

**Using System Dynamics to Understand UMG  
Customer Purchasing Patterns and the Evolution of  
Myanmar's Jadeite Industry**



Maria Auxiliadora Franco Mosquera

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by

María Auxiliadora Franco Mosquera

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Supervised by

David Wheat Ph.D.

Department of Geography

University of Bergen

Bergen, Norway

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## **Dedication**

To John - my soulmate, friend, confident, advisor, dive buddy, dream-mate, and much more. Thanks for walking along with me in the happiest and most turbulent moments.

To Sergio, Isabel, and Rodrigo – my strength and inspiration. Thanks for your permanent encouragement and infinite love.

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Maria Auxiliadora Franco Mosquera

European Master Programme in System Dynamics

University of Bergen

francomariuxi@gmail.com

## Abstract

*This research draws on the system dynamics methodology to investigate, through a dynamic study of Myanmar's jadeite industry that goes from the year 2000 to 2022, the causes of fluctuating purchases of mining equipment at one of Myanmar's major distributors of heavy machinery. Supported by data from multiple online sources and interviews to two of Myanmar's major mining companies, a simulation model is developed to dynamically explain the behavior of the industry. It is hypothesized demand and supply loops, coupled with delays of various nature, act to cause instability and oscillations in Myanmar's jade mining industry and subsequently in the demand of mining equipment. Results from the model show that in the face of a "mining rush" scenario, one in which the tendency of the government is to grant substantially more mining licenses than the base case, jade reserves are exhausted quickly and even get depleted within the simulation interval. In contrast, when less licenses than usual are granted, the market keeps requiring equipment for a longer time period, and the fact that reserves are not exhausted as quick, implies mineable land concessions and equipment purchases continue to take place, and that the sustainability or survival of UMG as a firm is not compromised as quick. However, in both scenarios ("base case" and "mining rush") jade production peaks at different points in time to then follow an imminent collapsing trend. Furthermore, sensitivity analysis to the parameters (a) tons per acre, and (b) initial jade reserves show greater or lesser values do not alter the collapsing behavior of jade production and equipment purchases, but simply move sales and production curves to upper or lower boundaries. Finally, a structure for financial assessment is added to the model to show that in the face of a "mining rush scenario," not favorable prices, and the due computation of a formal financial analysis, negative NPV results (from jade prices not being able to keep up with the vast amount of new machinery a boom in mining licenses requires) will deter license applications and will most likely be reflected into less purchases of equipment. This research is significantly relevant in that (a) it explains the fluctuations of equipment purchases dynamically, (b) results warn UMG about the imminent depletion of mineable land and with that the decay of its business, and (c) it sheds light on the research question, it explains the behavior of Myanmar's jade industry based on empirical data, something that has not been previously done.*

## Introduction

Multiple studies have identified customer demand as “the ultimate driver of business management and performance” (Levis & Papageorgiou, 2005) and “the most basic tool of empirical industrial organization” (Ackerberg, Benkard, Berry, & Pakes, 2005). From the perspective of the firm, customer demand is the force that guides decisions on production and distribution capacities, sales and marketing budgets, human resource planning, and even research and development activities across different industries (Goodwin, Dyussekeneva, & Meeran, 2012). Failing to accurately forecast customer demand can result in undesired high inventory costs, low customer satisfaction, and even loss of market share in the medium to long term (Gupta, Maranas, & McDonald, 2000).

From the customer perspective, the assurance of product availability becomes particularly important in circumstances where factors like seasonality confine operations to only a fraction of the year. In this context, product availability ensures planned production schedules are carried out and expected profitability achieved.

Recognition of the pivotal importance of customer demand forecasts on product availability is what motivated United Machinery Group (UMG) to commission a study that investigates the causes of fluctuating product demand among their customer base. UMG is a Myanmar-based supplier of heavy equipment that distributes, among many other products, excavators, dump trucks, and air compressors to local construction and mining companies. Although revenues from customers in the construction segment are significant, revenues generated by mining companies accounted for 70% of the total revenues perceived by UMG in 2011. Because most customers in the mining industry are engaged in jade mining, the behavior of Myanmar’s jade mining industry is deemed as key in determining forecasts of equipment sales.

Jade mining involves the extraction of jade from alluvial or in-situ deposits. Jade is a semiprecious stone classified either into jadeite or nephrite that is shaped mostly into ornaments and jewelry. Although jade occurrences in Myanmar are specifically of jadeite, for simplicity purposes the generic word “jade” will be used throughout the text from now on.

Myanmar’s jade industry can be described as one in which two well identifiable players interact: Myanmar being endowed with the most precious jadeite deposits worldwide, and China being the primary consumers of the jadeite mined in its neighbor’s mines. The fact the geology, extraction, appraisal, and consumption of jade involve a great deal detail has prompted most stakeholders in Myanmar’s jade mining industry to believe the industry is completely unpredictable and therefore undecipherable. The secrecy involved in all aspects of the industry, induced by the undisclosed policies of Myanmar’s military, further exacerbates this unpredictability sentiment.

In this thesis, the author adopts the system dynamics methodology to propose a dynamic hypothesis in which demand and supply loops, coupled with delays of various nature in the system (i.e. perception delay, payment from sales delay, license approval delay, equipment delivery delay, production delay), act to cause instability and oscillations in Myanmar’s jade mining industry and subsequently in the purchases of mining equipment. Validation tests prove the model to be insensitive to parameter changes and headed to inevitable decay in the long run.

The findings from this thesis are of major significance both for the client firm and other major players in Myanmar’s jade industry. First, this research is unprecedented in that it challenges current widespread beliefs about the “quantification impossibility” of the different parameters and relationships that interact in Myanmar’s jade industry. Second and last, it uses aggregate industry data not only to test a dynamic hypothesis of industry behavior to provide conclusions on



the fluctuations of customer equipment demand, but also to show how the development of the jade industry feeds back into the system until the inevitable exhaustion of mineable land and jade reserves prevent activities of mining companies, equipment suppliers, traders, and so on from continuing further.

The different components of this thesis have been organized as follows: chapter 1 provides the context for this research and an introduction to the client firm; chapter 2 reviews some of the most important studies conducted in the field of system dynamics, mining, and the study of mineral industries; chapter 3 describes the problem and research questions for this study; chapter 4 briefly mentions the methodology used for developing the study and gathering data; chapter 5 describes the hypothesis that explains the problem dynamically; chapter 6 introduces the stock and flow structure of the simulation model with the corresponding justification for different parameters values and relationships; chapter 7 discusses model behavior and model validation; chapter 8 proposes a policy for the proper financial evaluation of mining development initiatives; and finally chapter 9 discusses the conclusions and limitations of this research.

## Chapter 1. Research context

This research was commissioned by Win Strategic's owner and general manager to investigate the dynamics involved in the fluctuation of customers' purchases of equipment. The research material used for this thesis draws on a wide array of data sources and was collected throughout a 3-month period in Yangon, Myanmar. Provided the scarce disclosure, and therefore unreliable nature of the data related to Myanmar's mining industry, fieldwork was imperative to gain a truly realistic perspective of how operations both at the client firm and at the mines sites are carried out. Before describing the client firm, a written portrait of Myanmar and its natural resources is provided.

### 1.1. A brief introduction to Myanmar and its mineral resources

Rich in a variety of natural resources, among them the world's most precious rubies and jade stones, "Myanmar" or "Burma" has remained as one of the poorest nations in Southeast Asia suffering from continued isolation and poverty since the military junta led by General Ne Win took power in 1962.



Figure 1 Myanmar and its neighbors

[Source: The World Bank (2012c)]

Home to more than one hundred ethno-linguistic groups, Myanmar has also been subject to a long-lasting armed conflict between the central government and a range of armed ethnic groups that extends until present times (South, 2012) and threatens the well being and lives of many. Most of such armed conflicts take place especially in the area where most jade reserves lie.

Despite a long history of autocratic rule, slight changes in favor of democratization have sprouted in the last two years. In late March 2011 a new civil government led by president Thein Sein took place, and in April 2012 three dozen members of Aung San Suu Kyi's National League for Democracy (NLD), including her, took parliamentary oath at office, marking a pivotal milestone in the history of the country.

Although the junta ceded power last year, serving and retired military officers still dominate government as well as civil service seats at all levels and run an extensive network of state economic enterprises and government-organized nongovernmental organizations (Pedersen, 2011). It is in the framework of such a ruthless and totalitarian military-led state that mining operations have taken place in the last 40 years: government officials favoring small groups, receiving extraordinarily high amounts of income derived from the sale of gems (from which mining workers do not participate), and failing to be accountable for the environmental and human right catastrophe in which mining operations in Myanmar have resulted.

## **1.2. About the client firm**

Win Strategic is a Yangon-based business conglomerate that consists of three stand-alone firms: (a) UMG Myanmar (main operational one), (b) WIN Food (food business), and (c) WIN Resources (jade and gold mines) (see Figure 2).

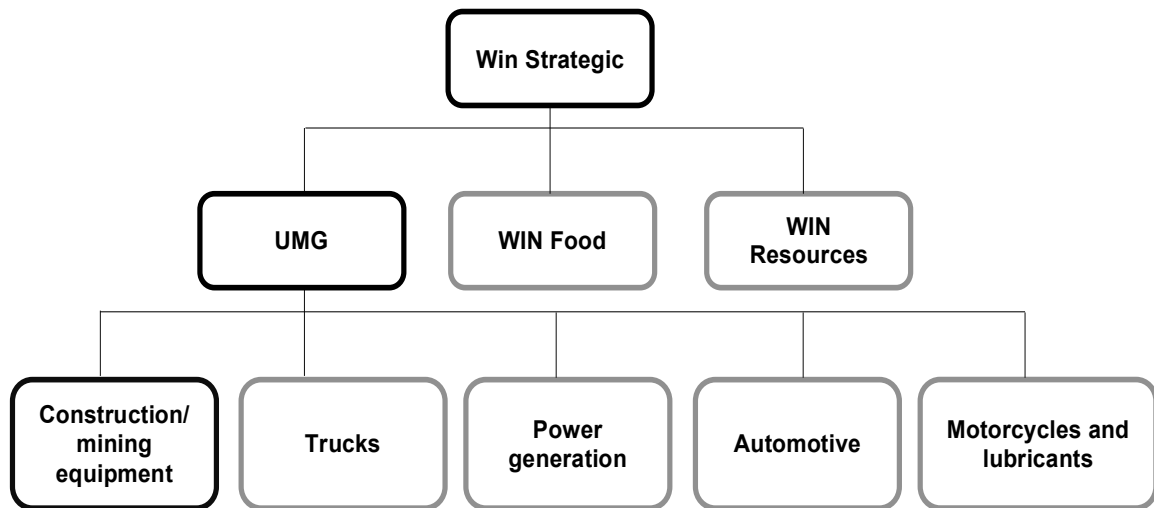


Figure 2 Organizational structure of Win Strategic

Established back in 1998, UMG is recognized as one of Myanmar’s major distributors of heavy machinery today. Equipment is first imported from different countries in Southeast Asia and then sold to mining and construction companies locally. UMG also operates a service network consisting of 18 branches that provide sales and technical support all over the country. In recent years, sales operations have expanded through overseas subsidiaries that now operate in Cambodia, Sri Lanka, Papua New Guinea, Laos, Singapore, and soon Vietnam.

It is worth pointing out that although construction/mining equipment represented UMG’s entire business focus since 1998 until 2011, today the company, partly as a result of Myanmar’s most recent political and economic reforms, has established four other business units that include (a) trucks, (b) power generation, (c) automotive, and (d) motorcycles/lubricants. All the information presented in this research relates only to UMG’s construction and mining equipment business unit.

### 1.2.1. Mining and UMG

19 products of 18 different brands make up UMG’s construction/mining equipment product portfolio. Items in the portfolio include excavators, dump trucks, drill machines, air compressors, dozers, loaders, compactors, and haulers, among

others. In terms of revenue contribution by product group, excavators accounted for approximately 60% of UMG's total revenues in 2011, while dump trucks and other construction equipment for 25%, and 15% respectively (see Figure 3). Note again that prior to 2012, UMG's product portfolio consisted solely of construction and mining equipment and not cars or motorcycles.

In regards to industry segmentation, while revenues from dump trucks are 100% traceable to the mining sector, about 60% of revenues from both excavators and other equipment can be attributed to the mining industry and the remaining 40% to the construction industry (UMG, 2011) (see Figure 4). It can therefore be concluded around 70% of the total revenues generated by UMG in 2011 were generated by mining firms, especially by those engaged in jade mining. The need to understand the evolution of Myanmar's jade industry and its possible impact on the company's finances and overall sustainability becomes now more apparent.

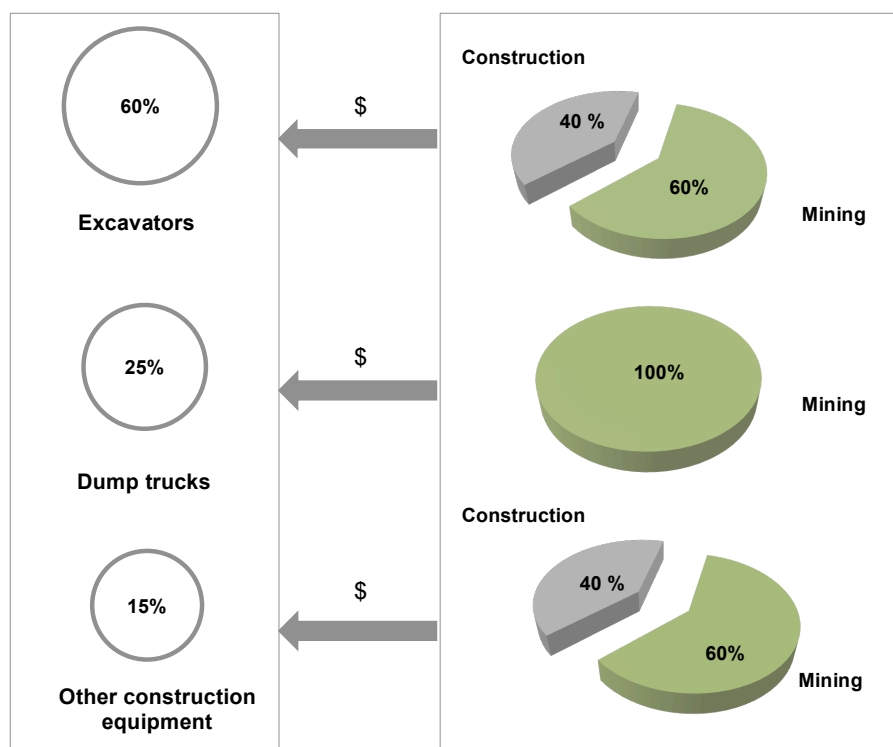


Figure 3 (left) Revenue contribution by product group in 2011

Figure 4 (right) Revenue generation by industry in 2011

## UMG and other main actors

Figure 5 summarizes the terminology that will be used throughout this text when referring to the main parties interacting with UMG. Suppliers or principals refer to UMG's suppliers of construction and mining equipment located in neighboring Asian countries. UMG stands as the client firm of this project and one of the major importers/distributors of construction and mining equipment in Myanmar. Last, mining firms refer to the local buyers of the construction and mining equipment commercialized by UMG or in other words, UMG's customers. Arrows connecting each player symbolize the equipment supply chain, meaning the flow of equipment from principals to UMG and from UMG to the final customer.

