred from equation 6.23 that technological change will decrease the resource scarcity by reducing the scarcity rent. Farzin (1995) created a model to study the effects of technological change on resource scarcity. According to his model, the impact of technological change can be divided into three forms: (i) extraction-biased, which decreases extraction costs, or $c_{xz} < 0$, (ii) depletion-biased, which decreases the marginal cost increase because of depletion, or $c_{Xz} < 0$, and (iii) neutral technological change, which decreases both costs by the same proportion. In conclusion, the extraction-biased technological change accelerates the rising pace of the scarcity measures—cost, price, and rent, while the depletion-biased technological change decelerates them. However, the effect of the neutral technological change on the rate of change in the shadow price is ambiguous. See Farzin (1995) for more details.

iv) The Consideration of External Costs

The following combined model of socially optimal resource extraction and external costs is adapted from Farzin (1996). In this regard, the external costs consist of environmental damage cost from pollution emissions and the pollution abatement cost.

The net social benefit function of the model is as follows:

$$W(x,n,X,S) = B(x) - c(x,X) - D(z,S) - E(n)$$

where $B(x)$ is the consumer surplus;

$c(x, X)$ is the extraction cost as a function of current extraction rate, x, and cumulative extraction, X;

$D(z, S)$ is the environmental damage as a function of net flow of emissions, z, and emission stock, S; and

n is abatement activity and its convex cost function is $E(n)$.

Let s be the flow of emissions, which directly varies with x. That is $s = \alpha x$. To simplify the model set $\alpha = 1$;

The stock of pollution accumulates by $\dot{S} = s(t) - n(t) = z(t)$. The problem is to find time paths for resource extraction and emission control that maximize the present value of net social benefit.

$$\text{Max} \int_0^\infty e^{-rt} W(t) dt$$

subject to $\dot{X} = x; \dot{S} = z; X(0) = X_0; S(0) = S_0$

The current-value Hamiltonian is

$$H = W(x, n, X, S) - \lambda x - \mu(x - n)$$

where λ is the shadow price of the resource stock and μ is the marginal cost of an increase in pollution stock.

The Hamiltonian condition for extraction is

$$H_x = p(x) - c_x - D_z - \lambda - \mu = 0$$

$$p(x) - c_x = D_z + \lambda + \mu$$

That is, the extraction will continue until the net benefit, $p(x) - c_x$, is equal to the sum of marginal damage from extraction, D_z, shadow price of resource stock, λ, and the marginal cost of an increase in pollution stock, μ.

The Hamiltonian condition for abatement is

$$H_n = D_z - E_n + \mu = 0$$

$$E_n = D_z + \mu$$

This implies that the marginal abatement cost E_n is equal to the sum of the marginal damage from extraction, D_z, and the marginal cost of an increase in pollution stock, μ. The policy implication of this result is that, to attain the social optimality, a government should apply an emission tax to the nonrenewable resource industry at the rate equal to the sum of marginal damage from extraction, D_z, and the marginal cost of an increase in pollution stock, μ.

c) Criticism of the Hotelling Model

i) Its Concept of Discounting Future Values

Discounting is the procedure of giving a present value to financial flows happening in the future. The function of the discount rate in the Hotelling model is to change future resource values into the present values because the resource stock is considered as an asset. Since the owner of an exhaustible supply wishes to make the present value of all his future resource rents maximum, the market rate of interest must be used by an entrepreneur in his calculations. Under this concept the consequence of a change in the discount rate is that the higher the discount rate the quicker the resource will be depleted. There have been discussions about whether the rates of extraction of exhaustible resources are too high from a social point of view. Thus Solow (1974) made a comment about Hotelling's (1931) work as follows.

"Hotelling mentions, but rather pooh-poohs, the notion that market rates of interest might exceed the rate at which society would wish to discount future utilities or consumer surpluses. I think a modern economist would take that possibility more seriously. It is certainly a potentially important question, because the discount rate determines the whole tilt of the equilibrium production schedule. If it is true that the market rate of interest exceeds the social rate of time preference, then scarcity rents and market prices will rise faster than they "ought to" and production will have to fall correspondingly faster along the demand curve. Thus the resource will be exploited too fast and exhausted too soon." (Solow, 1974)

Furthermore, Kay and Mirrlees (1975) state that "a general bias in the economy to consume now and leave too little to our children or our future selves . . . would be reflected in high rates of interest, which will lead to somewhat more rapid depletion of resources." Although higher discount rates increase extraction rates, they may also have other effects in the economy. Pearce and Turner (1990) conclude that higher discount rate may lead to declined demand for investment in general in the economy. As a result, utilization of materials, energy, and natural resources will decrease also.

The above discussion cautions the use of the market rate of interest to discount future values of a mineral asset. The economists have seriously looked into appropriate discount rates in an intertemporal dimension that involve more than one generation. It has been proposed that the discount rates to be used on matters related to sustainable development should be based on utility or consumption enjoyed by generations. Both utility and consumption discount rates are discussed below.

Utility Discount Rate

Instead of discounting the future financial benefits, we now measure the present values of future utility enjoyed by generations. Then

$$W = \int_{t=0}^{t=\infty} U_t e^{-\rho t} dt \tag{6.24}$$

where W is the sum of utilities of people from the present to future generations,

U_t is the utility of generation t, and

ρ is the utility discount rate, which is defined by economists in another term as the pure rate of time preference

There are two possible values of pure time preference rate. A zero pure time preference rate means that future generations are treated symmetrically with present generations, while a positive pure time preference rate means that utility is preferred sooner rather than later (Zhu and Weikard, 2003).

The presence of a positive pure time preference rate is controversial. A zero pure time preference rate is claimed to be the proper one because it is a moral obligation to treat all generations equally. Jevons (1871), Bohm-Bawerk (1884), Rae (1905), Pigou (1932), and Harrod (1948) proposed a low discount rate. Ramsey (1928), considering the intergenerational equity, suggested that a zero utility discount rate should be used because giving any less weight to the utility of future generations is "ethically indefensible and arises merely from the weakness of the imagination".

On the other hand, Fisher (1930), Eckstein (1957), Henderson (1965), and Lindstone (1973) argued that at the very least, mortality implies a positive time preference. Mortality is a rational reason to prefer consumption today than tomorrow. Moreover, the effect of lowering the pure time preference rate towards zero in the discounted-utility model is to increase the amount of saving that the current generation should undertake. Arrow (1995) argued that "the strong ethical requirement that all generations be treated alike, itself reasonable, contradicts a very strong intuition that it is not morally acceptable to demand excessively high saving rates of any generation, or even of every generation" and he suggested that the utility discount rate should be approximately equal to 1 per cent.

Consumption discount rate

The consumption discount rate, or the time preference rate of consumption, indicates how a unit of the future consumption is evaluated, in terms of utility, in comparison to a unit of the consumption today. Because the changes in utility of an individual are normally not proportionate to the changes in his/her consumption, the consumption discount rate varies with the level of consumption. Under the assumption that consumption will increase over time, the consumption discount rate may be defined as the rate at which the value of a small increment of consumption falls as time changes. Mathematically, for the time invariant utility function, $U_t = U(C_t)$, the equation 6.24 can be rewritten as:

$$W = \int_{t=0}^{t=\infty} U(C_t) e^{-\rho t} dt \qquad (6.25)$$

The consumption discount rate, *r*, can be expressed as:

$$r = -\frac{\frac{d}{dt}\left(\frac{d[U(C_t)e^{-\rho t}]}{dC_t}\right)}{\frac{d[U(C_t)e^{-\rho t}]}{dC_t}}$$

Simplifying the above expression we have the following relationship between utility discount rate and consumption discount rate:

$$r = \rho + \eta g$$

Where η is the elasticity of marginal utility with respect to consumption

$\eta = -\frac{C \cdot U_{CC}}{U_C}$, in case of diminishing marginal utility, $U_{CC} < 0$,

η is positive, and

g is the growth rate of consumption, $\frac{\dot{C}}{C}$.

Therefore, the consumption discount rate is determined by two factors. One is the impatience of individuals. An individual generally values future satisfaction of her needs lower than the immediate satisfaction and it is represented by the utility discount rate. The second factor is intertemporal consumption smoothing: because of a diminishing marginal utility of consumption, an individual wants to stretch consumption over time. In the case that consumption does not change, $g = 0$, the utility discount rate equals the consumption discount rate.

The above-mentioned theoretical analysis of the two discount rates does not disprove the validity of a positive discount rate. Therefore, it is fair to conclude at this stage that the efficient extraction path from the Hotelling model, shown to be a continuous decreasing trend, looked contrary to the concept of sustainable development that requires a non-decreasing consumption level over time.

ii) Validity of the Hotelling Model

Though there are some inconsistencies in its assumptions with facts of the real world, the Hotelling model looks very logical. Attempts have been made to test the validity of the Hotelling rule. An approach was to look into the difference between the market price of a resource and the marginal extraction cost. The studies of Slade (1982) and Stollery (1983) found evidence of increasing net price that support the Hotelling rule. But Halvorsen and Smith (1991) failed to find any significant increasing trend of net price, while Farrow's study (1985) implicitly showed the evidence of decreasing net price.

Another approach for testing the Hotelling rule used by Miller and Upton (1985) was the valuation principle. This states that the stock market value of a reserve of unextracted resources is equal to the present value of its resource extraction plan. As a result, if the Hotelling rule is valid, the market value of the reserve of unextracted resources will be constant. Using the market values of the reserves of U.S. domestic oil- and gas-producing companies, the result supports the Hotelling rule.

Pesaran (1990), in his study of North Sea Oil production, devised a model based on that of Hotelling to determine an optimal level of extraction. However, when real data were tested, the obtained results show some theoretical discrepancies. This led to a conclusion by Hanley *et al*. (2007) saying, "Pesaran's paper illustrates the problems of applying theoretical models of nonrenewable resource extraction to data. The assumption of profit maximization embedded in Hotelling's rule is a strong assumption when firms are uncertain about many aspects of the production process." Other approaches to testing the Hotelling rule can be found in a survey paper by Berck (1995).

It may be concluded that the results of the tests to verify the validity of the Hotelling rule are inconclusive. This is because, by theory, the Hotelling rule exists in a particular condition under a number of strong assumptions. A lot of the critical assumptions are not held in the real world. Besides, the errors from using the proxies of the unobservable variables, such as marginal extraction cost, might certainly be the main cause of the inconsistency between the results. However, the Hotelling rule is a theoretical concept pertaining to a particular condition. So unless it contains a logical error, the Hotelling rule can never be wrong (Perman *et al*., 2003).

6.2.2 Empirical Works

Not many empirical researches have been done in this hypothetical field of study. After a long search, two empirical papers involving maximization of people's total economic welfare were found. The two are: i) OPEC as a Social Welfare Maximizer, by Celta and Dahl (2000); and ii) Allocation of Canadian Natural Gas to Domestic and Export Markets, by Rowse (1986).

i) OPEC as a Social Welfare Maximizer, by Celta and Dahl (2000)

The paper sets a maximization model based on the different benefits accrued to an OPEC country from domestic consumption and from export of oil. However, its aim was to determine the optimal domestic oil price, not the optimal extraction path. This paper incorporated both consumer surplus and producer surplus into the model in the same manner that this thesis is planned to do. It said that social welfare in OPEC's oil market, *SW*, consists of consumer welfare, *CW*, in the domestic oil market plus resource rents from both the domestic, π_{dom}, and export market, π_x. That is:

$$SW = CW + \pi_{dom} + \pi_x$$

The basic model of this paper is stated as follows:

$$Max \qquad SW = \int_0^{Q_{dom}} P_d\,(Q_{dom})dQ + P_x(Q_x)Q_x - TC(Q_{dom} + Q_x)$$

Where $P_d\,(Q_{dom})$ = Inverse domestic demand function for OPEC

$P_x(Q_x)$ = Residual export demand function for OPEC, and

TC = Total production costs

However, static demand functions with constant elasticity for domestic consumption and export were assumed in this paper. The domestic demand elasticity was -0.050, which is highly inelastic, while the world demand elasticity was -0.406. The non-zero elasticity of both domestic demand and world demand for oil is essentially true since oil is a consumer good, which should conform to the normal theory of demand.

ii) Allocation of Canadian Natural Gas to Domestic and Export Markets, by Rowse (1986)

This paper is very close to what this thesis is planned to do. The paper's objective was to allocate Canadian natural gas to domestic and export markets using a non-linear optimization model. However, the maximization functions of this paper are discounted by discrete-time factors as opposed to continuous-time factors done normally by most literature. The objective function to be maximized in this paper is the difference between (1) the sum of the discounted Canadian consumer surplus and revenues from domestic and export gas consumption, and (2) the discounted costs of gas production and transport to domestic markets and border export points. Because this paper attempted to cover the large part of Canadian natural gas deposits and domestic markets, the objective function stated in this paper is complicated and needs a lengthy explanation. Therefore, the whole function will not be reproduced here. In short, the objective function is as follows:

$$\Omega = A + B + C - D - E - F - G$$

where Ω is the maximized net present value of the net social benefit of Canada.

The term "*A*" is the discounted total consumer surplus enjoyed by Canadians, consisting of the integrals under all Canadian inverse demand functions of every domestic consuming region. Constant elasticity demand functions were employed and no shifts in the demand functions were assumed. A consumer surplus is based on the area under each constant elasticity demand curve between the choke price and the equilibrium price. The choke price, the price at and above which natural gas demand is nil, may be the delivered price of backstop gas.

The non-zero elasticity of demand for natural gas applied in the paper is appropriate for the gas which is a consumer good consumed by households in cooking and heating. If the gas price is low a household may indulge themselves with warmer bed rooms and living rooms and when the gas price is high they may economize by lowering room temperature in the winter. This paper did not take into account the normal shift in a demand as a result of increases in individual and national incomes. However, it allowed the demand response to vary with time by assuming the absolute price elasticity to change, stepwise, over time, but no theoretical explanation was provided why the figures were chosen.

Term “*B*” is the discounted total differences between the export revenues and the relevant transport costs accrued to the Canadian natural gas producers.

Term “*C*” is the discounted total salvage values of all existing conventional gas left in the ground at the horizon. Salvage values are determined by the backstop cost at the horizon.

Term “*D*” is the discounted total costs of transporting gas within Canada from all supply regions to all domestic consuming regions

Term “*E*” is the discounted total supply costs, which consist of extraction and processing costs plus costs of transportation to a central collection point, from proved reserves.

Term “*F*” is similar to *E* but for new supply sources. It includes capital costs as well as all the costs in *E*.

Term “*G*” is the discounted total non-linear supply costs for the marginal costs of conventional gas production, which are assumed to rise linearly as the gas production progresses. Conventional gas production costs are expected to rise with cumulative production, owing to deeper wells, drilling in less hospitable environments, and smaller expected discoveries per meter drilled.

Another fact in this paper is the nature of conventional natural gas production. Conventional natural gas production typically follows a recovery profile due to factors such as reservoir pressure decline, gas processing for liquids extraction, contracted delivery rates, and so on. In this regard, the paper based on National Energy Board of

Canada assumes that the production of conventional natural gas is flat for eight years then declines at 8.22 per cent annually.

The paper employed a social discount rate of 5 %. By using a software package, it determined the optimal depletion paths for both domestic consumption and export of Canadian natural gas deposits as well as the domestic price trajectories for all consuming regions in Canada under various specific assumptions and scenarios. The most important assumption was export prices, which were discrete and were changed up or down in only few steps following no rules including Hotelling's rule. Another important assumption was the maximum allowed exports, which were also discrete. These two assumptions dictate the export and, as its outcomes, influence the domestic consumption and price. In one case it assumed the export price to be 4 $/gigajoule, which was higher than the domestic price, for just the first 3-year period, starting 1984, and 3 $/gigajoule for all later periods. As a result, all exports in that case will terminate in 2013 because there will be no profit from export while production for domestic consumption still goes on. In another case the export price was assumed to be 4 $/gigajoule for the first 3-year period, and 3 $/gigajoule for the second and third 3-year periods (6 years altogether), and 5 $/gigajoule for all later periods. Under this assumption export ends later and it was found that the higher export price would not reduce exports in the first three periods but it would increase future exports and reduce near-term Canadian consumption to accommodate future higher exports. Note that this paper found that the domestic price trajectory does not follow Hotelling's rule for resource pricing. It explains that factors such as the recovery profile, allowance for shut-in production, and technology transition constraints bear on optimal pricing and invalidate the standard Hotelling's rule.

6.3 Rationale behind the Model Formulation

The determination of the optimal depletion of Thailand's gypsum resource will be based on the concept of maximizing Net Present Value (NPV) of the total benefits accrued to a society. Here, the benefits accrued to a society are represented by the total economic welfare (also called social surplus or total surplus), which is composed of the consumer surplus and the producer surplus. However, the society in this study is Thailand only, covering just producers and consumers within Thailand's boundary, not the whole world as presumed by other studies. All gypsum production, either for domestic consumption or for export, renders producer surplus, but only gypsum consumed in the country offers consumer surplus. Therefore, the production of gypsum mineral for export gives less net benefit to Thailand than the production of gypsum for domestic consumption.

There are some minor economic effects resulted from extra foreign income from the export of gypsum. In an open economy as Thailand extra foreign earnings will either strengthen Thai currency, or enlarge the Thailand's total foreign exchange reserves, or do both in between. Rich foreign exchange reserves give at least some benefit to general investors since they will pay less interest on foreign loans as the country earns higher credit rating. However, a stronger domestic currency gives benefits to domestic consumers of foreign goods and helps push down inflation, while undesirably lowers the competitiveness of domestic products in foreign countries. Pressure to strengthen domestic currencies may not be always welcome by some governments of many developing countries as they pursue the policy of weak domestic currencies with the aim to support their export sectors. Because of its small effects, since the export of gypsum is small in comparison with the value of Thailand's total export, together with its associating complexity if it is taken into account, the effect of extra foreign earnings will be disregarded by this thesis.

It is an aim of this study to put an economic theoretical concept into practice by incorporating real data. However, to deal with real world complexity and other shortcomings, the following assumptions are applied:

i) Gypsum is an abundant mineral worldwide. After Thailand's gypsum resource is depleted completely, it is assumed that Thailand will import gypsum from other countries for consumption. (The imported gypsum is indeed the backstop resource as discussed in the subsection 6.2.1 part b of Chapter 6.) Therefore, the depletion of gypsum in the country means that, in the future, Thai consumers will have to import foreign gypsum at prices more expensive than Thai gypsum when it is plentifully available.

ii) Demand for gypsum in Thailand is very small in comparison with the total world demand for gypsum. Therefore, its effect on world gypsum price is either nil or negligible.

iii) The price paid by Thai consumers for gypsum produced domestically is on par with the F.O.B. (Free on Board) price or export price of gypsum. This assumption is based on the highly competitive nature of gypsum trade in Thailand, though in captive markets a producer may sell its product to different customers at different prices.

iv) The amount of gypsum reserves left in the ground in Thailand is not affected by a gypsum price rise. In other words, this thesis assumes a fixed stock of gypsum reserves left in the ground. Although ore deposits of the high price metal have various metal contents and they are generally unidentifiable by normal eyes, a price rise should induce extensive exploration for such metal ore deposits. Such a case is unlikely for cheap construction minerals such as limestone, granite, and gypsum. Economical or marginal deposits of these minerals are massive with mostly visible outcrops and easy to identify. They are cheap simply because they are abundant and easy to find, explore, excavate and process. As regards the exploration for gypsum, Sharpe and Cork (2006) stated as follows:

> "Commercial deposits of gypsum may be almost pure …... ….., much is known about the worldwide distribution of deposits. ….. The potential for the existence of evaporite minerals[19] can be determined by studying the stratigraphy in regions where sedimentary rocks occur. If shallow evaporite rocks[20] are believed to be present, then further information may be delivered by examining outcrops and topographic maps. Deeper deposits can be initially investigated by examining geophysical logs, oil and gas lithologic strip logs, or water-well information. ....., outcrops of gypsum support only sparse vegetation."

Gypsum deposits in Thailand are in geologically known areas of high potential for gypsum discovery and are located just a few meters beneath subsoil, which are shallower than most ground water tables. They are located in plains or slightly undulating terrains with sparse outcrops. Gypsum deposits in the Central region expose their outcrops, while those in the Northeastern region were found by a geophysics exploration done by the Department of Mineral Resources (DMR) (Utha-aroon and Rattanajaruraks, 1996). Some deposits in the Southern region were discovered by ground

[19] Evaporite minerals mean gypsum mineral.
[20] Shallow evaporite rocks mean gypsum mineral.

water-well information. Since Thailand has a rather complete Geological map done by the DMR, and drilling for ground water in Thailand has been extensive; therefore, it is rather pessimistic about a chance to discover substantially additional gypsum reserves in Thailand.

v) The price elasticity of demand for gypsum in Thailand and its client countries is very small. The rationale behind this assumption is the result of the analysis in section 5.7 of Chapter 5, which discarded the price variable out of the demand (or consumption) functions of gypsum. As a result and for reasons of simplicity, some models determining the optimal depletion path of Thailand's gypsum resource will be formulated under the assumption that the price elasticity of demand for gypsum is zero. This assumption might be contrary to the conventional wisdom; however, as presented in Chapter 5, several studies to forecast the consumption of metals either outright discarded price factors or found the price elasticities of demand for metals were close to zero or very small, except the elasticity of demand for gold in high-income countries. Furthermore, some results show positive price elasticities of demand for metals, which are contrary to the behaviour of normal goods that metals are supposed to be. The own price elasticity of demand for gold in high-income countries was also inelastic but substantially high as a major part of the total gold consumption is consumed directly by people. Table 6.1 is the summarizing results of the studies that were reviewed in Chapter 5 with regard to the own price elasticities of demand for metals. Note that similar studies on any industrial minerals have not been found.

However, to see the effect of the influence of prices on the optimal depletion path, a model with demand functions of constant price elasticity of demand will be formulated and tested in an empirical study in this thesis. Since no viable form of relation between the price and demand was found in the analysis of the last chapter, some specific small values of the price elasticity of demand for gypsum will be assumed. Note that, with a very low price elasticity of demand, the apparent significant change in consumption of gypsum is because of the shift in the demand curve as a result of the changes in consumer income and technology. Figure 6.2 shows the shifts in demand curves. In the Figure, X_1, X_2 and X_3 are productions in years 1, 2, and 3, respectively for the demand curves with the perfect price-inelasticity, and Q_1, Q_2 and Q_3 are productions in years 1, 2, and 3, respectively for the demand curves with constant price elasticity, *b*.

vi) The consumption model, as developed in the last chapter, comprises population and GDP variables. However, since there are not better methodologies to predict the future population and GDP of a country, constant growth rates of populations and real dollars GDPs are assumed.

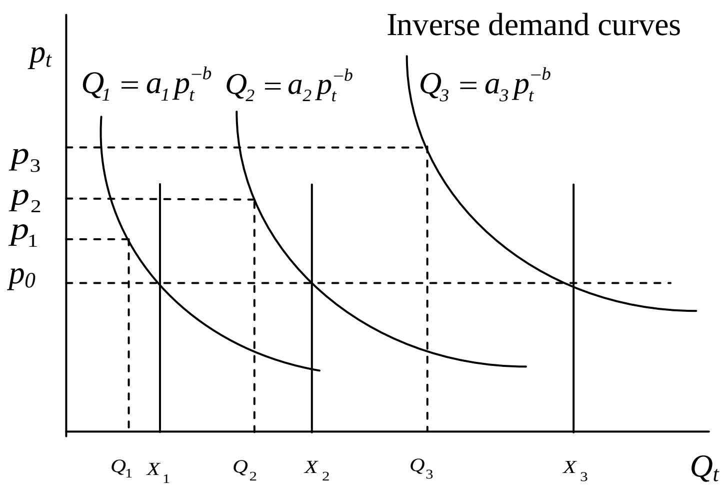

Figure 6.2 Showing the Shift in Demand Curve

Table 6.1 Own Price Elasticities of Demand of Some Metals

Method	Author	Condition	Country	Metal							
				aluminium	copper	lead	nickel	tin	zinc	steel	gold
Intensity of Use	Roberts (1990)	Outright discarding price factors	USA							0.000*	
	Valdes (1990)		Australia							0.000*	
	Roberts (1996)		World	0.000*	0.000*	0.000*			0.000*		
	Crompton (2000)		Japan							0.000*	
	Guzman *et al.* (2005)		Japan		0.000*						
	Rebiasz (2006)		Poland							0.000*	
Double-log demand function	Suslick and Harris (1990)		Brazil	-0.0824							
	Vial (1992)		USA		-0.103 to -1.050						
	Batchelor and Gulley (1995)		High-income								-0.5 to -0.9
	Pei and Tilton (1999)	Without time variable	High-income	0.000	0.110	0.080	-0.060	-0.010	0.010		
			Low-income	0.019	-0.025	-0.056	-0.313	-0.283	0.158		
		With time variable	High-income	-0.020	0.020	0.060	-0.030	-0.030	0.010		
			Low-income	0.317	0.188	-0.023	-0.313	-0.151	0.318		
	Tcha and Takashina (2002)	With a constant term	World	0.004	-0.025	-0.006	-0.047	-0.064	-0.020	-0.012	
		Without a constant term		-0.009	-0.025	0.001	-0.049	-0.053	-0.020	-0.013	

*Interpreted figures as this method does not take price factors into consideration.

6.4 Formulation of a General Model

6.4.1 A Function Maximizing the Total Surplus

The optimal control formulation of gypsum depletion in Thailand is to maximize the discounted flow of the total economic welfare or total surplus generated by the exploitation of gypsum, which is the sum of the producer surplus, or the resource rents of gypsum mining industry, from present to the time the gypsum resource in Thailand is depleted, and the consumer surplus from consuming gypsum from present to infinity. However, the consumer surplus can be divided into two parts. The first part is the consumer surplus from consuming cheap domestically produced gypsum, while the second part is the consumer surplus from consuming expensive imported gypsum after the gypsum resource in Thailand is depleted. Therefore, the maximizing function can be mathematically written as follows:

$$\text{Max} \int_0^T e^{-rt} B_t dt + \int_0^T e^{-rt} D_t \, dt + \int_T^\infty e^{-rt} D'_t \, dt \tag{6.26}$$

where r is discount rate,

T is time when the gypsum resource in Thailand is exhausted,

B_t is the producer surplus at time t,

D_t is the consumer surplus from consuming cheap domestically produced gypsum at time t,

D'_t is the consumer surplus from consuming expensive imported gypsum at time t after the gypsum resource in Thailand is exhausted.

If the function 6.26 is added and subtracted by $\int_0^T e^{-rt} D'_t \, dt$ we have:

$$\text{Max} \int_0^T e^{-rt} B_t dt + \int_0^T e^{-rt} D_t \, dt + \int_T^\infty e^{-rt} D'_t \, dt + \int_0^T e^{-rt} D'_t \, dt - \int_0^T e^{-rt} D'_t \, dt$$

which can be rewritten as:

$$\text{Max} \int_0^T e^{-rt} B_t dt + \int_0^T e^{-rt} (D_t \text{ - } D'_t) dt + \int_0^\infty e^{-rt} D'_t \, dt \tag{6.27}$$

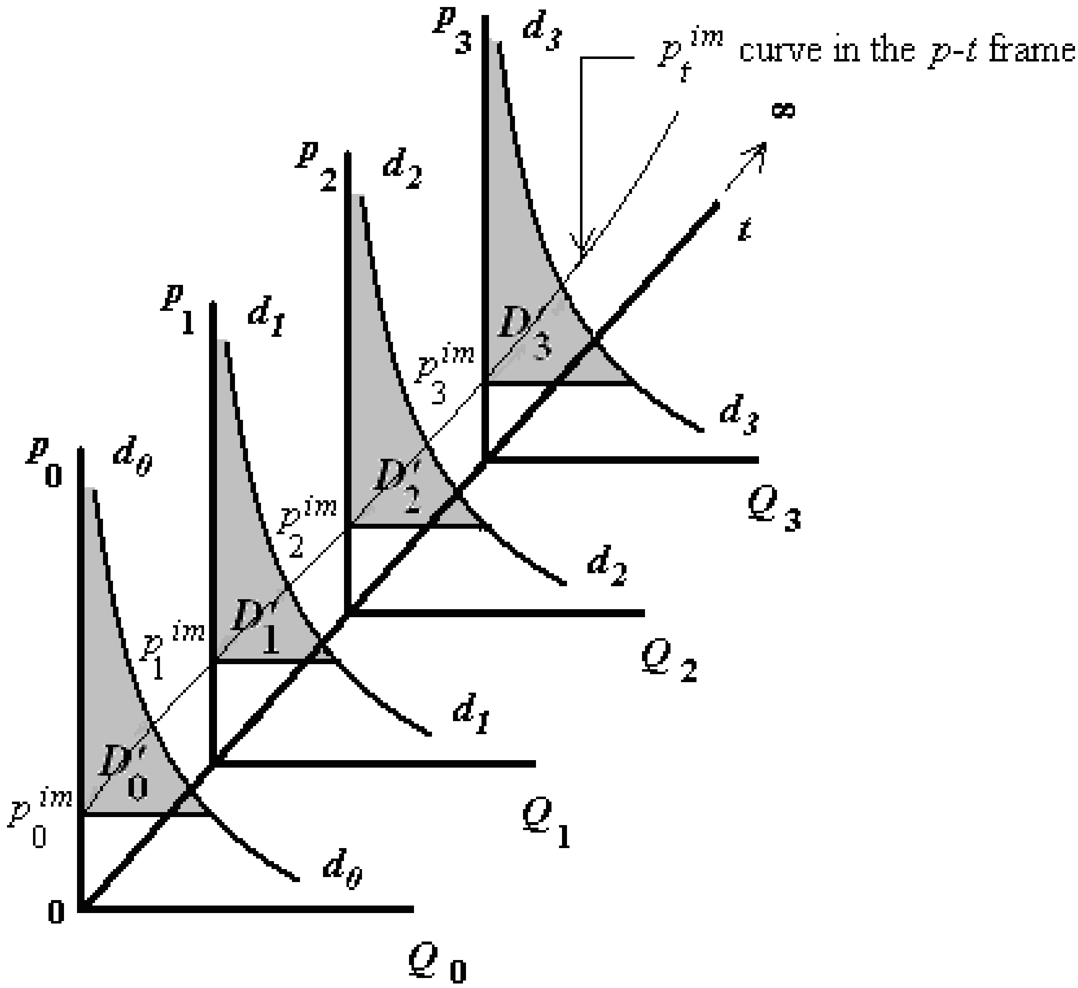

Figure 6.3 Demonstrating D'_t, consumer surplus (shaded areas) at time t, for t = 0, 1, 2, 3, …, ∞, in three dimensions, when gypsum consumption in Thailand is totally from import

Figure 6.3 shows D'_t's, for t = 0, 1, 2, 3, …. d_0-d_0, d_1-d_1, d_2-d_2, d_3-d_3, …, are domestic demand curves at time t = 0, 1, 2, 3, …, respectively. These domestic demand curves are fixed under a given function of domestic demand through time. p_t^{im}'s, for t = 0, 1, 2, 3, …, are the expected import prices, at time t = 0, 1, 2, 3, …, respectively. Since the demand for gypsum in Thailand will not affect the world gypsum price, as stated in the assumption ii) of the section 6.3, each of p_t^{im}'s, for t = 0, 1, 2, 3, …, ∞ is fixed in this analysis. Therefore, each of D'_t's, for $t = 0, 1, 2, 3, \ldots, \infty$, (shaded areas in Figure 6.3) is fixed. Hence, $\int_0^\infty e^{-rt} D'_t \, dt$ is a constant. Therefore, $\int_0^\infty e^{-rt} D'_t \, dt$ can be eliminated from the function 6.27 to become as follows:

$$\text{Max} \int_0^T e^{-rt} B_t dt + \int_0^T e^{-rt} (D_t - D'_t) dt \qquad (6.28)$$

The term $(D_t - D'_t)$ can be defined as the net consumer surplus from consuming cheap domestically produced gypsum at time t.