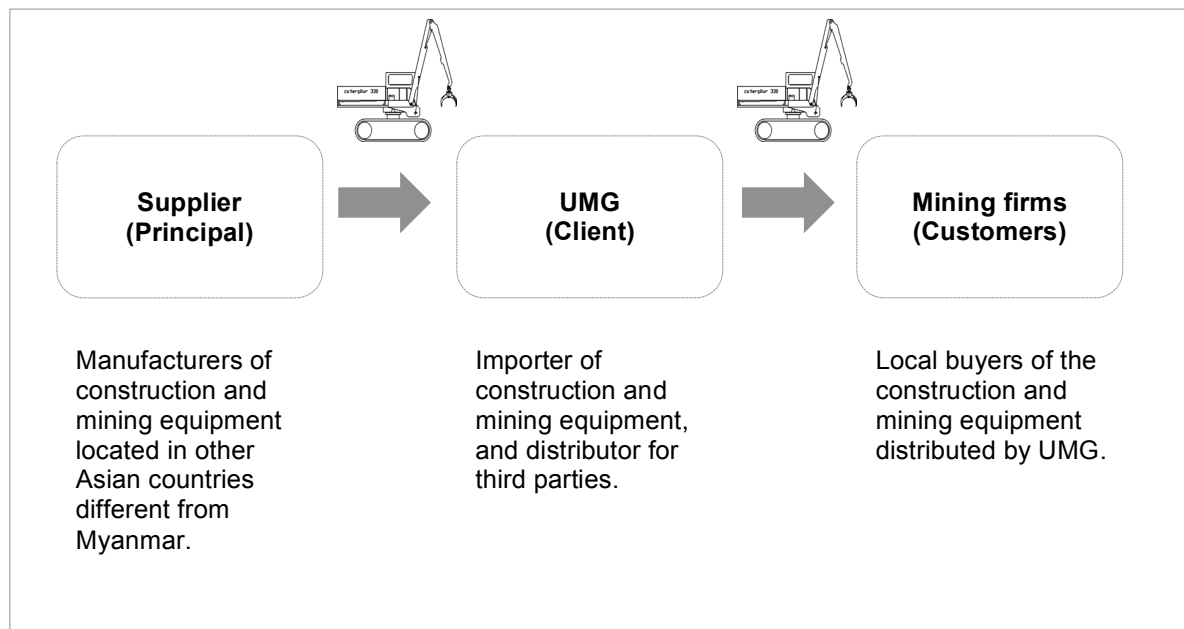


Figure 5 Main actors and their relationship with UMG

## Chapter 2. Literature review

### 2.1. The mining industry as a complex system

If one understands the definition of a complex system as one that is multi-variable, multi-feedback, and also one that exhibits non-linearities and time delays, there is no absolute doubt both the mining firm and the mining industry could be labeled as complex systems on their own. On one hand, a contemporary mining firm is a complex system in which decision making is both focused on (a) regularly adjusting mine management policies, as guided by current mine output, in order to meet planned production schedules and achieve desired profitability levels, and on (b) determining how and where such earned profits should be reinvested in the form of further exploration and development projects (O'Regan & Moles, 2006 ).

On the other hand, the mining enterprise is only one of the many elements within a broader complex system at the industry level. Interacting with mining companies are demand forces, the supply of capital goods and financial services, governmental policies, the environment, communities, and many more. Figure 6 displays the multi-variable nature of Myanmar's jade industry where arrows do not denote cause and effect relationships but instead the interchange of technical, physical, and economic resources among the different stakeholders in the industry. Feedback, non-linear relationships, and time delays within the mining industry are not part of this introduction and will be covered extensively in the further chapters.

Although not in the case of mining firms in Myanmar, most international mining companies rely on borrowed funds to support the exploration of new mineral bodies. Financial resources then flow from investors/creditors to mining firms as capital disbursements are completed and finally from mining firms back to investors/creditors when repayments are made. Similarly, vendors and contractors are in possession of mining equipment, raw material, and geologic and economic

information that is given to mining companies in exchange for a financial benefit. The same applies to workers who get remunerated in exchange for the skills or knowledge they bring to the workplace.

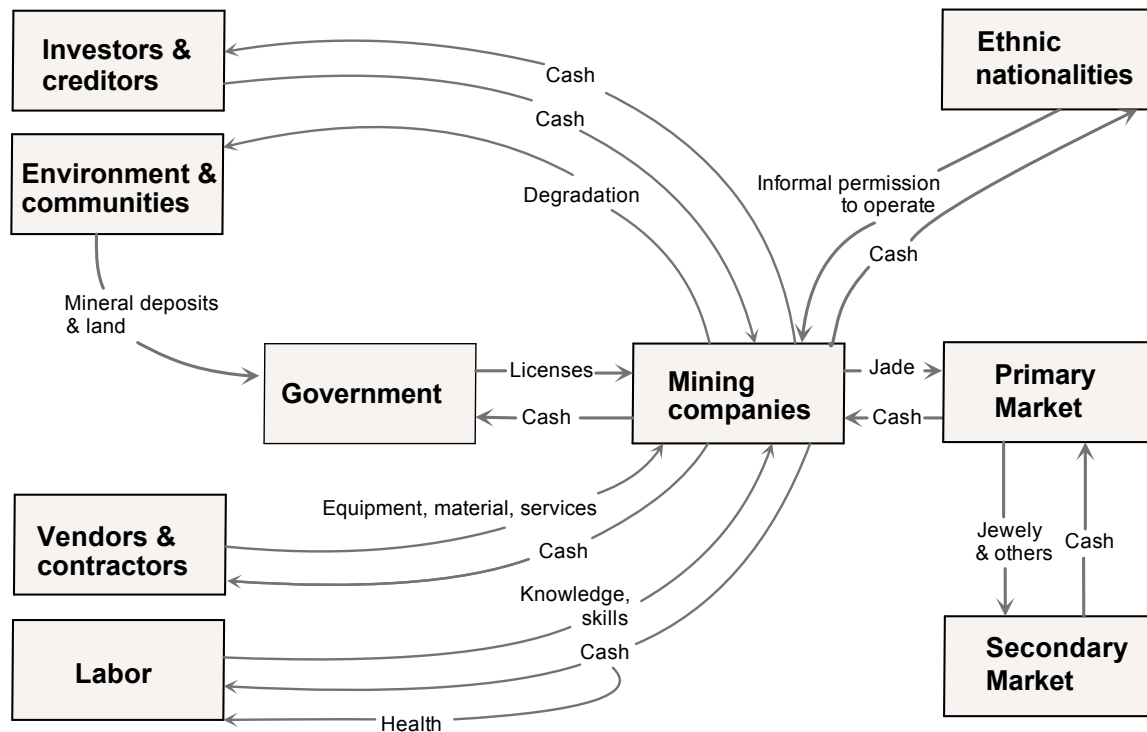


Figure 6 Myanmar’s jade mining value system

[Adapted from White (2008)]

Besides private parties, governments also take part in the resource exchange mechanism by receiving license revenues and royalty payments on production when they give away land, in the form of mining licenses, to mining companies. In the case of Myanmar, land comes at the expense of hundreds of villagers whose homes are expropriated for absurd monetary compensations. Bribes to the Kachin Independence Army (KIA), Myanmar’s most prominent ethnic militia, could also be seen as monetary compensations on behalf of mining companies to justify the extraction of the mineral resources that belong to the Kachin ethnic group. When contributions



are not materialized, mining firms take of risk of seeing their operations abruptly disrupted.

Besides resources traveling back and forth between mining firms and the government or ethnic nationalities, interchanges between mining firms and the environment also occur. Just as in many other mining locations around the world, it has been reported mining operations in Myanmar have caused tremendous environmental degradation not only in the form of destroyed large tracts of what used to be green and habitable land, but also as recurrent deathly floodings and landslides that result from rainwater overshooting riverbanks where mining waste has been irresponsibly deposited (Images Asia & Pan Kachin Development Society, 2004). Environmental ruin is then the by-product that flows from mining companies back to the environment.

Last, mining companies commercialize raw jade to primary buyers who then resell jewelry or other jade-based ornaments to a secondary market. Note these transactions not only refer to the sale of jade through legitimate channels but also through illegal trading networks that have historically extended to Thailand and China (Chang, 2004). In both cases, money is what flows back to both the mining company and the jade manufacturer in exchange for jade.

## **2.2. Previous studies in mining**

Despite the undeniable interrelated nature of the elements present in a mining industry, extensive studies have been mostly written within the framework of specific academic disciplines such as economics, finance, information technology, engineering, ecology, chemistry, geology, or archeology. Significantly less has been documented on Myanmar's jade and jade mining, and nothing, to the knowledge of the author, on the dynamics of Myanmar's jade industry. Given this reality, the following lines will present a review of what has been said about mining industries in general.

In perhaps one of the first and few models that display industry-wide interactions, Clough, Levine, Mowbray, and Walter (1965) make use of five subsectors (i.e. demand, government, operating mine, mine management, and closed mine) to simulate, using the system dynamics methodology, the effects of various government subsidies on Canada's uranium mining industry and their effects on production, employment, and finances both for the mining firm and the government. This study proves particularly insightful in showing how governmental policies related to subsidies can not only affect production rates but also the financial sustainability of mining firms and the communities whose lives and jobs revolve around the mining activity.

Similarly, in his seminal work on commodity cycles, (Meadows, 1970) adopts a holistic and more behavioral perspective when explaining how long-term commodity cycles in hog, cattle, and poultry markets are inherent to the interrelations of supply and demand forces and not explained by random influences or shocks as commonly thought. Because the model is a generic one that could be applied to any other mineral commodity such as nickel or tungsten, this reference is indeed greatly linked to the mining industry.

More recently, O'Regan and Moles (2002) present a system dynamics model that analyzes the exploration, development, and extraction patterns of 20 multinational mining firms as they explore mining investments in four different countries over a 100-year period. This model is particularly helpful in portraying how different deposits in different locations might prove economic or uneconomic depending not only on the country's level of geological endowments but also on the set of regulatory requirements posed by each country and the different growth and extraction profiles of the different players (i.e. passive, sensitive, aggressive).

Other system dynamics models concerned with mining have focused on the optimization of mining operations and the exploration of different financial scenarios

for mining conglomerates (Alpagut & Celebi, 2003). For instance, Wolstenholme and Holmes (1985) report on applications for mine planning (i.e. the optimization of an underground colliery), Wolstenholme (1980) on equipment selection (i.e. the optimization of blinker-conveyor belt system for coal haulage), Montaldo (1977) on the dynamics of an underground metal mine, Xiwen (2001) on the dynamics of checking and ratifying mine production capacity, and finally (Coyle, 1977) on corporate financial planning for a traditional international mining company. Except for the latter, most of these system dynamics based studies could be classified as pure mining engineering applications as they deal exclusively with the operation and management of a mine.

Last, acknowledging the scarcity of studies that examine the evolution of the mining industry in a particular country, Russell, Shapiro, and Vining (2010) use two theoretical approaches to industry evolution (i.e. density-dependence theory and variants of industrial organization economics), coupled with regulatory punctuation (i.e. sudden regulatory changes), to investigate the evolution pattern of mining firms in Canada between 1929 and 2006. The study concludes that even though neither theory can explain the birth or death of Canadian mining firms, there is evidence that the introduction of environmental legislation and tax reforms during the 1970s altered the cost structure of the industry in such a way that a decline in firm numbers was witnessed. Similar to an “event study,” and markedly different from a holistic view of the industry, this study focuses on exogenous forces to explain the growth and decline of mining firms regardless of the many other aspects acknowledged in a mining system.

This section navigated through major studies both outside and within the framework of system dynamics to shed light on the literature gaps this study could address. Mostly similar to the last reference, this thesis evades an event-oriented explanation and mostly focuses on dynamic interactions to explain industry behavior.

## **Chapter 3. Problem definition and research questions**

Having examined why Myanmar's mining industry can be identified as dynamic and having reviewed past research about the mining industry, the following two sections will define the problem under study in a dynamic way and will list the research questions for this study.

### **3.1. Dynamic problem**

“The problem is related to the investment behavior of jade miners which is not consistent; sometimes they make very big orders, then they disappear; thus, it is difficult for us to plan and we lose opportunities”

K.A., General Manager & Owner

Figure 7 and Figure 8 help identifying the pattern and magnitude of the inconsistent purchases UMG's general manager referred to. While Figure 7 displays mining equipment purchases for five selected UMG customers from 2000 until 2011, Figure 8 presents an aggregated account of the total mining equipment units purchased by all UMG customers during the same time period. Both individual and aggregated purchases display oscillatory behavior, peaking every three years with all peaks corresponding to the same years (i.e. 2004, 2007, 2010).

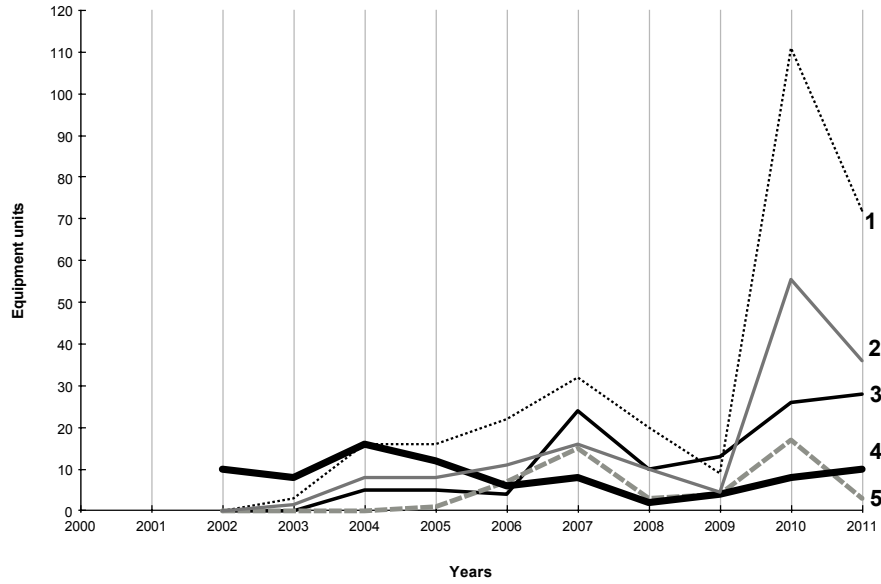


Figure 7 Yearly equipment purchases of 5 selected customers

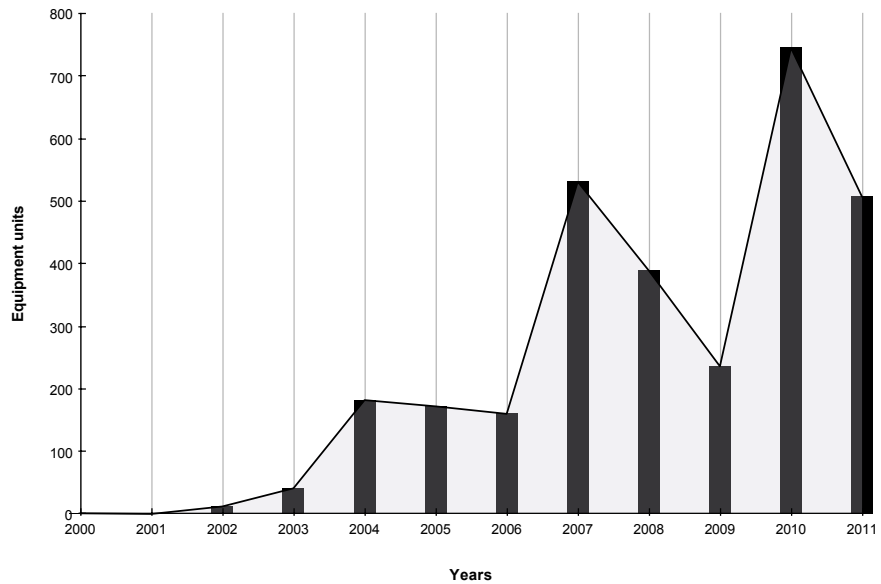


Figure 8 Aggregate yearly purchases of mining equipment

Since UMG’s market share is believed to be around 60%, it is critical to evaluate whether the purchasing trends of UMG customers can serve as a proxy to industry behavior so as to derive conclusions about jade depletion and the subsequent stagnation of jade mining and equipment purchases. A look at Myanmar’s jade production is perhaps necessary to crosscheck the possible effect of equipment purchases on aggregate jade production.

Yearly figures for jade production in tons from 1995 until 2010 (see

Figure 9), show oscillation with periods of 3 years just as the purchases of mining equipment. When Figure 8 and

Figure 9 are closely analyzed, as in Figure 10, in it can be noticed jade production follows purchases of jade equipment exactly after 1 year. [Note data for jade production in Figure 10 has been divided by 100 to fit into the graph]

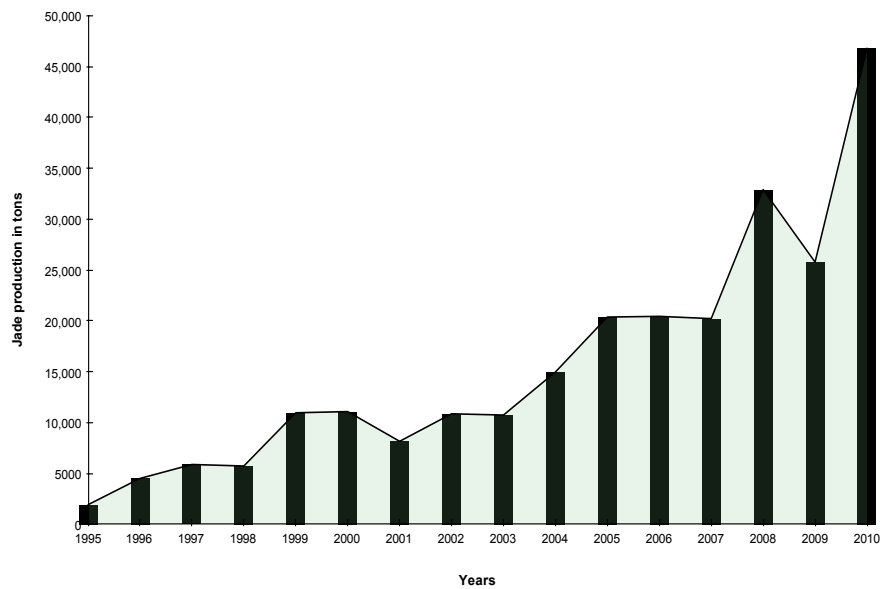


Figure 9 Jade production in tons from 1995 until 2010

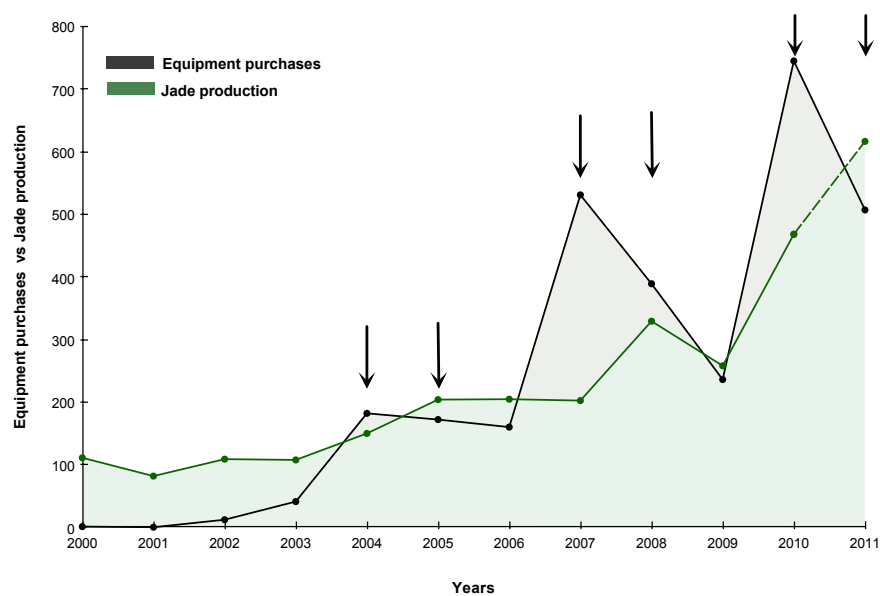


Figure 10 Equipment purchases vs. jade production

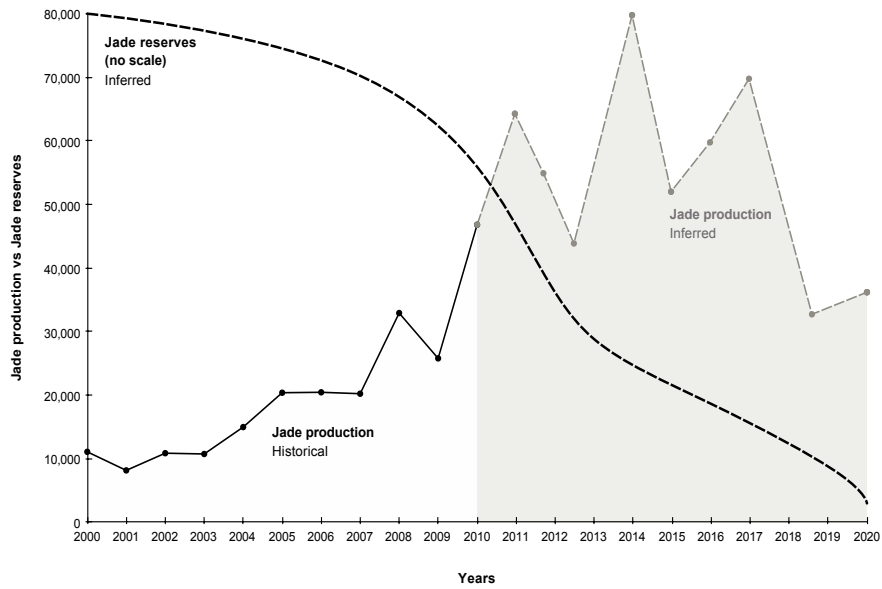


Figure 11 Inferred behavior of jade production and jade reserves

Figure 11 shows how the boom in jade production is thought to have materialized at the expense of jade reserves. As production continues to rise, jade reserves continue to be exhausted by mining companies until their unavoidable depletion prevents production from increasing further.

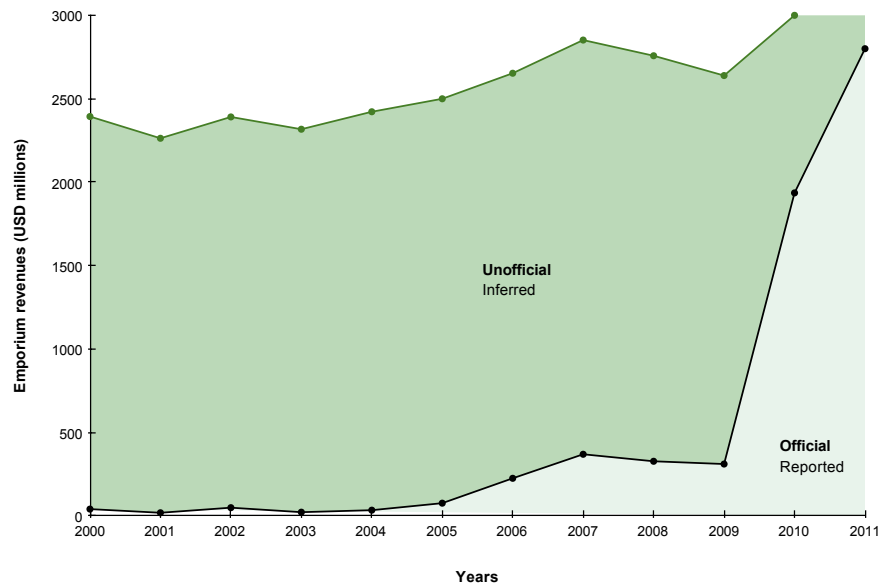


Figure 12 Emporium revenues (in USD millions)

Last, Figure 12 reveals inferred and actual reported revenues of government sponsored gem auctions from 2000 until 2011 (gem auctions are described in detail in section 6.3.5.3.1). While the light green shaded area represents the official reports on revenues in millions of USD, the dark green shaded area symbolizes the suspected non-reported or unofficial revenues from jade trade. In fact, Pick and Thein (2010) report that “a large proportion of economic activity in Myanmar is off the books to the point where the unofficial economy (including opium and jade trading) is at least as large as the size of the official economy.”

The problem under study is one centered on investigating the causes of oscillations that characterize equipment purchases from UMG. Jade production, jade prices, and suspected revenues from emporium sales have also been presented as means to draw a more complete picture on the effects of mining equipment additions on other industry indicators. Drawing from an industry-level understanding, the author expects to unveil the causes of the presented problematic behavior. Furthermore, industry behavior is also crucial at determining not only the pace and magnitude of future purchases, but also the sustainability of mining firms and UMG in the long run. For a brief complementary note on the process of building these reference modes, refer to Appendix 1.

### **3.2. Why are fluctuating purchases a problem to UMG?**

As a consequence of a heavy rainy season or “monsoon,” mining companies in Myanmar are forced to fully cease operations during May, June, July, and August of every year. In such circumstances, where only 8 out of the 12 months in the year are active, the guarantee of equipment availability and the avoidance of other major disruptions such as equipment breakdowns are of significant importance to jade miners.

A delay or pause in jade extraction caused by lack of equipment availability not only costs millions of US dollars in lost revenues to the mining firms but also



endangers customer satisfaction and results in lost sales for UMG. When the opposite happens and equipment availability is higher than it would have otherwise been, warehousing costs are incurred, as equipment must now be stored until there is demand for it. An understanding of the underlying causes of oscillatory purchases is therefore essential for UMG to ensure equipment availability at all times.

### **3.3. Research questions**

The system dynamics presented in this thesis is intended to answer the following three questions:

- Why is the investment behavior of jade mining firms cyclical?
- Which investment scheme can result in more stability for both jade mining firms and UMG?
- Which growth objective should be pursued by UMG given the years of jade extraction until exhaustion?

By having a deep understanding of the elements and relationships that lie behind customers' purchasing behavior, it is expected UMG's current ordering policy will better address customers' needs thus ensuring product availability and achieving target loyalty levels. Furthermore, insights from the model will shed light on UMG's corporate sustainability and on the future of Myanmar's jade industry in general.

### **3.4. Time horizon**

Because the main research question relates to the purchasing behavior of UMG customers, the year in which sales of heavy equipment took off in Myanmar seems an appropriate departure point. Evidence suggests it was not until 2000 when manpower was replaced by mining equipment in Myanmar's mining areas (AKSYU, 2008 ). Before this year, most mining was artisanal, thus labor intensive and based on rudimentary methods and tools (Smith, 2007).

In regards to the end of the “jade rush era,” locals estimate jade reserves will deplete in around 10 years from today (i.e. some say 6, others 15, others simply “soon”). The simulation interval has been consequently set to start in 2000 and extend until 2022, not only to match predictions about jade depletion but also to capture the delayed and indirect effects of potential policies (Sterman, 2000).

## Chapter 4. Methodology, data sources, and glossary

### 4.1. Methodology

As explained in the literature review, system dynamics is suitable for systems where the presence of time delays, feedbacks, and non-linearities are present. The jade industry is certainly one of such systems and will therefore be modeled following the modeling steps suggested in Sterman (2000).