6.4.2 Determining the Producer Surplus, B_t

a) A Basic Formula

The producer surplus of the expression 6.28 is simply the total resource rents earned by gypsum producers. In this analysis production of gypsum in Thailand is divided into two groups--for domestic consumption and for export--and the gypsum resource is divided accordingly. Therefore,

$$\begin{aligned} B_t &= p_t Q_t - C(Q_t) \\ &= p_t Q_t^d + p_t Q_t^e - C(Q_t) \qquad (6.29) \end{aligned}$$

Subject to: $\dot{S}_t = -Q_t = -(Q_t^d + Q_t^e)$

$S(0) = S_0$, $S(\mathrm{T}) = 0$

$S_0 = S_0^d + S_0^e$

$S_0^d = \int_0^T Q_t^d dt$, and $S_0^e = \int_0^{Te} Q_t^e dt$

where p_t = price of gypsum in Thailand at time t,

Q_t = production of gypsum at time t;

Q_t^d = domestic consumption of gypsum at time t;

Q_t^e = export of gypsum at time t;

$C(Q_t)$ = cost of extraction;

$S(t)$ = the amount of gypsum left in the ground at year t,

$\dot{S}_t$ = the rate of depletion of gypsum resource at year t;

S_0^d = gypsum resource allocated for domestic consumption;

S_0^e = gypsum resource allocated for export; and

T_e = the time that export of gypsum ceases, by measures enforced by the government such as heavy taxation or an outright prohibition of gypsum export. Since domestic consumption offers higher social benefit than export, the S_0^e and S_0^d are allocated such that $T_e \leq T$.

b) The Cost of Extraction, *C*(*Q*$_t$)

According to Hanley *et al*. (2007), the marginal cost of extraction should increase as the remaining stock in the ground decreases. Since the stock decreases at the same rate as accumulative production, it can be said that, under such hypothesis, the marginal cost of extraction increases when the accumulative production increases. However, it was found that mineral extraction costs have decreased over time due to technological advances, which improved mining productivity and efficiency (Wilburn *et al*., 2005). Therefore, given that c_0, c_1, c_2, and c_3, are positive constants, the general function of the cost of extraction of gypsum is as follows:

$$C(Q_t) = c_0 + \left(c_1 + c_2 \int_{\tau=0}^{t} Q_\tau d\tau - c_3 t \right) Q_t$$

Subject to $\int_{\tau=0}^{t} Q_\tau d\tau \leq S_0$, and $Q_\tau = Q_\tau^d + Q_\tau^e$

where Q_τ is the total production of gypsum in Thailand at time τ,

$\int_{\tau=0}^{t} Q_\tau d\tau$ represents the accumulative production up to year t,

Q_τ^d is the production of gypsum for domestic consumption at time τ,

Q_τ^e is the production of gypsum for export at time τ,

c_0 is the extraction fixed cost,

c_1 is the normal extraction variable cost,

$c_2 \int_{\tau=0}^{t} Q_\tau d\tau$ represents the increase in the marginal cost as a result of the decrease in the remaining stock at time t, and

$-c_3 t$ represents the decrease in the marginal cost as a result of technological advances at time t,

c) The Detailed Formula Determining the Producer Surplus, B_t

Therefore, equation 6.29 can be rewritten as follows:

$$B_t = p_t Q_t^d + p_t Q_t^e - c_0 - \left(c_1 + c_2 \int_{\tau=0}^{t} Q_\tau d\tau - c_3 t \right) Q_t$$

$$= p_t Q_t^d + p_t Q_t^e - c_0 - \left(c_1 + c_2 \int_{\tau=0}^{t} (Q_\tau^d + Q_\tau^e) d\tau - c_3 t \right) (Q_t^d + Q_t^e)$$

$$= \left[p_t - \left(c_1 + c_2 \int_{\tau=0}^{t} (Q_\tau^d + Q_\tau^e) d\tau - c_3 t \right) \right] Q_t^d + \left[p_t - \left(c_1 + c_2 \int_{\tau=0}^{t} (Q_\tau^d + Q_\tau^e) d\tau - c_3 t \right) \right] Q_t^e - c_0$$

(6.30)

6.4.3 Determining the Net Consumer Surplus, $(D_t - D'_t)$

In determining the net consumer surplus, $(D_t - D'_t)$, of the expression 6.28, let us assume that the domestic demand curve of gypsum with a constant price elasticity of demand, $-b$, in year t is $q = a_t p^{-b}$, where q_t is the gypsum quantity at time t, p_t is the gypsum price at time t, and a_t is a constant for year t. In a complex demand function that includes other parameters besides price, such as consumers' incomes, tastes, technology, etc., a_t may be considered as the factor covering the total effect of such parameters that are fixed in the partial analyses of the price and quantity relations. If a_t increases through time the demand curve will shift to the right as time passes.

Figure 6.4 shows the domestic demand curve and the net consumer surplus. Therefore,

$D_t = \int_{p_t}^{\infty} a_t\, p^{-b}\, dp$, the consumer surplus from consuming cheap domestically produced gypsum at time t; and

$D'_t = \int_{p_t^{im}}^{\infty} a_t\, p^{-b}\, dp$, the consumer surplus from consuming expensive imported gypsum at time t after the gypsum resource in Thailand is exhausted.

where p_t^{im} is the expected import price if the domestic production of gypsum is stopped or insufficient for domestic consumption. Hence, the net consumption surplus at time t, D_t - D'_t, which is the shaded area demonstrated in Figure 6.4, can be defined as follows:

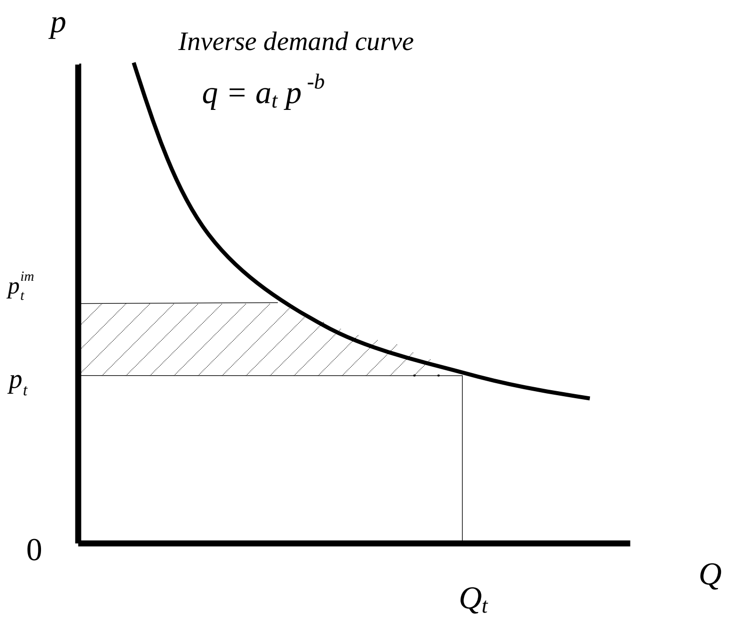

Figure 6.4 Demand Curve and the Net Consumer Surplus (the Shaded Area)

$$D_t - D'_t = \int_{p_t}^{p_t^{im}} a_t\, p^{-b} dp = \left[\frac{a_t\, p^{1-b}}{1-b} \right]_{p_t}^{p_t^{im}}$$

$$= \left[\frac{q_t p}{1-b} \right]_{p_t}^{p_t^{im}}$$

$$= \left(\frac{p_t^{im} - p_t}{1-b} \right) q_t$$

For $q_t = Q_t^d$; $$D_t - D'_t = \left(\frac{p_t^{im} - p_t}{1-b} \right) Q_t^d \qquad (6.31)$$

Because mineral gypsum is traded worldwide, price difference from place to place is mainly due to transportation cost. In Thailand, the difference between the expected import price, p_t^{im}, and the real domestic price, p_t, is certainly positive at present and in the near future. Being price takers gypsum producers have little market power to raise the domestic price to the level of the expected import price. For simplicity, this fact is assumed to hold true up until the time the gypsum resource in Thailand is exhausted. However, even if near the time of exhaustion the price of domestically produced gypsum rises to reach the level of the import price, the loss of consumer surplus, due to the increase in price, simply changes to be the gain of the producer surplus. As a result, error caused by the assumption will not significantly affect the analysis of this study. The analysis in a latter part of this chapter will show the insignificance of the real domestic price movement to the net social benefit (net consumer surplus + producer surplus) generated by the gypsum production for domestic consumption.

6.4.4 The General Model

Substituting expressions 6.30 and 6.31 in expression 6.28, we get:

$$\text{Max} \int_0^T e^{-rt} \left[\left\{ p_t - \left(c_1 + c_2 \int_{\tau=0}^{t} (Q_\tau^d + Q_\tau^e) d\tau - c_3 t \right) \right\} Q_t^d + \left\{ p_t - \left(c_1 + c_2 \int_{\tau=0}^{t} (Q_\tau^d + Q_\tau^e) d\tau - c_3 t \right) \right\} Q_t^e - c_0 \right] dt$$
$$+ \int_0^T e^{-rt} \frac{\left(p_t^{im} - p_t \right)}{1-b} Q_t^d \, dt$$

Or Max $\int_0^T e^{-rt}\left[\left\{\frac{p_t^{im}}{1-b}+\left(p_t-\frac{p_t}{1-b}\right)-\left(c_1+c_2\int_{\tau=0}^{t}(Q_\tau^d+Q_\tau^e)d\tau-c_3t\right)\right\}Q_t^d-c_0\right]dt$

$$+\int_0^T e^{-rt}\left[p_t-\left(c_1+c_2\int_{\tau=0}^{t}(Q_\tau^d+Q_\tau^e)d\tau-c_3t\right)\right]Q_t^e dt \qquad (6.32)$$

Let Q_t^e cease at T_e and $T_e \leq T$ since, politically and economically, export is certainly less favourable than domestic consumption. Therefore, the function 6.32 can be rewritten as:

Max $\int_0^T e^{-rt}\left[\left\{\frac{p_t^{im}}{1-b}+\left(p_t-\frac{p_t}{1-b}\right)-\left(c_1+c_2\int_{\tau=0}^{t}(Q_\tau^d+Q_\tau^e)d\tau-c_3t\right)\right\}Q_t^d-c_0\right]dt$

$$+\int_0^{Te} e^{-rt}\left[p_t-\left(c_1+c_2\int_{\tau=0}^{t}(Q_\tau^d+Q_\tau^e)d\tau-c_3t\right)\right]Q_t^e dt \qquad (6.33)$$

Subject to: $\dot{S}_t=-Q_t=-(Q_t^d+Q_t^e)$

$S(0) = S_0$, $S(\mathrm{T}) = 0$,

$S_0=S_0^d+S_0^e$, or

$$S_0=\int_0^T Q_t^d dt+\int_0^{Te} Q_t^e dt \qquad (6.34)$$

$T \geq 0$, $T_e \geq 0$, and $T_e \leq T$.

We can see that expression 6.33 has two parts. With a given set of S_0^e and S_0^d that satisfies equation 6.34, maximizing expression 6.33 means maximizing both parts. Therefore, under such conditions, expression 6.33 could be modified to be the general model as follows:

Max $\int_0^T e^{-rt}\left[\left\{\frac{p_t^{im}}{1-b}-p_t\left(\frac{b}{1-b}\right)-\left(c_1+c_2\int_{\tau=0}^{t}(Q_\tau^d+Q_\tau^e)d\tau-c_3t\right)\right\}Q_t^d-c_0\right]dt$

+ Max $\int_0^{Te} e^{-rt}\left[p_t-\left(c_1+c_2\int_{\tau=0}^{t}(Q_\tau^d+Q_\tau^e)d\tau-c_3t\right)\right]Q_t^e dt \qquad (6.35)$

Expression 6.35 is also bound by the same constraints stated below expression 6.33, including equation 6.34.

The model in the form of expression 6.35, which is discounted continuously, can be written as an annually discrete discounting function as follows:

$$\text{Max} \sum_{t=1}^{T} \frac{1}{(1+r')^t} \left[\left\{ \frac{p_t^{im}}{1-b} - p_t\left(\frac{b}{1-b}\right) - \left(c_1 + c_2 \sum_{\tau=1}^{t} (Q_\tau^d + Q_\tau^e) - c_3 t \right) \right\} Q_t^d - c_0 \right]$$

$$+ \text{Max} \sum_{t=1}^{Te} \frac{1}{(1+r')^t} \left[\left\{ p_t - \left(c_1 + c_2 \sum_{\tau=1}^{t} (Q_\tau^d + Q_\tau^e) - c_3 t \right) \right\} Q_t^e \right] \qquad (6.36)$$

Subject to: $S_t - S_{t-1} = -Q_t = -(Q_t^d + Q_t^e)$,

$S(0) = S_0$, $S(\mathrm{T}) = 0$,

$S_0 = S_0^d + S_0^e$, or

$S_0 = \sum_{t=1}^{T} Q_t^d + \sum_{t=1}^{Te} Q_t^e$,

$T \geq 0$, $T_e \geq 0$, and $T_e \leq T$.

Where r' is an annual discrete discount rate and:

$$r' = e^r - 1 \qquad (6.37)$$

The purpose of introducing an annually discrete discounting maximizing function here is for later utilization in the empirical study parts of this chapter when the integral functions cannot be simplified and are calculated with difficulty. Note that, of both expressions 6.35 and 6.36, the first parts represent the social benefit or the total surplus of the gypsum production for domestic consumption, while the second parts represent that of the gypsum production for export. We can also see that, if the absolute value of price elasticity of demand for gypsum, b, is very small, the domestic price, p_t, is less relevant to the social benefit of the gypsum production for domestic consumption of the above two maximizing functions, while the import price, p_t^{im}, is important.

6.5 Special Models

We can see that the full model with the assumed demand function of constant price elasticity, either in the general forms of expressions 6.35 or 6.36, consists of some parameters that are determined with difficulty and that this thesis failed to determine. The ones that are determined with difficulty are c_2, indicating the positive effect on the marginal cost of extraction, and c_3, denoting the negative effect of technology on the marginal cost of extraction. The parameter that cannot be determined in Chapter 5 of this thesis is the significant value of b, representing the influence of price on gypsum consumption.

With regard to b, the price elasticity of demand for gypsum, two approaches will be utilized in the empirical study of this thesis. However, both approaches will be based on the assumptions mentioned at the beginning of this chapter and the results of some other papers that found highly price inelastic demands for minerals. One approach, having the benefit of simplicity, will assume the value of b is zero, while, in the other approach, some small values of b will be tested to see the effects of them.

As for c_2 and c_3, their sizes should be small and they involve a long time-scale that makes them difficult to be determined. The coefficient c_2 is supposed to exist in theory on the belief that low cost or easy ores are mined first, while the higher cost or deeper ores with poorer grades are excavated latter. To conform to such an assertion a mineral has to have the total stock (the total ore reserve) comprising ore deposits of varied ore grades or qualities, very thick ore bodies, and/or varied depth. However, gypsum deposits in Thailand possess no such conditions. In general, mineral gypsum all around the world has a similar grade and quality, and most of its deposits are easily mined. All gypsum deposits in Thailand are a shallow flat bed type with only a 30-

metre thickness at most (only 2-3 levels of open-pit benches). After removing their overburdens, the costs of excavating the top and the bottom of the mineral beds are almost the same. Therefore, the value of c_2 should be very small, if any.

It should be noted that, even though mineral deposits have a variety of ore grades, ore body thicknesses, and depths, the belief that the marginal cost of extracting minerals increases when the stocks of minerals get smaller has not been proven to be true over time. As time passes minerals are mined from deeper deposits. Therefore, the average extraction cost of a mineral and its price, as a result of the change in cost, were supposed to have an increasing trend. But the real historical price-trends of most minerals, including Thai gypsum as shown in Figure 5.10 of Chapter 5, have not conformed to such a belief.

This anomaly was found and investigated by at least two studies. Tilton (2002), in his investigation of the falling trend of copper prices since 1970, quickly eliminated the downward shift of the demand curve as the cause of the decline in copper prices. His analysis pointed to the downward shift of the supply curve as the real culprit. He stated his rationales behind it as follows: "…copper producers have been spectacularly successful at increasing their productivity and reducing their costs by introducing a range of innovations and new technologies across the board, from exploration to mining to processing to fabrication and even recycling. Though widely viewed as an old, mature industry, copper has, in fact, much in common with the computer and other high technology sectors when it comes to using new technology to reduce costs." He also produced an empirical support for his conclusion, based on data from the Rio Tinto Mine Information System, to show the dramatic reduction in cash costs for copper producers between the years 1980, 1990 and 1999, as shown in Figure 6.5. Please note that most copper deposits are massive, and copper open pit mines at present are very deep. Kennecott Utah Copper Corporation (KUCC), a division of Rio Tinto Group, operates one of the largest copper mines in the world in Bingham Canyon, Salt Lake County, Utah. In 2008, the Bingham Canyon Mine is more than a kilometre deep. Tilton gave one conclusion that technological progress is more than offsetting the upward pressure on costs caused by the depletion of the best mineral resources over time and the need to mine deeper, lower-grade, remoter, and more difficult deposits.

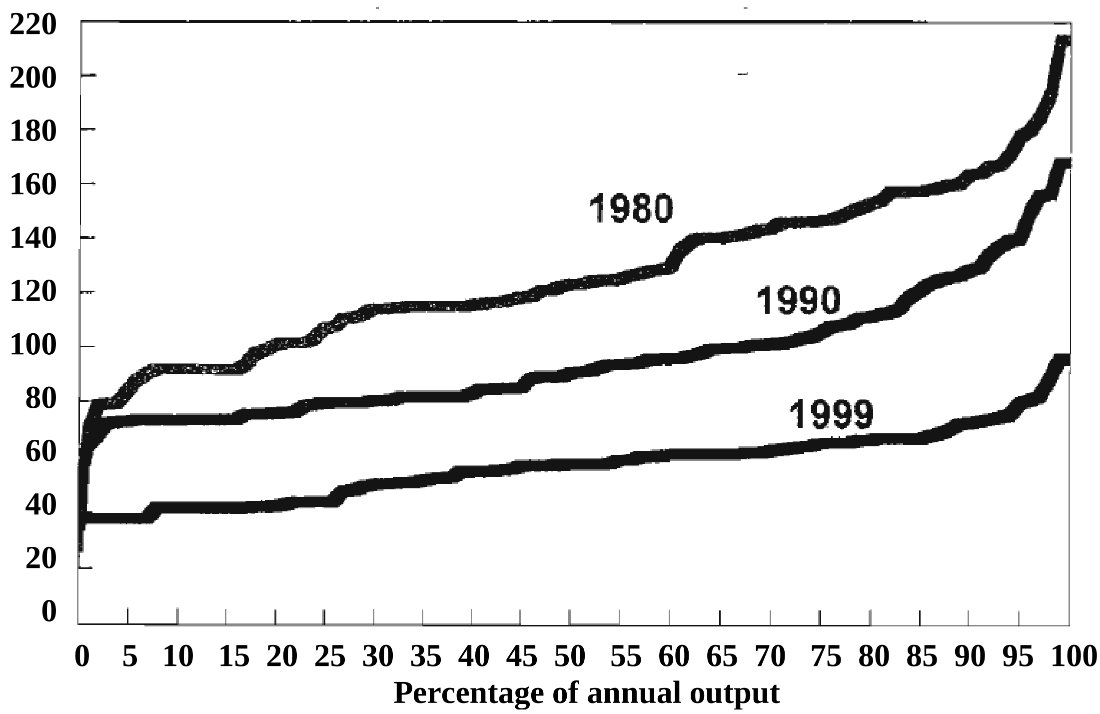

Figure 6.5 Copper Mine Costs (cents/lb, real 2001 terms)

Note: The figure shows pro rata costs. These are the cash costs of producing copper to refined metal minus capital costs (depreciation, amortization and interest on external debt). Costs are attributed to all salable metals that a mine produces in proportion to the contribution of each to sales.
Source: Tilton (2002)

Another investigation related to this matter is that of the USGS done by Wilburn *et al*. (2005), who provided case studies on aluminum, copper, potash, and sulfur to identify the effects of technology on resource supply. They postulated that decreasing prices for natural resources, expressed in constant dollars, would provide one kind of evidence that technological advances have been more than sufficient to overcome obstacles to supply. Their study found very strong evidence supporting this postulation. They demonstrated that between 1900 and 1998, world aluminum and copper production increased by 310- and 8-fold, respectively, but their prices decreased by 84 and 75 percent, respectively. The study also demonstrated that potash and sulfur had shown similar trends. As in the case of copper, the prices declined even though the copper ore grade mined in the U.S.A. decreased from above 1 percent (of copper content) in the early 1950's down to about 0.5 percent (of copper content) in 2000. This means that the copper extraction cost declined tremendously over time. The study explains that the decrease in mineral extraction costs, were due to the advances in blasting, drilling, and equipment design and capacity, as well as the use of larger capacity equipment and increased mechanization, which improved mining productivity and efficiency.

Notwithstanding exogenous technological progress that help reduce mineral extraction cost over a normally long mining life, improvement always occurs continuously in a mine as miners gain more experience. Therefore, the cost of mining a deeper part of an ore deposit will likely be lower than expected.

Anyway, it is not certain that future technological progress will leap forwards as smoothly and as fast as it has been, while the final depletion of many minerals are real. Therefore, to compromise the two opposite forces and to simplify the empirical analysis of this study, 'a special model' of this thesis will assume that the aggregate marginal cost to extract gypsum, in real terms, is approximately constant over time. Because the time frame in this study is not very long, the error caused by this assumption would not be too significant to alter the main message of this thesis. In the other words, the special model is under the assumption that:

$$c_2 \int_{\tau=0}^{t} Q_\tau d\tau - c_3 t \approx 0$$

Therefore, expression 6.35 can be modified to become as follows:

$$\text{Max} \int_0^T e^{-rt} \left[\left\{ \frac{p_t^{im}}{(1-b)} - p_t \left(\frac{b}{1-b} \right) - c_1 \right\} Q_t^d - c_0 \right] dt \ + \text{Max} \int_0^{Te} e^{-rt} (p_t - c_1) Q_t^e dt \qquad (6.38)$$

Subject to the same constraints stated below expressions 6.33 and 6.35.

Similarly, expression 6.36, an annually discrete discounting function, becomes as follows:

$$\text{Max} \sum_{t=1}^{T} \frac{1}{(1+r')^t} \left[\left\{ \frac{p_t^{im}}{(1-b)} - p_t \left(\frac{b}{1-b} \right) - c_1 \right\} Q_t^d - c_0 \right] + \text{Max} \sum_{t=1}^{Te} \frac{(p_t - c_1)}{(1+r')^t} Q_t^e \qquad (6.39)$$

Subject to the same constraints stated below expression 6.36.

6.5.1 A Special Model with Zero Price Elasticity of Demand

If the price elasticity of demand for gypsum is assumed to be perfectly inelastic or, in other words, the value of *b* is zero, expression 6.38 will become as follows:

$$\text{Max} \int_0^T e^{-rt} \left\{ (p_t^{im} - c_1) Q_t^d - c_0 \right\} dt \ + \text{Max} \int_0^{Te} e^{-rt} (p_t - c_1) Q_t^e dt \qquad (6.40)$$

Subject to the same constraints stated below expressions 6.33 and 6.35.

In the same manner, expression 6.39 will become as follows:

$$\text{Max} \sum_{t=1}^{T} \frac{1}{(1+r')^t} \left\{ (p_t^{im} - c_1) Q_t^d - c_0 \right\} \ + \text{Max} \sum_{t=1}^{Te} \frac{(p_t - c_1)}{(1+r')^t} Q_t^e \qquad (6.41)$$

Subject to the same constraints stated below expression 6.36.

In the first parts of expressions 6.40 and 6.41, representing the social benefit of gypsum production for domestic consumption, the domestic price is irrelevant and the gypsum producers in Thailand have no control over the import price, p_t^{im}. With the exception of Hotelling's rule, there is not any particular practical method to predict p_t^{im}.

Analyses based on two alternative assumptions with regard to p_t^{im} will be done here. The first one is that the $(p_t^{im} - c_{int})$ will rise in accordance with Hotelling's rule, where c_{int} is the marginal cost in other gypsum producing countries to supply gypsum to Thailand in the future plus the unit shipment cost to Thailand. c_{int} should have the same structure as its counterpart, c_1, which is assumed to be a constant. Therefore, if the unit shipment cost in constant dollars is fixed, c_{int} is also a constant. For the sake of an economic theory, the $(p_t - c_1)$ will also be assumed to follow Hotelling's rule in this first alternative analysis. The second alternative will disregard Hotelling's rule and assume that gypsum prices anywhere will follow the same price trends of most minerals studied by Lin and Wagner (2007). Using data from 1970 to 2004, the two, who re-examined Hotelling's model, found that the prices for 13 of 14 minerals exhibited a zero growth rate. Therefore, p_t^{im} and p_t in constant dollars are treated as fixed and equal to p_0^{im} and p_0, respectively, in the second alternative analysis.

a) Case I: with Zero Price Elasticity of Demand and Applicable Hotelling's Rule

i) The Model of Case I

Expression 6.40 can be rewritten as follows:

$$\text{Max}\left\{\int_0^T e^{-rt}(p_t^{im} - c_{int})Q_t^d dt + (c_{int} - c_1)\int_0^T e^{-rt}Q_t^d dt - c_0\int_0^T e^{-rt} dt\right\} + \text{Max}\int_0^{Te} e^{-rt}(p_t - c_1)Q_t^e dt \qquad (6.42)$$

Subject to the same constraints stated below expressions 6.33 and 6.35.

Under Hotelling's rule, we have:

$(p_t^{im} - c_{int}) = (p_0^{im} - c_{int})e^{rt}$, and

$(p_t - c_1) = (p_0 - c_1)e^{rt}$

Therefore, expression 6.42 can be rewritten as follows:

$$\text{Max}\left\{(p_0^{im} - c_{int})\int_0^T Q_t^d\,dt + (c_{int} - c_1)\int_0^T e^{-rt} Q_t^d\,dt - c_0\int_0^T e^{-rt}dt\right\} + \text{Max }(p_0 - c_1)\int_0^{Te} Q_t^e\,dt \quad (6.43)$$

From equation 6.34, $\int_0^{Te} Q_t^e\,dt = S_0 - \int_0^T Q_t^d\,dt$. Hence, expression 6.43 can be modified as follows:

$$\text{Max }\left\{(p_0^{im} - c_{int})\int_0^T Q_t^d\,dt + (c_{int} - c_1)\int_0^T e^{-rt} Q_t^d\,dt - c_0\int_0^T e^{-rt}dt\right\} + \text{Max }(p_0 - c_1)\left\{S_0 - \int_0^T Q_t^d\,dt\right\}$$

$$\text{Or Max}\left[\left\{(p_0^{im} - p_0) - (c_{int} - c_1)\right\}\int_0^T Q_t^d\,dt + (c_{int} - c_1)\int_0^T e^{-rt} Q_t^d\,dt - c_0\int_0^T e^{-rt}dt + (p_0 - c_1)S_0\right] \quad (6.44)$$

$$\text{Let } F_1 = \left\{(p_0^{im} - p_0) - (c_{int} - c_1)\right\}\int_0^T Q_t^d\,dt + (c_{int} - c_1)\int_0^T e^{-rt} Q_t^d\,dt - c_0\int_0^T e^{-rt}dt + (p_0 - c_1)S_0 \quad (6.45)$$

With a given set of S_0^e and S_0^d that satisfies equation 6.34, all other terms of the right-hand side of equation 6.45 are fixed except the second one,

$(c_{int} - c_1)\int_0^T e^{-rt} Q_t^d\,dt$.

Since c_{int} includes the unit transportation cost from other countries to Thailand and the gypsum deposits in Thailand are easily mined, the value of (c_{int} - c_1) is certainly positive. This means that, to maximize the net present value of the net social benefit, Thailand should supply gypsum to the domestic demand as much and as fast as possible because the discount rate factor, e^{-rt}, is weighted against future values. However, because of the highly price inelastic demand, increased consumption cannot be induced by lowering prices. Therefore, gypsum producers have no other option but to fulfil the maximum domestic demand, $X^d(t)$, the function of which is defined as equation 5.17 in Chapter 5.

If the population and the GDP of Thailand are assumed to grow at constant rates, equation 5.17 of Chapter 5 can be rewritten as follows:

$$X_t^d(t) = \beta_1^d GDP_0^d e^{k_d t} + \beta_0^d POP_0^d e^{h_d t} + \beta_2^d (t + 2007) POP_0^d e^{h_d t}, \text{ or}$$

$$X_t^d(t) = \beta_1^d GDP_0^d e^{k_d t} + (\beta_0^d + 2007\beta_2^d) POP_0^d e^{h_d t} + \beta_2^d POP_0^d t e^{h_d t} \quad (6.46)$$

Where $X_t^d(t)$ is the domestic consumption at time *t*, which is in the function of time *t*;

GDP_0^d is the Gross Domestic Product of Thailand at present (year 2007);

POP_0^d is the total population of Thailand at present (year 2007);

β_1^d, β_0^d, and β_2^d are the coefficients β_1, β_0, and β_2 of Thailand of equation form no. 2.5 in Table 5.10 of Chapter 5, respectively;

k_d is the growth rate of the Gross Domestic Product of Thailand, assumed to be constant; and

h_d is the growth rate of the population of Thailand, assumed to be constant.

Substituting $X_t^d(t)$ from equation 6.46 for Q_t^d in equation 6.45 and solving the definite integrals, we have:

$$\begin{aligned}
F_1 = &\{(p_0^{im} - p_0) - (c_{\text{int}} - c_1)\}\left[\frac{\beta_1^d}{k_d} GDP_0^d (e^{k_d T} - 1)\right. \\
&\left. + \frac{\{\beta_0^d h_d + \beta_2^d (2007 h_d - 1)\}}{h_d^2} POP_0^d (e^{h_d T} - 1) + \frac{\beta_2^d}{h_d} POP_0^d T e^{h_d T}\right] \\
&+ (c_{\text{int}} - c_1)\left[\frac{\beta_1^d}{(k_d - r)} GDP_0^d (e^{(k_d - r)T} - 1)\right. \\
&+ \frac{\{\beta_0^d (h_d - r) + \beta_2^d (2007(h_d - r) - 1)\}}{(h_d - r)^2} POP_0^d (e^{(h_d - r)T} - 1) \\
&\left. + \frac{\beta_2^d}{(h_d - r)} POP_0^d T e^{(h_d - r)T}\right] \\
&+ \frac{c_0}{r}\left(e^{-rT} - 1\right) + (p_0 - c_1) S_0
\end{aligned} \quad (6.47)$$

On the right-hand side of equation 6.47, all parameters are fixed or assumed to be fixed except for *T*, the time when gypsum resource in Thailand is exhausted. *T* can be varied as the result of changing the size of S_0^e, the gypsum resource allocated for export. T is longest if S_0^e is zero or, in other words, if all gypsum resources are totally allocated for domestic consumption with no export allowed.