### 4.2. Data sources

Figure 13 summarizes the main data sources used for this research project along with their corresponding “accessing method” (Verschuren & Doorewaard, 2010

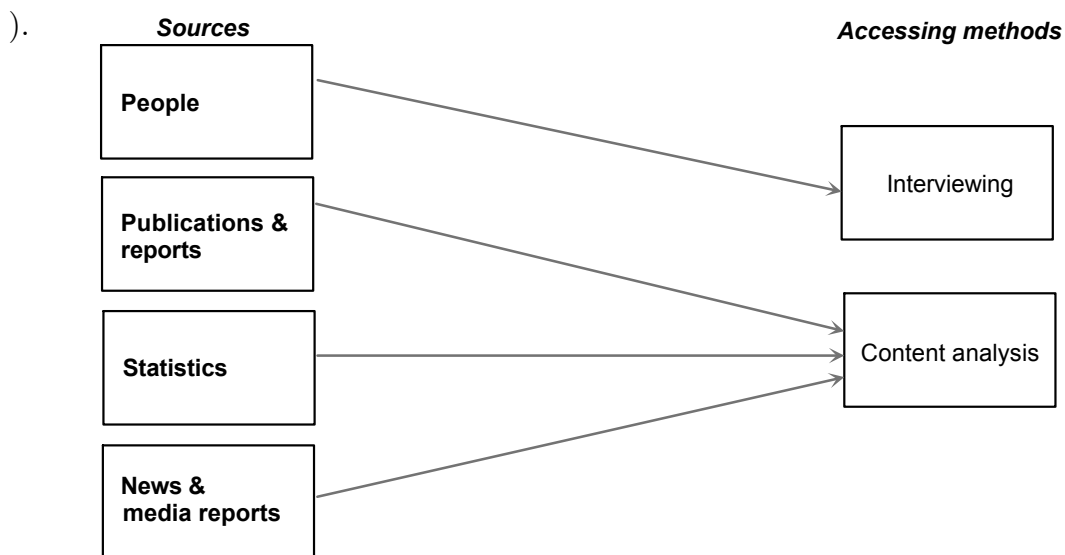


Figure 13 Research sources and accessing methods

#### 4.2.1. Interviews

Guided by the nature of the proposed research question, input from UMG employees and jade mining companies seemed of great relevance to understand the decision rules that govern UMG customers’ purchases of mining equipment. Semi-structured interviews were then chosen as means to analyze data, look for patterns,

definitions, and stories common to all respondents (Luna-Reyes & Andersen, 2003 ). Furthermore, in order to try to approach respondents' own concepts within a systemic framework Richardson (2006), a concept model was used to begin each interview. The concept model shown in Figure 14 proved helpful at introducing the system dynamics iconography that later on served as a strong foundation for model validation with some of the interviewees at the end of different model iterations.

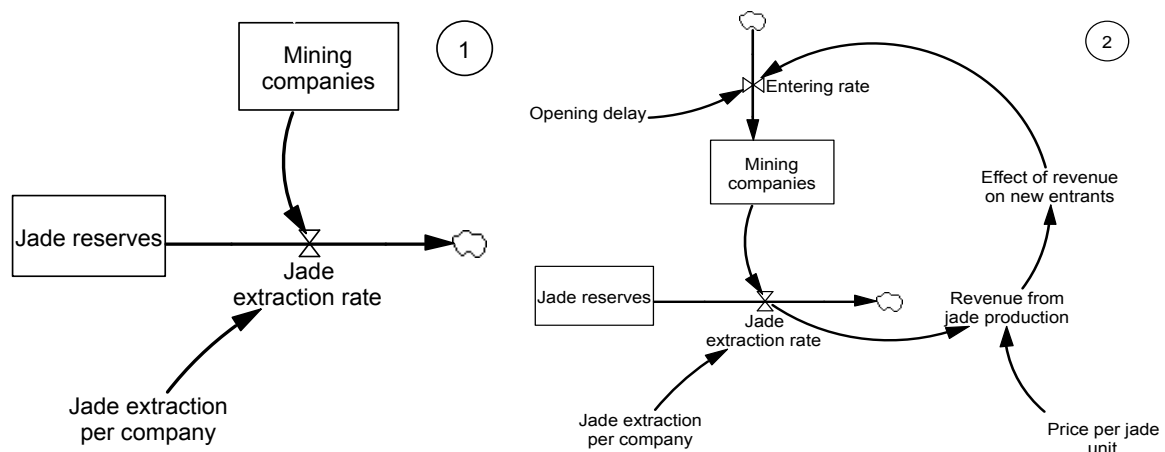


Figure 14 Concept model used in interviews

One of UMG sales officers, one of its senior salesman, and two branch managers participated as interviewees for this research project. Additionally, two former customers of UMG, one of them perhaps one of the biggest mining companies in Myanmar, and two local PhD geologists constituted other essential sources of information as well.

#### 4.2.2. Content analysis

Because Myanmar's military government appears reluctant to release truthful economic and social data, most information related to Myanmar's jade industry is to be found in secondary sources such as online newspapers, magazines, blogs, or publications reporting on human rights violations, environmental degradation, or the country's changing political prospect. Throughout the last century, for instance, only

few foreign gemologists have been granted government permission to visit Myanmar's mining areas and consequently only few journal articles have been published on the state of Myanmar's jade mining (Hughes, 1999). Publications and reports as well as other online resources were used as means to get acquainted with the subject matter and were accessed via content analysis.

### 4.3. Glossary

Though most of the terms used in this research are of general knowledge, there are some that pertain particularly to mining and hence deserve a short definition.

- *Gem*: a mineral or organic substance, cut and polished, and used as an ornament (Lagassé & Columbia University, 2000). Along with stones like aquamarine, quartz, and amethyst, jade belongs to the gem subgroup of semiprecious stones.
- *Imperial jadeite*: an emerald-green, translucent form jadeite often referred to as "imperial jade" or "gem jade." In Myanmar this type of jadeite is referred to as "mya yay" or "yay kyauk." (Howard, 2002).
- *Ore*: an metal-bearing mineral mass that can be profitably mined (Lagassé & Columbia University, 2000).
- *Grade*: the concentration of an element of interest, in this case jade, in a potentially mineable ore deposit (Allaby, 2008).
- *Open-pit*: a mine where all the ground above the mineral deposits or coal is removed so that the miners can get to the mineral; also called an open-pit mine, strip mine, or surface mine (The Burma Environmental Working Group, 2011).
- *Emporium shows*: government-controlled auctions selling different types of gems, including jade, and organized 3 times per year at Myanmar's capital city Naypyidaw.

## Chapter 5. Qualitative model description

### 5.1. Model boundary chart

Before describing the model qualitatively, and later on quantitatively, a model boundary chart will summarize the scope of the model by pointing out major endogenous, exogenous, and excluded variables (see Table 1).

ENDOGENOUS	1. JADE PRICE	5. JADE PRODUCTION
	2. JADE PER-CAPITA CONSUMPTION	6. EQUIPMENT PURCHASES AND SCRAPPING
	3. CAPACITY UTILIZATION	7. JADE INVENTORIES
	4. MINING LICENSES	8. INDUSTRY FINANCIAL PERFORMANCE
EXOGENOUS	1. CONSUMER POPULATION GROWTH	2. MINING LICENSES
EXCLUDED	1. MINE MANAGEMENT	4. NUMBER OF MINING COMPANIES
	2. MINE CLOSURE	
	3. SUBCONTRACTING OF MINING OPERATIONS	
	4. ENVIRONMENTAL DYNAMICS	

Table 1 Model boundary chart

Endogenous variables are all those within each model subsector in Figure 15. Exogenous inputs are only two, namely (a) the growth fraction that drives the increase in the population of consumers, and (b) mining licenses. Finally, excluded from the model are mine management dynamics, the dynamics of mine closure, the process by which big mining corporations subcontract jade mining operations to smaller ones when land concessions greatly exceed their expansion frontiers, the number of individual mining companies operating, and last, environmental and community dynamics.

## 5.2. Dynamic hypothesis

Figure 15 shows a simplification of the underlying feedback structure responsible for the oscillations in jade production and equipment purchases. Physical, perceptual, and administrative delays important to the behavior of the system are also explicit in this basic model by means of delay marks in some of the variable links. Figure 15 also shows the relationships among the three most important model subsectors: (a) land, (b) production, and (c) market.

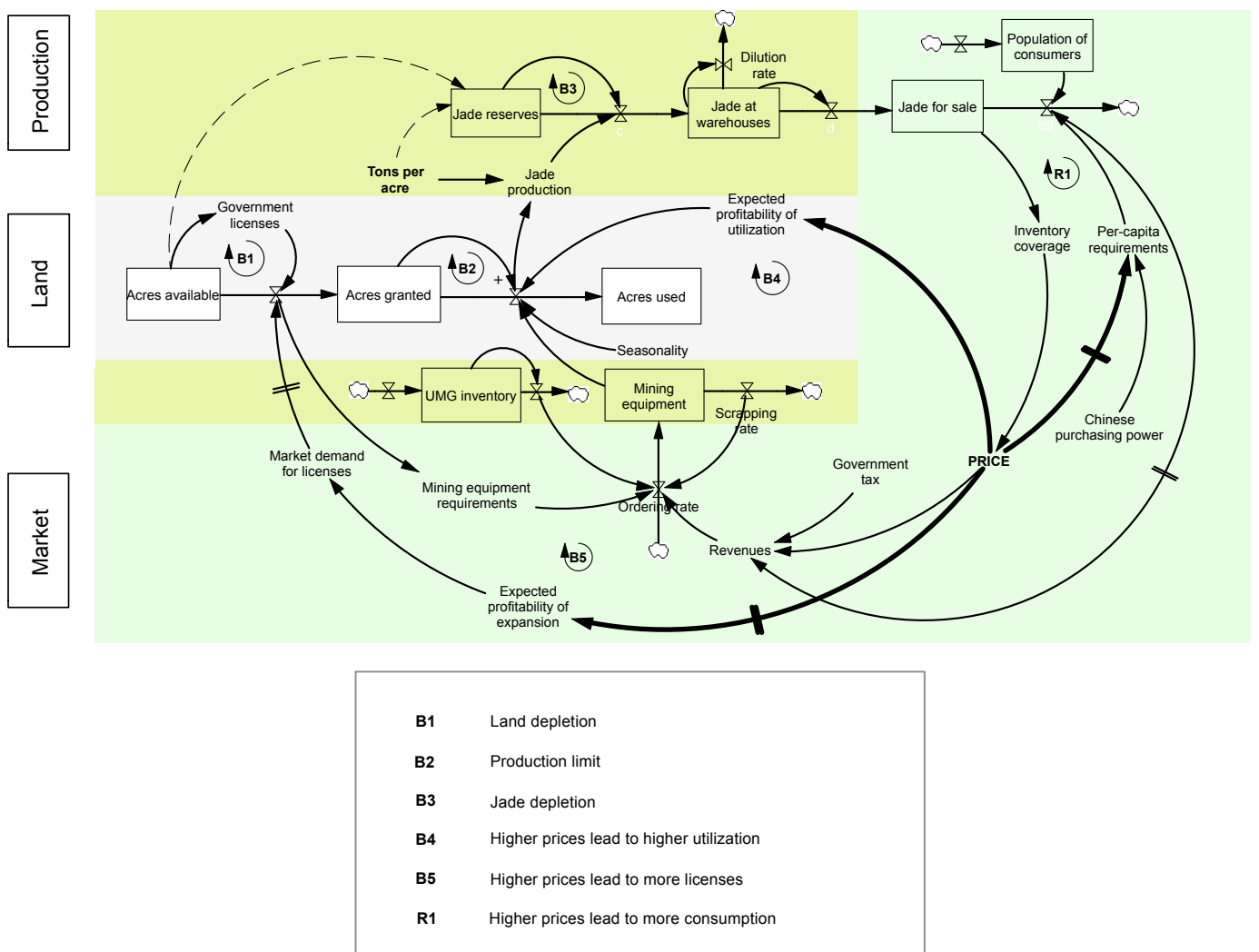


Figure 15 Model subsectors

Generally speaking, when more land is passed to mining companies (land subsector), jade supply or production increases (production subsector), thus affecting

prices through changes in inventory coverage (market subsector). Market prices feedback into consumption in the demand side, and into capacity expansion and capacity utilization in the supply side. Each of these interactions will be expanded further in the following sections.

### **5.3. Dynamic hypothesis**

Demand and supply loops, coupled with delays of various nature in the system, act to cause instability and oscillations in Myanmar's jade mining industry and subsequently in the purchases of mining equipment. On the supply side, high prices lead to higher utilization of current capacity in the short-term (B4). When high prices persist, mining companies expand by applying for more mining licenses and by acquiring more equipment to cope with new land concessions (B5). Note that while utilization decisions are made based on the difference between variable costs and price, no financial analysis is computed (not even among the biggest mining companies) for land expansion decisions. Later in this document, a stock-and-flow structure for financial analysis will be incorporated to the model to test whether development decisions would have resulted in something different in the face of prior financial assessments.

Jade prices depend on the balance between demand and supply. Stocks of raw jade increase with increased production and decrease with the sales rate controlled by the demand or consumption of jade. Prices increase when the inventory coverage falls (inventory coverage is defined as the ratio of inventory to consumption) and vice-versa. Although the existence of substitute goods also influences price, the model assumes jadeite jade has none given its legendary and unique significance to the Chinese society (main buyers of the green stone). For the Chinese, there is simply no other stone that could replace jade in any respect. Therefore inventory coverage is taken as the only determinant of price in this model.



On the demand side, it has been empirically found jade consumption increases with increases in price, emulating the demand curve of a Veblen good (R1). When consumption increases, inventory decreases, and jade prices soar. Price increases encourage land and capacity expansion among jade mining companies. However, because production cannot adjust immediately, inventories continue to be depleted. Once initiated, production accumulates in excess of demand, which despite being high remains less than supply. Inventory coverage is now high, prices drop, and land expansion stabilizes given the inability of lower prices to support further expansion. Balancing feedback loops in the system coupled with delays of diverse nature are responsible for the oscillations that characterize Myanmar's jade mining industry. The subsequent sections (starting by the acre and jade aging chains and followed by the effects of price on utilization, expansion and consumption) will expand on the dynamic descriptions for each of the loops involved in the jade industry model.

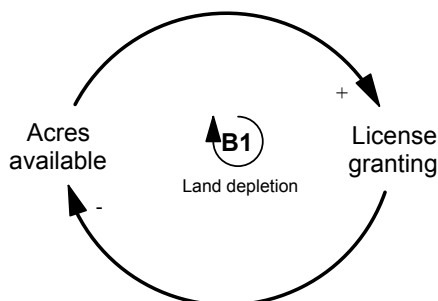
### **5.3.1. Acre aging chain**

The acre aging chain replicates the transfer of land from the central government to jade mining companies. In accordance with Myanmar 's mines law of 1994, "all naturally occurring minerals found either on or under the soil of any land in the continental shelf are deemed to be owned by the state" (Ministry of Mines, 2004). This translates into the exclusive and official rights of the government to approve all land and water concessions related to mining.

Within this context, "acres available," meaning pristine or not exploited land, are first transferred from government hands to mining companies through mining licenses. After a production delay, jade resources start to be mined and the land stripped. Utilized or stripped land finally accumulates in the stock of "acres used." As it will be explained in section 8.4, stripped land in Myanmar is not rehabilitated or vegetated further after mining operations have come to an end. Therefore, a flow

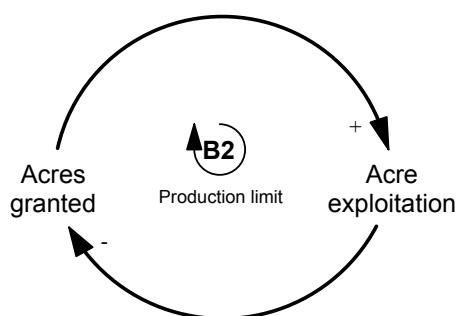
that connects the stock of “acres used” back to “acres available” has not been included. Loops B1 and B2, part of the acre again-chain, are described next.

### 5.3.2.B1 – “Land depletion”



Consider the structure of the balancing loop B1 or the “land depletion loop” in the acre aging chain. The more the licenses are granted for mining, and in consequence the more the land given away to miners, the less the land available for further mining concessions. The balancing loop 1 denotes the “carrying capacity” of the system in relation to available land. In other words, regardless of market demand, the gradual exhaustion of economically mineable land will mark the gradual decrease in license granting at some point in time.

### 5.3.3.B2 – “Production limit”



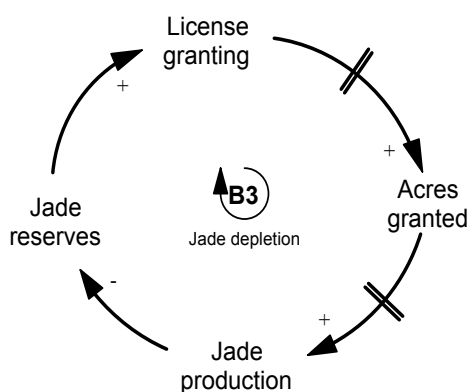
Balancing loop 2, named the “production limit” loop, limits jade extraction whenever the stock of acres granted proves inadequate. The more the acres ceded to mining companies, the more the land exploitation and jade extraction, and the more the exploitation and extraction, the less the land remaining for further works.

### 5.3.4. Jade aging chain

The jade aging chain is a 3-stock supply chain that shows the movement of jade out of the reserves, via jade production, to the stock of jade in warehouses, and finally to the stock jade ready for sale. The stock of jade reserves is formulated as the product of the initial acres available and the parameter tons per acre. The

dilution fraction (explained in detail in section 0) prevents all mined and stored jade to be put for sale. In the last stage, the product of per-capita consumption and population of consumers drains the stock of jade for sale through purchases. An explanation of loops B3, B4, B5, and R1 follows next.

### 5.3.5.B3 – “Jade depletion”



Similar to B1, balancing loop B3 denotes the process through which, along with mineable land, mineable reserves are also depleted as a result of resource use or jade extraction. Though not literally exhausted, the term scarcity of gems is normally used to indicate the “decreasing concentrations of mineral

resources at some time in the far future” (Brent & Hietkamp, 2006).

Reserves exhaustion is irreversible given the finite, and hence non-renewable, nature of jade deposits. In this respect, mention should be also made of the current mining situation in Myanmar perfectly fitting the tragedy of the commons dilemma, in which “the more users there are, the more resource is used; the more resource is used, the less there is per user” (Meadows & Wright, 2008). Translated to B3, the more the licenses, the more the acres granted; the more the acres granted, the more the jade production; the more the production, the less the reserves; and finally the less the reserves, the less the license granting.

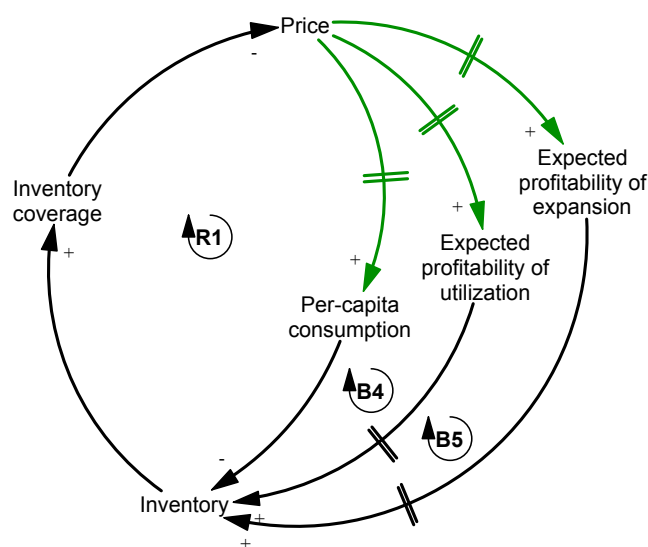
Because there is no incentive for the government or the mining companies to preserve the resources shared by the commons (i.e. mineable land and jade deposits), overextraction of jade is taking place by jeopardizing entire villages through ecologically damaging mining techniques banned everywhere else (EarthRights Interantional, 2007), land erosion, deforestation, polluted rivers, floods, landslides, and social and health costs absorbed the communities involved.

The tragedy of the commons arises from the delayed or missing feedback from the state of the resource to the growth in the amount of users who take advantage of the resource. The latter increase jade production at a rate that is not influenced by the condition of the commons. This detachment holds true for jade, as reported in Howard (2002):

“There is a subsidiary claim that "the stock of the best-quality jade is getting smaller." Perhaps, but again substantiating evidence is lacking and it is likely that in the face of increasing demand for high quality jadeite there is the perception of a shrinking pool of "good-quality" jadeite, whereas the actual situation is that the supply of good quality jadeite is proving unable to keep pace with growing demand”

Unless meaningful changes at the government level divert the course of gem mining from indiscriminate depletion and irresponsible environmental damage, jade along with other mineral resources in Myanmar will be wiped out and all users who benefited from it ruined.

### 5.3.6. The role of prices on utilization, expansion, and consumption



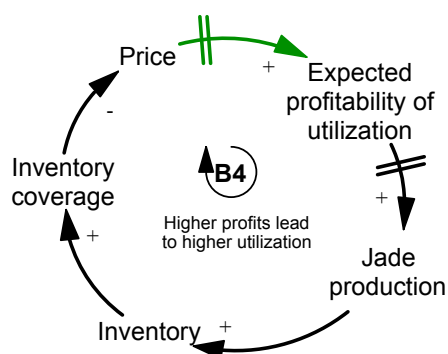
In the model, prices play a critical role by determining changes in (a) capacity utilization, (b) land expansion, and (c) consumption. In the first case, short-term expectations of a high price encourage higher utilization of installed capacity to raise production and consequently profitability. In the

second case, long-term expectations of high prices motivate mining companies to

expand production by acquiring, through mining licenses, more mineable land. In regards to industry demand, it is hypothesized that for the case of jade higher prices lead to higher consumption.

In the three cases, different adjustment delays form first-order responses in assessing profitability for utilization and expansion decisions, as well as in forming price expectations on consumers. Once expectations are formed, physical delays in the utilization and expansion loops prevent production and inventories from rising instantaneously. Note also that except for the last case, utilization and expansion lead to higher production, bringing prices down again via increased inventories and inventory coverage.

### 5.3.7.B4 – “Higher prices lead to higher utilization”



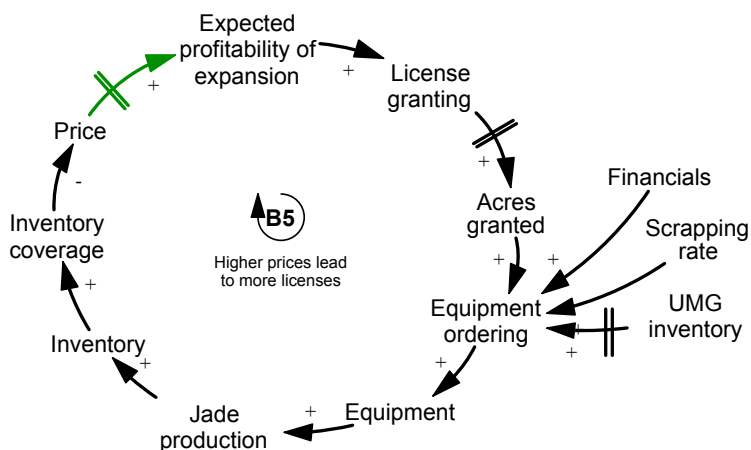
Utilization depends on mining companies’ short-term expectations of profitability of operations. When prices rise, the fastest measure that can be implemented to take advantage of the expected profitability is to use installed capacity to raise production. In Myanmar, the two mining companies

interviewed reported most companies increase production temporarily when jade prices increase. A jump in jade production is possible given mining equipment only operates 20 hours per day and not 24 as in most mining industries anywhere else. Also, some companies might continue mining operations during the first days of the “wet monsoon season” (a description of monsoon in provided in section 6.3.4.2.1).

Because decisions towards price changes are not made immediately and after that utilization cannot be adjusted instantly (i.e. new shifts for machine operators must be ensured for instance), a delay mark lies on the arrow linking price and expected profitability of utilization, and utilization and production respectively.

When increased utilization is finally a reality, jade production rises, inventories increase as inventory coverage does, and prices fall as a result.

### 5.3.8.B5 – “Higher prices lead to more licenses”

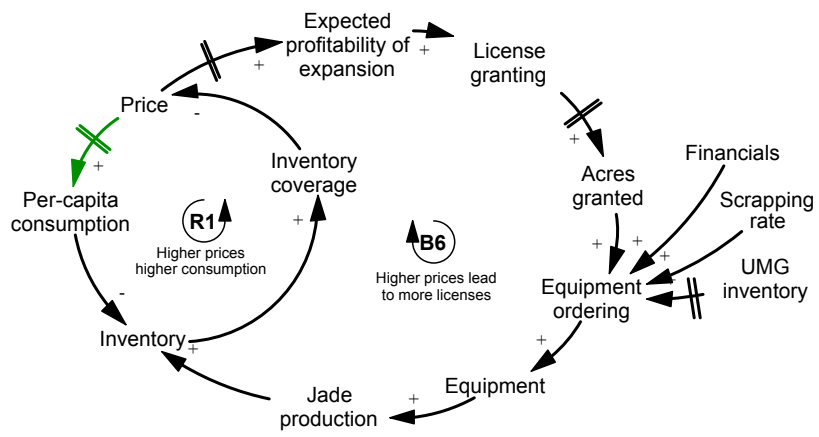


Balancing loop 6 shows the effect of jade mining companies’ long-term price expectations on additions to capacity. When stocks of warehoused jade are lower than desired, inventory coverage

decreases, causing increases in price. Higher prices raise miners’ price forecasts prompting them to expand by applying for more licenses and after a delay, proceed with purchases of equipment. Equipment orders are not only affected by land concession, but also by financial flows, that either allow or constraint purchases, the equipment scrapping rate, and UMG’s product availability. When equipment is finally obtained, production kicks off, increasing stocks of inventory, restoring inventory coverage, and bringing price down again.

### 5.3.9.R1 – “Higher prices lead to higher consumption”

Different from the demand function identified in commodity cycles, purchases of jade and other gems increase with increases in price (refer to section 6.3.5.3.2.2 for a more detailed explanation). The green arrow in R1 suggests that besides altering utilization and fueling producers’ desires for further expansion, higher prices also trigger higher per-capita consumption, thus slowly bringing down inventory levels, and causing slight increases in price.



## Chapter 6. Stock-and-flow model structure

A summarized causal diagram in Chapter 5 emphasized the feedback structure causing oscillations in the production of jade. Now, a description of the complete stock-and-flow is incorporated in order to emphasize the exact physical structure of the model, and the assumptions, justifications, and mathematical formulation behind it.

The following list introduces the notation used across the model to differentiate among subsectors and special parameters:

- LND or land: denotes the land available for mining, the land being used by mining companies, and the total land already exploited;
- PROD or production: denotes the process of determining mining equipment requirements and the actual extraction of jade;
- MRK or market: denotes all market-related variables such as consumer demand, jade prices, and demand for mining licenses;
- GOVMT or government: denotes government related elements such as taxes on emporium transactions;
- FIN or financial: tracks cash inflows and outflows resulting from mining-related transactions;
- NPV or net present value: denotes the discounted cash flow analysis performed in the model for mining development projects;
- EFF or effects: denotes a graphical function;
- SWITCH: denotes a switch parameter;
- NOISE: denotes the intervention of noise in a variable.
- SCE: parameter inputs for the scenarios presented in section 7.2.2.

Each of these prefixes will appear in future sections at the moment of quantifying parameters or describing relationships among variables. Before starting,



a brief introduction to jadeite and its significance are provided as means to describe the gem around which most of the mining activity in Myanmar revolves.

### **6.1. An introduction to jadeite**

The name jade is derived from the Spanish word “piedra de ijada,” or “stone of the flank” (it was believed to cure renal colic), and is a generic term for two different gems that differ from one another mainly in their chemical composition, texture, and colors. The first and most common type, nephrite jade, is a white-to-green amphibole rock, also known as the “toughest natural stone on earth” (Hughes et al., 2000), that has the property of maintaining its integrity even when carved into delicate shapes (Naylor, 2010 ). The discovery of nephrite is attributed to the Chinese and its use for the fabrication of weapons and various ornaments extends back to around 5000 BC (Sax, Meeks, Michaelson, & Middleton, 2004).

The second and most sought-after type, jadeite jade, is a pyroxene compact rock that can be found in white, yellow, brown, purple, black, and various shades of green to emerald green colors depending on the relative concentration of chemicals like chromium, manganese, or oxides of iron and manganese (Win, 1968) (see Appendix 2). Jadeite jade is rarer and more valuable than nephrite because it possesses all the wanted physical traits of the latter yet is also endowed with a specially vivid imperial green color (Naylor, 2010 ), greater translucency, and very fine and compact texture. Upon the discovery of jadeite in Myanmar in the 18<sup>th</sup> century, China’s passion for what is believed to be the “stone of heaven” (i.e. it connects heaven and earth) has grown incommensurably.