Let T_{max} be the longest possible T. T_{max} can be determined by substituting $Q_t^d = X_t^d(t)$ and $Q_t^e = 0$ in equation 6.34. Hence,

$$S_0 = \int_0^{T_{max}} X_t^d(t)dt + 0 \tag{6.48}$$

Therefore, the optimal T, denoted T^*, that maximizes F_1, has to satisfy the following inequality (as required by equation 6.34 and the nonnegative T_e):

$$0 \le T^* \le T_{max} \tag{6.49}$$

In determining T^*, equation 6.47 is differentiated by dT and set to equal zero as follows:

$$\begin{aligned}\frac{dF_1}{dT} &= \{(p_0^{im} - p_0) - (c_{int} - c_1)\} \\ &\quad [\beta_1^d GDP_0^d e^{k_d T} + (\beta_0^d + 2007\beta_2^d) POP_0^d e^{h_d T} + \beta_2^d POP_0^d T e^{h_d T}] \\ &\quad + (c_{\text{int}} - c_1)[\beta_1^d GDP_0^d e^{(k_d - r)T} + (\beta_0^d + 2007\beta_2^d) POP_0^d e^{(h_d - r)T} + \beta_2^d POP_0^d T e^{(h_d - r)T}] \\ &\quad - c_0 e^{-rT} = 0\end{aligned} \tag{6.50}$$

Equation 6.50 cannot be simplified further and needs to be solved by trial and error or a computer program if all fixed parameters are known. Mathematically, at the determined T^*, the value of F_1 is at its maximum if the value of its second derivative is negative and all constraints are obeyed. The second derivative of the function 6.47 is as follows:

$$\begin{aligned}\frac{d^2 F_1}{dT^2} &= \{(p_0^{im} - p_0) - (c_{\text{int}} - c_1)\}\big[k_d \beta_1^d GDP_0^d e^{k_d T} \\ &\quad + \{\beta_0^d h_d + \beta_2^d (2007 h_d + 1)\} POP_0^d e^{h_d T} + h_d \beta_2^d POP_0^d T e^{h_d T}]\end{aligned}$$

$$+(c_{\text{int}}-c_1)[(k_d-r)\beta_1^d GDP_0^d e^{(k_d-r)T}$$

$$+\{\beta_0^d(h_d-r)+\beta_2^d(2007(h_d-r)+1)\}POP_0^d e^{(h_d-r)T}+(h_d-r)\beta_2^d POP_0^d T e^{(h_d-r)T}]$$

$$+rc_0 e^{-rT} \tag{6.51}$$

ii) An Empirical Solution for the Special Model of Case I

Further attempts will be made to test the special model with perfect price-inelasticity of demand Case I, empirically. Some parameters of Thailand in the model are real and known. Some are real but unknown and a parameter, c_{int}, is just a hypothetical figure. These parameters and their sources of data, for the real and known ones, or their basic assumptions, for the unknown or hypothetical ones, are shown in Table 6.2.

Table 6.2 Values of Parameters and their Sources or Basic Assumptions

Parameters	Value	Source and Basic Assumption
β_1^d	9.162	Table 5.10 in Chapter 5.
β_0^d	-2243722	Table 5.10 in Chapter 5.
β_2^d	1124.918	Table 5.10 in Chapter 5.
GDP_0^d	208.649 (Billion 2006$)	World Economic and Financial Surveys World Economic Outlook Database April 2008 Edition, IMF.
k_d	0.056	World Economic and Financial Surveys World Economic Outlook Database April 2008 Edition, IMF; five year average, 2003-2007.
POP_0^d	0.066 (Billion)	World Economic and Financial Surveys World Economic Outlook Database April 2008 Edition, IMF.
h_d	0.009	World Economic and Financial Surveys World Economic Outlook Database April 2008 Edition, IMF; five year average, 2003-2007.
p_0^{im}	32.77 (2006$/ton)	p_0^{im} is a hypothetical figure. This study assumes that Thailand will pay the same CIF price for gypsum imported from Australia as Japan is paying now. The figure is the five year average, 2003-2007, of CIF price of the Australian gypsum at Japan ports.
p_0	14.35 (2006$/ton)	The five year average, 2003-2007, of FOB price of gypsum in Thailand.
c_1	6.14 (2006$/ton)	The fixed cost, c_0, and variable cost, c_1, are derived from an unpublished study of DPIM on a typical gypsum mine. The fixed cost of the studied mine is multiplied by the total number of gypsum mines in Thailand to represent c_0.
c_0	5.586 (million 2006$)	
c_{int}	24.57 (2006$/ton)	Real c_{int} is a confidential figure. Since all gypsum deposits around the world are similar, this study assumes that the production cost and market structure of gypsum in Australia are the same as in Thailand. Therefore, producers in both countries earn a similar resource rent margin. That is: $p_0^{im} - c_{int} \approx p_0 - c_1$. Hence, $c_{int} \approx p_0^{im} - p_0 + c_1$. A higher figure (1 cent/ton higher) of c_{int} is assumed.
r	10% or 0.1	The discount rate used by the World Bank for project evaluation in developing countries (Hayes and Smith, 1993).
S_0	270.73 (million tons)	Department of Primary Industries and Mines, Thailand.

With the parameters in the Table 6.2 and by equations 6.50 and 6.51, we find that: T^* = 75.17 years with the second derivative function having a negative figure. In addition, dF_1/dT is positive for all values of T from 0 to 75.17. However, when we put in the values of T^* = 75.17 and substitute $X_t^d(t)$ from equation 6.46 into equation 6.34, with corresponding parameters in the Table 6.2, we find that $\int_0^{Te} Q_t^e dt$ or S_0^e, the total gypsum resource allocated for export; is negative. Therefore the solution of T^* = 75.17 from equation 6.50 is out of the bound of reality. Hence, F_1 will be maximum when T is at its possible highest. The possible highest T is achieved only when all gypsum reserves in Thailand are allocated for domestic consumption with none being allocated for export.

Therefore, S_0^e = 0, and $\boldsymbol{T_e^*}$**,** the optimal time that export of gypsum ceases, = 0. By substituting $X_t^d(t)$ from equation 6.46 in equation 6.48, with corresponding parameters in the Table 6.2, and by trial and error, we also have:

T_{max} = 33.07 years

Therefore, the adopted $\boldsymbol{T^*}$ **= 33.07 years**.

The above solution means that, because the benefit of producing and consuming within the country is higher than that of producing for export, Thailand should stop export of gypsum and all the remaining gypsum reserves should be produced for domestic consumption only. In this case the gypsum resource in Thailand is expected to exhaust completely in 33.07 years.

iii) Sensitivity Analysis of the Special Model of Case I with Respect to Different Discount Rates

From equation 6.50, we can see that T^* and, as a result, T_e^* are influenced by the discount rate, *r*. Therefore, it is worth seeing how the solution changes when the discount rate changes. Table 6.3 shows the effect on the T^* and T_e^* of the special model with perfect price-inelasticity of demand Case I, if the discount rate varies.

Table 6.3 Solutions of T^* and T_e^* of the Special Model with Perfect Price-Inelasticity of Demand Case I, with Respect to Different Discount Rates

Discount Rate (r) %	T^* obtained from equation 6.50 (years)	Time when gypsum resource exhausted (adopted T^*) (years)	Time when export of gypsum ended (T_e^*) (years)	Gypsum resource for domestic consumption (S_0^d) (million tons)	Gypsum resource for export (S_0^e) (million tons)§
2.50	300.77	33.07	0	270.730	0
5.00	150.38	33.07	0	270.730	0
7.50	100.25	33.07	0	270.730	0
10.00	75.17	33.07	0	270.730	0
12.50	60.12	33.07	0	270.730	0
15.00	50.08	33.07	0	270.730	0
17.50	42.90	33.07	0	270.730	0
20.00	37.52	33.07	0	270.730	0
22.50	33.34	33.07	0	270.730	0
22.68	33.07	33.07	0	270.730	0
25.00	29.99	29.99	7.22	222.299	48.431

Note: § Derived from equation: $S_0^e = \int_0^{Te} X^e(t)dt$, where $X^e(t)$ is the production of gypsum for export at time t as defined in equation 6.53 to be demonstrated later.

We can see from Table 6.3 that, of all eleven discount rates we tried only at the discount rate of 25.0 %, is T^* as the solution of equation 6.50 smaller than T_{max} and becomes the adopted one. For the discount rates at 22.5 and below, the adopted T^* remains 33.07 years. The turning point is at the critical discount rate of 22.68 % when the adopted T^* begins to be equal or smaller than 33.07 years and the T_e^* starts to emerge above zero. However, such a rate is considered to be too high to be accepted as a social discount rate for a country.

iv) Sensitivity Analysis of the Special Model of Case I with Respect to the Size of Gypsum Reserve

The amount of gypsum left in the ground at present, S_0, or the gypsum ore reserve updated in 2006, assumed to be fixed in this thesis, may be a parameter that is not very accurately estimated because the present figure is the combination of proven and probable reserves. Therefore, it is interesting to see how the solutions change if the size of S_0 alters. Table 6.4 shows the effect on the T^* and T_e^* of the special model with perfect price-inelasticity of demand Case I, when the size of gypsum ore reserve changes.

Table 6.4 Solutions of T^* and T_e^* of the Special Model of Case I with Respect to Different Sizes of Gypsum Reserve

Total gypsum reserve (S_0) (million tons)	T^* obtained from equation 6.50 (years)	Time when gypsum resource exhausted (adopted T^*) (years)	Time when export of gypsum ended (T_e^*) (years)	Gypsum resource for domestic consumption (S_0^d) (million tons)	Gypsum resource for export (S_0^e) (million tons)
135.365	75.17	22.89	0	135.365	0
270.730	75.17	33.07	0	270.730	0
406.095	75.17	39.82	0	406.095	0
541.460	75.17	44.85	0	541.460	0
2,756.031	75.17	75.17	0	2,756.031	0

We can see from Table 6.4 that only when the size of gypsum reserve or S_0 is above 2,756.031 million tons (918 % larger than the estimated reserve of 270.730 million tons as updated in 2006) does the solution of T^*, the optimal time to completely extract all available gypsum reserves, obtained from equation 6.50 become real, and the T_e^*, the optimal time that export of gypsum ceases starts to be a positive figure. Equation 6.50, in effect, weights the earlier benefit of producing and exporting an amount of gypsum now against the later benefit of the producing such an amount for domestic consumption at the time when the total gypsum reserves are being depleted. It is weighted this way because the additional consumption of such an amount of gypsum will be realized by domestic consumers only when the gypsum reserves originally allocated for domestic consumption are depleted. Therefore, the larger the total gypsum reserves, which means the depletion of gypsum reserves allocated for domestic consumption will last longer, the more favourable the export of gypsum at present.

However, the critical size of the total gypsum reserve of above 2,756.031 million tons is too high to be possibly realistic.

v) Conclusion of the Empirical Study of the Special Model of Case I

The solution of the special model with perfect price-inelasticity of demand Case I means that if Hotelling's rule works, to maximize its social benefit through time in terms of total economic welfare, Thailand should allocate none of its gypsum resource for export from now on or, in other words, should stop export of gypsum immediately. This is because the discounted total economic welfare, comprising both producer surplus and consumer surplus, earned from the production and consumption of gypsum at the time when the total Thailand's gypsum reserves are being depleted is still higher than the total economic welfare earned from the production and export of gypsum now since the latter comprises only the producer surplus. This special model will recommend export of gypsum at present either when, with the estimated reserve of 270.730 million tons, the social discount rate is higher than 22.68 % or if the total gypsum reserves of Thailand are higher than 2,756.031 million tons—more than 10 times larger than the total estimate in 2006 of 270.730 million tons—at 10 % social discount rate. The rate of 22.68 % is too high to be considered as an acceptable social discount rate, while the Thailand's total gypsum reserves of 2,756.031 million tons is unlikely possible. Therefore, it can be said that the solution is not altered by the change in the social discount rate within the reasonable range of accepted values or a possible size of the total gypsum ore reserve of Thailand.

Based on this special model, the gypsum extraction path is simply the path matching domestic demand, which, under the assumption of the model is

unaffected by gypsum price, and the total gypsum resource in Thailand will last 33.07 years.

b) Case II: with Zero Price Elasticity of Demand and Constant Prices

i) The Model of Case II

In this case, the p_t^{im} and p_t in constant dollar do not rise in accordance with Hotelling's rule and are assumed to be fixed and equal to p_0^{im} and p_0, respectively. Therefore, the expression 6.40 can be rewritten as follows:

$$\text{Max}\int_0^T e^{-rt}\left\{(p_0^{im}-c_1)Q_t^d - c_0\right\}dt + \int_0^{Te} e^{-rt}(p_0-c_1)Q_t^e dt$$

$$\text{Or Max}\,(p_0^{im}-c_1)\int_0^T e^{-rt}Q_t^d dt + (p_0-c_1)\int_0^{Te} e^{-rt}Q_t^e dt - \frac{c_0}{r}\left(1-e^{-rT}\right)$$

Subject to the same constraints stated below expressions 6.33 and 6.35.

Because the discount rate factor, e^{-rt}, is weighted against future values and because the demand for the mineral is highly inelastic, producers will fulfil the demand as much and as fast as possible. Hence, the gypsum extraction path in this case is also the path matching the demands for domestic consumption and for export. As a result, $X_t^d(t)$ and $X_t^e(t)$ will respectively substitute for Q_t^d and Q_t^e in the above function, in the same manner as Case I, as follows:

$$\text{Max}\,(p_0^{im}-c_1)\int_0^T e^{-rt}X_t^d(t)dt + (p_0-c_1)\int_0^{Te} e^{-rt}X_t^e(t)dt - \frac{c_0}{r}\left(1-e^{-rT}\right)$$

$$\text{Let } F_2 = (p_0^{im}-c_1)\int_0^T e^{-rt}X_t^d(t)dt + (p_0-c_1)\int_0^{Te} e^{-rt}X_t^e(t)dt - \frac{c_0}{r}\left(1-e^{-rT}\right) \qquad (6.52)$$

The function $X_t^d(t)$ to be utilized in equation 6.52 is that of equation 6.46, the same as in Case I. Regarding $X_t^e(t)$, it is not easily and truly determinable without assumptions. In this case, the gypsum import from Thailand of a country is assumed to be a fixed proportion to such a country's consumption. The consumption functions of seven major client countries of Thailand determined in Chapter 5 will be the basis for defining $X_t^e(t)$. Furthermore, since a few minor client countries, covering only 4 % of the present total gypsum export of Thailand, are not studied in Chapter 5, the sum of the gypsum imports from Thailand of the seven countries will be multiplied by a factor to become $X_t^e(t)$.

The population and the GDP of all the seven countries are assumed to grow at constant rates. Therefore, in the same way in deriving equation 6.46, we can define that:

$$X_t^e(t) = \frac{1}{(1-w)} \sum_{i=1}^{7} z_i [\beta_1^i GDP_0^i e^{k_i t} + (\beta_0^i + 2007\beta_2^i) POP_0^i e^{h_i t} + \beta_2^i POP_0^i t e^{h_i t}] \quad (6.53)$$

where w is the ratio of the total share of imports of minor countries in the total export of Thailand, w = 0.04 in this case;

i is country number as in Table 6.5, for i = 1, 2, 3, ….7;

Table 6.5 Coefficients and Factors for Equation 6.53

Country	Indonesia	Japan	Korea	Malaysia	Philippines	Taiwan	Vietnam
i	1	2	3	4	5	6	7
β_1^i	0.918	0.181	1.006	5.433	1.472	2.496	20.494
β_0^i	-568497.9	2268538	-7214542	-900731.2	-334353.6	1969560	-1545571
β_2^i	285.621	-1104.577	3620.388	451.575	168.171	-992.767	777.901
z_i	0.995	0.111	0.127	0.999	0.928	0.998	0.327
k_i	0.051	0.018	0.048	0.056	0.052	0.045	0.078
h_i	0.013	0.001	0.004	0.019	0.022	0.004	0.014
GDP_0^i	375.401	4334.693	902.655	152.605	120.428	369.709	64.234
POP_0^i	0.225	0.128	0.048	0.027	0.089	0.023	0.086

Note: 1) β_1^i, β_0^i and β_2^i are from Table 5.10 of Chapter 5.
2) z_i, k_i and h_i are the five-year averages of the relevant statistics from 2003 to 2007.

z_i is the proportion of the import from Thailand to the total consumption of country i;

β_1^i, β_0^i and β_2^i are the coefficients β_1, β_0 and β_2 of country *i* of equation 5.17 of Chapter 5 as shown in Table 5.10, respectively;

GDP_0^i is the GDP of country *i* in 2007;

POP_0^i is the total population of country *i* in 2007;

k_i is the GDP growth rate of country *i*; and

h_i is the population growth rate of country *i*.

Substituting equations 6.46 and 6.53 for $X_t^d(t)$ and $X_t^e(t)$, respectively, in equation 6.52 and solving the definite integrals, we get:

$$
\begin{aligned}
F_2 = (p_0^{im} - c_1)\Bigg[& \frac{\beta_1^d}{(k_d - r)} GDP_0^d \left(e^{(k_d - r)T} - 1\right) \\
& + \frac{\{\beta_0^d (h_d - r) + \beta_2^d (2007(h_d - r) - 1)\}}{(h_d - r)^2} POP_0^d \left(e^{(h_d - r)T} - 1\right) \\
& + \frac{\beta_2^d}{(h_d - r)} POP_0^d T e^{(h_d - r)T} \Bigg] \\
& + \frac{(p_0 - c_1)}{(1-w)} \sum_{i=1}^{7} \Bigg[\frac{z_i \beta_1^i}{(k_i - r)} GDP_0^i \left(e^{(k_i - r)T_e} - 1\right) \\
& + \frac{z_i \{\beta_0^i (h_i - r) + \beta_2^i (2007(h_i - r) - 1)\}}{(h_i - r)^2} POP_0^i \left(e^{(h_i - r)T_e} - 1\right) + \frac{z_i \beta_2^i}{(h_i - r)} POP_0^i T_e e^{(h_i - r)T_e} \Bigg] \\
& - \frac{c_0}{r}\left(1 - e^{-rT}\right) \qquad (6.54)
\end{aligned}
$$

From the constraint equation 6.34, we have:

$$
S_0 - \int_0^T X_t^d(t)dt = \int_0^{Te} X_t^e(t)dt
$$

Substituting equations 6.46 and 6.53 for $X_t^d(t)$ and $X_t^e(t)$, respectively, in the above equation and solving the definite integrals, we get:

$$
\begin{aligned}
& S_0 - \frac{\beta_1^d}{k_d} GDP_0^d \left(e^{k_d T} - 1\right) - \frac{\{\beta_0^d h_d + \beta_2^d (2007 h_d - 1)\}}{h_d^2} POP_0^d \left(e^{h_d T} - 1\right) - \frac{\beta_2^d}{h_d} POP_0^d T e^{h_d T} \Bigg] \\
& = \frac{1}{(1-w)} \sum_{i=1}^{7} \frac{z_i \beta_1^i}{k_i} GDP_0^i \left(e^{k_i T_e} - 1\right) + \frac{z_i (\beta_0^i h_i + \beta_2^i (2007 h_i - 1))}{h_i^2} POP_0^i \left(e^{h_i T_e} - 1\right) \qquad (6.55)
\end{aligned}
$$

Equations 6.54 and 6.55 are the two equations that can be used in determining the two important variables T and T_e. They cannot be further simplified as in Case I.

ii) An Empirical Solution for the Special Model of Case II

After putting the figures from Table 6.2 and Table 6.5 into equations 6.54 and 6.55 and by trial and error with a computer program we find:

$\boldsymbol{T^*}$ **= 25.27 years**, and

$\boldsymbol{T_e^*}$ **= 13.68 years.**

With the known T^* and T_e^* we can find that:

$$S_0^d = \int_0^T X_t^d(t)dt$$

S_0^d = 161.164 million tons, and

$$S_0^e = \int_0^{Te} X_t^e(t)dt$$

S_0^e = 109.566 million tons

iii) Sensitivity Analysis of the Special Model of Case II with Respect to Different Discount Rates

Table 6.6 shows the solutions of the T^*, T_e^*, S_0^d, and S_0^e of the special model with perfect price-inelasticity Case II with different discount rates. We can see that the lower the discount rate the smaller the resource to be allocated for export and, hence, the shorter the time to end export of gypsum, T_e^*. At the discount rates equal and below the critical rate of 3.59 %, T_e^* is zero, which means that all gypsum resource should be totally dedicated for domestic consumption, and, therefore, the export of gypsum should be ended immediately. As for the time period with no export, (T^*- T_e^*) before Thailand's gypsum resource is exhausted, it is shorter when the discount rate gets larger. This means that at very high discount rates the net benefit from production for export weights almost the same as the net benefit from production for domestic consumption.

Table 6.6 Solutions of T^*, T_e^*, S_0^d, and S_0^e of the Special Model of Case II with Respect to Different Discount Rates

Discount Rate (r) (%)	Time when gypsum resource exhausted (T^*) (years)	Time when export of gypsum ended (T_e^*) (years)	Time period with no export (T^*- T_e^*) (years)	Gypsum Resource for Domestic Consumption (S_0^d) (million tons)	Gypsum Resource for Export (S_0^e) (million tons)
2.50	33.07	0.00	33.07	270.730	0
3.59	33.07	0.00	33.07	270.730	0
5.00	30.16	6.91	23.25	224.413	46.317
7.50	27.08	11.61	15.47	182.511	88.219
10.00	25.27	13.68	11.59	161.164	109.566
12.50	24.10	14.83	9.27	147.854	122.876
15.00	23.28	15.56	7.72	139.516	131.214
17.50	22.67	16.07	6.60	133.258	137.472
20.00	22.21	16.43	5.78	128.493	142.237
22.50	21.85	16.71	5.14	124.795	145.935
25.00	21.55	16.93	4.62	121.955	148.775

Table 6.7 shows the changes in percentages of the T^*, T_e^*, S_0^d, and S_0^e of Case II when the discount rate varies. Except for those of T_e^* and S_0^e at low discount rates, the absolute values of the changes in the solutions are less than the absolute values of the changes in the discount rate. Note that T_e^* and S_0^e are more sensitive to the change in the discount rate, r, than T^* and S_0^d.

Table 6.7 The Changes of T^*, T_e^*, S_0^d, and S_0^e of the Special Model of Case II with Respect to Different Discount Rates

Discount Rate (r) (%)	% Change of r from the Base Case	% Change of T^* from the Base Case	% Change of T_e^* from the Base Case	% Change of S_0^d from the Base Case	% Change of S_0^e from the Base Case
2.50	-75.0	30.87	-100.00	67.98	-100.00
3.59	-64.1	30.87	-100.00	67.98	-100.00
5.00	-50.0	19.35	-49.49	39.25	-57.73
7.50	-25.0	7.16	-15.13	13.25	-19.48
10.00§	0.0	0.00	0.00	0.00	0.00
12.50	25.0	-4.64	8.41	-8.26	12.15
15.00	50.0	-7.89	13.74	-13.43	19.76
17.50	75.0	-10.31	17.47	-17.32	25.47
20.00	100.0	-12.10	20.10	-20.27	29.82
22.50	125.0	-13.55	22.15	-22.57	33.19
25.00	150.0	-14.72	23.76	-24.33	35.79

Note: § The base case is at r = 10 %.

iv) Sensitivity Analysis of the Special Model of Case II with Respect to the Size of the Total Gypsum Ore Reserve

Table 6.8 shows the solutions of the special model with perfect price-inelasticity of demand Case II with different sizes of S_0, the total gypsum ore reserve of Thailand. We can see that both T^* and T_e get larger when S_0 get bigger. Note that the change in the size of the total gypsum ore reserve barely affects the time period with no export, (T^* - T_e). This is because the assumed benefit and cost per ton of production for both domestic consumption and export are not changed.

Table 6.8 Solutions of T^*, T_e^*, S_0^d, and S_0^e of the Special Model of Case II with Respect to the Size of the Total Gypsum Reserve of Thailand, S_0

Total Gypsum Reserve (S_0) (million tons)	Time when gypsum resource exhausted (T^*) (years)	Time when export of gypsum ended (T_e^*) (years)	Time period with no export (T^*- T_e^*) (years)	Gypsum Resource for Domestic Consumption (S_0^d) (million tons)	Gypsum Resource for Export (S_0^e) (million tons)
135.365	18.08	6.58	11.50	92.025	43.340
270.730	25.27	13.68	11.59	161.164	109.566
406.095	30.55	18.92	11.63	230.327	175.768
541.460	34.73	23.08	11.65	300.005	241.455
2,756.031	62.78	51.05	11.73	1430.022	1326.009

v) Conclusion of the Empirical Study of the Special Model of Case II

The solution of the special model with perfect price-inelasticity of demand Case II means that, with the social discount rate at 10 %, if Hotelling's rule is disregarded and gypsum prices remain constant Thailand should allocate a total of 109.566 million tons of gypsum resource for export and a total of 161.164 million tons of gypsum resource for domestic consumption. The export will last 13.68 years, while production for domestic consumption will end in 25.27 years, when all gypsum resource in Thailand is totally depleted. There will be a period of 11.59 years, starting 13.68 years from now, that gypsum will be produced just for domestic consumption. The gypsum extraction path for Thailand is simply the path matching the sum of the domestic demand and the demand for export, which is hardly affected by gypsum prices.

If the size of the total gypsum ore reserve is larger, both the time when gypsum resource of Thailand is totally depleted and the time that export should end will get longer. The opposite is also true. But the size of the total gypsum ore reserve barely affects the length of the period of no export before the total depletion of gypsum in Thailand.

The amount of gypsum resource allocated for export and the period of time from now that export of gypsum should be allowed get longer if the discount rate is higher. The higher the discount rate the more favourable the production and export of gypsum now because a higher discount rate weights more against the discounted total economic welfare earned from the production and consumption of gypsum at a time far into the future. Therefore, a larger portion of the gypsum resource should be allocated for export and, as a result, the time period that export of gypsum should be allowed get longer. Certainly, this comes at the expense of domestic consumption.

The opposite is also true. Furthermore, if a social discount rate is less than or equal to 3.59 %, any amount of gypsum resources should not be allocated for export from now on; and, therefore, Thailand should stop export of gypsum immediately. This is because a small discount rate gives more weight to the discounted future total economic welfare earned from the production and consumption of gypsum in the future. If the discount rate is small enough—smaller than 3.59%, in this case—all the discounted total economic welfare earned from the production and consumption of gypsum at any time, up until the total Thailand's gypsum reserves are depleted, are larger than the total economic welfare earned from the production and export of gypsum now. At such a rate, export of gypsum renders negative net benefit to Thailand.

6.5.2 A Special Model with Non-Zero Price Elasticity of Demand

As was stated at the beginning of this chapter that the analysis in Chapter 5 of this thesis could not determine the relationship between gypsum price and consumption, the figures of price elasticities of demand for gypsum produced in Thailand have to be assumed. The assumed price elasticity of demand will be combined with the consumption functions defined in Chapter 5, which take account of the effect of incomes on consumption, to form demand functions with constant price elasticity. It is assumed as if, from now on, the price starts to become an influential factor. Therefore, equation 6.46 will truly forecast future consumptions only when prices do not change or $p_t = p_0$. Hence, in the form of the demand function with constant price elasticity, we get:

$$X_t(t) = a_t p_0^{-b}$$

Therefore,

$$a_t = X_t(t) p_0^b$$

That is

$$Q_t(t, p) = a_t p_t^{-b} = \left\{X_t(t) p_0{}^b\right\} p_t{}^{-b} = X_t(t)\left(\frac{p_t}{p_0}\right)^{-b}$$

Where: $X_t(t)$ is the demand function from Chapter 5, which is in the function of time t only;

$Q_t(t, p)$ is the demand function in the function of time t and price p that takes the price elasticity of demand, *-b*, into account;

p_0 is the gypsum price at present; and

p_t is the gypsum price at time t.

Figure 6.2 also shows the movement of the demand curves and the relationship between $X_t(t)$ and $Q_t(t, p)$ for t = 1, 2 and 3 under the above assumption.

A further assumption is that gypsum consumers in Thailand and its client countries react on prices in the same way. In other words, the price elasticity of demand for gypsum is the same for Thailand and its client countries. There are no grounds for this assumption. But since this thesis cannot define the relationships between gypsum price and consumption of any countries, to assume each figure of price elasticity of demand for each country will make this empirical study more complicated without putting an additional credit to it. Therefore,

$$Q_t^d(t,p) = X_t^d(t)\left(\frac{p_t}{p_0}\right)^{-b} \tag{6.56}$$

and $$Q_t^e(t,p) = X_t^e(t)\left(\frac{p_t}{p_0}\right)^{-b} \tag{6.57}$$

Substituting equation 6.46 in equation 6.56, we get:

$$Q_t^d(t,p) = \left\{\beta_1^d GDP_0^d e^{k_d t} + (\beta_0^d + 2007\beta_2^d) POP_0^d e^{h_d t} + \beta_2^d POP_0^d t e^{h_d t}\right\}\left(\frac{p_t}{p_0}\right)^{-b} \tag{6.58}$$

Similarly, substituting equation 6.53 in equation 6.57, we get:

$$Q_t^e(t,p) = \left[\frac{1}{(1-w)}\sum_{i=1}^{7} z_i \left\{\beta_1^i GDP_0^i e^{k_i t} + (\beta_0^i + 2007\beta_2^i) POP_0^i e^{h_i t} + \beta_2^i POP_0^i t e^{h_i t}\right\}\right]\left(\frac{p_t}{p_0}\right)^{-b}$$

(6.59)

The maximizing functions of a special model with price elasticity of demand are expressions 6.38 and 6.39. When consumption of gypsum is influenced by price, the empirical study is more complicated. Therefore, function 6.39, the annually discrete discounting form, will be used as the basic model in this part of the study, and it can be modified as follows:

$$\text{Max}\left\{\frac{1}{(1-b)}\sum_{t=1}^{T}\frac{(p_t^{im} - c_{int}) - b(p_t - c_1)}{(1+r')^t}Q_t^d + \frac{1}{(1-b)}\sum_{t=1}^{T}\frac{(c_{int} - c_1)}{(1+r')^t}Q_t^d - \frac{(1+r')^T - 1}{r'(1+r')^T}c_0\right\}$$

$$+ \text{ Max}\sum_{t=1}^{Te}\frac{(p_t - c_1)}{(1+r')^t}Q_t^e \tag{6.60}$$

Subject to: $S_t - S_{t-1} = -Q_t = -(Q_t^d + Q_t^e)$,

$S(0) = S_0$, $S(\mathrm{T}) = 0$,

$S_0 = S_0^d + S_0^e$, or

$$S_0 = \sum_{t=1}^{T} Q_t^d + \sum_{t=1}^{Te} Q_t^e \,, \tag{6.61}$$

$T \geq 0$, $T_e \geq 0$, and $T_e \leq T$.

The same as in the special model with the perfect price-inelasticity of demand, c_{int} is the marginal cost in other gypsum producing countries to supply gypsum to Thailand in the future plus the unit shipment cost to Thailand. Also assuming to have the same structure as c_1, c_{int} is considered as a constant, and the value of (c_{int} - c_1) is treated as positive.