Although jadeite can be also found in many other locations such as Guatemala, China or Russia, the world’s trop-grade most important jadeite deposits are confined in Myanmar (Ehrmann, 1957). Geologically unique, jadeite was formed at the place where the largest layers of the earth collided against each other on Myanmar’s Tawmaw plateau around 200 million years ago (Hughes, et al., 2000). As

a result of this collision, parts came out at very high speed to emerge as mountain ranges (Htwe, 2011). These ranges are known as jade “primary deposits” or deposits that hold their original relationship with their host rock (Schumann, 1997 ). Most jade extracted in Myanmar, though, comes from “secondary deposits” or rocks that have been washed away, transported, and deposited to a second location. While primary deposits are found in many parts of the Tawhmaw region, secondary deposits are located around Hpakan and other townships west of the Uru River.

## **6.2. Jade mining method**

The type of gem deposit is the major determinant of the mining method to be chosen. Win (1968) classifies jade mines as dyke mines and boulder mines, the former being of primary nature in which fire is used to break up the jadeite underground, and the latter being of secondary occurrence in which pit, beds of streams, and sluicing methods of mining are used depending on the season. Although the mining operation is not explicitly represented in the model, the choice of mining method certainly influences the nature of the extraction rate. Therefore, the open-pit method, the one most extensively applied during the dry season when operations are ongoing, has been chosen as the framework for modeling the shape of gem-grade extraction.

## **6.3. Overview of the stock and flow description**

The following subsections will go through the model’s structure following a logical sequence. Starting from the moment mining companies apply for a jade mining license, the descriptions explain the subsequent selection and purchase of equipment, the beginning of jade production, its storage and posterior sale, and finally the effect of inventories on prices, capacity expansion, capacity utilization, and consumption. At the end, a description of the model’s financial sector is also included.

### 6.3.1. Mining licenses

Land is transferred to mining companies via mining licenses. It is crucial to have in mind that the number of licenses granted to jade mining is absolutely discretionary (Chovanec, 2011) and that the exploitation of jade mines by private companies can only take place through partnerships or joint ventures (JVs) with the state-owned “Myanmar Economic Holdings Ltd. (MEH).” MEH is part of one of the four corporations created to take charge of the exploration, production, and commercialization of different groups of minerals and gems in Myanmar (i.e. (1) Mining enterprise 1 in charge of non-ferrous metals, (2) Mining enterprise 2 with oversight on tin and tungsten metals, (3) Mining enterprise 3 responsible for industrial minerals, and (4) MGE responsible for jade and other gems) (Moody, 1999).

The allocation of new mining licenses under a JV agreement is carried out through a bidding system where prospect buyers must first put down a 100,000-kyat deposit (around USD100) and then bid with a starting amount of 1 million kyats (USD 1,000) for each plot. For the best areas, the bidding can go up to 55 million kyats (USD 55,000) per plot (Rangoon Embassy, 2002). One of the mining companies interviewed revealed private companies not entering a JV agreement with the government bid with a starting amount of 100 million kyats (USD 10,000).

Figure 16 shows estimations of the number of blocks licensed for jade mining from 2000 until 2001 and from 2005 to 2008. Because the number of licenses approved by the government is strictly confidential, only figures for six years could be obtained as reference. The gray dotted line denotes the inferred behavior by the author.

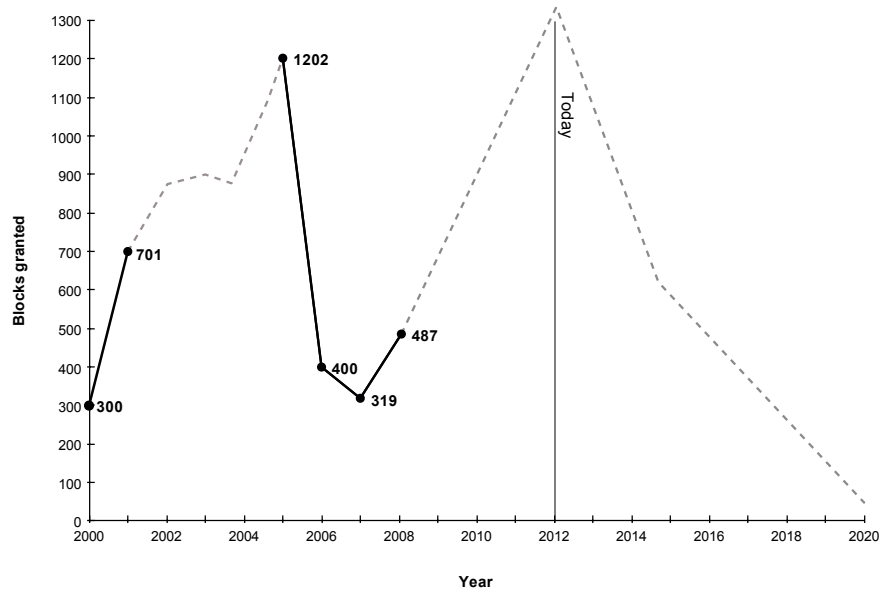


Figure 16 Mining blocks granted by the government

[Source: Wu (2000), Wu (2001), Palagems (2012)]

It is widely acknowledged only those with strong ties to the junta reap the benefits of the licenses being offered, meaning license demand is somehow a game that only those with the best connections can play. By 2008, more than 450 private companies and some 30 joint ventures were reported to be operating in Myanmar’s mining sites, the majority of which are owned by Burmese with Chinese heritage (Pepper, 2008 ) (AKSYU, 2008 ).

### 6.3.1.1. Mining licenses in the model

In the model, government supply of mining licenses responds to government officials’ long-term expectations of high jade prices and therefore to beliefs of high profitability. Demand for licenses, though, is eventually constrained by the depletion of proven land reserves as reflected by the land utilization fraction. The more the licenses granted, the less the land available for mining, and the less the amount of licenses that can be offered by the government even in the face of high demand (see Figure 17).

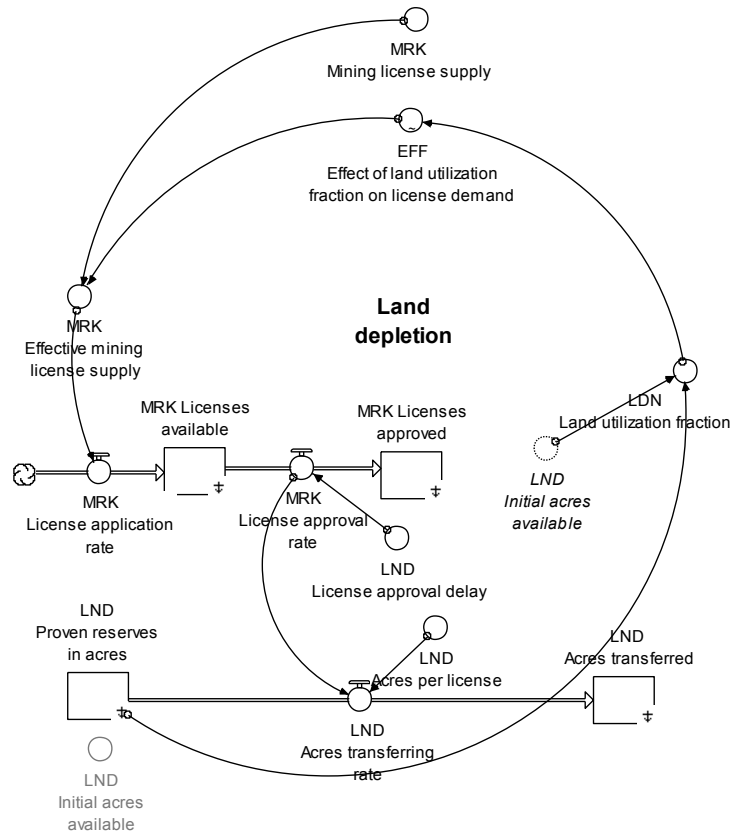


Figure 17 Stock and flow structure for mining licenses

Assuming a first-order license approval delay of 2 months, licenses approved are converted into acres (one mining license is equivalent to one acre of land with tenure of five years and the option for a three-year renewal) and begin depleting the stock of proven land reserves. Note the stock of land is finite and has been initialized at 50,000 acres as explained in section 6.3.2.1. Land beginning to accumulate in the stock of acres transferred trigger the “equipment expansion loop” involving the purchase of mining equipment and the consequent increase of labor and other indirect mining costs. This process will be explained next.

### 6.3.2. Land transferring



acres (Htay, 2011) (Jade-Jadeite, 2008). Because each jade mining license is equivalent to 1 acre of land, the stock of “acres available” has been initialized at 50,000 acres. Acres available refer to the total amount of unexploited jade-rich land that will eventually be granted to mining companies through mining licenses.

$$LND \text{ Initial acres available} = 50000 \ll \text{acres} \gg$$

Sensitivity analysis in later chapters will test the model’s behavior under different parameter values for the jade mining extension.

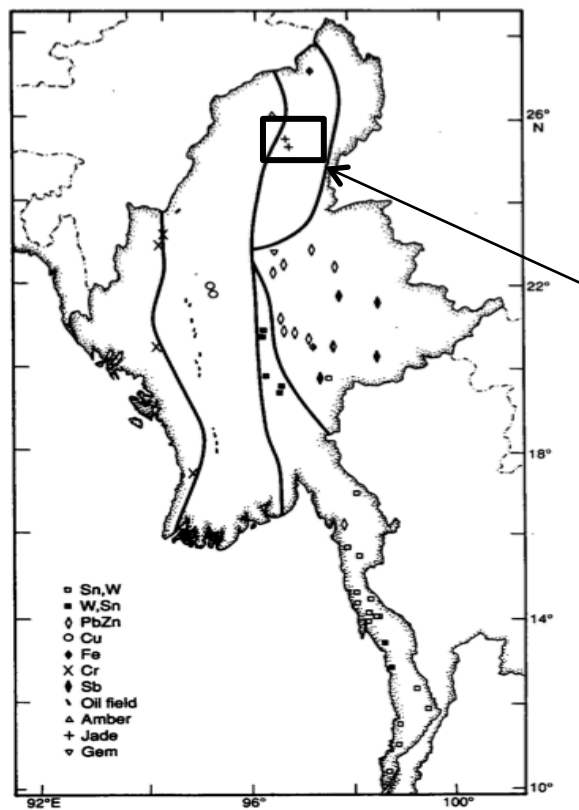


Figure 19 Jade mining area

[Source: Fan and Ko (1994)]

### 6.3.3. Mine life and equipment requirements

After acres have been granted to mining companies, the purchase of mining equipment follows. Mining equipment selection usually starts by determining the optimum sizes of equipment and the number of units required for a given production

schedule (Society for Mining Metallurgy & Exploration, 2001). In this model, all mining equipment (e.g. excavators, trucks, drilling machines, etc.) will be considered as “standard,” meaning no type, model, or serial discriminations will be made at the moment of ordering equipment. Although models and serials do matter (i.e. they determine the sizes of buckets or benches and therefore equipment productivities per load and equipment productivities per shift), it will be simply assumed standard mining equipment can process x fraction of an acre per shift instead of a tonnage amount per shift. Some of the factors that usually govern the selection of mining equipment, and how they were addressed in the model formulation, are described below:

- *Mine life*: the number of operating years of a mine that guide the production plan or schedule for the extraction of jade. In this model, the validity period of a mining license defines the production lifespan of a particular mining site;

$$PROD\ Mine\ life = 5 \ll years \gg$$

- *Mine geometry*: the area of the mining site. In this model, the number of licenses granted to a mining firm, each equivalent to 1 acre of land, equals the area to be mined;
- *Site location*: refers either the location of the mining site in relation to the dumping site, its location in relation to neighboring sites property of other mining companies, or simply the geographical characteristics of the site. In this model, site location does not play any role;
- *Topography*: the physical features of a particular mining site. Topographic details are not included in the model;
- *Total material movement*: relates to transporting distances (e.g. from the mining site to the dumping site) or the features of the material (e.g. dense minerals). In this model, drilling, blasting, loading, or dumping activities,



just to mention some, are not considered and therefore total material movement is ignored;

- *Work schedule:* dictated by the number of shifts per day, the duration of each shift, and the scheduled number of working days per year. In the case of Myanmar, mining shifts are 3/day with an average duration of 7 hours each. Seasonality, specifically the monsoon season, modifies the amount of operating hours per month as will be explained in the next section.

Table 2 shows the calculation used for defining the size of the equipment fleet and Figure 20 how such calculation was incorporated in the model:

PERIOD	TOTAL ACRES	ACRES/SHIFT	REQUIRED SHIFTS	SCHEDULED SHIFTS	OPERATING SHIFTS	% UTILIZATION	FLEET
1	20	0.001	20000	750	27	0.8	33
2	20	0.001	20000	750	27	0.8	33
3	20	0.001	20000	750	27	0.8	33
4	20	0.001	20000	750	27	0.8	33
5	20	0.001	20000	750	27	0.8	33

Table 2 Calculation for equipment fleet



number of scheduled shifts in a year. The division of required shifts and yearly scheduled shifts is then calculated to obtain the number of equipment units needed to handle the required shifts and achieve the targets set for each mining period. Finally, when the equipment utilization rate is below 100%, more units are added to the required equipment fleet.

### 6.3.3.1. Equipment purchases

When the desired equipment fleet has been defined, the process of ordering equipment starts. The structure in Figure 21 shows incoming orders accumulated in a backlog that is only emptied when deliveries are materialized. Note the ordering process of supplier firms have not been explicitly modeled as more than finding an optimal ordering policy, the purpose of this model is to investigate a particular behavior pattern in purchases.

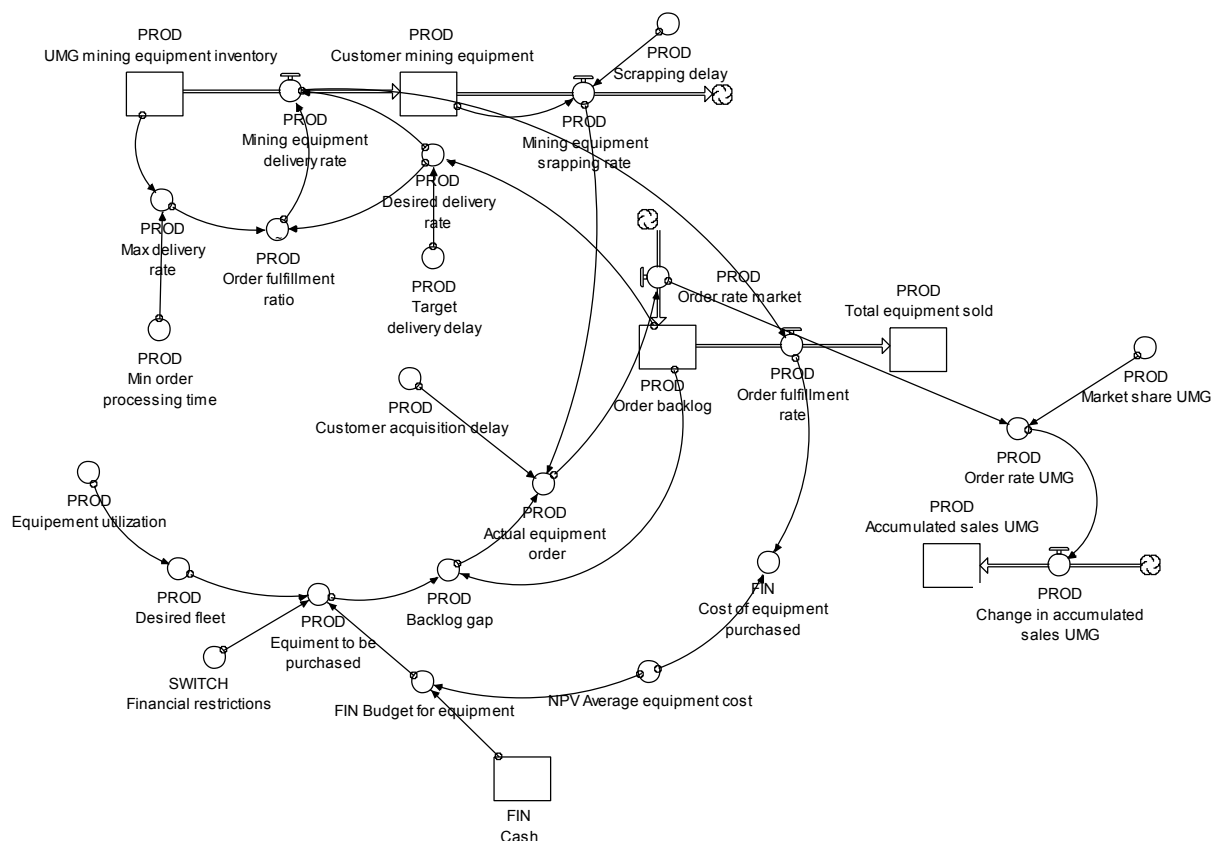


Figure 21 Stock and flow structure for equipment purchases

For simplicity purposes, it is assumed that even when there is lack of product availability at UMG, customers switch and will find the equipment elsewhere.

### 6.3.4. Jade production

The stock and flow structure in Figure 22 shows the production process that follows after the mining equipment has entered the stock of “customer mining equipment.”

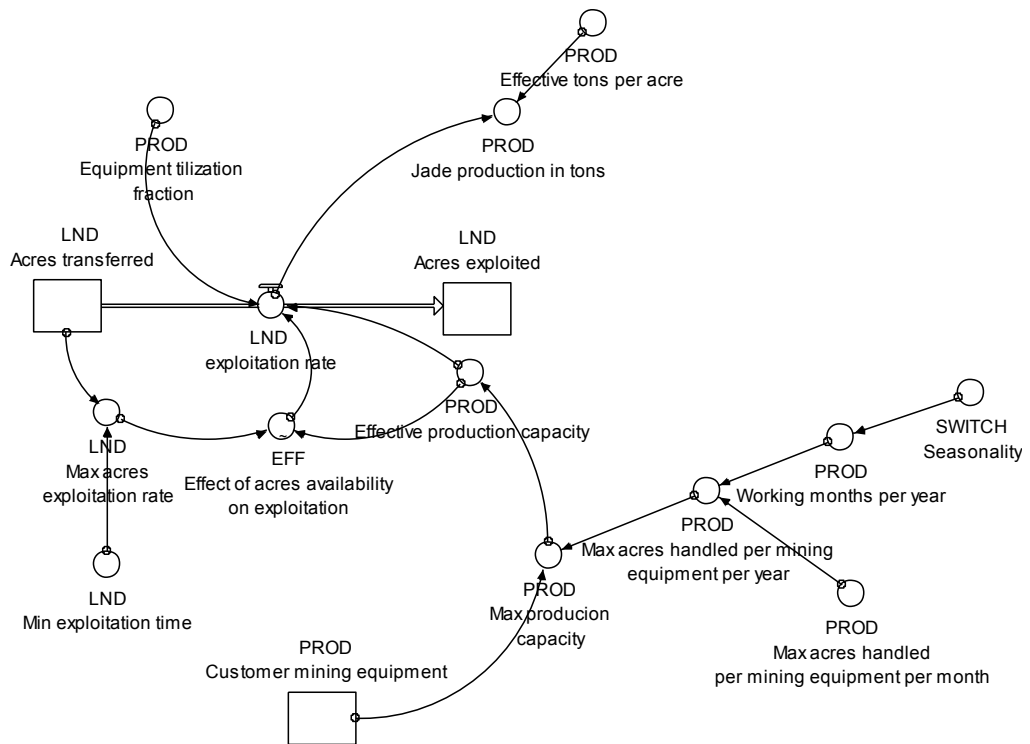


Figure 22 Stock and flow structure for production

#### 6.3.4.1. Exploitation rate

Jade production, or the jade exploitation rate, is calculated as the product of the effective production capacity and the effect of acres availability on exploitation. The latter is a first-order control introduced to reflect miners’ behavior upon the exhaustion of the land they own.

$$LND \text{ exploitation rate} = PROD \text{ Effective production capacity} * EFF$$

$$\text{Effect of acres availability on exploitation}$$

The effective production capacity is the product of the equipment utilization fraction and the maximum production capacity. The former gets activated through a capacity expansion feedback, explained in detail in section 0, in which mining companies raise production following positive profitability expectations driven by short-term expectations of jade prices.

$$\begin{aligned} \textit{PROD Effective production capacity} &= \textit{PROD Equipment tilization} \\ &\textit{fraction} * \textit{PROD Max producion capacity} \end{aligned}$$

Finally, the maximum production capacity is the product of the total equipment owned by mining companies and the maximum amount of acres one mining equipment unit, say an excavator, can process per year. This last measure was calculated from data provided by one of the mining companies.

$$\begin{aligned} \textit{PROD Max producion capacity} \\ &= \textit{PROD Customer mining equipment} \\ &* \textit{PROD Max acres handled per mining equipment per year} \end{aligned}$$

$$\textit{PROD Max acres handled per mining equipment per month} = 0.1 \ll \frac{\textit{acres}}{\textit{mont}} \gg$$

#### **6.3.4.2. The monsoon and jade production**

One cannot refer to jade production in Myanmar without mentioning the effect of the monsoon on yearly mining operations.

##### **6.3.4.2.1. Monsoon**

Harsh climate conditions in Myanmar, namely the wet monsoon, make mining sites almost inaccessible about one third of the year. The wet monsoon is a seasonal prevailing wind in the region of South and Southeast Asia mostly characterized by heavy rains between May and September. Whereas during the dry season mining operations run 7 days/week an average of 20 hours/day, when the wet monsoon season arrives fully in June, mining activities must cease entirely as shafts are completely filled by water (Ehrmann, 1957).

Mining operations start gradually dropping in April, as rain intensity is still manageable by then. From June to August rainfall is at its highest and works drop to zero. Throughout September, mining activities have not yet fully recovered since mines now need to be dewatered.

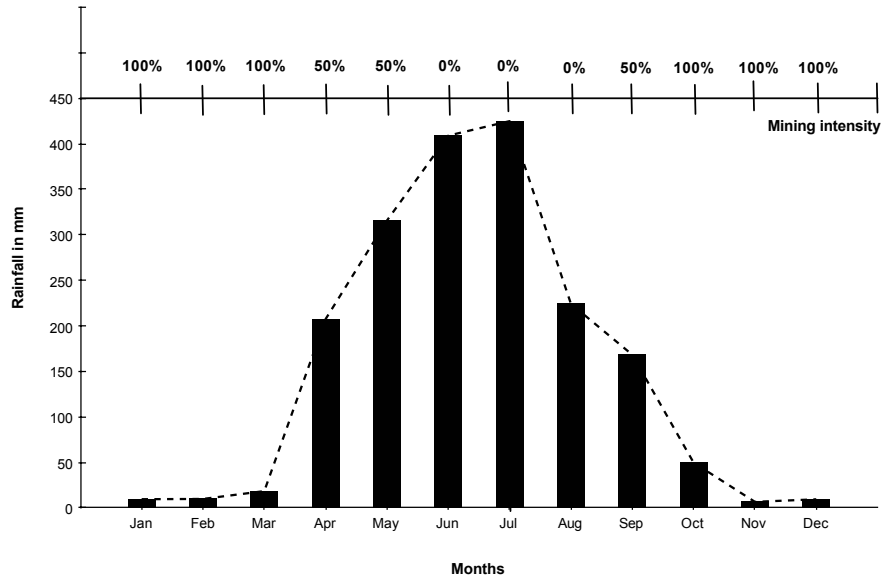


Figure 23 Average monthly rainfall in Myanmar from 1960 to 1990

[Source: The World Bank (2012a)]

Figure 23 shows in a bar graph mean monthly precipitation values in mm from 1960 to 1990 with an indicator on top displaying mining intensity percentages throughout the year. To prevent the noise, seasonality has been incorporated in the model as if operations would run 8 out of 12 months in a year when a seasonality switch is operating.

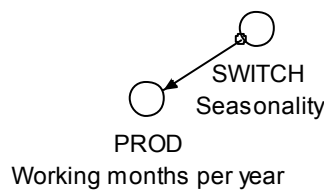


Figure 24 Seasonality in the model

### 6.3.4.3. Effective tons per acre

“Miners were asked how often they find jade. They said it depends on luck. While in some days they might find up to 25 pieces, other times they might go for days without anything. In terms of size, some boulders are 200–300kg, some even as big as a but most are less than 1kg”

Hughes, Galibert, Smith, and Oo (1997)

When asked how many tons of jade could be found in one acre of land all interviewees coincided with the quote above in that it is all about luck. Luck plays such a big role among Myanmar’s people that purchases of mining equipment are often materialized quicker when the buyer’s lucky number matches that of the equipment’s serial number, sales officers at UMG report. A closer look at production data from one of the mining companies revealed the tonnage per acre of land can range from 1 up to 24 tons/acre. The constant used for the simulation model has been set as the mean of both limits.

$$PROD \text{ Tons per acre} = 12 \ll \frac{\text{tons}}{\text{acre}} \gg$$

### 6.3.5. Jade extracted, jade in warehouses, and jade for sale

The jade aging chain shown in Figure 25 emulates the physical flow of jade being taken out from reserves, being classified, being stored, and finally being sold.

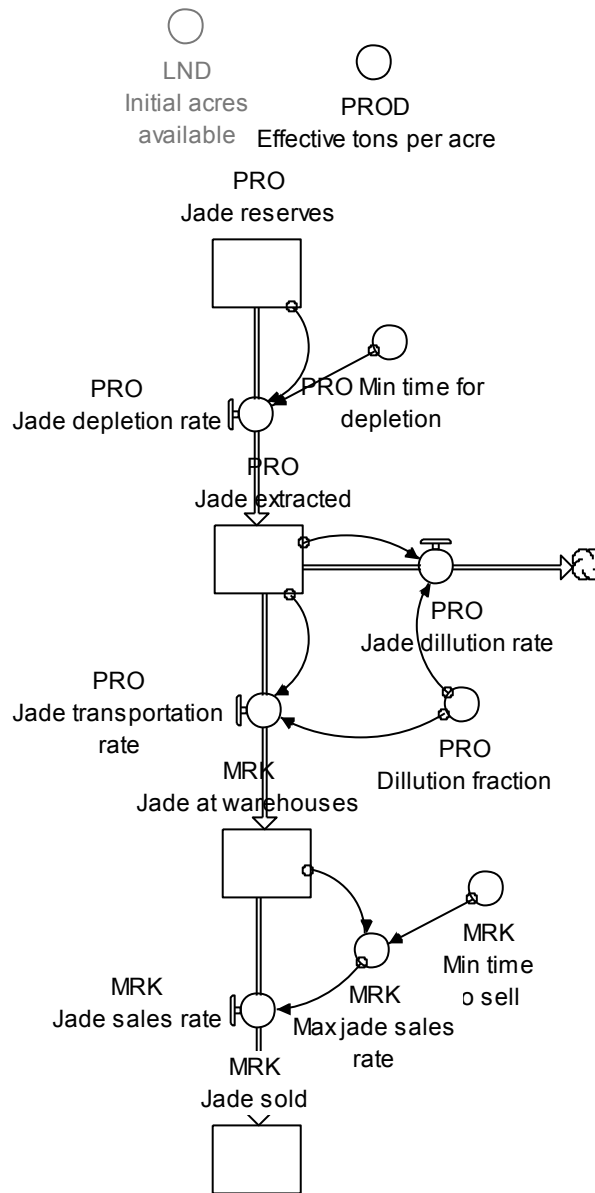


Figure 25 Jade aging chain

### 6.3.5.1. Jade reserves

“I am not geologist. I think even expert geologists cannot know. Only God can know this.”

A.M.H. UMG branch manager

Whereas estimations for Chinese nephrite jade reserves can be easily accessed (Jade-Jadeite, 2008), proven reserves for jadeite jade in Myanmar remain unknown. Part of the explanation resides in the fact that the government relies on antiquated geological data, much of it prepared by geologists who have now fled the country, or on data which may not have been efficiently updated (Moody, 1999). Even when



hypothetically reliable information on the state of jade reserves might exist, this is a sensitive governmental issue and hence subject to a high degree of secrecy. The initial value for the stock of jade reserves in the model is determined by the multiplication of the initial value for the stock of acres available and the constant tons per acre.

*PRO Jade reserves=*

*LND Initial acres available \* PROD Effective tons per acre*

### 6.3.5.2. Jade extracted and jade in warehouses

After being extracted from its host rock, jade stones undergo a special process before they are put out to sale (see Figure 26).