Solving this special model also faces the same problems as those of the special model with perfect price-inelasticity of demand in determining the p_t^{im} and p_t. Alternative assumptions are needed. The first one is the same as that of the special model with perfect price-inelasticity of demand Case I, which assumed that gypsum producers in both Thailand and its competitor act in accordance with Hotelling's rule. The other will treat p_t^{im} as an exogenous variable that cannot be controlled by Thailand; therefore, it will be assumed as fixed. This second alternative will allow p_t, as well as the extraction path, to be manipulated to maximize the function 6.39 or 6.60.

a) Case III: with Low Price Elasticity of Demand and Producers Raising Their Resource Rents in Accordance with Hotelling's Rule

i) The Model of Case III

If gypsum producers both in Thailand and other countries maximize the net prices of their gypsum in accordance with Hotelling's rule, then

$$(p_t^{im} - c_{\mathrm{int}}) = (p_0^{im} - c_{\mathrm{int}})(1 + r')^t \text{ and } (p_t - c_1) = (p_0 - c_1)(1 + r')^t$$

Therefore, expression 6.60 can be rewritten as follows:

$$\text{Max}\left\{\frac{(p_0^{im}-c_{\text{int}})-b(p_0-c_1)}{(1-b)}\sum_{t=1}^{T}Q_t^d+\frac{(c_{int}-c_1)}{(1-b)}\sum_{t=1}^{T}\frac{Q_t^d}{(1+r')^t}-\frac{(1+r')^T-1}{r'(1+r')^T}c_0\right\}$$

$$+\ \text{Max}\,(p_0-c_1)\sum_{t=1}^{Te}Q_t^e$$

From the constraining equation 6.61, we have $\sum_{t=1}^{Te}Q_t^e=S_0-\sum_{t=1}^{T}Q_t^d$. Therefore, the above equation can be modified as follows:

$$\text{Max}\left\{\frac{(p_0^{im}-c_{\text{int}})-b(p_0-c_1)}{(1-b)}\sum_{t=1}^{T}Q_t^d+\frac{(c_{int}-c_1)}{(1-b)}\sum_{t=1}^{T}\frac{Q_t^d}{(1+r')^t}-\frac{(1+r')^T-1}{r'(1+r')^T}c_0\right\}$$

$$+\ \text{Max}\,(p_0-c_1)(S_0-\sum_{t=1}^{T}Q_t^d)$$

$$\text{Or Max}\left\{\frac{(p_0^{im}-c_{\text{int}})-(p_0-c_1)}{(1-b)}\sum_{t=1}^{T}Q_t^d+\frac{(c_{int}-c_1)}{(1-b)}\sum_{t=1}^{T}\frac{Q_t^d}{(1+r')^t}-\frac{(1+r')^T-1}{r'(1+r')^T}c_0\right\}$$

$$+(p_0-c_1)S_0$$

Substituting equation 6.58 in the above function, we get:

$$\begin{aligned}\text{Max}\Bigg[&\frac{(p_0^{im}-c_{\text{int}})-(p_0-c_1)}{(1-b)}\sum_{t=1}^{T}\Big\{\beta_1^d GDP_0^d e^{k_d t}+(\beta_0^d+2007\beta_2^d)POP_0^d e^{h_d t}\\&+\beta_2^d POP_0^d te^{h_d t}\Big\}\left(\frac{p_t}{p_0}\right)^{-b}\\&+\frac{(c_{int}-c_1)}{(1-b)}\sum_{t=1}^{T}\frac{1}{(1+r')^t}\Big\{\beta_1^d GDP_0^d e^{k_d t}+(\beta_0^d+2007\beta_2^d)POP_0^d e^{h_d t}\\&+\beta_2^d POP_0^d te^{h_d t}\Big\}\left(\frac{p_t}{p_0}\right)^{-b}-\frac{(1+r')^T-1}{r'(1+r')^T}c_0+(p_0-c_1)S_0\Bigg]\end{aligned}\qquad(6.62)$$

We can see that function 6.62, in the annually discrete discounting form, is not much different from function 6.44, in the continuously discounting form, of Case I. For $b < 1$, the factor 1/(1-b) just makes the first two terms of function 6.62 higher than those of function 6.44. As a result, the solutions of T^* and T_e^* can be determined in the same manner as those of Case I.

ii) An Empirical Solution for the Special Model of Case III

Under the assumption that the price elasticity of demand for gypsum in Thailand and its client countries is very small, function 6.62 will be tested by a couple of small values of *b*, 0.05 and 0.10. With the parameters in Table 6.2 and by trial and error, it was found that for $b = 0.05$, $T^* = 74.66$ years and for $b = 0.10$, $T^* = 74.65$ years. However, substituting $Q_t^d(t, p)$ from equation 6.58, and $S_0^e = 0$ in equation 6.61, and by trial and error, we also have:

For $b = 0.05$, $T_{max} = 34.09 < 74.66$ years, and

for $b = 0.10$, $T_{max} = 35.69 < 74.65$ years.

This means that the T^* found by function 6.62 violates the constraining inequality $T^* \leq T_{max}$.

Therefore,

for $b = 0.05$, $\boldsymbol{T^* = 34.09}$ **years,**

for $b = 0.10$, $\boldsymbol{T^* = 35.69}$ **years**, and

$\boldsymbol{T_e^* = 0}$ in all two cases**.**

iii) Critical Discount Rate and Reserve for the Special Model of Case III

Similar to the solutions of Case I, when the discount rate and the reserve (or the total stock in the ground) of the mineral gypsum are high enough, T_e^* becomes positive. Table 6.9 shows the critical discount rates and reserves, at which $T^* = T_{max}$, for the price elasticity of demand, *b*, = 0, 0.05, and 0.10. The discount rates and reserves being more than the values appearing in Table 6.9 will render positive T_e^*. We can see that the higher the elasticity of demand the smaller the discount rates and the reserve. However, the continuous discount rates of 20.48 % and 18.64 % are too high to be a universally acceptable social discount rate for any country. The same as that of Case I the critical reserves for b = 0, 0.05, and 0.10 (7.87 and 6.13 times, respectively, of the present known reserve updated in 2006) are still too high to be possibly true.

Table 6.9 The Critical Discount Rates and Reserves, at Which $T^* = T_{max}$

b	T_{max} and T^*	Critical Annual Discrete Discount Rate (r'^*) (%)	Critical Continuous Discount Rate (r^*) (%)	Critical Reserve (S_0^*) (million tons)
0.00§	33.07§	25.46§	22.68§	2,756.03§
0.05	34.09	22.73	20.48	2,131.44
0.10	35.69	20.49	18.64	1,660.38

Note: § Solutions of Case I.

iv) Conclusion of the Empirical Study of the Special Model of Case III

The solution of the special model with low price elasticity of demand and producers raising the net prices of their gypsum in accordance with Hotelling's rule is similar to that of Case I, the special model with perfect price-inelasticity of demand and applicable Hotelling's rule. It means that Thailand should allocate none of its gypsum resource for export from now on or, in other words, should stop export of gypsum immediately. The gypsum extraction path is the path that makes the net price of gypsum grow at the rate of the social discount rate. The total gypsum resource in Thailand will last 34.09 years for the price elasticity of demand of 0.05 and 35.69 years for the price elasticity of demand of 0.10. The solution is not altered by the change in the social discount rate within the reasonable range of accepted

values. Furthermore, the solution is not changed for a possible size of the total gypsum ore reserve of Thailand.

b) Case IV: with Price Elasticity of Demand and Fixed Foreign Gypsum Price

This case will allow the price of gypsum produced in Thailand, p_t, as well as the extraction path of gypsum resources, to be manipulated to maximize the function 6.39 or 6.60. However, the import or foreign price, p_t^{im} is an exogenous variable that cannot be controlled by Thailand. To distinguish from Cases I and III; this case will assume p_t^{im}, in constant dollars, as fixed. That is:

$$p_t^{im} = p_0^{im}$$

In Thailand, p_0^{im} will be the ultimate backstop price for domestic gypsum. If p_t is higher than such a price, gypsum users will switch to imported gypsum instead, and domestic gypsum producers will have to close their gypsum mines. Therefore, to maximize benefit, p_t shall never be greater than p_t^{im}.

Constant p_t^{im} also means gypsum prices abroad, including in Australia, are fixed too. Therefore, if the p_t is controlled in such a way that it is increasing while p_t^{im} remains fixed, Thailand's price advantage over its competitor, Australia, will be diminishing and totally lost some time in some or all markets. Hence, a constant market share in the client countries as in Cases I, II, and III cannot be assumed here. For a constant unit cost of transportation, the prices of Thai gypsum abroad will also rise when the p_t rises. Thailand will first lose the market in the farthest client country, where Thai gypsum has some price advantage over Australian gypsum at present, when the price of gypsum from Thailand becomes more expensive than that from Australia. If the price of Thai gypsum rises further to a certain point, below p_t^{im}, Thailand will lose the market in its closest client country, and as a result the export of gypsum from Thailand will totally stop. The demand curve for Thai gypsum abroad should kink twice as shown in Figure 6.6.

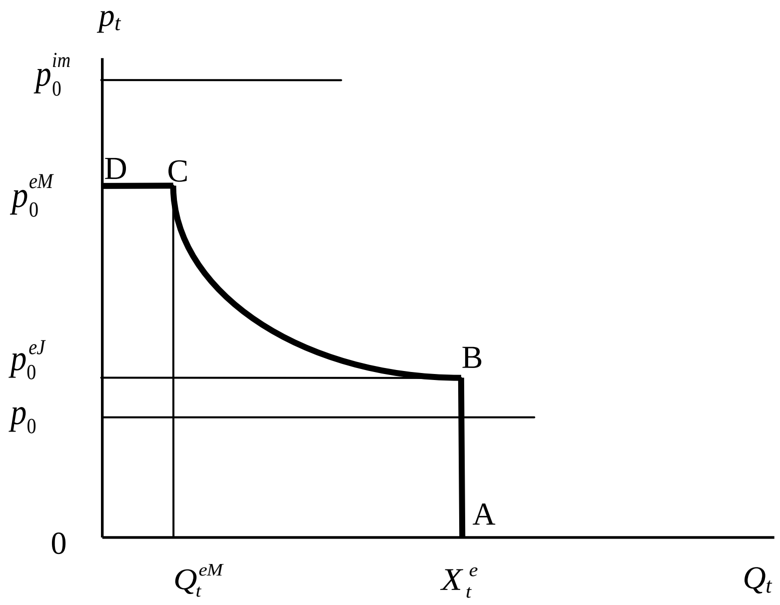

Figure 6.6 The Characteristic of the Demand Curve for Exported Gypsum

In Figure 6.6, line ABCD is the demand curve for Thai gypsum abroad. All prices depicted in the figure are domestic prices. Line AB is the section that the prices of Thai gypsum are cheaper than those of its competitor in all client countries. Therefore, this section should be zero price elasticity of demand and the total quantity of export from Thailand is X_t^e. Price p_0^{eJ} is the price that, when the transportation cost from Thailand to the farthest client country is added, is equal to the price of gypsum imported from Thailand's competitor. The farthest client country means the country where Thailand's distance advantage, in comparison with its competitor, is smallest. Therefore, when the gypsum price from Thailand rises above that price level, the demand for Thai gypsum there will start to decline because some gypsum users will switch to buy from other sources. Line BC should be stepwise; however, for simplicity, it is assumed to be smooth with single constant price elasticity. Line CD is the demand section at the price p_0^{eM} that, when the transportation cost to the client country closest to Thailand is added, is equal to the price of gypsum of Thailand's competitor in that country. It should be infinite price elasticity of demand simply by the fact that none should import from Thailand when the price of Thailand's gypsum is higher than the others. Q_t^{eM} is the quantity of export to the country closest to Thailand at time *t* during the time that the price of gypsum from Thailand there is cheaper than those from the others.

i) The Model of Case IV

With the demand curve for exported gypsum as shown in Figure 6.6, if $-b^e$ is denoted as the price elasticity of demand for exported gypsum, then:

$$-b^e = 0 \text{ for } p_t \leq p_0^{eJ}, \tag{6.63}$$

$$-\infty < -b^e < 0 \text{ for } p_0^{eJ} < p_t < p_0^{eM}, \text{ and} \tag{6.64}$$

$$-b^e = -\infty \text{ for } p_t = p_0^{eM}. \tag{6.65}$$

In addition, expression 6.57 for Case IV will become as follows:

$$Q_t^e = X_t^e(t)\left(\frac{p_t}{p_0^{eJ}}\right)^{-b^e} \tag{6.66}$$

While expression 6.56 remains the same as follows:

$$Q_t^d = X_t^d(t)\left(\frac{p_t}{p_0}\right)^{-b^d} \tag{6.67}$$

where $-b^d$ is the price elasticity of domestic demand for gypsum.

Under the assumption that $p_t^{im} = p_0^{im}$ and Thailand is able to manipulate the gypsum price inside the country, p_t, expression 6.39 can be modified as follows:

$$\text{Max}\sum_{t=1}^{T}\frac{1}{(1+r')^t}\left[\left\{\frac{p_0^{im}}{(1-b^d)}-p_t\left(\frac{b^d}{1-b^d}\right)-c_1\right\}Q_t^d-c_0\right]+\text{Max}\sum_{t=1}^{Te}\frac{(p_t-c_1)}{(1+r')^t}Q_t^e \quad (6.68)$$

Because of the none zero $-b^d$ and $-b^e$, for the optimum price path of p_t, there will be the matched optimum production paths of Q_t^d and Q_t^e. Maximizing expression 6.65 can be done by maximizing the discounted net social benefits at every time *t*, for *t* = 1, 2, 3, ……., *T*, under the constraint of equation 6.61.

Let H_t be the discounted net social benefit at time *t*. Therefore,

$$H_t=\frac{1}{(1+r')^t}\left[\left\{\left(\frac{p_0^{im}}{(1-b^d)}-p_t\left(\frac{b^d}{1-b^d}\right)-c_1\right)Q_t^d-c_0\right\}+(p_t-c_1)Q_t^e\right] \quad (6.69)$$

If p_t is manipulated to change by an amount of dp_t, then the resulting changes in Q_t^d and Q_t^e shall be defined by differentiating equations 6.67 and 6.66 as follows:

$$dQ_t^d=\left\{-b^dX_t^d(t)\frac{p_t}{p_0^{-b^d}}^{-(b^d+1)}\right\}dp_t\text{, and} \quad (6.70)$$

$$dQ_t^e=\left\{-b^eX_t^e(t)\frac{p_t}{p_0^{eJ-b^e}}^{-(b^e+1)}\right\}dp_t \quad (6.71)$$

The change in the net social benefit at time *t*, dH_t, as a result of the change in price at time *t*, dp_t, shall be defined by differentiating equation 6.69 as follows:

$$dH_t=\frac{1}{(1+r')^t}\left[\frac{p_0^{im}}{(1-b^d)}dQ_t^d-\left(\frac{b^d}{1-b^d}\right)(p_tdQ_t^d+Q_t^ddp_t)-c_1dQ_t^d+(p_tdQ_t^e+Q_t^edp_t)-c_1dQ_t^e\right]$$

Because $\frac{dQ}{dp}\bullet\frac{p}{Q}=-b$, then $dQ=-b\frac{Q}{p}dp$ and $pdQ=-bQdp$.

Therefore,

$$dH_t = \frac{1}{(1+r')^t}\left[\frac{p_0^{im}}{(1-b^d)}\left(\frac{-b^d Q_t^d}{p_t}\right)dp_t - \left(\frac{b^d}{1-b^d}\right)(-b^d Q_t^d dp_t + Q_t^d dp_t) - c_1\left(\frac{-b^d Q_t^d}{p_t}\right)dp_t\right.$$
$$\left. + (-b^e Q_t^e dp_t + Q_t^e dp_t) - c_1\left(\frac{-b^e Q_t^e}{p_t}\right)dp_t\right] \qquad (6.72)$$

Substituting equations 6.66 and 6.67 in equation 6.72 and simplifying it, we have

$$dH_t = \frac{1}{(1+r')^t}\left[\left\{\frac{p_0^{im}}{(1-b^d)} + p_t - c_1\right\}\left\{-b^d X_t^d(t)\frac{p_t}{p_0^{-b^d}}^{-(b^d+1)}\right\}dp_t\right.$$
$$\left. + \left\{(1-\frac{1}{b^e})p_t - c_1\right\}\left\{-b^e X_t^e(t)\frac{p_t}{p_0^{eJ-b^e}}^{-(b^e+1)}\right\}dp_t\right] \qquad (6.73)$$

Under the constraint of equation 6.61, the mineral stock in the ground is fixed. The changes in production at time *t* as a result of a change in price at time *t*, will cause a negative change in the production at time *T* equal to $-(dQ_t^d + dQ_t^e)$. Let dJ_t be the discounted change in the net social benefit at time *T* as the result of the change in production (for domestic consumption only) at time *T* for an amount of $-(dQ_t^d + dQ_t^e)$. dJ_t is simply the discounted result of the unit net social benefit at time *T* multiplied by $-(dQ_t^d + dQ_t^e)$ as follows:

$$dJ_t = -\frac{1}{(1+r')^T}\left\{\frac{p_0^{im}}{(1-b^d)} - p_T\left(\frac{b^d}{1-b^d}\right) - c_1\right\}(dQ_t^d + dQ_t^e)$$
$$= -\frac{1}{(1+r')^T}\left\{\frac{p_0^{im}}{(1-b^d)} - p_T\left(\frac{b^d}{1-b^d}\right) - c_1\right\}\left[\left\{-b^d X_t^d(t)\frac{p_t}{p_0^{-b^d}}^{-(b^d+1)}\right\}dp_t\right.$$
$$\left. + \left\{-b^e X_t^e(t)\frac{p_t}{p_0^{eJ-b^e}}^{-(b^e+1)}\right\}dp_t\right] \qquad (6.74)$$

Let K_t be the sum of the discounted net social benefits at times *t* and *T*. Therefore, the discounted net social benefits as a result of manipulating p_t at time *t* will be at its maximum when K_t is also at its maximum. Maximization of the discounted net social benefits as a result of manipulating p_t at time *t* can be done by maximizing K_t. Each maximum K_t has a set of optimum Q_t^d, Q_t^e and p_t. Therefore, the optimum extraction and price paths of Thai gypsum can be determined by maximizing every K_t, for t = 1, 2, 3, ….., T. Since the export demand for Thai gypsum kinks with three different values of price elasticities, the optimum price and extraction paths of Thai gypsum for each section of the demand have to be determined by three different functions. K_t is at its maximum when the value of its first derivative is equal to zero, the value of its second derivative is negative, and all constraints are obeyed. However, within the range of constraints, if the value of the first derivative of K_t remains either positive or negative, K_t is at its maximum when the optimum Q_t^d, Q_t^e and p_t are at either end of the enforcing constraint.

dK_t can be defined as: $dK_t = dH_t + dJ_t$. Hence,

$\frac{dK_t}{dQ_t} = \frac{dH_t}{dQ_t} + \frac{dJ_t}{dQ_t}$ and $\frac{dK_t}{dp_t} = \frac{dH_t}{dp_t} + \frac{dJ_t}{dp_t}$

Note that $\frac{dH_t}{dQ_t}$ can be called "marginal social benefit of producing a unit of gypsum at time t" and $\frac{dJ_t}{dQ_t}$ can be called "marginal social benefit of producing and consuming such a unit of gypsum at the time when the total Thailand's gypsum reserves are being depleted". Maximizing K_t can be solved by set either $\frac{dK_t}{dQ_t}$ or $\frac{dK_t}{dp_t}$ equal to 0. By setting $\frac{dK_t}{dQ_t} = 0$, we get $\frac{dH_t}{dQ_t} = -\frac{dJ_t}{dQ_t}$, which can be said, in words, that maximizing K_t can be solved by setting the marginal social benefit of producing a unit of gypsum at time t to equal the marginal social benefit of producing such a unit of gypsum at the time when the total Thailand's gypsum reserves are being depleted. However, for a shorter explanation the following mathematical analysis will utilize the equation $\frac{dK_t}{dp_t} = \frac{dH_t}{dp_t} + \frac{dJ_t}{dp_t}$.

For a Constant $-b^e$ Not Equal to Zero and Minus Infinity, Where $p_0^{eJ} < p_t < p_0^{eM}$

$$\frac{dK_t}{dp_t} = \frac{1}{(1+r')^t}\left[\left\{\frac{p_0^{im}}{(1-b^d)} + p_t - c_1\right\}\left\{-b^d X_t^d(t)\frac{p_t}{p_0^{-b^d}}^{-(b^d+1)}\right\}\right.$$

$$\left. + \left\{(1-\frac{1}{b^e})p_t - c_1\right\}\left\{-b^e X_t^e(t)\frac{p_t}{p_0^{eJ^{-b^e}}}^{-(b^e+1)}\right\}\right]$$

$$-\frac{1}{(1+r')^T}\left\{\frac{p_0^{im}}{(1-b^d)} - p_T\left(\frac{b^d}{1-b^d}\right) - c_1\right\}\left[\left\{-b^d X_t^d(t)\frac{p_t}{p_0^{-b^d}}^{-(b^d+1)}\right\}\right.$$

$$\left. + \left\{-b^e X_t^e(t)\frac{p_t}{p_0^{eJ^{-b^e}}}^{-(b^e+1)}\right\}\right] \qquad (6.75)$$

The second derivative of K_t for a constant $-b^e$ not equal to zero and minus infinity is as follows:

$$\frac{d^2K_t}{dp_t^{\,2}} = \frac{1}{(1+r')^t}\left\{\frac{p_0^{im}}{(1-b^d)} + p_t - c_1\right\}\left\{-b^d X_t^d(t)(-b^d-1)\frac{p_t}{p_0^{-b^d}}^{-(b^d+2)}\right\}$$

$$+\frac{1}{(1+r')^t}\left\{-b^d X_t^d(t)\frac{p_t}{p_0^{-b^d}}^{-(b^d+1)}\right\}$$

$$+\frac{1}{(1+r')^t}\left\{(1-\frac{1}{b^e})p_t - c_1\right\}\left\{-b^e X_t^e(t)(-b^e-1)\frac{p_t}{p_0^{eJ^{-b^e}}}^{-(b^e+2)}\right\}$$

$$+\frac{1}{(1+r')^t}\left\{-b^e X_t^e(t)\frac{p_t}{p_0^{eJ^{-b^e}}}^{-(b^e+1)}\right\}\left\{(1-\frac{1}{b^e})\right\}$$

$$-\frac{1}{(1+r')^T}\left\{\frac{p_0^{im}}{(1-b^d)} - p_T\left(\frac{b^d}{1-b^d}\right) - c_1\right\}\left[\left\{-b^d X_t^d(t)(-b^d-1)\frac{p_t}{p_0^{-b^d}}^{-(b^d+2)}\right\}\right.$$

$$\left. + \left\{-b^e X_t^e(t)(-b^e-1)\frac{p_t}{p_0^{eJ^{-b^e}}}^{-(b^e+2)}\right\}\right] \qquad (6.76)$$

For $-b^e$ Equal to Zero, Where $p_t \le p_0^{eJ}$

Substituting equations 6.66 and 6.67 in equation 6.72 as well as putting zero for $-b^e$ and simplifying it, we have

$$dK_t = \frac{1}{(1+r')^t}\left[\left\{\frac{p_0^{im}}{(1-b^d)} + p_t - c_1\right\}\left\{-b^d X_t^d(t)\frac{p_t}{p_0^{-b^d}}^{-(b^d+1)}\right\}dp_t + X_t^e(t)dp_t\right]$$

$$-\frac{1}{(1+r')^T}\left\{\frac{p_0^{im}}{(1-b^d)}-p_T\left(\frac{b^d}{1-b^d}\right)-c_1\right\}\left\{-b^d X_t^d(t)\frac{p_t}{p_0^{-b^d}}^{-(b^d+1)}\right\}dp_t$$

Therefore, the first derivative of K_t is as follows:

$$\frac{dK_t}{dp_t}=\frac{1}{(1+r')^t}\left[\left\{\frac{p_0^{im}}{(1-b^d)}+p_t-c_1\right\}\left\{-b^d X_t^d(t)\frac{p_t}{p_0^{-b^d}}^{-(b^d+1)}\right\}+X_t^e(t)\right]$$

$$-\frac{1}{(1+r')^T}\left\{\frac{p_0^{im}}{(1-b^d)}-p_T\left(\frac{b^d}{1-b^d}\right)-c_1\right\}\left\{-b^d X_t^d(t)\frac{p_t}{p_0^{-b^d}}^{-(b^d+1)}\right\} \qquad (6.77)$$

For $-b^e$ Equal to - ∞, Where $p_t = p_0^{eM}$

On the assumption that export of gypsum ceases when $p_t = p_0^{eM}$,

$$\frac{dK_t}{dp_t}=\frac{1}{(1+r')^t}\left\{\frac{p_0^{im}}{(1-b^d)}+p_t-c_1\right\}\left\{-b^d X_t^d(t)\frac{p_t}{p_0^{-b^d}}^{-(b^d+1)}\right\}$$

$$-\frac{1}{(1+r')^T}\left\{\frac{p_0^{im}}{(1-b^d)}-p_T\left(\frac{b^d}{1-b^d}\right)-c_1\right\}\left\{-b^d X_t^d(t)\frac{p_t}{p_0^{-b^d}}^{-(b^d+1)}\right\} \qquad (6.78)$$

ii) An Empirical Solution for the Special Model of Case IV

The model of Case IV will be empirically tested by the data in Tables 6.2 and 6.5 together with assumed and roughly calculated parameters shown in Table 6.10.

Table 6.10 Assumed and Roughly Calculated Parameters

Parameter	Value	Source and basic assumption
$-b^d$	-0.1	An assumed figure.
$-b^e$	-3.5	An approximate figure roughly calculated and based on X_0^{eM} = 1.019 million tons, p_0^{eM} = 29.27 2006$/ton X_0^{eJ} = 5.543 million tons, and p_0^{eJ} = 17.85 2006$/ton.
p_0^{eM}	29.27 2006$/ton	A hypothetical figure that is equal to the assumed CIF price of Australian gypsum at a Malaysian port minus unit transportation cost from Thailand to Malaysia.
p_0^{eJ}	17.85 2006$/ton	A hypothetical figure that is equal to the CIF price of Australian gypsum at a Japanese port minus unit transportation cost from Thailand to Japan.

After putting in all data into equation 6.78, it is found that, when the mineral is produced for domestic consumption only, $\frac{dK_t}{dp_t}$ is negative for any positive p_t. This means that if gypsum is produced for domestic consumption only, maximum net social benefit will be obtained if the price is at its lowest possible. However, forcing down the price in combination with export prohibition measure may be unconventional and such a policy may be difficult to defend. Therefore it is recommended that the price is fixed at just above p_0^{eM}. At such a price, it will not need to enforce export prohibition, for Thailand will have already priced itself out of the international gypsum market.

For the price range of $p_0^{eJ} < p_t < p_0^{eM}$, it is found that the second derivative of K_t demonstrated by equation 6.76 is negative. This means that the set solution by equating the first derivative of K_t of equation 6.75 to zero is the optimal one. Equation 6.75 can be solved by trial and error.

With regard to equation 6.77, it is found that $\frac{dK_t}{dp_t}$ is all positive for $p_t \leq p_0^{eJ}$. This means that relatively large export volumes favour pushing the gypsum price up to the maximum end of the price constraint. This means that to maximize net social benefit over time, for any time *t*, p_t must not be cheaper than p_0^{eJ}.

The empirical results of the price p_t and the rates of extraction Q_t^d, Q_t^e and Q_t are shown in Table 6.11. By such solutions, ***T**** **= 23.91 years and** ***T***

Table 6.11 The Optimal p_t, Q_t^d, Q_t^e and Q_t of Case IV

Time *t*	p_t (2006$/ton)	Q_t^d (thousand tons)	Q_t^e (thousand tons)	Q_t (thousand tons)
1	17.849	2,970	5,840	8,809
2	17.849	3,168	6,150	9,318
3	17.849	3,374	6,474	9,848
4	17.849	3,589	6,813	10,402
5	17.849	3,812	7,169	10,981
6	17.849	4,045	7,540	11,586
7	17.849	4,288	7,930	12,218
8	17.849	4,541	8,337	12,879
9	17.849	4,805	8,764	13,570
10	17.849	5,081	9,212	14,292
11	18.104	5,361	9,213	14,574
12	19.021	5,632	8,143	13,776
13	20.013	5,914	7,161	13,075
14	21.082	6,205	6,271	12,476
15	22.233	6,507	5,469	11,976
16	23.466	6,820	4,756	11,576
17	24.785	7,145	4,125	11,270
18	26.191	7,482	3,572	11,054
19	27.685	7,833	3,090	10,923
20	29.270	8,198	1,587	9,785
21	29.271*	8,625		8,625
22	29.271*	9,073		9,073
23	29.271*	9,541		9,541
24	29.271*	9,105		9,105
Total		143,115	127,615	270,730

Note: * These are non optimal but recommended prices. At such a price, there is no need to implement export prohibition. Mathematically, the optimal prices at this range of demand curve are the lowest possible ones.

iii) Conclusion of the Empirical Study of the Special Model of Case IV

The solution of the special model with price elasticity of demand and fixed foreign gypsum means that Thailand should immediately push up its gypsum price such that in the farthest country (Japan) the price of Thai gypsum is almost on par with that of its competitor if such price disparity exists. At such a price, Thai gypsum should still have a small advantage of being cheaper than that of its competitor; therefore, the amount of gypsum exported should be maintained, under the assumption that the price elasticity of demand for gypsum in such a client country is close to zero. Hence, Thailand should reap all the benefit of higher gypsum price with a negligible decline in domestic consumption. The price should be fixed at that level for about ten years. During this early period of time, the discounted total economic welfare earned from the production and export of gypsum, though comprising only the producer surplus, is greater than the discounted total economic welfare, comprising both producer surplus and consumer surplus, earned from the production and consumption of gypsum at the time when the total Thailand's gypsum reserves are being depleted. Therefore, it is imperative that the price of Thai gypsum must not be set too close to that of its competitor to jeopardize the demand from abroad. After this early period, the price should be manipulated to increase again but gradually, along the demand functions for Thai gypsum. During this second period of time, the prices should be set so as to equate the discounted marginal social benefit of producing a unit of gypsum at a time and the discounted marginal social benefit of producing and consuming such a unit of gypsum at the time when the total Thailand's gypsum reserves are being depleted. The amount of gypsum to export each year during this second period of time will determined by the demand function

for Thai gypsum from abroad. The price should be pushed to reach the level that, when the transportation cost is added, is equal to the price of gypsum of Thailand's competitor in the client country closest to Thailand (Malaysia). At just above that price level, export of gypsum from Thailand will totally stop since Thailand will have priced itself out of all the international gypsum markets. Thereafter the price of gypsum in Thailand should be fixed just above that price level to make export prohibition unnecessary. The time that export will end is 19.60 years from now because beyond this point in time the discounted marginal social benefit of producing a unit of gypsum for export is smaller than the discounted marginal social benefit of producing and domestically consuming such a unit of gypsum at the time when the total Thailand's gypsum reserves are being depleted. The remainder of the resource will be produced for domestic consumption only for another 4.31 years. Note that the time that gypsum should be produced for domestic consumption only of Case IV is shorter than that of Case II. This is because the advantage in the net social benefit per unit of gypsum produced for domestic consumption over the gypsum produced for export of Case IV is smaller than that of Case II as a result of the price increment of Case IV. Finally, all Thai gypsum resource will be totally depleted in 23.91 years from now.

6.6 Conclusions

The four case of the economic model developed in this Chapter assumed different indeterminable conditions or scenarios. However, all cases found that, because the consumer surpluses elsewhere are not beneficial to Thailand, exporting gypsum is not always good for the country.

The first case adopts the assumptions that the price elasticity of demand for gypsum is zero and that the interaction between gypsum producers and consumers in both the domestic and international markets uphold Hotelling's rules. Under these assumptions, Thailand should promptly stop the export of gypsum. All the gypsum mineral resources should be dedicated solely for domestic consumption. In this case, the gypsum mineral resources in Thailand will be totally depleted in 33.07 years. This conclusion, which is based on the social discount rate of 10 %, will not be altered by the change in the discount rate if it remains within a universally accepted social domain. The conclusion is also not affected by a reasonable possibility of discovering new gypsum mineral resources in Thailand, for the total ore reserves needs to be over ten times the presently known figure before the exportation of mineral gypsum is allowed to continue for a short while.

The second case, which also assumes the zero price elasticity of demand for gypsum, disregards Hotelling's rule and assumes that gypsum prices remain constant. Under this scenario, of all the gypsum reserve of 270.73 million tons, Thailand should allocate a total of 109.566 million tons for export and a total of 161.164 million tons for domestic consumption. These solutions are based on a 10 % social discount rate. By such allocation, export will last 13.68 years and, after that, all remaining gypsum resource should be produced for domestic consumption only for another 11.59 years. The total time of gypsum mineral production in Thailand until the resource is exhausted will be 25.27 years, which is 7.80 years shorter than that of the first scenario. While the length of time allowing for gypsum export and the total time of gypsum production in Thailand vary in the same direction as the size of the gypsum reserve, the length of time that all gypsum should be produced for domestic consumption change very little. With regard to the discount rate, if it is higher the amount of gypsum resources allocated for export will be larger and the time allowed for gypsum export gets longer. It is certainly at the expense of domestic consumption. The opposite is also true and if the social discount rates are equal to or below 3.59 %, no amount of gypsum resources should be allocated for export.

For the first two cases—Case I and Case II-- the gypsum extraction path for Thailand is simply the path matching the sum of the domestic demand and the demand for export, which is not affected by gypsum prices. This is the result of the assumption of zero price elasticity of demand for gypsum.

The third case is under the assumptions that there is a small correlation between gypsum price and gypsum consumption and the demand curve has low price elasticity of demand. It is also assumed that producers raise the net price of gypsum in accordance with Hotelling’s rule. The outcomes of this case are very similar to those of Case I, the special model with zero price elasticity of demand and applicable Hotelling’s rule. By this case Thailand should allocate none of its gypsum resources for export from now on. The gypsum extraction path is the path that makes the net price of gypsum grow at the rate of the social discount rate. The total gypsum resources in Thailand will last 34.09 years for the price elasticity of demand of 0.05 and 35.69 years for the price elasticity of demand of 0.10. Similar to the first case, the conclusion is not altered by the change in the social discount rate within the reasonable range of accepted values and the possible size of the total gypsum ore reserve of Thailand.

The fourth case is close to a perfect model but with a lot more assumptions and assumed data. The case assumes that domestic demand is low price-elastic, while the demand from abroad composes of three sections with different price elasticities of demand: zero elasticity at low prices, high elasticity at intermediate prices, and infinite elasticity at a high price. The gypsum price of Thailand's competitor, treated as an exogenous parameter, is assumed to be fixed over time, while the price of Thai gypsum is manipulated in such a way to maximize the total discounted net social benefits. It is found that Thailand should immediately push up its gypsum price such that in the farthest country (Japan) the price of Thai gypsum is equal to that of its competitor. Then the price should be maintained at that level for about ten years before it should be forced to increase again but gradually to reach the level that, when the transportation cost is added, is equal to the price of gypsum of Thailand's competitor in the client country closest to Thailand (Malaysia). The export will end just above that price level at the time 19.60 years from now. The remainder of the resource will be produced for domestic consumption only for another 4.31 years. Finally, all Thai gypsum resource will be totally depleted in 23.91 years from now. Note that because of the domestic price increment of Case IV, which makes the advantage in the net social benefit per unit of gypsum produced for domestic consumption over the gypsum produced for export of Case IV smaller, the time that gypsum should be produced for domestic consumption only of Case IV is shorter than that of Case II.

Chapter 7 Discussion

7.1 Overall Discussion

The ultimate aim of the thesis is to use economic theories to develop long-term strategies and plans for the government of Thailand to manage its gypsum mineral resources with the aims to avoid pitfalls and to attain sustainable development. In doing so, the thesis lays down the theoretical, conceptual and practical backgrounds relevant to a national administration of natural resources as its introductory parts for supporting and easily comprehending the developed economic models as well as its recommendations. The recommendations, which include ways and means for achieving the optimal solutions of the analysis of this thesis, will be presented in Chapter 8.

7.1.1 Chapter 1

Chapter 1 begins by talking about the group of construction minerals, to which gypsum belongs, of Thailand and some of their problems. Thailand's gypsum resource is peculiarly unique for it is the major source of gypsum supply in the regions of east, south-east and south Asia with almost no rivals. As a cheap and bulky commodity, transportation costs constitute a large proportion of gypsum prices paid by users. Note that, in U.S.A., freight and logistics costs can be 50% to 70% of delivered cost of the mineral to customer (Barker, 2007) and, as demonstrated in Chapter 5, from 1988 to 2004, the average Cost, Freight and Insurance (CIF) price of Thai gypsum at Japan's ports, which included transportation costs, was almost double the average Free on Board (FOB) price of gypsum at Thailand's ports, during the same period. For Thai gypsum, the closest competitor in the region is Australia, and the more distant Mexico and Morocco. Theoretically, Thai gypsum producers could set their gypsum prices in a consuming country to a level almost as high as that of the farther Australian gypsum. But Thai gypsum producers have almost never realized this advantage because of the intense competition by price-cutting among themselves. This is the reason why the government has intervened by imposing export control, enforceable by the country's mining law, and inducing collusion among gypsum exporters.

7.1.2 Chapter 2

In the second chapter, briefs of mining laws, taxation, and policies of Canada, Australia, Brazil, as well as that of Thailand are presented as examples of how countries manage their mineral resources. Canada and Australia are the world's leading exporters of minerals, while Brazil is similar to Thailand for it is a developing country with diversified economies that export some minerals. This thesis shows that all four countries manage their mineral resources alike. Notwithstanding their different governmental structures, geographies, environments, and population density, all treat their mining industries as special businesses that need tight control and are taxed extraordinarily. All support their mining industry by way of investment promotion in mineral exploration activities, at least by supplying potential investors with geoscience data and other useful information to private investors. They also attempt to solve environmental and social problems resulting from mining, such as land use conflicts, pollution, abandoned mined out areas, similarly. Indeed, the similarities of the ways they manage their mineral resources have stemmed from the roles of mineral resources in their economies and the problems caused by them. At the time when the mineral sectors were important, the attentions of the governments were more focused on revenue collection and nurturing their mineral industries with the purpose of increasing export earnings and tax revenues. Pollution and environmental damage were not matters of concern to anyone since most mines were located in remote areas. However, it is clear that the relative importance of mineral resources to the economies of these four countries has been on a declining path as the countries have developed. Furthermore, eyesores and accumulated environmental damage caused by mining activities, which expanded exponentially worldwide in the last century, have become more evident. In addition, populations and communities have grown. Many of the remote areas in the past are not remote anymore. At present, land use conflicts, pollution, and environmental damage caused by mining have become social issues in all four countries. No wonder that at present the governments of these four countries work more toward rectifying past mistakes and lay greater stress on environmental and social issues.

In Thailand's case, several decades ago, with a much smaller population, mining activities were almost exclusively conducted in the less populated and faraway areas in the southern part of the country. As stated in Chapter 1, only until just over twenty years ago, the mineral sector contributed significantly to the economy of Thailand. During such time, laws and policies were aimed toward maximizing government revenue and export earnings from minerals, while laws involving environmental protection were weak. As people became better off and more and more affected by the environmental problems caused by mining, pressure for change mounted on the government. In 1992, Thailand enacted the National Environmental Quality Act B.E. 2535. Since then, all mining applicants have to submit and get their Environmental Impact Assessment reports approved by the authority before mining leases can be granted. Also by that legislation, some restricted areas need the Cabinet's approval before mining leases can be granted, and some environmentally sensitive areas have been declared prohibitive to mining. Now it is difficult and takes time for a mining investor to obtain a mining lease, as he or she has to entangle with several bureaucratic agencies. It is fair to say that Thailand at present adopts the inefficient system of check and balance in trying to curb the adverse effects from mining. The era of full mining promotion without questions in Thailand has been literally closed.

However, it is the opinion of the author of this thesis that the policy and practice of Thailand in managing its mineral resources might go too far to the conservation extreme. Though it is true that the direct contribution of the mining sector to Thailand's economy is very small, Thailand cannot do well without some mining. Thailand is not rich enough to import all kinds of raw minerals for its domestic industries. In addition, as demonstrated in Chapter 3, which talks about "resource curse", neither the "curse" resulting from the exploitation nor the depletion of some of its mineral resources deterred Thailand from achieving a high average economic growth during the last few decades. Hence, the question is not whether or not Thailand should totally conserve all of its mineral resources, but how Thailand exploits its mineral resources to attain the maximum intertemporal social benefit. Therefore, some sensible changes in the mineral policy of Thailand might be as follows:

i) Adopt social cost-benefit analysis and other economic tools to decide a specific mineral policy, and to solve land use conflicts;

ii) Give priority to the production of minerals for domestic consumption, especially construction minerals;

iii) Tighten command and control approach to prevent pollution and to minimize environmental damages; and

iv) Adopt a "polluter pays principle" and employ economic measures to transfer environmental costs back to be the private costs of polluters.

7.1.3 Chapter 3

In Chapter 3, a phenomenon, called the “resource curse”, which seemed to affect resource-rich countries, was presented together with an investigation on Thailand’s first-hand experience of the phenomenon. The chapter gives readers an important background that a government should bear in mind in administrating its mineral resources and setting up a mineral policy.

Based on empirical studies, many scholars reported that resource rich countries appeared to have experienced worse economic performance than resource poor countries. It seems as if the exploitation of wealthy natural resources, especially mineral deposits, is a curse not a gift. It appears that the resource curse might be the effects of long term decline in terms of trade, revenue volatility, undesirable structural economic change, and socio-cultural and political impacts as a result of the government and some of the people of those nations who get suddenly and easily rich. However, not all resource-rich countries appear to have suffered a long-lasting resource curse. A few resource-rich countries—notably, Botswana, Chile, Malaysia, and Thailand—have been able to surpass the resource curse and become high economic growth countries. In Thailand’s case, before 1985, when agricultural and mineral commodities played major roles in total export, it showed some symptoms of the resource curse—export revenue fluctuation and decline in terms of trade. Thailand overcame the problems by implementing prudent and conservative economic policies and being open to foreign investment. Interest rates were kept high, commercial loans were kept tight, domestic currency was devaluated, zero growth government budgets were adopted, and tax rates were increased. The impressive growth of the manufacturing sector as a result of the influx of foreign direct investment can be claimed to be the most important factor in Thailand overcoming the recourse curse. Thailand might be a magnet of foreign investment because of the rather stable internal politics, strong elite bureaucrats, and cultural homogeneity. Geo-politics—Thailand was a frontline state fighting communism—and regional events, such as the Vietnam War, also helped Thailand economically.

The results of Chapter 3 confirm that the resource curse is probably real. But the curse is just a factor among many others that affect a county's development both in good and bad ways. The postulate of the curse might be only one-sided. The easy money from the exploitation of natural resources can be used as a springboard for development. It is very difficult for a poor country, whose people normally associate with poor education—or, in other words, meager human capital—to develop. In fact, not very long ago, nearly all developed countries, including the U.S.A. and Japan, used to depend more or less on a resource-based economy. Therefore, the question for a country is not whether or not to exploit the country's rich natural resources, but how to mitigate the effect of the resource curse.

At present, the resource curse is not anymore a problem for Thailand. However, as Thailand is a developing country, which means that it is not out of the woods yet, and natural resources are still important to its economy, Thailand should not low down its guard against the curse. Some recommendations to the Thai government about the exploitation of its gypsum mineral resource, with regard to the resource curse, will be presented in Chapter 8.

7.1.4 Chapter 4

The principle and concept of sustainable development are presented in Chapter 4, for the exploitation of minerals, which are non-renewable resources, entwines with it. The globally accepted general definition for sustainable development—"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"—was established by the UN Commission on the Environment and Development (UNCED) and first appeared in the Brundtland Report or "Our Common Future" in 1987. However, because the definition is short and vague, and the concept deals with the future, different scholars with different backgrounds, interests and motivations have interpreted the concept differently. In the field of economics, Pezzey (1992) classified the economic definitions of sustainable development into two approaches as follows:

i) The definitions based directly on the welfare of people, such as the one that consumption (or utility) is non-declining through time.

ii) The definitions based on the means to provide people with welfare, such as the one that the total capital stock is non-declining through time.

With regard to the first approach of the economic definitions of sustainable development, Solow (1974) showed that, with Cobb-Douglas production function, zero population growth, and no technical progress, the constant consumption could be sustained over time by a suitable path of capital accumulation. Later Hartwick (1977, 1978) proposed a rule stating that a constant level of consumption can be sustained if all the rents on non-renewable resources extracted at each point in time are totally invested in reproducible capital. This rule is now known as Hartwick rule. However, Hartwick rule is just a necessary but not sufficient condition. Other three necessary conditions are: 1) an economy has to be already on a sustainable path, 2) the resource extraction path must be efficient in a competitive economy, and 3) the economy's production technology is right. The second condition pertains to Hotelling rule, while the possible production functions are that of the Cobb-Douglas and the Constant

Elasticity of Substitution ones, or if a backstop technology is permanently available (Perman *et al*., 2003).

The second approach of the economic definitions of sustainable development, the non-declining through time of the total capital stock (the natural capital plus the human-made capitals, comprising manufactured capital, human capital, social capital, and financial capital) is also called the weak sustainability approach. Weak sustainability is based on the assumption of perfect substitution between natural and human-made capitals, as opposed to the strong sustainability that does not accept the concept of unlimited substitutability of capitals and requires not only the non-declining total capital stock but also the non-declining natural capital stock to attain sustainability.

The weak sustainability approach was more often adopted in economic literatures involving sustainable development and was the basis in formulating the sustainable development indicators to measure and monitor the sustainable development of a country. Six proposed indicators for sustainable development are briefed in Chapter 4, together with numerical studies to see how well Thailand fared in sustainable development. The six indicators are Genuine Savings (GS), Green Net National Product (GNNP), augmented GS, augmented GNNP, UN Commission on Sustainable Development (CSD) Indicators of Sustainable Development, and World Bank World Development Indicators.

It is found that when applying GS, augmented GS, GNNP, augmented GNNP and sustainable development composite index to Thailand, different indicators provide different answers. This is because each indicator is derived from different fundamental concepts and methods. GS and augmented GS show that the development of Thailand during the period of study, between 1993 and 2004, was sustainable because both sets of figures were all positive. On the other hand, the development of Thailand was unsustainable sometime during the period when GNNP, augmented GNNP, or the sustainable development composite index were used as indicators. It should be noted that, in Thailand's case, the green and augmentation terms have a small effect on NNP; therefore, sustainable development of a country depends almost entirely on the conventional NNP. If we take all these five sustainable development indicators into consideration it is still unclear whether the development of Thailand has achieved sustainability or not. However, we may say that all indicators, especially GS, GNNP, and the sustainable development composite index, are useful policy tools for guiding Thailand to attain long-term sustainable development. Individually, these indicators, which incorporate environmental and social components, offer critical markers for the government to monitor closely and prevent its development becoming unsustainable. Collectively, the government could treat one or two negative indicators among the five indicators as a serious warning sign for initiating remedial actions.

With regard to the role of minerals in sustainable development, minerals production could be physically sustainable—in other words, minerals outputs could at least be maintained for a long time—because of the following three factors: 1) depleted mineral reserves are replaced by investing in mineral exploration and development; 2) technological innovation makes it possible to extract mineral resources that were previously either technically difficult or commercially unfeasible to be mined; and 3) recycling adds mineral productions to markets. In the views of proponents of the "weak" concept of sustainable development, intergenerational equity will be satisfied as long as exploration and technological progress offset the depletion and degradation of mineral resources (Eggert, 2000). It is debatable whether these views are too optimistic for the rate of technological progress in the long run while the world's resources are finite. Notwithstanding this unsettling belief, a country can always supplant its depleted mineral resources by import. Therefore, the finite quantity of minerals within its boundary is not necessarily a barrier to economic development of a country.

With an attempt to determine the optimal depletion of Thailand's gypsum mineral resource by following the Hotelling's concept of maximizing the present value through time of the resource rents, this thesis has indeed conformed to the second approach of the economic definitions of sustainable development, the non-declining through time of the total capital stock. It should be noted that, as shown in Table 7.1, from 1993 to 2007, the budgets of the Thai government allocated for capital expenditures—expenses on equipments, land, buildings and related expenses—ranged from 172 to 375 billion bahts, in addition to huge sums for education and research (human capital investments) ranging from 101 to 358 billion bahts (Bureau of the Budget, 2007). In comparison, the Gross Domestic Products (GDPs) originated from mining and quarrying sector, including petroleum, ranged from 44 to 277 billion bahts, which were lower than either the capital investments or the education and research expenditures in all years (Office of the National Economic and Social Development Board, 2008). Therefore, Thailand, in effect, has surpassed the requirement of Hartwick rule. But, as mentioned above, whether or not Thailand is already on a sustainable path, depends on which indicator is adopted. Furthermore, the economy's production technology is unknown. Anyway, Chapter 8 of this thesis will recommend Thailand to achieve and maintain sustainable development with regard to the exploitation of its mineral resources.

Table 7.1 Governmental Budgets Allocated for Capital Expenditures and Education and Research and the GDPs Originated from Mining and Quarrying Sector, from 1993 to 2007, of Thailand

(billion bahts)

Year	GDP Originated from Mining and Quarrying*	Governmental Budgets Allocated for**	
		Capital Expenditure	Education and Research
1993	44	172	101
1994	49	213	108
1995	50	254	132
1996	63	327	144
1997	82	380	154
1998	84	279	180
1999	87	234	178
2000	117	217	193
2001	126	219	195
2002	136	224	206
2003	155	211	225
2004	175	293	250
2005	223	319	279
2006	257	358	314
2007	277	375	358

Source: * Office of the National Economic and Social Development Board (2008)
** Bureau of the Budget (2007)

7.1.5 Chapter 5

Chapters 5 and 6 are the quantitative and major analyses of this thesis, which aims to propose strategies for maximizing the social benefit from the exploitation of Thailand's gypsum mineral resource. In Chapter 6 the economic models based on Hotelling's concept of maximizing Net Present Value (NPV) of resource rents accrued to a society is developed to determine the optimal depletion of Thailand's gypsum resource. Solutions of the models of Chapter 6 will be the bases for the recommended strategies for maximizing the social benefit from the exploitation of Thailand's gypsum mineral resource. The details of Chapter 6 will be discussed later. However, the models of Chapter 6 require the gypsum consumption or demand functions of countries that consumed Thailand's gypsum. Therefore, a model determining gypsum consumption in Thailand and some countries that imported gypsum from Thailand is developed in Chapter 5. Because of the very small and incomplete data, the demand equations of the model derived from the Ordinary Least Squares technique are very simple and the model should be treated as a very rough method of approximation of the demands for gypsum that is better than a guesstimate.

The analysis of Chapter 5 found that the gypsum price does not affect consumption or, in other words, the price elasticity of demand for gypsum is zero, at least, in the short run. Though the analysis has some shortcomings as mentioned above, its results conform to other empirical studies on demands for minerals and metals. Eleven papers on the demands for metals were reviewed in this chapter. In their determinations of demand or consumption functions, all either outright discarded price factors or found the price elasticities of the demands for metals, except the demand for gold in high-income countries, were close to zero or very small. Note that all five main authors of the papers that did not take price factors into account have sufficient knowledge of economics since they either were teaching at relevant departments in universities or were mineral economists by profession.

The empirical solutions of the adopted general consumption models for Thailand and seven other Asian countries in Chapter 5 reaffirm many other studies in the field of minerals that the consumption of a mineral is strongly influenced by consumer income, but insignificantly affected by the mineral price. Almost all minerals and metals are raw materials for the production of consumer goods. Hence, the costs (or prices) of mineral raw materials constitute only fractions of the prices of consumer goods. In the case of gypsum, its price accounts for less than 0.5 % of the Portland cement's price (Department of Primary Industries and Mines, 2004). A reasonable movement of a mineral price affects the prices of consumer goods very little; therefore, the consumption of consumer goods and its mineral raw materials will not change much.

Moreover, in most cases industrial plants require retooling if raw material is changed. Hence, it costs somewhat and takes time for industrial plants to switch over to new substitute raw materials. As in the case of gypsum wallboard, consumers may substitute plywood or other kinds of partitions for gypsum wallboard at will. But gypsum wallboard producers have no choice but to be faithful to gypsum in their production or else to make heavy reinvestment to produce other different products instead. Furthermore, in fighting to maintain or to increase its market share, an industry would tend to refrain from passing the burden of a small additional cost on to consumers. Therefore, the demand for the product will not decrease, and as a result the demand for minerals used in the production of such a product will not be affected.

This thesis as well as other studies has found that while the relation between the price and the consumption of a mineral can hardly be determined from historical data, the correlation between the GDP per capita and the mineral consumption of a country is prominent. This means that a change in mineral consumption is the result of a shift in the demand function due to a change in consumer income, consumer taste, technology, etc.

7.1.6 Chapter 6

In Chapter 6, the economic models, based on the concept of maximizing Net Present Value (NPV) of resource rents accrued to a society from the exploitation of a mineral resource, are formulated. The concept is that of Hotelling model in 1931, which is presented in the introductory section of Chapter 6 as a previewing background. Hotelling model basically explored an optimal path of mineral resource exploitation that maximizes the present value of resource rents through time. Though, Hotelling presented his paper in 1931 several decades before the inception of the idea of sustainable development, his model has been connected with the concept of “weak sustainability”. Under the concept, the capitals in various forms—natural, manufactured, human, social and financial —which are necessary tools for a human-being to have a good quality of life, are interchangeable. Hartwick (1977, 1978) has shown that, under some conditions, non-decreasing consumption could be maintained if the Hotelling rent generated by the exploitation of nonrenewable resources is reinvested in some forms of capital stocks to provide for future consumption. Therefore, as nonrenewable resources are depleted, weak sustainability requires that the Hotelling rent must be reinvested to develop substitute capital stocks for the time when the resource is depleted. The concept of the Hotelling model is later adopted as the basis of the economic models of this thesis to define the optimal extraction path of Thailand’s gypsum mineral resources. This is essentially the first step for Thailand to attain sustainable development in the exploitation of its gypsum resources. The further step is for Thailand to reinvest the resource rent from the exploitation of gypsum resources in some forms of capital stocks to provide for future consumption, in accordance with the Hatwick’s rule.

The economic models created are under the presumption that the benefits are represented by the total economic welfare and the society covers just gypsum producers and consumers within Thailand’s boundary. In addition, it is assumed, in brief, as follows:

1) After the gypsum resource in Thailand is depleted completely Thailand will import gypsum from other countries for consumption;

2) The effect on the world gypsum price of the relatively small demand for gypsum in Thailand is negligible;

3) The price paid by Thai consumers for gypsum produced domestically is on par with the Free on Board (F.O.B.) price;

4) The amount of gypsum reserves left in the ground is fixed;

5) The price elasticity of demand for gypsum in Thailand and its client countries is very small; and

6) The rates of growth of populations and GDPs of Thailand and other Asian countries importing gypsum from Thailand are constant.

Admittedly, with such many assumptions, the general model created in Chapter 6 cannot be construed as a theoretical one. However, it is the intention of this thesis to put presently available theories into practice in real complex world rather than proposing a new theory.

The assumption no. 1) is true up until the total depletion of all gypsum resources in the world if mineral gypsum is indispensable for domestic industries. However, it is more likely that the by-product synthetic gypsum will play a part in substituting for mineral gypsum when the price rises as the gypsum mineral resources in Thailand are nearly depleted. The assumption no. 2) is logical but it is not certain in the future. It depends on future development of Thailand since the demand for the mineral correlates with GDP. The assumption will start to fall apart if Thailand economically develops faster than other countries in the region and the share of Thailand in the total regional demand for gypsum grows more significant.

The assumption no. 3) gets the backing of the law of one price and there is no evidence to say otherwise. However, the no. 4) assumption, stating that the total gypsum reserves are fixed when prices change, is contrary to an economic theory. The assumption is first and foremost for sake of simplicity, but it may not be far off from reality in the case of the gypsum mineral resources in Thailand. As explained in Chapter 6 when this assumption was stated, it is unlikely that there will be a discovery of substantially additional gypsum reserves in Thailand.

Among all the assumptions in this thesis, the most controversial one is the assumption no. 5), which treats price as an irrelevant factor, literally. Lengthy discussion was done in the subsection on Chapter 5 of this chapter, above; therefore, it is too cumbersome to repeat here again.

The assumption no. 6), which is about the rates of growth of populations and GDPs of countries are constant, is just for the convenience of the analysis of this thesis. The constant growth rates result in the continual of gypsum consumption with no downturns. Most countries have rather slowly down trends in population growth, but the GDP of a country has been neither stable nor always positive.

In Chapter 6 a general model, which is closer to be a theoretical ideal, was created. However, the general model consists of some parameters that are difficult to determine and that this thesis failed to determine. The parameters that are determined with difficulty are the positive effect on the marginal cost of extraction, and the negative effect of technology on the marginal cost of extraction. The one that cannot be determined in Chapter 5 of this thesis is the significant value of the price elasticity of demand for gypsum. To solve this shortcoming, Chapter 6 presents four cases of special models with some assumed parameters and scenarios. The special models together with their empirical solutions, which will be the bases of the recommendations to the Thai government, are to be discussed in the next section.

The maximizing function of the general model is the function maximizing the discounted flow of the sum of the producer surplus, or the resource rents of gypsum mining industry, from the present to the time the gypsum resource in Thailand is depleted, and the consumer surplus from consuming gypsum from the present to infinity. However, after some mathematical manipulation, the function becomes maximizing the discounted flow of the sum of the total surplus (producer surplus plus net consumer surplus) of the gypsum production for domestic consumption, from the present to the time the gypsum resource in Thailand is depleted, and the producer surplus only of the gypsum production for export, from the present to the time the export of gypsum from Thailand stops. From the general model, it is found that the real domestic price movement insignificantly affects the net social benefit (net consumer surplus + producer surplus) generated by the gypsum production for domestic consumption, if the absolute value of price elasticity of demand for gypsum is very small. But the level of the expected import price if the domestic production of gypsum is stopped significantly affects the net social benefit. The higher the level of the expected import price the bigger the net social benefit generated by the gypsum production for domestic consumption. It can be deduced from Expressions 6.35 or 6.36 of the general model that, under the condition that the price elasticity of demand for gypsum in Thailand is highly inelastic, Thailand will gain a better total discounted net social benefit if the gypsum price within the country is elevated to the level close to the expected import price. The additional gain is obviously from the higher export value.

7.2 Discussion on the Empirical Solutions of the Special Models of Chapter 6

7.2.1 Assumptions and Solutions

As stated in the above section, the created general model consists of some parameters that are difficult to determine and that this thesis failed to determine. To solve this shortcoming, Chapter 6 presents four cases of special models with some assumed parameters and scenarios. All four cases assume that the positive effect on the marginal cost of extraction, and the negative effect of technology on the marginal cost of extraction cancel each other out. It should be noted that the belief that the marginal cost of extracting minerals increases when the stocks of minerals get smaller has not been evidenced over time. As time passes minerals are mined from deeper deposits and their grades are poorer. Therefore, the average extraction cost of a mineral and its price, as a result of the change in the cost, were supposed to have an increasing trend. But the real historical price-trends of most minerals, including Thai gypsum as shown in Figure 5.10 of Chapter 5, have not conformed to such a belief. Since the consumption of a mineral, in general, has increased over time, the downward shift, if any, of the demand curve alone as the cause of the fall in the mineral price can be eliminated. The downward shift of the supply curve because of the fall in the extraction cost should be the main culprit in the decline in price. As already discussed in Chapter 5, mineral extraction costs actually have slowly declined over time as the results of the successful increase in productivity due to innovations and new technologies. Furthermore, over a normally long mining life, improvement always occurs continuously in a mine as miners gain more experience. Therefore, the cost of mining a deeper part of an ore deposit will likely be lower than expected. However, future technological progress is not certain to leap forwards as smoothly and as fast as it has been, while the depletion of many minerals are geologically real. Therefore, to compromise the two opposite forces and to simplify the problem, the special models assume that the aggregate marginal cost to extract gypsum, in real terms, is constant over time.

The additional assumptions and the solutions of the four cases of special models are as follows.

i) Case I assumes that the price elasticity of demand for Thailand's gypsum is zero and the gypsum producers in both Thailand and abroad push up the net prices (sale prices – marginal costs) to rise in accordance with Hotelling's rules. The first assumption stems from the result of Chapter 5 and other studies that found consumptions of minerals are insignificantly affected by the mineral prices. The latter assumption has no particular reason but the belief in such a hypothesis. Under these assumptions, Thailand should promptly stop the export of gypsum now. All the gypsum mineral resources of 270.73 million tons should be dedicated solely for domestic consumption. This is because the discounted sum of producer surplus and consumer surplus, earned from the production and consumption of an amount of gypsum at the time when the total Thailand's gypsum reserves are being depleted is still higher than the only producer surplus earned from the production of such an amount of gypsum for export. At 10 % social discount rate, export of gypsum at present gives higher benefit if the total gypsum reserves of Thailand are higher than 2,756.031 million tons—more than 10 times larger than the total estimate in 2006 of 270.730 million tons. With the total gypsum reserves of 270.730 million tons, export of gypsum at present also gives higher benefit if the discount rate is higher than 22.68 %. In case the export of gypsum stops now, the gypsum mineral resources in Thailand will be totally depleted in 33.07 years. The gypsum extraction path is simply the path matching domestic demand, which is under the assumption that it is not affected by gypsum price. The results of Cases I, with regard to future domestic price trend, expected import price trend, production for domestic consumption, and total production are shown in Table 7.2.

Table 7.2 The Optimal Import Price (p_t^{im}), Domestic Price (p_t), Production for Domestic Consumption (Q_t^d), and Total Production (Q_t) of Case I

Time t	Import Price (p_t^{im}) (2006$/ton)	Domestic Price (p_t) (2006$/ton)	Production for Domestic Consumption and Total Production $(Q_t^d = Q_t)$ (thousand tons)
1	33.63	15.21	3,035
2	34.59	16.17	3,238
3	35.64	17.22	3,449
4	36.80	18.39	3,668
5	38.09	19.68	3,897
6	39.51	21.10	4,135
7	41.08	22.67	4,383
8	42.82	24.41	4,641
9	44.74	26.33	4,911
10	46.86	28.46	5,193
11	49.20	30.80	5,487
12	51.79	33.40	5,793
13	54.66	36.26	6,114
14	57.82	39.43	6,448
15	61.32	42.93	6,798
16	65.18	46.80	7,164
17	69.46	51.08	7,546
18	74.18	55.81	7,946
19	79.39	61.03	8,365
20	85.16	66.80	8,803
21	91.53	73.18	9,262
22	98.58	80.24	9,743
23	106.36	88.03	10,246
24	114.96	96.64	10,774
25	124.47	106.16	11,327
26	134.97	116.68	11,908
27	146.58	128.30	12,516
28	159.42	141.15	13,155
29	173.60	155.35	13,825
30	189.27	171.04	14,528
31	206.59	188.39	15,267
32	225.74	207.55	16,042
33	246.89	228.73	11,121
Total			270,730

ii) The same as Case I, Case II assumes that the price elasticity of demand for Thailand's gypsum is zero. However, in this case Hotelling's rule is disregarded and it is assumed that gypsum prices anywhere will remain constant. In fact, the assumption of constant gypsum prices is much close to reality than the assumption that prices increase continuously in accordance with the Hotelling rule as in Case I. As shown in Figures 5.7, 5.9, and 5.10, the price trends in the past were rather flat and even in decline in some markets. Under these assumptions, at a 10% social discount rate, Thailand should allocate a total of 109.566 million tons for export and a total of 161.164 million tons for domestic consumption. By such allocation, export will last 13.68 years and all remaining gypsum resource will be produced for domestic consumption only for another 11.59 years. The total time of gypsum mineral production in Thailand until the resource is exhausted will be 25.27 years. If the social discount rate is higher, the amount of gypsum resources allocated for export will be larger and the period of time allowing gypsum to be exported will be longer. The is because a higher discount rate weights more against the discounted total economic welfare (producer surplus and consumer surplus) earned from the production and consumption of gypsum at a time far into the future. Therefore, a larger portion of the gypsum resources should be allocated for export and, as a result, the time period that export of gypsum should be allowed get longer. However, the opposite is also true, and if the social discount rate that is equal to or below 3.59 % is adopted, no amount of gypsum resources should be allocated for export from now on, meaning that Thailand should stop export of gypsum immediately. This is because below such a discount rate all the discounted total economic welfares earned from the production and consumption of gypsum at any time, up until the total Thailand's gypsum reserves are depleted, are larger than the total economic welfare earned from the production and export of gypsum now. If the size of the total gypsum ore reserve is larger, both the time when the gypsum resources of Thailand are totally depleted and the time that export should end will get longer. The opposite is also true. But the size of the total gypsum ore reserve barely affects the length of the period of no export before the total depletion of gypsum in Thailand. The same as in Case I, the gypsum extraction path is simply the path matching domestic demand, which is under the assumption that it is not affected by gypsum price. The results of Cases II, with regard to future domestic price trend, expected import price trend, production for domestic consumption, production for export, and total production are shown in Table 7.3.

Table 7.3 The Optimal Import Price (p_t^{im}), Domestic Price (p_t), Production for Domestic Consumption (Q_t^d), Production for Export (Q_t^e), and Total Production (Q_t) of Case II

Time t	Import Price (p_t^{im}) (2006$/ton)	Domestic Price (p_t) (2006$/ton)	Production for Domestic Consumption (Q_t^d) (thousand tons)	Production for Export (Q_t^e) (thousand tons)	Total production $(Q_t = Q_t^d + Q_t^e)$ (thousand tons)
1	32.77	14.35	3,035	5,840	8,875
2	32.77	14.35	3,238	6,150	9,388
3	32.77	14.35	3,449	6,474	9,923
4	32.77	14.35	3,668	6,813	10,481
5	32.77	14.35	3,897	7,169	11,065
6	32.77	14.35	4,135	7,540	11,675
7	32.77	14.35	4,383	7,930	12,312
8	32.77	14.35	4,641	8,337	12,979
9	32.77	14.35	4,911	8,764	13,676
10	32.77	14.35	5,193	9,212	14,404
11	32.77	14.35	5,487	9,680	15,167
12	32.77	14.35	5,793	10,172	15,965
13	32.77	14.35	6,114	10,687	16,801
14	32.77	14.35	6,448	4,799	11,247
15	32.77	14.35	6,798		6,798
16	32.77	14.35	7,164		7,164
17	32.77	14.35	7,546		7,546
18	32.77	14.35	7,946		7,946
19	32.77	14.35	8,365		8,365
20	32.77	14.35	8,803		8,803
21	32.77	14.35	9,262		9,262
22	32.77	14.35	9,743		9,743
23	32.77	14.35	10,246		10,246
24	32.77	14.35	10,774		10,774
25	32.77	14.35	10,123		10,123
Total			161,164	109,566	270,730

iii) In Case III, the assumption about future price trends is that the gypsum producers in both Thailand and abroad push up the net prices to rise in accordance with Hotelling's rules, the same as in Case I. But the price elasticity of demand for Thailand's gypsum is not zero. A couple small figures of the price elasticity of demand for gypsum were assumed. The case was really to test the effect of the price elasticity of demand for gypsum on the solutions of Case I. It found out that Thailand should allocate none of the gypsum resources for export from now on. Such a result is similar to that of Case I. The gypsum extraction path is the path that makes the net price grow at the rate of the social discount rate. At 10% social discount rate, the total gypsum resources in Thailand will last 34.09 years, for the price elasticity of demand of 0.05, and 35.69 years, for the price elasticity of demand of 0.10. It means that the higher the price elasticity of demand the longer the time the Thai gypsum reserves will last. This is because, with higher price elasticity of demand, the price rise in accordance with Hotelling's rule will slow the growth of the demand for gypsum. Similar to Case I, if the discount rate or the total gypsum reserves are high enough the export of gypsum at present will render higher benefit. But such a rate is too high to be a social discount rate and such a total gypsum reserves is too high to be possible. The results of Cases III, with regard to future domestic price trend, expected import price trend, production for domestic consumption, production for export, and total production are shown in Table 7.4.

Table 7.4 The Optimal Import Price (p_t^{im}), Domestic Price (p_t), Production for Domestic Consumption (Q_t^d), and Total Production (Q_t) of Case III

Time *t*	Import Price (p_t^{im}) (2006$/ton)	Domestic Price (p_t) (2006$/ton)	Production for Domestic Consumption and Total Production $(Q_t^d = Q_t)$ (thousand tons)	
			b = 0.05	*b* = 0.1
1	33.63	15.21	3,027	3,018
2	34.59	16.17	3,219	3,200
3	35.64	17.22	3,417	3,386
4	36.80	18.39	3,623	3,578
5	38.09	19.68	3,836	3,776
6	39.51	21.10	4,056	3,978
7	41.08	22.67	4,284	4,187
8	42.82	24.41	4,520	4,401
9	44.74	26.33	4,764	4,622
10	46.86	28.46	5,018	4,849
11	49.20	30.80	5,281	5,083
12	51.79	33.40	5,554	5,324
13	54.66	36.26	5,837	5,572
14	57.82	39.43	6,131	5,828
15	61.32	42.93	6,436	6,093
16	65.18	46.80	6,753	6,365
17	69.46	51.08	7,082	6,647
18	74.18	55.81	7,425	6,937
19	79.39	61.03	7,781	7,238
20	85.16	66.80	8,152	7,548
21	91.53	73.18	8,538	7,870
22	98.58	80.24	8,939	8,202
23	106.36	88.03	9,358	8,547
24	114.96	96.64	9,794	8,903
25	124.47	106.16	10,249	9,273
26	134.97	116.68	10,723	9,656
27	146.58	128.30	11,218	10,054
28	159.42	141.15	11,734	10,466
29	173.60	155.35	12,273	10,895
30	189.27	171.04	12,835	11,339
31	206.59	188.39	13,423	11,801
32	225.74	207.55	14,036	12,281
33	246.89	228.73	14,678	12,780
34	270.28	252.15	15,349	13,299
35	296.12	278.02	1,391	13,839
36	324.68	306.61		9,893
Total			270,730	270,730

iv) Case IV is close to the general model but with a lot more assumptions and assumed data. The case assumes that domestic demand is low price-elastic, while the demand from abroad composes of three sections, as shown in Figure 6.6, with different price elasticities of demand: zero elasticity of demand at low prices, high elasticity of demand at intermediate prices, and infinite elasticity of demand at a high price. The gypsum price of Thailand's competitor, Australia, treated as an exogenous parameter, is assumed to be fixed over time. At the zero elasticity section of the demand curve, Thai gypsum still has the advantage of being cheaper than its competitor in every market. But when the price of Thai gypsum goes up above that section and moves into the intermediate section of the demand curve, Thailand will start to lose first its customer in the farthest market from Thailand but closest to its competitor. If the price of Thai gypsum increases further the loss of its market shares will be bigger and bigger when closer and closer customers desert its gypsum. At a certain price height, Thailand will lose all its markets when the closest customer switches over to import gypsum from its competitor. The last section of the demand curve is infinite elasticity because it is more likely that the last customer will immediately stop import gypsum from Thailand. It is found that, under these assumptions and with the social discount rate at 10%, Thailand should immediately push up its gypsum price such that in the farthest country (Japan) the price of Thai gypsum is almost equal to that of its competitor. At such a price, Thai gypsum should still have a small advantage of being cheaper than that of its competitor; therefore, the amount of gypsum exported should be maintained. The price should be maintained at that level for about ten years. During this early period of time, the discounted total producer surplus earned from the production of a unit of gypsum for export is greater than the discounted sum of the producer surplus and consumer surplus, earned from the production and consumption of such a unit of gypsum at the time when the total Thailand's gypsum reserves are being depleted. Then, it should be forced to increase again but gradually. During this second period of time, the prices should be set so as to equate the discounted marginal social benefit of producing a unit of gypsum at a time and the discounted marginal social benefit of producing and consuming such a unit of gypsum at the time when the total Thailand's gypsum reserves are being depleted. The amount of gypsum to export each year during this second period of time will be determined by the demand function. When the price of Thai gypsum in the client country closest to Thailand (Malaysia) is raised to the level just above that of Thailand's competitor, export of gypsum from Thailand will end. The time to reach such a critical price level is 19.60 years from now. Beyond this point in time, the discounted marginal social benefit of producing a unit of gypsum for export is smaller than the discounted marginal social benefit of producing and domestically consuming such a unit of gypsum at the time when the total Thailand's gypsum reserves are being depleted. Thereafter, the price of gypsum in Thailand should be fixed just above that price level to deter export. As Thailand prices itself out of all the international gypsum markets, the remainder of the resources will be produced for domestic consumption only for another 4.31 years. All Thai gypsum resource will be totally depleted in 23.91 years from now. The results of Case IV, with regard to future domestic price trends, expected import price trends, production for domestic consumption, production for export, and total production are shown in Table 7.5.

Conclusively, all cases found that the export of gypsum is not always good to Thailand. All solutions suggest that at some point in time before all gypsum resources are depleted—ranging from immediately as in Case I and Case III to 19.60 years from now as in Case IV—Thailand should stop export of mineral gypsum.

Table 7.5 The Optimal Import Price (p_t^{im}), Domestic Price (p_t), Production for Domestic Consumption (Q_t^d), Production for Export (Q_t^e), and Total Production (Q_t) of Case IV

Time t	Import Price (p_t^{im}) (2006$/ton)	Domestic Price (p_t) (2006$/ton)	Production for Domestic Consumption (Q_t^d) (thousand tons)	Production for Export (Q_t^e) (thousand tons)	Total Production $(Q_t = Q_t^d + Q_t^e)$ (thousand tons)
1	32.77	17.850	2,970	5,840	8,809
2	32.77	17.850	3,168	6,150	9,318
3	32.77	17.850	3,374	6,474	9,848
4	32.77	17.850	3,589	6,813	10,402
5	32.77	17.850	3,812	7,169	10,981
6	32.77	17.850	4,045	7,540	11,586
7	32.77	17.850	4,288	7,930	12,218
8	32.77	17.850	4,541	8,337	12,879
9	32.77	17.850	4,805	8,764	13,570
10	32.77	17.850	5,081	9,212	14,292
11	32.77	18.104	5,361	9,213	14,574
12	32.77	19.021	5,632	8,143	13,776
13	32.77	20.013	5,914	7,161	13,075
14	32.77	21.082	6,205	6,271	12,476
15	32.77	22.233	6,507	5,469	11,976
16	32.77	23.466	6,820	4,756	11,576
17	32.77	24.785	7,145	4,125	11,270
18	32.77	26.191	7,482	3,572	11,054
19	32.77	27.685	7,833	3,090	10,923
20	32.77	29.270	8,198	1,587	9,785
21	32.77	29.271	8,625		8,625
22	32.77	29.271	9,073		9,073
23	32.77	29.271	9,541		9,541
24	32.77	29.271	9,105		9,105
Total			143,115	127,615	270,730

7.2.2 Comparisons between Cases of the Special Models

The differences between the four cases of the special models are their assumptions and possible scenarios. The order of the cases also reflects the development the special models, from a simple one to a complex one. Each case gives different solutions from the others. The comparison of the results of the four cases is shown on Table 7.6.

Table 7.6 Comparison of the Assumptions and Results of All Four Cases

Case	Assumed price elasticity of demand		Price trends		Time when gypsum resource exhausted (T^*) (years)	Time when export ended (T_e^*) (years)	NPV of the total surplus (billion 2006 $)
	Domestic ($-b^d$)	From abroad ($-b^e$)	Domestic price (p_t)	Import price (p_t^{im})			
I	0		Assumed to follow Hotelling rule	Assumed to follow Hotelling rule	33.07	0	3.073
II	0		Assumed to be constant	Assumed to be constant	25.27	13.68	1.538
III	- 0.05		Assumed to follow Hotelling rule	Assumed to follow Hotelling rule	34.09	0	3.090
	- 0.1		Assumed to follow Hotelling rule	Assumed to follow Hotelling rule	35.69	0	3.109
IV	- 0.1	$[0, -\infty]$	Manipulated	Assumed to be constant	23.91	19.60	1.791

a) An Analysis of Case III and Case I

We can see from Table 7.6 that Case III with the price elasticity of demand of -0.1 gives the highest Net Present Value (NPV) of the total surplus. However, NPV cannot be the criterion to justify which case is the best because all cases have different assumptions. The assumption that net prices grow in accordance with Hotelling rule results in high NPVs for Case III and Case I. To adopt Case III or Case I, such an assumption should be, at least, highly probable or can be attainable by some means. But, past price data have not supported the working of Hotelling rule in the extraction of gypsum. Furthermore, if the price elasticity of the aggregate demand for gypsum is inelastic (b < 1) as assumed by this thesis, it can be proven below that a price rise in accordance with Hotelling rule cannot be attainable by market forces.

At a point on a demand curve, $d(PQ) = Qdp + pdQ$

where p is price, and Q is quantity.

Therefore,

$$d(PQ) = \frac{Q}{p} \bullet \frac{dp}{dQ} \bullet pdQ + pdQ$$

$$= -\frac{1}{b} \bullet pdQ + pdQ$$

$$= \left(1 - \frac{1}{b}\right) pdQ$$

Where $-b$ is the price elasticity of demand at such a point.

Then

$$\frac{d(pQ)}{dQ} = \left(1 - \frac{1}{b}\right) p$$

Since $b < 1$; therefore, $\left(1 - \frac{1}{b}\right) p < 0$

Hence

$$\frac{d(pQ)}{dQ} < 0$$

The above inequality means that the increase in the aggregate demand will result in the reduction of the aggregate revenue (pQ) earned by all producers combined. Therefore, to increase sales, the whole industry producing the mineral will earn less. A single producer in a competitive market may face a price elasticity of demand that is elastic ($b > 1$) and could enlarge its revenue by increasing its production and sale. Such a producer can maximize the NPV of the stream of net benefits from the extraction and sale of a mineral by following Hotelling rule. But such a producer can do so successfully only if few follow him/her. If every producer thinks and does the same, the above inequality tells us that he/she will get the reverse outcomes—losing money—because the enlarging aggregate supply will result in the reduction in the overall incomes of the whole industry producing a mineral. Instead, postponing the production and sale of a ton of the mineral now means an increase in the industry's revenues now. In addition, the sale of the postponed tonnage, sometime in the future, will add more to the present value of the overall revenues no matter what the future price and the discount rate are and when it will be sold. But at any time, if the price elasticity of demand is still inelastic the condition favoring the postponement of the production and the sale of such a ton of the mineral remains unchanged, disregarding any positive discount rates. In effect, even if the aim of the industry is to maximize the NPV of its revenues, the discount rate has no role in deciding the rates of extraction of a mineral in the case that the price elasticity of demand for the mineral is inelastic. Without the involvement of a discount rate, Hotelling rule is irrelevant. This means that a monopoly or a collective action of all miners cannot achieve the maximum NPV of their streams of net benefits from the extractions and sales of a mineral by following Hotelling rule. Therefore, there will be no monopolistic or collective action to follow Hotelling rule. As a result, the price of a mineral has no chance to rise in accordance with Hotelling rule by market forces if the price elasticity of demand of the mineral is inelastic. Of course, this analysis is valid only if all parts of the demand curve are totally inelastic. If the price elasticity of demand is elastic, the above inequality tells us that producing and selling a ton of the mineral now renders additional revenue. In such a case, Hotelling rule is logically valid. Except a vertical line, all linear demand curves, no matter how steep their slopes are, always have sections that are elastic. Therefore, this analysis does not totally invalidate the Hotelling rule. The analysis will not change when cost is taken into account. Therefore, it can be said that the price inelasticity of demand for minerals may be the critical culprit that fails Hotelling rule in the real world since the price elasticities of the demands for most minerals are supposedly inelastic.

As a result, Case III and Case I should be discarded. Indeed, they were presented in Chapter 6 just to see the effects of price rises and the price elasticity of demand on the optimal extraction paths.

b) Advantages and Disadvantages of Case II and Case IV

With regard to Case II and Case IV, they assume that the world gypsum price is constant over time. Case II also treats the domestic price as a constant, while Case IV allows the domestic price to be manipulated by some means. As already discussed, constant prices of gypsum are, more or less, close to reality. Other minor differences between the two are the assumption about price elasticities of demands for gypsum. Case II assumes zero price elasticity of domestic demand and the demand from abroad. This assumption is supported by the study of Chapter 5 and other studies on mineral demands. Therefore, Case II, though a simple case, is close to reality if authorities do not intervene in prices.

Case IV assumes a small price elasticity of domestic demand, while the price elasticity of demand from abroad is determined under two assumptions that 1) the world gypsum price is constant, and 2) countries will buy gypsum from Thailand if the gypsum price realized by them is cheaper than that of the Thailand's competitor. The first assumption is evidenced by past price data, while the second assumption is logical. Therefore, the scenario of Case IV can be realized if price manipulation can be done effectively by some means.

Advantages of Case II

1) It is a realistic case;
2) It allows market forces to play before the enforcement of export prohibition;
3) The case is simple and therefore easy to monitor, and to make readjustment;

4) It is easy for the Thai government to enforce since the current mining law has already empowered the government to prohibit the export of a mineral; and
5) In comparison with Case IV, the NPV of the total surplus of this case is not much lower than that of Case IV.

Disadvantages of Case II

1) It does not give the highest NPV of the total surplus to Thailand; and
2) It may against World Trade Organization (WTO) agreements, of which Thailand is a member.

Advantage of Case IV

1) It is a realistic case if the domestic gypsum price can be manipulated effectively;
2) Export prohibition is not necessary; and
3) It gives the highest NPV of the total surplus to Thailand;

Disadvantages of Case IV

1) It is a complicated model and therefore requires a lot of works to monitor, and to make readjustment;
2) It requires heavy intervention and close monitoring of the government;
3) Price fixing is really a difficult matter;
4) A further study to reconfirm or dispute the assumption of a small price elasticity of demand for gypsum;
5) Legislation is needed in order to enforce price intervention; and
6) Prices intervention by the authority may against World Trade Organization (WTO) agreements, of which Thailand is a member.

Case II and Case IV are both high probable scenarios and have both advantages and disadvantages. To choose which case to pursue, consultation among stakeholders may be necessary before a decision is made.

Chapter 8 Conclusions and Recommendations

The conclusions of this thesis and the recommendations for the Thai government on its gypsum resource are as follows.

8.1 Conclusions

Since the aim of the thesis is to propose a strategy involving the administration of a construction mineral resource, the thesis is begun by giving a preview of the situation of the construction minerals in Thailand and some of their problems in Chapter 1. It points out that the peculiar uniqueness of Thailand's gypsum resource for Thailand is the major source of gypsum supply in the regions of east, south-east and south Asia with almost no rivals. Thailand's closest competitor in the region is Australia. As a cheap and bulky commodity, transportation costs constitute a large proportion of gypsum prices paid by users. Therefore, Thailand should have a big influence in setting the gypsum price in the region. In reality, Thai gypsum producers have had almost no power in dictating the gypsum price because of the intense competition by price-cutting among themselves.

Briefs of mining laws, taxation, and policies of Canada, Australia, Brazil, as well as those of Thailand are presented in Chapter 2 for readers to understand how countries administrate their mineral resources. The four countries manage their mineral resources similarly and they treat their mining industries as special businesses that need tight control and to be taxed extraordinarily. All support their mining industry at least by supplying potential investors with geoscience data and other useful information to private investors. They also attempt to solve environmental and social problems resulting from mining, such as land use conflicts, pollution, abandoned mined out areas, similarly.

A phenomenon, called the "resource curse" is presented in Chapter 3 together with an investigation on Thailand's experience of the phenomenon. The phenomenon is based on empirical studies of many scholars that found resource rich countries appeared to have experienced worse economic performance than resource poor countries. It sounds as though the possession of wealthy natural resources is a curse not a gift. These scholars attributed the resource curse to the effects of long term decline in terms of trade, revenue volatility, undesirable structural economic change, and socio-cultural and political impacts resulted from the sudden and easy wealth of the government and some of its people. However, a few resource-rich countries—notably, Botswana, Chile, Malaysia, and Thailand—appeared to overcome the resource curse. In the case of Thailand, before 1985, it showed some symptoms as if it was under the curse—export revenue fluctuation and decline in terms of trade. Thailand fought such dire problems by implementing prudent and conservative economic policies and being open to foreign investment. The influx of foreign direct investment might be the most important factor in overcoming the recourse curse. Foreign investors have been attracted by Thailand because of its rather stable internal politics, strong elite bureaucrats, and cultural homogeneity. Regional events, such as the Vietnam War, also helped Thailand economically. Though, at present, the resource curse does not seem to be a problem for Thailand, as a developing country, it should not yet low down its guard against the curse.

Exploitation of mineral resources affects the environment and results in their depletion. There has been fear that the present wellbeing of humanity is gained at the expense of the future. The principle and concept of sustainable development are presented in Chapter 4, as it should be an aim for Thailand to attain sustainable development in its exploitation of its gypsum resources. It should at least follow

Hartwick rule. Hartwick (1977, 1978) proposed a rule, now known as Hartwick rule, stating that a constant level of consumption can be sustained if all the rents on non-renewable resources extracted at each point in time are totally invested in reproducible capital. However, Hartwick rule is just a necessary but not sufficient condition. Other three necessary conditions are: 1) an economy has to be already on a sustainable path, 2) the resource extraction path must be efficient in a competitive economy, and 3) the economy's production technology is right (Perman *et al*., 2003).

Another approach to the economic definitions of sustainable development is based on the means to provide people with welfare, such as the one that the total capital stock is non-declining through time. Indeed, to maintain non-declining total capital, Hartwick rule is also needed to follow if the exploitation of non-renewable resources is involved. The non-declining through time of the total capital stock is also called the weak sustainability approach, which is based on the assumption of perfect substitution between natural capital and human-made capitals (comprising manufactured capital, human capital, social capital, and financial capital). In the views of proponents of the "weak" concept of sustainable development, intergenerational equity will be satisfied as long as exploration and technological progress offset the depletion and degradation of mineral resources (Eggert, 2000). It is debatable whether these views are too optimistic. However, a country can always supplant its depleted mineral resources by import. Therefore, the finite quantity of minerals within its boundary is not necessarily a barrier to economic development of a country.

The weak sustainability approach was the basis in formulating the sustainable development indicators to measure and monitor the sustainable development of a country. Six proposed indicators for sustainable development, comprising Genuine Savings (GS), Green Net National Product (GNNP), augmented GS, augmented GNNP, UN Commission on Sustainable Development (CSD) Indicators of Sustainable Development, and World Bank World Development Indicators, are briefed in Chapter 4. In addition, numerical studies to see how well Thailand fared in sustainable development are presented. It is found that, for Thailand, different indicators provide different answers. GS and augmented GS show that the development of Thailand during the period of study, between 1993 and 2004, was sustainable. On the other hand, the development of Thailand was unsustainable sometime during the period when GNNP, augmented GNNP, or the sustainable development composite index were used as indicators. Therefore, it is still unclear whether the development of Thailand has achieved sustainability or not. Noted that the green and augmentation terms had a small effect on NNP of Thailand; therefore, its sustainable development depended almost entirely on the conventional NNP.

The quantitative and major analyses of this thesis, which aims to propose strategies for maximizing the social benefit from the exploitation of Thailand's gypsum mineral resource, are presented in Chapters 5 and 6. In Chapter 6 the economic models based on Hotelling's concept are developed to determine the optimal depletion of Thailand's gypsum resource. However, the models of Chapter 6 require the gypsum consumption or demand functions of countries that consumed Thailand's gypsum. Therefore, a model determining gypsum consumption in Thailand and some countries that import gypsum from Thailand is developed in Chapter 5. Because of the very small and incomplete data, the demand equations of the model are very simple and the model should be treated as a very rough method of approximation.

The analysis of Chapter 5 did not find a significant relationship between the gypsum price and its consumption. These results conform to other empirical studies on demands for minerals and metals. Many studies (eleven in all) on the demands for metals either outright discarded price factors or found the price elasticities of the demands for metals were close to zero or very small. The analysis of Chapter 5 also reaffirms those studies that the consumption of a mineral is strongly influenced by consumer income. This means that a change in mineral consumption is the result of a shift in the demand function due to a change in consumer income, consumer taste, technology, etc.

In Chapter 6, the economic models, based on the concept of maximizing Net Present Value (NPV) of resource rents accrued to a society from the exploitation of a mineral resource, are formulated. The optimal extraction path of Thailand's gypsum mineral resources is essentially the first step for Thailand to attain sustainable development in the exploitation of its gypsum resources. The further step is for Thailand to reinvest the generated resource rent in accordance with the Hartwick's rule.

The economic models created are under the presumption that the benefits are represented by the total economic welfare and the society covers just gypsum producers and consumers within Thailand's boundary. Under some assumptions a practical general model is formulated. The initial maximizing function of the general model is the function maximizing the discounted flow of the sum of the producer surplus, or the resource rents of gypsum mining industry, from the present to the time the gypsum resource in Thailand is depleted, and the consumer surplus from consuming gypsum from the present to infinity. From the general model, it is found that the real domestic price movement insignificantly affects the net social benefit (net consumer surplus + producer surplus) generated by the gypsum production for domestic consumption, if the absolute value of price elasticity of demand for gypsum is very small. But the higher the level of the expected import price, the bigger the net social benefit generated by the gypsum production for domestic consumption.

However, the general model still consists of some parameters that can be determined with difficulty. To solve this shortcoming, Chapter 6 presents four cases—Case I, Case II, Case III, and Case IV—of special models with some assumed parameters and scenarios together with their empirical solutions. Case I and Case III are based on a strong assumption that the net prices of gypsum both domestic and from abroad grow in accordance with Hotelling rule. In Case II, it is assumed that the prices of both domestic gypsum and gypsum from abroad are fixed. Case IV is also under an assumption that world gypsum price is constant overtime but domestic price is manipulated by some means to obtain the maximum discounted flow of the sum of the total surplus. Conclusively, all cases found that the export of gypsum is not always good to Thailand. All solutions suggest that at some point in time before all gypsum resources are depleted—ranging from immediately as in Case I and Case III to 19.60 years from now as in Case IV—Thailand should stop export of mineral gypsum.

Overall discussions and a discussion on the empirical solutions of the special models of Chapter 6 are presented in Chapter 7. The overall discussions were done chapter by chapter. This thesis finds that land use conflicts, pollution, and environmental damage caused by mining have become social issues in all four countries—Canada, Australia, Brazil, and Thailand—that their mining laws, taxation, and policies were studied. As a result, in the case of Thailand, now it is difficult and takes time for a mining investor to obtain a mining lease, as he or she has to entangle with several bureaucratic agencies. It is fair to say that Thailand at present adopts a system of check and balance in trying to curb the adverse effects from mining. The era of full mining promotion without questions in Thailand has been literally closed.

With regard to the "resource curse" phenomenon, some of its effects may be real. But the curse is just a factor among many others that affect a county's development both in good and bad ways. The question for a country is not whether or not to exploit the country's rich natural resources, but how to mitigate the effect of the resource curse.

Sustainable development, its indicators, and the computed indicators for sustainable development inThailand were also discussed in Chapter 7. It found that, from 1993 to 2007, Thailand fulfilled the requirement of Hartwick rule as its government had budgeted for the capital expenditures (expenses on equipments, land, buildings and related expenses) in excess of the Gross Domestic Products (GDPs) originated from mining and quarrying sector in every year. But, it was unclear whether the development of Thailand had achieved sustainability or not because when applying Genuine Savings (GS), augmented GS, Green Net National Product (GNNP), augmented GNNP and sustainable development composite index to Thailand, they provided different answers. Furthermore, the economy's production technology is unknown.

The reasons why the consumption of a mineral is strongly influenced by consumer income but insignificantly affected by the mineral price and the solutions of the adopted general consumption models of Chapter 5 together with those of many other studies in the field of minerals are also discussed in Chapter 7. This thesis speculates that it may be because the costs (or prices) of mineral raw materials constitute only fractions of the prices of consumer goods. Therefore, a reasonable movement of a mineral price affects the prices of consumer goods very little, and, as a result, the consumption of consumer goods and its mineral raw materials will not change much. Moreover, in most cases, industrial plants cannot promptly switch over to new substitute raw materials without heavy reinvestment and time for retooling. This thesis also concludes that a change in mineral consumption is the result of a shift in the demand function due to a change in consumer income, consumer taste, technology, etc.

The assumptions of a general model and the assumptions and empirical solutions of the special models of Chapter 6 are also discussed in Chapter 7. Assumptions are necessary because some parameters are difficult to determine and it is the intention of this thesis to put presently available theories into practice in real complex world rather than proposing a new theory. With regard to the assumption about the extraction costs of minerals of the special models, it should be noted that the belief that the marginal cost of extracting minerals increases when the stocks of minerals get smaller has not been evidenced over time. Exactly the opposite is more common as evidenced by the decreasing trends of the mineral prices despite the increase in the consumption of the minerals.

Concerning the comparison between cases of the special models, this thesis recommends discarding Case I and Case III, in which the net prices of gypsum are assumed to grow in accordance with Hotelling rule. This thesis has proven, at Subsection 7.2.2 of Chapter 7, that if the price elasticity of the aggregate demand for gypsum is inelastic, a monopoly or collusion among all mining companies cannot achieve the maximum NPV of their streams of net benefits by following Hotelling rule. Therefore, a price rise in accordance with Hotelling rule cannot be attainable by market forces. The supposed price inelasticity of demand for minerals may be the critical culprit that fails Hotelling rule in real world.

The remaining Case II and Case IV are both highly probable scenarios. Both cases assume that the world gypsum price is constant over time. Case II also treats the domestic price as a constant. Constant prices of gypsum are, more or less, close to reality. But in Case IV the domestic price is manipulated by some empowered means.

The major advantages of Case II are as follows: it is simple; it is easy for the Thai government to enforce; and it requires no new legislation. But Case II has the disadvantages of rendering a smaller NPV of the total surplus to Thailand, and being possibly against the WTO agreements in enforcing export prohibition. Case IV has the major advantages of rendering the highest NPV of the total surplus to Thailand and requiring no declaration of export prohibition. The disadvantages of Case IV are as follows: it requires heavy intervention and close monitoring of the authority; legislation is needed in order to effectively enforce price intervention; and it may be against the WTO agreements in enforcing price intervention. Conclusively, Case II and Case IV have both advantages and disadvantages. Therefore, to choose which case to pursue, consultation among stakeholders may be necessary before a decision is made.

8.2 Recommendations for the Thai Government on Gypsum

Thailand should aim to attain sustainable development with regard to the exploitation of its mineral resources. Therefore, in the case of gypsum, the resource extraction path of gypsum must be, at least, efficient besides obeying Hartwick rule. The possible optimal resource extraction paths of Thailand's gypsum are formulated, as Case I, Case II, Case III, and Case IV, in Chapter 6. Thailand must select and follow the best suitable case, in addition to adopting Hartwick rule and taking actions to avoid resource curse, which will be proposed in the next section.

In short, the models in Chapter 6 demonstrate that Thailand will gain better intertemporal social benefit by doing two things as follows:

i) Ending export of gypsum some time before the total gypsum resource of Thailand is exhausted, and

ii) Raising gypsum prices up to the level close to the expected import price.

8.2.1 A Plan for Ending Export of Gypsum

The conclusive empirical results of all cases of Chapter 6 suggest that, for Thailand to obtain a better total social benefit, represented by the total economic welfare (also called social surplus or total surplus), its export of gypsum should be ended some time before the total gypsum resource of Thailand is exhausted. This is because all gypsum production, both for domestic consumption and export, renders producer surplus to Thailand, but only gypsum consumed in the country offers consumer surplus to the country. With a positive consumer surplus, the production of gypsum mineral for export gives less net benefit to Thailand than the production of gypsum for domestic consumption. As a result, at least near the time that the total gypsum resource of Thailand is exhausted, the country should be economically better off if all remaining gypsum in the ground is allocated for domestic consumption only. However, the optimal results of all cases of Chapter 6 cannot be attained without government intervention because the social benefit, the sum of producer surplus and consumer surplus, is not the same as private benefit, producer surplus only, of private gypsum producers. For producers, there is no difference between selling their product for domestic consumption and selling their product for export. Besides, in the past when the gypsum producers were left to interact among themselves and their clients in a competitive world, they resort to competition by price cutting.

Among the cases of Chapter 6, historic data of mineral prices incline to discount the scenarios of Case I and Case III, which are based on the assumption that the minerals world follows Hotelling's rule. Therefore, this thesis will not recommend Thailand to cease export of gypsum immediately. The objective of this thesis in presenting Case I and Case III are just to test the outcome of a theory and to demonstrate the extreme possible cases.

Though its results depend on many assumed data, Case IV, which allows export of gypsum to continue for 19.60 years, is the most interesting model that Thailand should follow if it can force the domestic gypsum price up at will. Expression 6.36 of Chapter 6 shows that gypsum price movement in Thailand below an expected import price level has minimal effect on the country's total social welfare accrued from the production of mineral gypsum for domestic consumption. Therefore, while export is allowed, Thailand will gain a better total discounted net social benefit if the gypsum price within the country is elevated in accordance with the solution of Case IV. The additional gain is obviously from the higher export value. However, this has to be done by some measures of market intervention by the Government. The second best model for the Government to follow is that of Case II. Under this case gypsum producers are allowed to freely trade in the international competitive gypsum market for 13.68 years.

Since an abrupt end to exporting gypsum is not a recommended option and the next possible critical time is 13.68 years from now, the Thai government has ample time to plan, adjust and readjust a selected model, and to refine important parameters. The recommended plan for ending export of gypsum is as follows:

a) Discuss the political and legal feasibility of raising gypsum price in accordance with the solution of Case IV. Ways to raise gypsum price will be presented later. Decision to raise gypsum price should be made as soon as possible because the earlier the price is raised the greater the net social benefit accrued to Thailand. If gypsum prices can be raised in accordance with the solution of Case IV, there will not be a need to implement export prohibition because the high gypsum prices of the solution of Model IV will automatically force Thai gypsum out of the international market. In this case, the process to enact export prohibition should stop. But even if it is infeasible to totally follow the optimal price trend of Case IV, the Thai government should not relinquish an attempt to raise the gypsum price. Equation 6.36 of Chapter 6 shows that the higher the domestic price the greater the total social benefit accrued to Thailand.

b) Start the legislation process if raising gypsum price is politically feasible but the chosen way to raise gypsum price has no laws to implement.

c) Conduct exploration to ascertain the correct total reserve of mineral gypsum in Thailand because it affects the time when the export of gypsum should be stopped.

d) Conduct research to refine the parameters of the chosen model—Case IV or Case II—and, especially, the consumption functions because of their dynamic nature and their effects on the model solutions. The parameters and the model should be updated regularly.

e) In the case that it is infeasible to raise gypsum prices in accordance with the solution of Case IV, pronounce the policy to stop export of gypsum clearly and firmly to let producers, exporters, and foreign clients know in advance as early as possible or at least five years before the export prohibition date.

f) Finally, prepare to implement export prohibition when the time is near.

8.2.2 Methods and Plans for Raising Gypsum Price

As stated in the "Conclusion" and mentioned in topic 8.2.1 section a) above, the Thai government should attempt to raise gypsum price to increase the Net Present Value of social benefit accrued to Thailand. Government intervention can raise gypsum price using two approaches:

a) Pushing up costs by taxation, and

b) Organizing collusion between exporters or monopolizing export.

a) Taxation Approach

Taxes are costs which will cause the price to increase, as shown in Figure 8.1. In Figure 8.1, before imposing an extra tax, the equilibrium price and quantity are p_t^b and Q_t^b, respectively. After an extra tax is imposed at the rate of α per unit of Q_t , the price paid by consumers is p_t^d , the price received by producers is p_t^s, and the quantity of gypsum produced after imposing an extra tax is Q_t^a. Hence,

$$p_t^d - p_t^s = \alpha$$

The revenue from the extra tax is equal to $(p_t^d - p_t^s)Q_t^a$. In the case that price elasticity of demand for gypsum is not perfectly inelastic the extra tax shall be borne by both consumers and producers. The amounts of extra tax paid by consumers and producers are $(p_t^d - p_t^b)Q_t^a$ and $(p_t^b - p_t^s)Q_t^a$, respectively. It should be noted that in case of inelastic demand the amount of extra tax paid by consumers is larger than that paid by producers and the deadweight loss (shown in Figure 8.1 as the dark shaded area) is small. It means that after imposing an extra tax, the Thai government can collect a large part of the extra tax from consumers, but the Thai gypsum producers also bear a small part of the extra tax. However, in the case that price elasticity of demand for gypsum is perfectly inelastic (see Figure 8.1 (b)), the extra tax revenue, p_t^d times Q_t^a , shall be totally borne by consumers with no deadweight loss, and the Thai gypsum producers do not bear any extra tax burden at all.

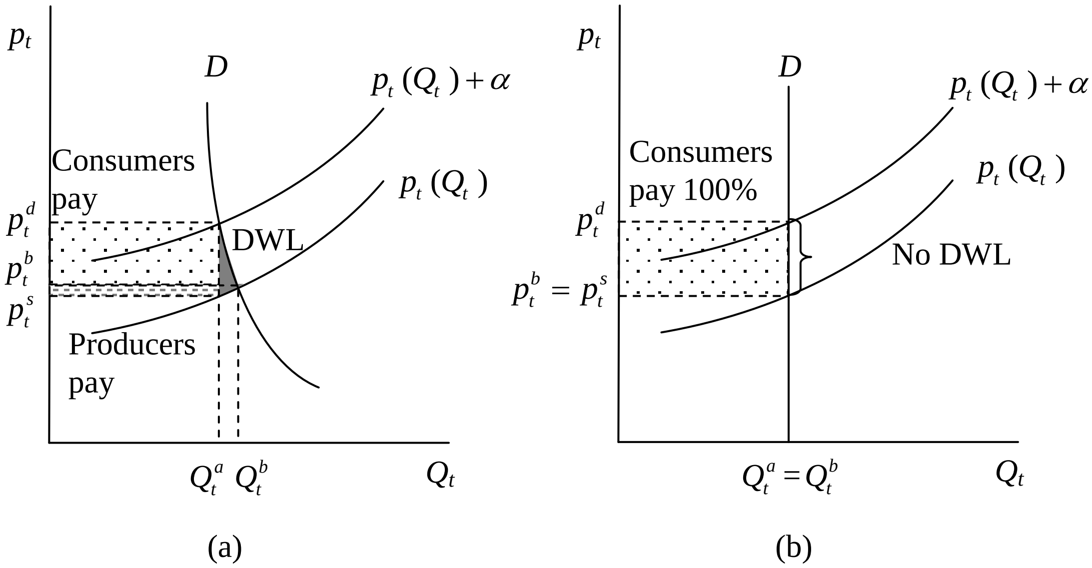

Figure 8.1 The Effect of an Extra Tax with Price Elasticity of Demand: (a) Inelastic, and (b) Perfectly Inelastic

Source: Binger and Hoffman (1998)

Raising gypsum price by imposing an extra tax has an advantage of transferring a major economic rent resulting from the rising price to the government. It will certainly be opposed by exporters, who appear to bear the burden of the extra tax. However, in actual fact, as demonstrated above, because the price elasticity of demand for gypsum is highly inelastic, the main burden of the extra tax is transferred to consumers. Since the major use of gypsum is in construction, the largest final consumers are people who buy, build or repair homes. This group of people is mostly the middle class. House or apartment renters also pay indirectly, in the form of rent payment, for higher cost of construction. Furthermore, the analysis in Chapter 5 found that gypsum is an inferior good in Japan. Therefore, unfortunately, the consumers who bear the slight burden of extra tax are mostly the middle class and the poor.

It should be noted that if it is politically feasible to increase price in accordance with the solution of Model IV, the taxation approach has another advantage of rendering export prohibition unnecessary because the increased price will automatically force Thai gypsum out of the international gypsum market. Extra tax can be levied in the following forms:

i) Export Duty

Imposing export duty has an advantage of direct influence on the export price. Domestic consumers will not oppose it since it does not affect domestic price. However, at present mineral gypsum is not on the list of goods required to pay export duty. Parliamentary legislation is needed to include it and the rate of levy on the list. This legislation requirement is really the disadvantage of imposing export duty.

ii) Mineral Royalty

Mineral royalty is an ad valorem tax imposed by the government on the sale of minerals. For mineral gypsum, the royalty rate at present is four per cent, and it is applied to gypsum produced for both export and domestic consumption. A ministerial regulation, which needs just a cabinet approval, is required to increase a mineral royalty rate. That is an advantage over an attempt to impose export duty. The maximum that it can be increased is twenty per cent, as stated in the Mineral Royalty Rates Act, B.E. 2509 (1966). However, to follow the solution of Case IV requires the price to increase by about twenty-four per cent immediately, and to be more than double the present price twenty years from now. Hence, the present law is not a complete instrument that can be implemented once and for all. It needs parliamentary actions to revise the Act, anyway. A disadvantage of raising mineral royalty is its effect on domestic gypsum users. Gypsum users together with gypsum producers will certainly protest, though they actually can pass on the burden of the additional mineral royalty to consumers. In spite of that fact, its easiness and quickness to implement makes it suitable as an instrument of first choice, at least temporarily.

iii) Environmental Tax

Mining in general causes unavoidable environmental damage and creates pollution such as dust, contaminated water, noise, and vibration. Therefore, it is fair to a society if the Pollution Pay Principle (PPP) is adopted, especially in case of gypsum production and consumption, which will not be much affected by some price increment. At present there is not really an environmental tax system in Thailand. It is well worth establishing one and immediately applying it to the production of gypsum, so that all hidden environmental costs will be included in the gypsum production cost.

iv) Plans for the Taxation Approach

If the taxation approach is adopted either as a sole instrument or as an additional instrument to other approaches, the following plan of actions is recommended.

- The royalty rate of gypsum should be increased as high as possible, under the constraint of the present Mineral Royalty Rates Act, and as soon as possible;
- Discuss and select which tax or taxes are to be amended so that gypsum prices can be raised to reach the optimal point, and then, initiate the legislation process;
- Conduct exploration to ascertain the correct total reserve of mineral gypsum in Thailand;
- Conduct research to refine the parameters of the chosen model and the consumption functions; and

- Levy the tax or taxes in accordance with the refined model.

b) Monopolization Approach

A monopoly always sets the price of its product higher than the price at which it could sell in a competitive market. Therefore, the gypsum price can be raised to a certain degree by monopolizing the export of Thai gypsum. Such a monopoly, which will be authorized to be the sole exporter of Thai gypsum, can be formed as: 1) a state enterprise with the aim to serve the public, or 2) a private enterprise. In any forms, legislation is needed to authorize a monopoly in export of the commodity.

i) State Enterprise

A state enterprise as the sole gypsum exporter will serve the purposes of increasing export prices and looking after the public interest. A state enterprise can be set up by legislation. Thailand used to have state enterprises in the mining industry. However, past experience did not support the establishment one for most state enterprises have been inefficient, prone to corruption, and often interfered with by politicians. Most of all, the present economic and political trend makes the establishment of a state enterprise rather difficult and it will certainly be opposed by present gypsum exporters.

ii) Private Monopoly

If the monopoly is owned by the private sector, it will not act in accordance with the solution of Case IV because private benefit is not the same as social benefit. A private monopoly will give Thailand better total social benefit than the present free market approach, but it needs a supplement of the taxation approach to get the optimal result. To reduce opposition, private monopoly can be formed by letting the present gypsum stakeholders become the shareholders of the monopolistic central gypsum exporting company in accordance with their present sizes of interests.

iii) Plans for Monopolization Approach

If a monopolization approach is chosen, the following plans are recommended.

- The royalty rate of gypsum should be increased as high as possible, under the constraint of the present Mineral Royalty Rates Act, and as soon as possible. The action is recommended because it takes time to establish a monopoly.
- Discuss and choose the form of monopoly. If the private form is chosen, a decision is also needed on whether to supplement it with the taxation approach.
- Start the legislation process to authorize a sole exporter of gypsum and also to set up a state enterprise if it is chosen. In the case that a private form of monopoly is chosen, the supplemental taxation approach in topic 8.2.2 section a) part iv) should be considered.
- Organize and let the monopoly operate.
- Conduct exploration to ascertain the correct total reserve of mineral gypsum in Thailand for guiding the monopoly based on accurate data.
- Conduct research to refine the parameters of the chosen model and the consumption functions for guiding the monopoly.

8.3 Recommendation for the Thai Government with Regard to Hartwick Rule and Resource Curse

8.3.1 Obeying Hartwick Rule

To have a chance to attain sustainable development in the exploitation of its mineral resources, Thailand has to obey the Hartwick rule, which states that a constant level of consumption can be sustained if all the rents on non-renewable resources extracted at each point in time are totally invested in reproducible capital. However, Thailand has committed to develop its mineral resources through the private sector and the government has only limited means to capture the resource rents. Therefore, direct reinvestments of the resource rents are in the hands and the will of the private sector. But it is the duties of a government to build infrastructure and support education and research, whether or not non-renewable resources are exploited. Infrastructure is manufactured capital while the expenditure on education and research is an investment in human capital. Therefore, a government can circumvent the problem of privately owned resource rent by allotting annual budgets to capital investment, education and research large enough to cover the total resource rent earned from the extraction of the country's non-renewable resources in each year. As already discussed in the sub-section 7.1.4 of Chapter 7, the government of Thailand has done so. The recommendation of this thesis is for the government to maintain the present budgeting practice. Expenditures on capital investment, education and research must always exceed the GDP originated from mining and quarrying sector.

8.3.2 Avoiding Resource Curse

As stated at the conclusion of Chapter 3 and other places in this thesis that Thailand has steered itself through the resource curse successfully. With their small contribution to the national economy now, non-renewable resources in Thailand could not invoke another round of the resource curse. However, Thailand has not been economically well developed and there is always a slim chance that Thailand will discover economically large deposits or sources of non-renewable resources. It is still possible that Thailand might depend on non-renewable resources again. Therefore, Thailand should not low down its guard against the curse. In case that it discovers a very rich deposit of a non-renewable resource, Thailand should do as follows:

a) Gradual Exploitation

The slower the development of mining projects, the greater the chance the economy and society have to adjust to the inflow of revenue. Different forms of extractive agreements—concession based on royalty and taxes, joint ventures, production sharing agreements, service agreement etc—will create different patterns of revenue flow.

b) Sterilization of Revenue

Sterilization of resource revenue is to neutralize the impact of the large windfall revenue inflow on the rest of economy. Ideally, a government should resist spending pressures and either to accumulate budget surpluses or to channel the revenues into some form of fund to be spent appropriately later. If Thailand is in danger of the resource curse because it is about to develop a new rich mineral deposit, it may follow the way Norway, Chile and Indonesia has done by establishing a revenue fund. The fund, to which all revenues from such a rich mineral resource have accrued, should be used not only by the current generation but also by future generations. The fund should also aim to serve as a buffer between current mineral revenues and the use of these revenues in the Thai economy. Thus the domestic economy is shielded from fluctuations in prices and extraction rates in the non-renewable resource sector.

Withdrawal from the fund might be capped by a fixed small percentage of the fund or the expected real return on the fund. Indeed, putting all revenues from a rich mineral resource into a fund, which is a financial capital, partly fulfils Hartwick rule if the government has good effective means to capture almost all of the resource rents. Therefore, avoiding resource curse is nearly the same as attempting to attain sustainable development.

8.4 Summary

8.4.1 Main Messages

The main messages of this thesis are as follows:

a) Economic tools involving Hotelling's concept, consumer surplus and producer surplus can be applied to justify a policy of a specific mineral.

b) The Hotelling's concept of maximizing Net Present Value (NPV) of resource rents accrued to a society is rational, but it is debatable whether the Hotelling's rule works in the real world. Among the culprits that cause the Hotelling's rule to fail may be the apparent price inelasticity of demand for minerals and the non-increasing cost of extracting deeper and poorer minerals due to the fast progress of mining technology.

c) The effects of a country boundary make export of a mineral of finite reserves less important than domestic consumption. If the Hotelling's concept is accepted, near the time of exhaustion of that mineral stock, it is economically favourable to stop export of such mineral.

d) Thailand is in a unique position as the only major supplier of mineral gypsum in the region of Far East Asia. To gain a better net social benefit in according to the Hotelling's concept, the government of Thailand should not allow Thai gypsum exporters to freely compete for limited foreign demand and should prepare to enforce a measure to stop the export of gypsum some time before all its gypsum reserves are exhausted.

8.4.2 Further Studies

Some further studies suggested by this author are as follows:

a) Academically, the price elasticity of demand for a mineral should be further studied to prove or disprove that it is really highly inelastic.

b) The government of Thailand should sponsor a complete study about the demand for gypsum that takes into account the whole relevant variables including synthetic gypsum production and prices.

c) A full research determining GS, augmented GS, GNNP, and augmented GNNP of Thailand that cover all natural resources and pollution as much as possible should be done.

d) Academically, the linkage between Genuine Saving and Green Net National Product as proposed by Pezzey and Toman (2002) that the time derivative of augmented GNNP is always the interest rate times augmented GS should be further analysed. This suggestion stems from fact that there was a very significant mismatch between the hypothesis and the empirical study done on Scotland by Pezzey *et al.* (2006) and on Thailand in this thesis.

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Appendix A The Estimation of User Cost

Atkinson and Hamilton (2007) stated that (i) asset values should be measured as the present value of economic profits over the life of the resource; and (ii) asset depreciation should be measured as the user cost. The user cost is defined as the change in asset value associated with mineral extraction over the accounting period.

For extraction, extraction costs $c(q_i)$ and constant discount rate r, the value of subsoil assets, in the form of minerals and mineral fuels, that will be exploited to exhaustion over $N + 1$ years should be the present value of the sequence of profits,

$$V_t = \sum_{i=0}^{N} \frac{p_i q_i - c(q_i)}{(1+r)^i} \tag{A1}$$

Let S_t be the total stock. Then, $S_t = \sum_{i=0}^{N} q_i$

The user cost, UC_t, is measured by

$$UC_t = V_t - V_{t-1} \tag{A2}$$

Observing from the equations A1 and A2, to calculate user cost requires the forecast of both prices and quantities. A number of solutions to this problem are shown in Table A.1.

Table A.1 Alternative Measures of Resource Depletion (User Cost)

Method	**Formula**	**Assumptions**
Total rent	$pq_t - \bar{c}q_t$	Constant unit extraction cost $\bar{c}$, Hotelling rule: $\dot{p}/(p - \bar{c}) = r$
Marginal rent	$pq_t - c'(q_t)q_t$	Constant price, increasing marginal extraction cost, Hotelling rule
Exhaustion	$\frac{pq_t}{(1+r)^N}$	Constant price, increasing marginal extraction cost, Hotelling rule
Simple PV	$\frac{pq - c}{(1+r)^N}$	Constant total rent
Quasi-optimal	$\frac{\varepsilon(pq - c)}{1 + (\varepsilon - 1)(1+r)^N}$	Constant price, isoelastic cost function with increasing marginal costs, 'near-optimal' path for extraction and marginal rents

Source: Atkinson and Hamilton (2007)

The first three approaches, total rent, marginal rent and exhaustion, need the assumptions of optimality. In other words, these approaches provide correct measurement when the extraction path is optimal.

For the total rent approach, the assumptions are that marginal extraction costs are fixed at $\bar{c}$ and a rising resource price satisfying the equation: $\dot{p}_t/(p_t - \bar{c}) = r$, in accordance to the Hotelling rule. In this case, the user costs are equal to total rents. Therefore,

$$UC_t = pq_t - \bar{c}q_t \tag{A3}$$

The marginal rent approach is under the assumptions that resource prices are constant, while marginal extraction costs are increasing. According to the Hotelling rule, the user costs are equal to the scarcity (or marginal) rent, as expressed by the following equation:

$$UC_t = pq_t - c'(q_t)q_t \tag{A4}$$

For the exhaustion approach, the assumptions of constant resource prices, increasing marginal extraction cost, and the effectiveness of the Hotelling rule are also applied. In addition, it has to conform to the exhaustion condition for the optimal extraction path, which states that:

$$[p - c'(q_t)](1+r)^N = p$$

where N is the number of years until resource is exhausted. Then the user cost can be calculated as follows:

$$UC_t = \frac{pq_t}{(1+r)^N} \tag{A5}$$

The fourth method in Table A.1, the simple present value approach, as proposed by El Serafy (1989) requires no optimization of the extraction path. The approach assumes that the total rents in each period are constant at level $pq - c$. In this case, therefore, the user costs can be calculated as:

$$UC_t = \frac{pq - c}{(1+r)^N} \tag{A6}$$

The fifth method in Table A.1, quasi-optimal approach, as proposed by Vincent (1997) offering a compromise valuation by additionally assuming that the extraction cost function is isoelastic with increasing marginal cost defined by: $c(q) = \frac{a}{\varepsilon} q^{\varepsilon}$ for $a > 0$ and elasticity $\varepsilon > 1$. Therefore, the marginal extraction cost is $c'(q) = \varepsilon c / q$, where c/q is the average extraction cost. The approach is termed 'quasi-optimal' because it combines the constant price assumption, the Hotelling rule and the exhaustion condition together. It follows that

$$(p - \varepsilon c / q)(1+r)^N = p$$

Then the user cost is measured as

$$UC_t = \frac{\varepsilon(pq - c)}{1 + (\varepsilon - 1)(1+r)^N} \tag{A7}$$

Since Vincent defined N to be the reserves-to-production ratio, the approach understates the reserve lifetime and, hence, overstates the user cost.

The estimated user costs for oils of the 21 oil-producing countries by the five above-mentioned methods are shown in Table A.2. To compare the user cost figures resulting from these five methods, one should be reminded of their drawbacks. The total rent approach, which requires a rising resource price path, runs counter to the fact that real prices of resources are flat or slightly declining. The marginal rent and exhaustion approaches, which requires the optimal extraction path or, in other words, quantity extracted must fall over time, is not supported by the fact that quantity extracted fluctuates all the time. The simple present value approach, which is based on the assumption of no optimization, means that resource owners are implicitly holding assets with a zero rate of return, suggesting that it would be rational to liquidate as much as possible in the current period.

The ranking of user costs of the approaches in Table A.2, for 15 of the 21 countries, is the same: total rent > marginal rent > quasi-optimal > exhaustion > simple present value. The total rent and marginal rent approaches provide very similar results at least for the assumed value of ε. The exhaustion approach is the most erratic. The user cost estimated by the exhaustion approach provides values extremely in excess of any other approach for countries with high extraction cost and small reserve life. However, the exhaustion approach provides the same results as those derived by the simple value approach for countries with low extraction cost and large reserve life.

The quasi-optimal approach provides the most interesting result, giving some middle ground between the total rent and simple present value approaches. This quasi-optimal approach is inconsistent with optimal depletion regarding the assumed terminal time and the interdependence of parameters (price, cost, terminal time and elasticity). Moreover, it offers the depletion values being a decreasing function of the deposit size, which seems correct for a 'real world' estimate that does not assume full optimality (Atkinson and Hamilton, 2007).

Table A.2 Depletion Estimates for Oil in 2000

	Reserve life (N) in years	Total rent as proportion of total revenues	Total rent	Marginal rent	Exhaustion	Simple present value	Quasi-optimal
			Percentage of gross national income (GNI)				
Argentina	11	0.46	1.4	1.1	1.8	0.8	1.2
Bolivia	35	0.45	1.8	1.5	0.7	0.3	1.1
Canada	7	0.44	1.2	1.0	1.9	0.8	1.1
Ecuador	14	0.85	30.3	29.5	18.2	15.4	26.9
Egypt	12	0.57	4.0	3.6	4.0	2.3	3.7
Gabon	25	0.52	35.0	30.1	20.3	10.5	26.8
Indonesia	11	0.74	7.0	6.6	5.6	4.1	6.4
Iran	67	0.97	36.5	36.3	1.5	1.4	8.6
Kuwait	131	0.94	46.4	45.9	0.1	0.1	0.6
Malaysia	17	0.84	7.0	6.8	3.7	3.1	6.0
Mexico	25	0.85	4.9	4.8	1.7	1.5	3.7
Nigeria	27	0.84	53.2	51.6	16.6	14.0	38.9
Norway	8	0.30	6.0	3.9	13.7	4.1	5.7
Peru	9	0.62	1.2	1.1	1.3	0.8	1.1
Russia	21	0.79	21.2	20.4	9.8	7.8	17.3
Saudi Arabia	87	0.97	43.9	43.7	0.7	0.6	4.5
Trinidad and Tobago	15	0.72	12.4	11.7	8.2	5.9	10.9
Ukraine	21	0.89	1.6	1.6	0.7	0.6	1.3
UK	6	0.35	0.6	0.4	1.3	0.4	0.6
USA	10	0.62	0.4	0.3	0.4	0.2	0.3
Venezuela	65	0.85	23.7	23.1	1.2	1.0	6.0

Note: Assumes $r = 0.05$, $\varepsilon = 1.15$

Source: Atkinson and Hamilton (2007)

Appendix B National Product, People's Welfare and Convex Economy

A convex economy is an economy with convex production possibilities and preferences, as demonstrated in Figure B.1, for a simplified economy of two consumer goods (X and Y) and a single consumer. The convex production possibilities and preferences mean that the production possibility frontier curve (TT′ in Figure B.1) is concave to the origin, while the consumer's indifference curves (I_1 I_1' and I_2 I_2' in Figure B.1) are convex to the origin. A convex economy of the Figure B.1 will attain an equilibrium at the optimal point A, at which the production possibility frontier curve touches the highest-possible consumer's indifference curve I_1 I_1' and the common tangent of the two curves, pp′, defines the optimal prices of the two consumer goods.

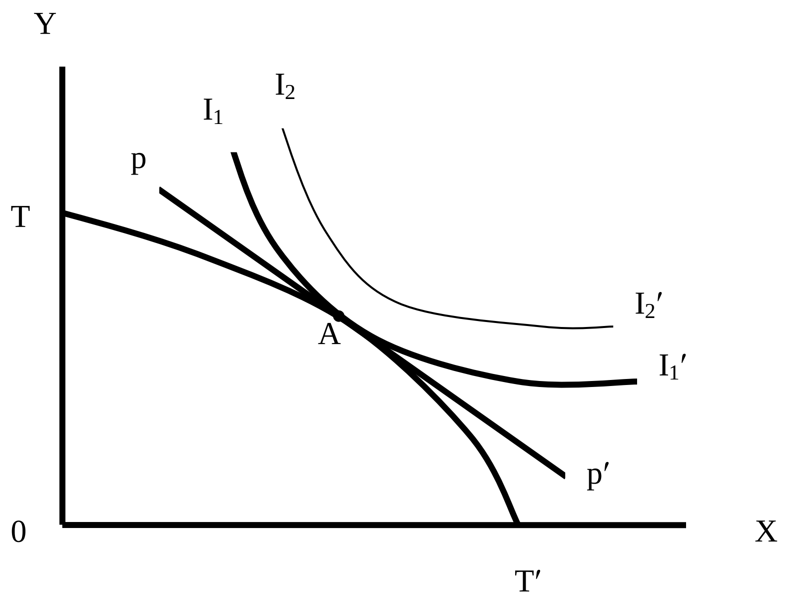

Figure B.1 An Equilibrium for a Simplified Economy with Convex Production Possibilities and Preferences

Let p_x and p_y be the prices (whether optimal or not) of the two consumer goods. Then, the national product of such an economy, NP, shall be defined as:

$$NP = p_xX + p_yY$$

For a change in the economy that does not affect the real prices of the two consumer goods; therefore, the price ratio, p_x/p_y, or the slope of a price ratio line is unchanged. The change in the national product,

$$\Delta NP = p_x \Delta X + p_y \Delta Y$$

$$= p_y (p_x/ p_y \cdot \Delta X + \Delta Y)$$

Hence, the change in the national product, ΔNP, will be positive only when:

$$p_x/ p_y \cdot \Delta X + \Delta Y > 0$$

That is: $\Delta Y > - p_x/ p_y \cdot \Delta X$

For $\Delta X > 0$, then $\Delta Y/\Delta X > - p_x/ p_y$ (B1)

For $\Delta X < 0$, then $\Delta Y/\Delta X < - p_x/ p_y$ (B2)

The conditions set forth by the inequalities B1 and B2 dictate that the changes in economy that increase the national product have to go in the directions pointing above the price ratio line as shown in Figure B.2.

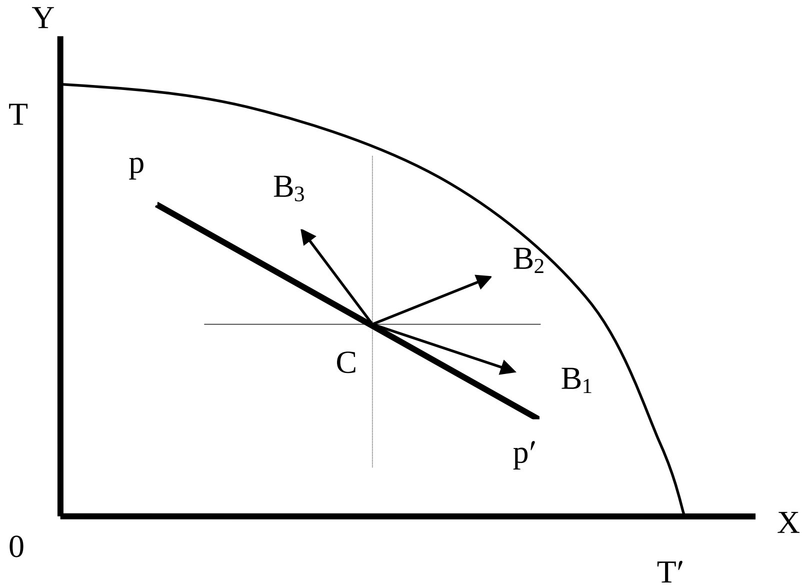

Figure B.2 The Directions of the Changes in Economy from Point C to Points B_1, B_2 and B_3, within the Production Possibility Frontier Curve, that Increase the National Product.

Theorem: Under the condition that the real prices are not affected, the national product shall increase only when changes in the economy are in the directions pointing above the price ratio line that passes through the beginning point of the changes.

In proving that an economy has to be convex for the GNNP (Green Net National Product) or the NP to be a good welfare indicator, two possibilities of non-convex economies will be analyzed here: i) an economy with both the production possibility frontier curve and the consumer's indifference curves being convex to the origin, as shown in Figure B.3; and ii) an economy with both the production possibility frontier curve and the consumer's indifference curves being concave to the origin, as shown in Figure B.4;

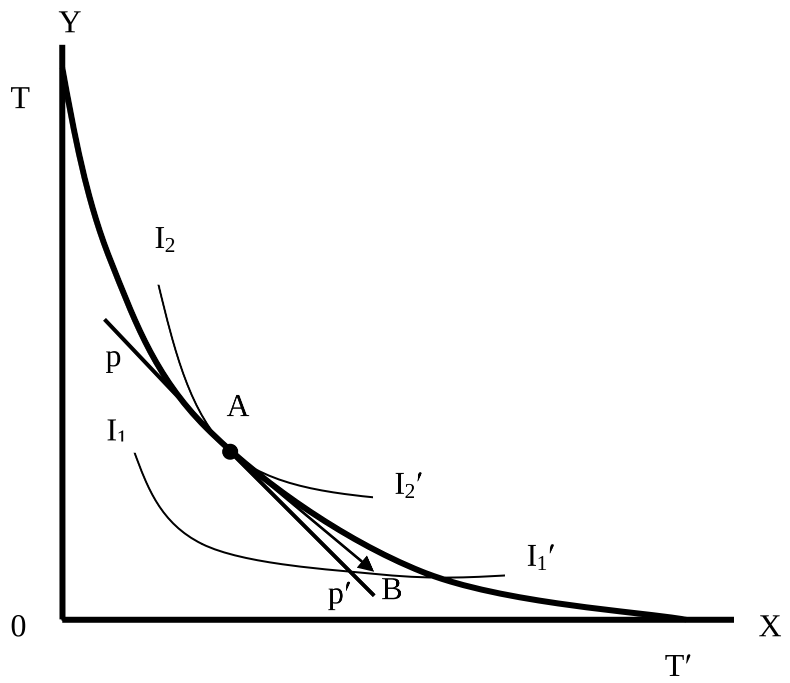

Figure B.3 A Non Convex Economy with both the Production Possibility Frontier Curve and the Consumer's Indifference Curves being Convex to the Origin

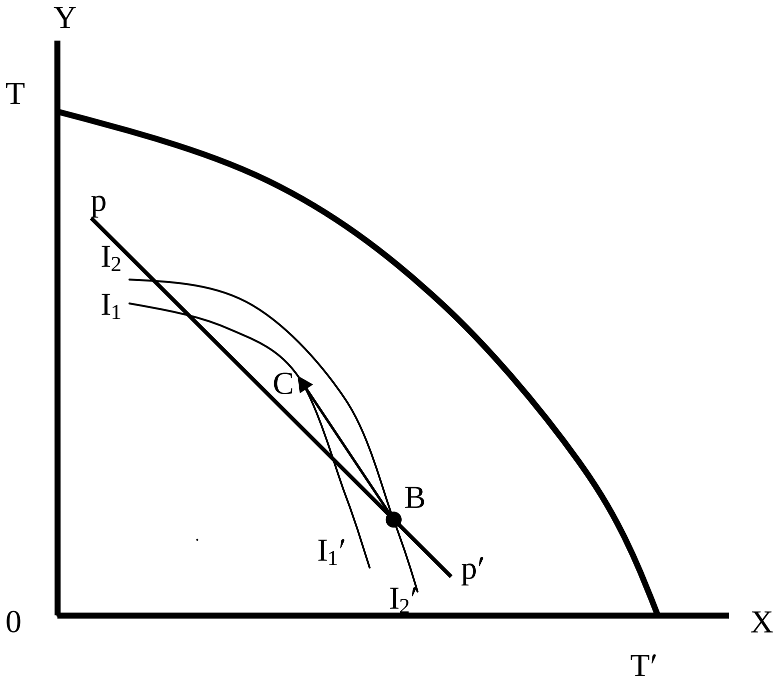

Figure B.4 A Non Convex Economy with both the Production Possibility Frontier Curve and the Consumer's Indifference Curves being Concave to the Origin

It is shown in Figure B.3 that, with both the production possibility frontier curve and the consumer's indifference curves being convex to the origin, a change in economy from an optimal point A to point B makes the consumer worse off. But the economic movement from A to B improves the national product because it moves in the direction pointing above the price ratio line, pp′, satisfying the above-proven *Theorem*. In the case that the consumer's preferences are concave as in Figure B.4, an economic movement, within the production possibility frontier curve, from point B to C also satisfies the *Theorem*; therefore, the movement improves the national product. But at point C, the consumer attains a lower indifference curve. Therefore, it may be concluded that in both cases of non convex economy the change in the national product is not an indicator of people's welfare.

Appendix C The t-statistics and Values of All Coefficients in All Equation Forms of All Eight Countries

Table C.1 Coefficients of Equation Form no. 1.1

Country	Coefficient						
	beta0	beta1	beta2	beta3	beta4	beta5	beta6
Indonesia	-233709	2.678	116.053	-0.093	8.855	-25.375	0.031
Japan	-825029	-1.339	408.735	1804.460	887.366	1.172	0.139
Korea	-5464211	4.215	2739.649	981.889	-1245.998	-25.810	0.001
Malaysia	-384587	5.525	192.657	-71.043	-284.641	-1.862	0.011
Philippines	-380466	2.021	190.820	38.818	60.982	-8.700	-0.004
Taiwan	-39911	0.471	5.036	637.421	-147.620	4.473	0.041
Vietnam	-3131599	-5.659	1576.829	-27.287	-61.413	198.923	-0.020

Table C.2 t-statistics of Coefficients of Equation Form no. 1.1

Country	t-statistic of coefficient (critical t-value = 1.812)						
	beta0	beta1	beta2	beta3	beta4	beta5	beta6
Indonesia	-1.473	1.441	1.449	-0.001	0.150	-1.319	2.280
Japan	-0.983	-2.661	0.984	2.999	1.720	0.308	3.564
Korea	-2.760	1.592	2.769	0.972	-1.326	-1.490	0.052
Malaysia	-0.733	2.539	0.729	-0.227	-0.852	-0.133	0.814
Philippines	-7.456	2.405	7.462	1.061	1.702	-0.958	-1.140
Taiwan	-0.032	0.289	0.008	1.711	-0.386	0.257	3.888
Vietnam	-3.300	-0.333	3.303	-0.164	-0.444	1.237	-1.945

Table C.3 Coefficients of Equation Form no. 1.2

Country	Coefficient					
	beta0	beta1	beta2	beta3	beta4	beta5
Indonesia	-573549	5.844	287.911	-53.409	-18.612	-55.232
Japan	790792	-1.274	-358.714	363.933	841.146	8.513
Korea	-5426101	4.264	2720.951	989.180	-1266.044	-25.981
Malaysia	-686716	6.562	345.438	-60.545	-417.243	-3.489
Philippines	-335816	1.649	168.387	36.282	78.909	-12.475
Taiwan	-613978	-0.453	307.477	1092.211	36.843	28.283
Vietnam	-1644199	10.462	828.646	-139.182	22.108	124.478

Table C.4 t-statistics of Coefficients of Equation Form no. 1.2

Country	t-statistic of coefficient (critical t-value = 1.796)					
	beta0	beta1	beta2	beta3	beta4	beta5
Indonesia	-8.945	4.025	9.054	-0.638	-0.273	-3.332
Japan	0.779	-1.763	-0.703	0.568	1.135	1.848
Korea	-3.098	1.814	3.099	1.037	-1.553	-1.602
Malaysia	-1.881	3.777	1.886	-0.197	-1.453	-0.255
Philippines	-10.134	2.101	10.175	0.980	2.418	-1.456
Taiwan	-0.331	-0.186	0.328	2.043	0.064	1.149
Vietnam	-2.613	0.630	2.619	-0.798	0.150	0.712

Table C.5 Coefficients of Equation Form no. 1.3

Country	Coefficient					
	beta0	beta1	beta2	beta3	beta4	beta6
Indonesia	-89163	0.334	43.207	15.731	13.927	0.043
Japan	-743652	-1.226	365.347	1863.514	875.920	0.146
Korea	-7813565	0.659	3916.572	1053.924	-787.128	0.006
Malaysia	-412762	5.307	206.861	-58.734	-276.964	0.012
Philippines	-414255	1.570	207.785	56.230	48.120	-0.006
Taiwan	259996	0.857	-147.242	621.847	-146.315	0.041
Vietnam	-2684950	12.022	1351.187	10.554	2.861	-0.017

Table C.6 t-statistics of Coefficients of Equation Form no. 1.3

Country	t-statistic of coefficient (critical t-value = 1.796)					
	beta0	beta1	beta2	beta3	beta4	beta6
Indonesia	-0.752	0.596	0.722	0.206	0.228	4.197
Japan	-0.974	-3.710	0.976	3.412	1.777	4.629
Korea	-6.192	0.546	6.238	0.991	-0.842	0.326
Malaysia	-0.902	3.912	0.897	-0.206	-0.882	0.882
Philippines	-11.276	2.264	11.304	1.777	1.454	-1.605
Taiwan	0.671	1.439	-0.760	1.768	-0.400	4.443
Vietnam	-2.988	1.278	2.992	0.063	0.022	-1.660

Table C.7 Coefficients of Equation Form no. 1.4

Country	Coefficient					
	beta0	beta1	beta2	beta3	beta5	beta6
Indonesia	-237438	2.724	117.978	0.768	-25.562	0.030
Japan	-915311	-1.017	453.960	1897.428	0.699	0.137
Korea	-6653114	2.535	3329.437	675.832	-18.275	0.010
Malaysia	-290828	4.573	144.683	-123.598	0.215	0.017
Philippines	-416604	2.252	209.035	62.549	-2.910	-0.007
Taiwan	-41712	0.394	6.217	580.153	4.384	0.040
Vietnam	-3078272	-4.094	1549.839	-55.291	172.144	-0.018
Thailand	-2797371	-2.221	1403.745	303.425	79.241	0.027

Table C.8 t-statistics of Coefficients of Equation Form no. 1.4

Country	t-statistic of coefficient (critical t-value = 1.796)					
	beta0	beta1	beta2	beta3	beta5	beta6
Indonesia	-1.587	1.557	1.564	0.011	-1.395	2.407
Japan	-1.006	-2.006	1.009	2.918	0.169	3.245
Korea	-3.645	1.055	3.643	0.665	-1.080	0.638
Malaysia	-0.574	2.480	0.567	-0.408	0.016	1.426
Philippines	-8.293	2.509	8.312	1.707	-0.319	-1.939
Taiwan	-0.035	0.254	0.010	1.767	0.262	4.029
Vietnam	-3.396	-0.256	3.400	-0.374	1.200	-1.975
Thailand	-2.821	-0.352	2.807	0.791	1.414	1.993

Table C.9 Coefficients of Equation Form no. 1.5

Country	Coefficient					
	beta0	beta1	beta2	beta4	beta5	beta6
Indonesia	-233687	2.677	116.041	8.849	-25.371	0.031
Japan	333730	-1.090	-145.104	1026.362	4.820	0.060
Korea	-4749573	4.750	2383.524	-1037.441	-26.616	0.003
Malaysia	-436452	5.370	218.486	-299.582	-0.915	0.011
Philippines	-356529	2.421	178.923	75.463	-13.484	-0.004
Taiwan	316449	0.653	-173.074	113.446	-0.369	0.046
Vietnam	-3187048	-5.724	1604.560	-70.048	194.062	-0.020

Table C.10 t-statistics of Coefficients of Equation Form no. 1.5

Country	t-statistic of coefficient (critical t-value = 1.796)					
	beta0	beta1	beta2	beta4	beta5	beta6
Indonesia	-1.555	1.605	1.531	0.157	-1.401	2.518
Japan	0.341	-1.671	-0.297	1.520	1.016	1.591
Korea	-2.590	1.839	2.600	-1.137	-1.542	0.190
Malaysia	-0.967	2.719	0.958	-0.957	-0.071	0.843
Philippines	-7.747	3.208	7.741	2.265	-1.701	-1.071
Taiwan	0.240	0.371	-0.259	0.298	-0.020	4.299
Vietnam	-3.764	-0.353	3.764	-0.573	1.286	-2.235

Table C.11 Coefficients of Equation Form no. 1.6

Country	Coefficient				
	beta0	beta1	beta2	beta3	beta4
Indonesia	-529654	1.394	266.734	-74.303	-41.856
Japan	2399554	-0.087	-1171.434	280.475	701.529
Korea	-7660747	0.836	3842.682	1106.599	-902.423
Malaysia	-753961	6.190	379.358	-36.542	-408.430
Philippines	-369062	0.714	185.072	63.789	66.725
Taiwan	1454110	2.180	-740.757	1056.165	77.226
Vietnam	-1497257	20.572	754.087	-102.847	56.358

Table C.12 t-statistics of Coefficients of Equation Form no. 1.6

Country	t-statistic of coefficient (critical t-value = 1.782)				
	beta0	beta1	beta2	beta3	beta4
Indonesia	-6.219	1.804	6.308	-0.656	-0.455
Japan	4.189	-0.239	-4.132	0.401	0.868
Korea	-6.798	0.808	6.823	1.094	-1.084
Malaysia	-3.115	6.830	3.140	-0.130	-1.492
Philippines	-14.703	1.514	14.831	1.916	2.023
Taiwan	3.251	2.640	-3.296	1.953	0.133
Vietnam	-2.572	2.440	2.579	-0.629	0.413

Table C.13 Coefficients of Equation Form no. 1.7

Country	Coefficient				
	beta0	beta1	beta2	beta3	beta5
Indonesia	-575334	5.836	288.727	-56.859	-55.697
Japan	686562	-0.969	-306.986	468.693	7.980
Korea	-6386384	2.855	3200.029	709.099	-18.975
Malaysia	-802899	5.749	403.108	-151.305	-1.091
Philippines	-346838	1.629	174.017	71.650	-7.159
Taiwan	-615310	-0.436	308.120	1108.144	28.380
Vietnam	-1623524	10.293	818.312	-131.181	133.046
Thailand	-3536238	0.369	1776.514	253.766	78.815

Table C.14 t-statistics of Coefficients of Equation Form no. 1.7

Country	t-statistic of coefficient (critical t-value = 1.782)				
	beta0	beta1	beta2	beta3	beta5
Indonesia	-9.389	4.185	9.493	-0.716	-3.516
Japan	0.671	-1.428	-0.597	0.731	1.721
Korea	-3.686	1.246	3.683	0.716	-1.152
Malaysia	-2.157	3.344	2.156	-0.480	-0.077
Philippines	-8.918	1.752	8.964	1.778	-0.729
Taiwan	-0.347	-0.188	0.343	2.444	1.206
Vietnam	-2.759	0.648	2.764	-0.824	0.840
Thailand	-3.442	0.053	3.430	0.593	1.259

Table C.15 Coefficients of Equation Form no. 1.8

Country	Coefficient				
	beta0	beta1	beta2	beta3	beta6
Indonesia	-93367	0.379	45.398	17.275	0.042
Japan	-865829	-0.952	427.599	1932.111	0.141
Korea	-8169595	0.205	4090.822	822.401	0.012
Malaysia	-287172	4.596	142.838	-125.232	0.017
Philippines	-426785	2.058	214.141	67.376	-0.007
Taiwan	252297	0.773	-143.069	565.382	0.041
Vietnam	-2684581	12.066	1351.003	12.348	-0.017
Thailand	-1552307	6.242	775.247	203.413	0.027

Table C.16 t-statistics of Coefficients of Equation Form no. 1.8

Country	t-statistic of coefficient (critical t-value = 1.782)				
	beta0	beta1	beta2	beta3	beta6
Indonesia	-0.831	0.754	0.800	0.237	4.428
Japan	-1.049	-2.999	1.057	3.265	4.148
Korea	-6.956	0.192	6.987	0.810	0.705
Malaysia	-0.666	4.250	0.659	-0.460	1.492
Philippines	-11.432	3.246	11.474	2.099	-2.159
Taiwan	0.676	1.438	-0.767	1.820	4.594
Vietnam	-3.121	1.372	3.125	0.089	-1.794
Thailand	-3.267	2.970	3.250	0.518	1.910

Table C.17 Coefficients of Equation Form no. 1.9

Country	Coefficient				
	beta0	beta1	beta2	beta4	beta5
Indonesia	-595986	5.691	298.909	-25.166	-56.025
Japan	880936	-1.196	-402.807	901.846	8.328
Korea	-4588445	4.950	2304.316	-1106.088	-27.273
Malaysia	-728029	6.419	365.989	-428.698	-2.665
Philippines	-315731	2.044	158.417	91.542	-16.762
Taiwan	-87333	-0.349	48.333	581.515	25.332
Vietnam	-1713623	12.813	862.635	-13.784	83.699

Table C.18 t-statistics of Coefficients of Equation Form no. 1.9

Country	t-statistic of coefficient (critical t-value = 1.782)				
	beta0	beta1	beta2	beta4	beta5
Indonesia	-11.399	4.076	11.471	-0.384	-3.476
Japan	0.904	-1.736	-0.822	1.266	1.866
Korea	-2.943	2.187	2.943	-1.377	-1.682
Malaysia	-2.543	4.239	2.536	-1.590	-0.213
Philippines	-12.146	3.043	12.158	3.059	-2.278
Taiwan	-0.042	-0.128	0.046	1.017	0.917
Vietnam	-2.793	0.796	2.794	-0.100	0.508

Table C.19 Coefficients of Equation Form no. 1.10

Country	Coefficient				
	beta0	beta1	beta2	beta4	beta6
Indonesia	-89280	0.408	43.368	15.038	0.042
Japan	880120	-0.537	-426.835	994.769	0.078
Korea	-7123677	1.115	3572.987	-547.337	0.009
Malaysia	-446795	5.267	223.730	-294.048	0.011
Philippines	-403949	1.863	202.844	62.366	-0.007
Taiwan	291775	0.620	-160.540	113.876	0.046
Vietnam	-2658383	12.221	1337.878	6.946	-0.017

Table C.20 t-statistics of Coefficients of Equation Form no. 1.10

Country	t-statistic of coefficient (critical t-value = 1.782)				
	beta0	beta1	beta2	beta4	beta6
Indonesia	-0.785	0.986	0.755	0.258	4.496
Japan	1.074	-1.494	-1.059	1.473	2.327
Korea	-6.773	1.002	6.831	-0.606	0.482
Malaysia	-1.091	4.089	1.082	-1.012	0.904
Philippines	-10.252	2.547	10.279	1.788	-1.741
Taiwan	0.694	0.985	-0.764	0.313	4.735
Vietnam	-3.497	1.440	3.498	0.063	-1.870

Table C.21 Coefficients of Equation Form no. 1.11

Country	Coefficient				
	beta0	beta1	beta2	beta5	beta6
Indonesia	-237644	2.731	118.087	-25.595	0.030
Japan	298070	-0.700	-125.643	4.488	0.054
Korea	-5989642	3.128	2999.134	-19.776	0.011
Malaysia	-375796	4.202	186.875	2.126	0.018
Philippines	-387660	3.111	194.762	-9.334	-0.008
Taiwan	347348	0.738	-188.773	-0.685	0.047
Vietnam	-3191815	-3.728	1606.516	151.719	-0.019
Thailand	-2589500	-0.562	1300.422	71.074	0.026

Table C.22 t-statistics of Coefficients of Equation Form no. 1.11

Country	t-statistic of coefficient (critical t-value = 1.782)				
	beta0	beta1	beta2	beta5	beta6
Indonesia	-1.673	1.744	1.650	-1.479	2.665
Japan	0.289	-1.108	-0.244	0.899	1.353
Korea	-4.013	1.435	4.005	-1.208	0.689
Malaysia	-0.844	2.716	0.831	0.172	1.509
Philippines	-7.613	3.886	7.626	-1.044	-2.021
Taiwan	0.275	0.442	-0.294	-0.038	4.760
Vietnam	-3.880	-0.242	3.879	1.187	-2.227
Thailand	-2.751	-0.096	2.737	1.311	1.977

Table C.23 Coefficients of Equation Form no. 1.12

Country	Coefficient			
	beta0	beta1	beta2	beta3
Indonesia	-532873	1.291	268.184	-82.542
Japan	2226805	0.108	-1084.946	373.169
Korea	-7937089	0.461	3979.113	865.735
Malaysia	-823455	5.636	413.483	-143.082
Philippines	-366215	1.056	183.732	85.192
Taiwan	1466188	2.234	-746.946	1089.427
Vietnam	-1409401	22.075	709.957	-72.879
Thailand	-2295862	8.780	1150.383	154.424

Table C.24 t-statistics of Coefficients of Equation Form no. 1.12

Country	t-statistic of coefficient (critical t-value = 1.771)			
	beta0	beta1	beta2	beta3
Indonesia	-6.479	1.803	6.564	-0.762
Japan	4.185	0.381	-4.126	0.545
Korea	-7.183	0.470	7.201	0.872
Malaysia	-3.314	6.517	3.332	-0.502
Philippines	-13.133	2.159	13.252	2.426
Taiwan	3.482	3.231	-3.534	2.363
Vietnam	-2.688	3.000	2.695	-0.514
Thailand	-7.683	4.914	7.750	0.359

Table C.25 Coefficients of Equation Form no. 1.13

Country	Coefficient			
	beta0	beta1	beta2	beta4
Indonesia	-560163	1.090	281.695	-51.492
Japan	2442347	-0.046	-1191.932	750.889
Korea	-6843159	1.416	3436.603	-702.066
Malaysia	-770893	6.154	387.707	-417.444
Philippines	-348471	0.890	175.000	86.806
Taiwan	1755722	2.014	-886.072	601.653
Vietnam	-1592252	19.795	801.289	18.289

Table C.26 t-statistics of Coefficients of Equation Form no. 1.13

Country	t-statistic of coefficient (critical t-value = 1.771)			
	beta0	beta1	beta2	beta4
Indonesia	-8.029	1.800	8.090	-0.580
Japan	4.487	-0.137	-4.419	0.972
Korea	-8.049	1.580	8.051	-0.858
Malaysia	-3.932	7.427	3.943	-1.640
Philippines	-13.991	1.755	14.083	2.528
Taiwan	3.792	2.223	-3.789	1.060
Vietnam	-2.901	2.431	2.903	0.153

Table C.27 Coefficients of Equation Form no. 1.14

Country	Coefficient			
	beta0	beta1	beta2	beta5
Indonesia	-600461	5.667	301.021	-56.739
Japan	795225	-0.838	-360.066	7.686
Korea	-5673428	3.496	2845.281	-20.594
Malaysia	-918887	5.319	460.797	1.229
Philippines	-303968	2.547	152.797	-15.199
Taiwan	40466	0.016	-14.802	26.412
Vietnam	-1730584	13.022	871.084	76.195
Thailand	-3345666	1.706	1681.671	71.965

Table C.28 t-statistics of Coefficients of Equation Form no. 1.14

Country	t-statistic of coefficient (critical t-value = 1.771)			
	beta0	beta1	beta2	beta5
Indonesia	-12.188	4.203	12.227	-3.666
Japan	0.800	-1.303	-0.720	1.695
Korea	-4.078	1.690	4.063	-1.287
Malaysia	-3.345	3.735	3.317	0.095
Philippines	-9.225	3.051	9.242	-1.616
Taiwan	0.020	0.006	-0.014	0.955
Vietnam	-3.054	0.849	3.052	0.541
Thailand	-3.517	0.268	3.501	1.200

Table C.29 Coefficients of Equation Form no. 1.15

Country	Coefficient			
	beta0	beta1	beta2	beta6
Indonesia	-93867	0.465	45.770	0.042
Japan	808891	-0.195	-389.064	0.071
Korea	-7501943	0.702	3759.092	0.012
Malaysia	-347426	4.404	172.454	0.017
Philippines	-418388	2.615	210.246	-0.009
Taiwan	301599	0.678	-165.533	0.047
Vietnam	-2642713	12.472	1330.032	-0.017
Thailand	-1497103	6.788	748.497	0.026

Table C.30 t-statistics of Coefficients of Equation Form no. 1.15

Country	t-statistic of coefficient (critical t-value = 1.771)			
	beta0	beta1	beta2	beta6
Indonesia	-0.867	1.380	0.838	4.755
Japan	0.947	-0.680	-0.927	2.034
Korea	-9.083	0.817	9.100	0.765
Malaysia	-0.873	4.556	0.860	1.562
Philippines	-10.034	4.044	10.078	-2.486
Taiwan	0.746	1.168	-0.819	5.213
Vietnam	-3.825	1.727	3.824	-1.952
Thailand	-3.328	3.842	3.309	1.935

Table C.31 Coefficients of Equation Form no. 2.1

Country	Coefficient					
	beta0	beta1	beta2	beta7	beta5	beta6
Indonesia	-228887	3.120	113.672	-0.280	-26.435	0.031
Japan	201479	-0.721	-78.961	0.046	4.211	0.059
Korea	-5526941	2.893	2770.236	1.112	-25.762	0.001
Malaysia	-502884	3.962	250.733	0.416	2.479	0.015
Philippines	-373978	3.345	187.917	-0.180	-11.609	-0.007
Taiwan	192481	0.426	-111.453	0.305	1.803	0.046
Vietnam	-3260174	-6.396	1640.866	2.131	155.940	-0.021

Table C.32 t-statistics of Coefficients of Equation Form no. 2.1

Country	t-statistic of coefficient (critical t-value = 1.796)					
	beta0	beta1	beta2	beta7	beta5	beta6
Indonesia	-1.550	1.745	1.528	-0.510	-1.473	2.605
Japan	0.177	-1.088	-0.140	0.256	0.793	1.290
Korea	-3.760	1.378	3.758	1.418	-1.582	0.078
Malaysia	-0.991	2.409	0.980	0.583	0.194	1.108
Philippines	-6.124	3.406	6.139	-0.444	-1.097	-1.685
Taiwan	0.153	0.254	-0.174	1.113	0.101	4.623
Vietnam	-3.795	-0.383	3.794	0.518	1.180	-2.211

Table C.33 Coefficients of Equation Form no. 2.2

Country	Coefficient				
	beta0	beta1	beta2	beta7	beta5
Indonesia	-596821	5.974	299.185	-0.204	-57.590
Japan	851032	-0.802	-387.591	-0.049	7.678
Korea	-5485338	2.924	2749.910	1.137	-25.977
Malaysia	-975639	4.549	488.993	0.735	2.129
Philippines	-288372	3.188	145.011	-0.411	-19.302
Taiwan	-183260	-0.431	95.936	0.468	28.980
Vietnam	-1746726	13.475	879.227	-0.721	76.796

Table C.34 t-statistics of Coefficients of Equation Form no. 2.2

Country	t-statistic of coefficient (critical t-value = 1.782)				
	beta0	beta1	beta2	beta7	beta5
Indonesia	-11.381	3.474	11.411	-0.307	-3.537
Japan	0.812	-1.182	-0.736	-0.292	1.632
Korea	-4.184	1.482	4.166	1.657	-1.690
Malaysia	-3.523	2.895	3.494	1.114	0.165
Philippines	-7.921	3.036	7.946	-1.006	-1.883
Taiwan	-0.089	-0.157	0.092	1.050	1.048
Vietnam	-2.922	0.832	2.921	-0.161	0.525

Table C.35 Coefficients of Equation Form no. 2.3

Country	Coefficient				
	beta0	beta1	beta2	beta7	beta6
Indonesia	-83968	0.696	40.783	-0.205	0.042
Japan	600479	-0.281	-286.682	0.075	0.077
Korea	-7498461	0.013	3759.912	0.791	0.006
Malaysia	-467873	4.200	232.946	0.410	0.014
Philippines	-419608	2.593	210.851	0.035	-0.009
Taiwan	312733	0.584	-172.524	0.301	0.046
Vietnam	-2688353	10.565	1352.952	1.832	-0.018

Table C.36 t-statistics of Coefficients of Equation Form no. 2.3

Country	t-statistic of coefficient (critical t-value = 1.782)				
	beta0	beta1	beta2	beta7	beta6
Indonesia	-0.728	0.950	0.701	-0.359	4.593
Japan	0.597	-0.788	-0.580	0.433	1.992
Korea	-9.067	0.012	9.091	0.984	0.331
Malaysia	-1.028	4.006	1.016	0.598	1.150
Philippines	-9.305	3.655	9.351	0.099	-2.373
Taiwan	0.783	1.008	-0.864	1.158	5.149
Vietnam	-3.729	1.225	3.729	0.440	-1.934

Table C.37 Coefficients of Equation Form no. 2.4

Country	Coefficient			
	beta0	beta1	beta2	beta7
Indonesia	-572482	0.690	287.619	0.198
Japan	2324595	0.217	-1132.205	-0.051
Korea	-7383030	0.046	3704.525	0.892
Malaysia	-943788	4.752	472.819	0.729
Philippines	-332471	1.562	167.245	-0.105
Taiwan	1936570	2.309	-978.487	0.427
Vietnam	-1559028	20.963	784.690	-0.661

Table C.38 t-statistics of Coefficients of Equation Form no. 2.4

Country	t-statistic of coefficient (critical t-value = 1.771)			
	beta0	beta1	beta2	beta7
Indonesia	-8.020	0.590	8.052	0.219
Japan	4.104	0.775	-4.043	-0.284
Korea	-10.202	0.043	10.149	1.244
Malaysia	-4.930	5.035	4.910	1.149
Philippines	-10.908	2.392	10.992	-0.255
Taiwan	4.598	2.841	-4.590	0.957
Vietnam	-3.351	2.823	3.349	-0.152

Table C.39 t-statistics and Values of Coefficients of Equation Form no. 2.5

Country	Coefficient							
	β_0		β_1		β_2		R^2	F-statistic
Indonesia	-568497.9	(-8.53)	0.918154	(1.78)	285.6207	(8.57)	0.87	45.60
Japan	2268538	(4.42)	0.181293	(0.75)	-1104.577	(-4.35)	0.74	19.71
Korea	-7214542	(-9.96)	1.005988	(1.34)	3620.388	(9.90)	0.90	63.60
Malaysia	-900731.2	(-4.74)	5.432618	(7.31)	451.5747	(4.72)	0.63	11.84
Philippines	-334353.6	(-11.70)	1.472246	(2.77)	168.1712	(11.78)	0.91	75.00
Taiwan	1969560	(4.71)	2.496265	(3.17)	-992.7673	(-4.68)	0.62	11.44
Vietnam	-1545571	(-3.51)	20.49411	(3.15)	777.9013	(3.51)	0.54	8.33
Thailand	-2243722	(-8.87)	9.162343	(6.59)	1124.918	(8.91)	0.86	42.73

Note: Figures in parentheses are t-statistics and critical t-value is 1.761.

Table C.40 Coefficients of Equation 5.16

Country	Coefficient						
	beta0	beta1	beta2	beta3	beta4	beta5	beta6
Indonesia	-108.227	0.540	0.052	-0.148	0.190	-0.320	0.866
Japan	-10.174	-0.789	0.006	0.336	0.154	0.131	1.117
Korea	-339.720	-0.752	0.176	0.017	0.255	0.483	0.132
Malaysia	-13.669	0.786	0.006	-0.036	-0.102	0.036	0.345
Philippines	-118.510	0.570	0.062	0.186	0.328	0.014	-0.147
Taiwan	9.390	0.701	-0.012	0.421	-0.130	-0.021	1.321
Vietnam	138.053	1.058	-0.070	-0.151	0.093	-0.019	0.492

Table C.41 t-statistics of Coefficients of Equation 5.16

Country	t-statistic of coefficient (critical t-value = 1.812)						
	beta0	beta1	beta2	beta3	beta4	beta5	beta6
Indonesia	-2.368	0.841	2.046	-0.388	0.640	-0.698	1.585
Japan	-0.673	-2.280	0.879	2.570	1.481	0.541	2.857
Korea	-7.717	-0.960	7.824	0.059	0.853	1.022	0.297
Malaysia	-0.686	2.246	0.573	-0.211	-0.618	0.305	1.187
Philippines	-3.920	1.103	3.794	0.618	1.257	0.042	-0.464
Taiwan	0.161	0.664	-0.389	1.552	-0.585	-0.060	3.174
Vietnam	1.400	2.662	-1.364	-0.733	0.455	-0.061	1.577