Figure 26 Jade from its extraction to its sales phase

Except for big jade pieces, which are easily identifiable, stone “finders” or “pickers” are first in charge of separating jade from the rest of the sediment product of the extraction process. Big stones are then carefully cut into more manageable pieces, polished if necessary, and finally stored for their subsequent sale

In the model, the “jade extracted” stock is fed by the jade production rate and drained by two outflows, namely (a) the jade dilution rate, and (b) the jade transportation rate. These two outflows are a representation of a selection process whereby waste material is separated from the valuable one by means of the “dilution fraction.” Although the average dilution fraction in open-pit mining is an average of

5% (Camm, 2010), in the model it is set at 20% of the total production in one year following the experience of the mining companies interviewed.

$$PRO\ Dillution\ fraction = 0.2 \ll \frac{1}{year} \gg$$

The jade dilution rate is given by the product of the stock of jade extracted and the dilution fraction, meant to encompass both “external dilution” (i.e. low-grade material taken unintentionally during extraction) and “internal dilution” (i.e. waste material so ingrained within the ore that physical separation is unfeasible) (Pincock Perspectives, 2004).

$$PRO\ Jade\ dilution\ rate = PRO\ Jade\ extracted * PRO\ Dilution\ fraction$$

On the other hand, the jade transportation rate represents the amount of gem ore actually recovered from a jade deposit. In this case the rate is given by the multiplication of the stock of jade extracted and the “recovery fraction” or simply 1 minus the dilution fraction.

$$PRO\ Jade\ transportation\ rate = PRO\ Jade\ extracted * (1 - PRO\ Dilution\ fraction)$$

### **6.3.5.3. Jade sales**

Although sales of Myanmar’s jade take place through legal and illegal channels, this model assumes there is only one rate of sales, one that is basically derived from the information about government gem auctions. Before describing the stock and flow structure for the demand side, an introduction on gem auctions is first provided.

#### **6.3.5.3.1. Auctions**

Held three times per year, government controlled “jade emporium shows” are one of the existing channels for jade sales and an important source of foreign currency to the junta. The annual sale of jade, rubies, sapphires, and pearl lots began in 1962, with a mid-year sale edition being introduced in 1992, and a third special edition in 2004 (AKSYU, 2008 ). While annual shows take place during

March of every year, mid-year auctions are held each October or November, and special editions in July or August. Appendix 3 shows statistics related to the different gem emporium editions that have taken place since 2003.

During each emporium show, jade is showcased in “lots” (i.e. boulders of raw jade of similar quality) and purchased mainly by Chinese buyers. Depending on the quality, each jade lot offered through a competitive bidding system has a different reserve or floor price that can range from USD 2,000 to USD 100,000 or even more. In the case of JVs, a 50% government tax on each emporium transaction is levied on mining companies. According to the miners, one of the benefits of the auctions, besides its legality and sometimes higher profitability when compared to illegal sales of jade along the Chinese and Thai borders, is that foreign exchange profits from these sales are "white" and thus can be used for other transactions (Rangoon Embassy, 2002).

#### **6.3.5.3.2. Jade sales rate**

Chinese consumers account for the majority of foreign visitors to the emporium show each year (see Appendix 3). For the Chinese, by far the world’s greatest jade connoisseurs and consumers, jade has a legendary and very special meaning. According to traditional Chinese culture jade is able to bring happiness and luck to one’s live and to keep the evil away. Jade has been valued in China even more than gold and silver in the Western world (Telenko, 2001).

With the rise of the Chinese economy and the awakened desire for luxury items, jade has not only become the continuation of a cultural phenomenon that dates from long ago, but also an investment vehicle for many people. Because, as opposed to real state for example, jade does not need to be registered and it is therefore non-traceable, it has become an attractive storage of value for many.

In the model, the jade sales rate is determined by two stocks: (a) population of consumers, and (b) per-capita consumption (see Figure 27).

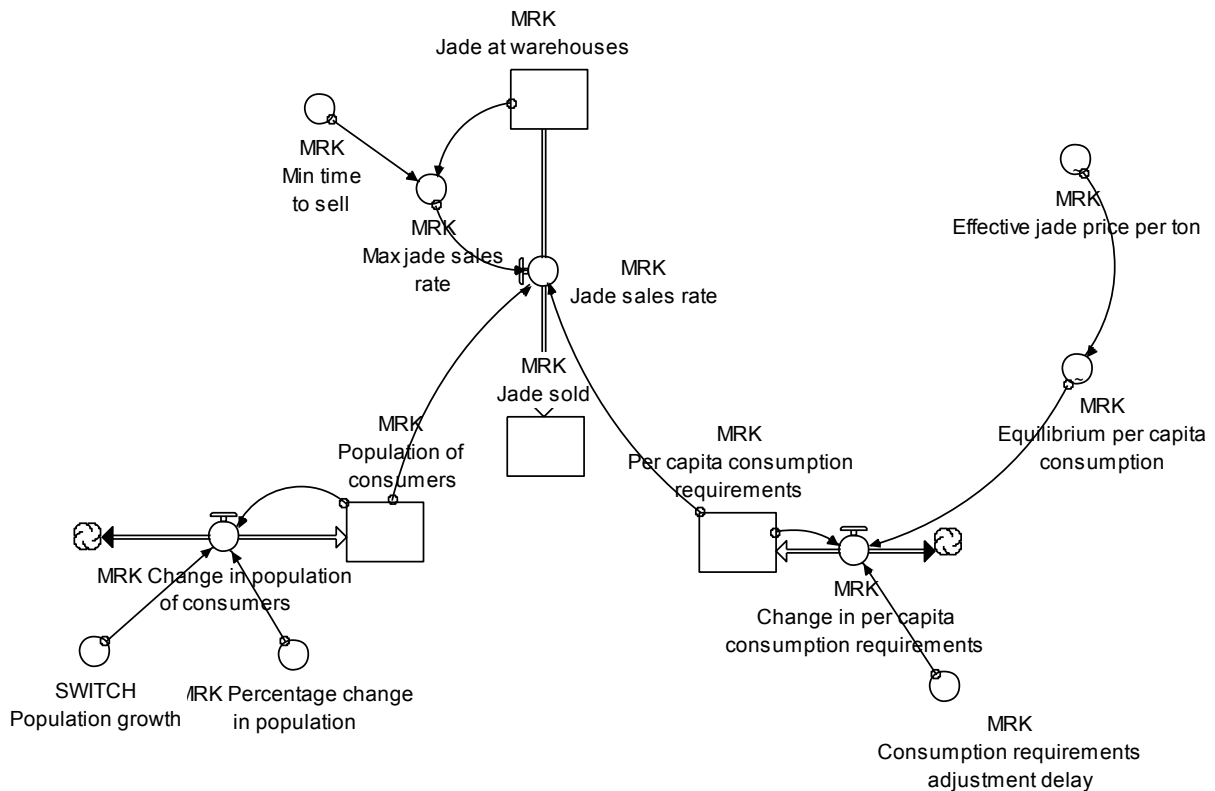


Figure 27 Stock and flow structure for jade sales

### 6.3.5.3.2.1. Population of consumers

Estimations for this variable are based on yearly figures of visitors to the gem emporiums displayed in Appendix 3. Note the author built approximations for the number of visitors during the period 2000-2002, as this information could not be found.

Table 3 shows the number of foreign visitors per auction, the total number of visitors per year (i.e. the product of 3 auctions per year and the number of visitors per auction), and finally a normalized number of yearly visitors. Foreign visitors for each emporium sale, 90% of which are usually Chinese, have risen since 2000 consistent with the increased purchasing power of Chinese citizens. The drop

evidenced in 2009 is attributed to the effects of the global financial crisis on China’s economy.

Normalized values for visitors suggest that besides buyers at auctions, buyers from illegal border trade also exist. It is assumed the former represent about 30% of total jade buyers. The stock of population of consumers grows after a fractional growth rate multiplies the stock when a switch parameter is activated.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
PER AUCTION	162	243	364	546	600	765	1000	2189	3000	2433	3500	3773	3000
PER YEAR	485	728	1092	1638	1800	2294	3000	6568	9000	7300	10500	11319	9000
NORMALIZED	1618	2427	3640	5460	6000	7645	10000	21893	30000	24333	35000	37730	30000

Table 3 Population of consumers

### 6.3.5.3.2.2. Per-capita requirements

The per-capita consumption stock is modeled as a first-order exponential smoothing with a 4-month adjustment delay to better reflect the gradual adjustment of consumers’ demand to a change in price. Any value of per-capita requirements is defined by the graph function “equilibrium per-capita consumption” which is in turn a function of the “effective jade price per ton.”

Table 4 presents the empirical numerical relationship between per-capita consumption (i.e. per-cap C) and the price of jade per ton (i.e. price) in Myanmar’s market. The former results from the division between the normalized consumption rate (i.e. norm C), or the sum of all jade tons that were sold at each auction multiplied by the number of auctions/year, and the normalized population of consumers (i.e. norm P) introduced in Table 3. Note total consumption is also normalized to suggest the consumption of jade during each emporium show is estimated to be an average of 30% of the total consumption.

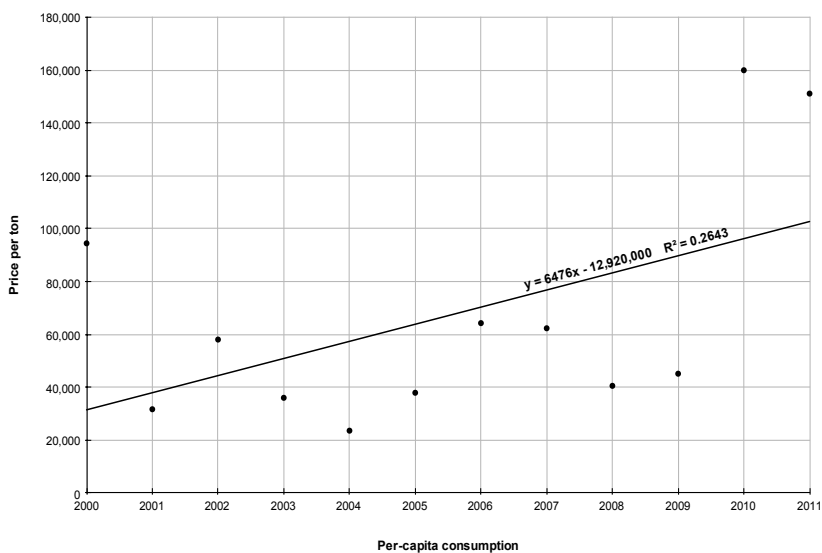
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
C	439	615	861	426	1483	2029	3515	5935	8085	6899	12104	18529	14643
NORM C	1464	2050	2878	1418	4943	6765	11718	19783	26950	22995	40345	61762	48810
<b>PRICE</b>	<b>94472</b>	<b>31707</b>	<b>58072</b>	<b>36036</b>	<b>23602</b>	<b>37943</b>	<b>64289</b>	<b>62342</b>	<b>40569</b>	<b>45155</b>	<b>159954</b>	<b>151119</b>	<b>N/A</b>
NORM P	1618	2427	3640	5460	6000	7645	10000	21893	30000	24333	35000	37730	30000
<b>PER-CAP C</b>	<b>0.26</b>	<b>0.24</b>	<b>0.23</b>	<b>0.26</b>	<b>0.82</b>	<b>0.88</b>	<b>1.17</b>	<b>0.90</b>	<b>0.90</b>	<b>0.95</b>	<b>1.15</b>	<b>1.64</b>	<b>1.63</b>

Table 4 Per-capita consumption requirements and price

Bolded rows in

Table 4 highlight time-series data on jade prices per ton and per-capita requirements. All coordinates from this table have been plotted in

Figure 28 to show the jade demand function is the opposite of the downward slope curve of traditional demand in which substitution allows demand to decrease



when the price of a good increases.

Figure 28 Empirical relationship of per-capita requirements and jade prices

In fact, when the demand of goods like jewelry, diamonds, and gems increase with increases in price, they are classified as articles of distinction or Veblen goods. According to Thorstein Veblen's theory of conspicuous consumption, individuals emulate the consumption patterns of other individuals situated at higher points in the hierarchy to increase their status (Trigg, 2001). The jade demand function has

been shown to be one in which consumers' preference for buying it increases with increases in price.

### 6.3.5.4. Inventory coverage and jade prices

The upcoming subsections will describe how changes in jade inventories, affect inventory coverage, and how changes in inventory coverage feedback to jade prices.

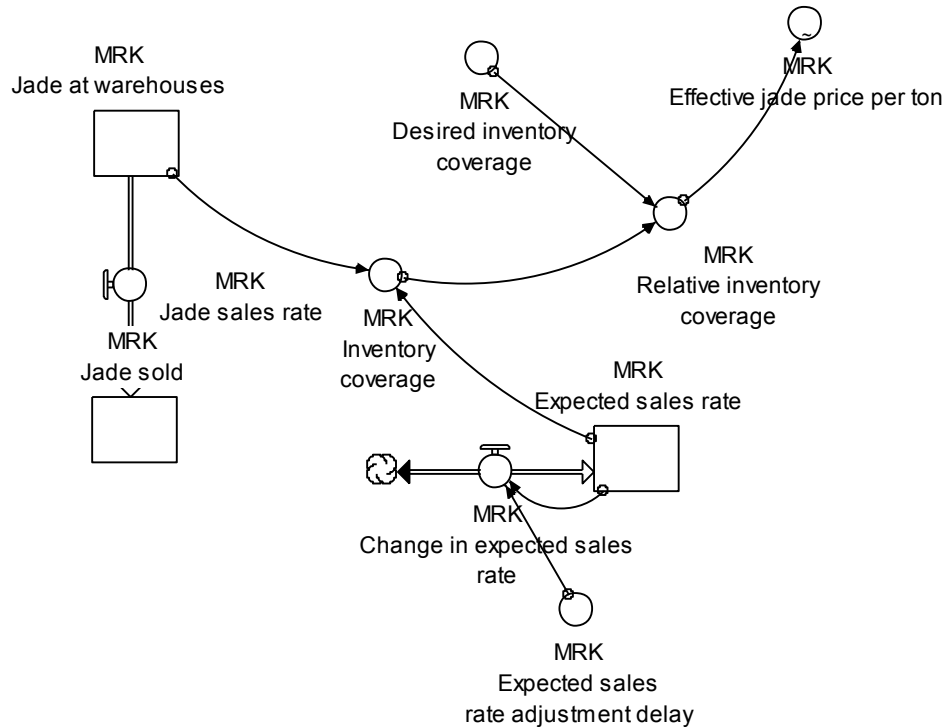


Figure 29 Stock and flow structure for inventory coverage and price

#### 6.3.5.4.1. Inventory coverage

The desired holding stock for mining companies has been set at 4 months or the equivalent to the accumulated production for one emporium show. The jade in warehouses stock is divided by the expected sales rate, modeled as a first order smoothing with a 3-month delay, to calculate the actual inventory coverage in months. This actual is then compared to the desired coverage of 4 months to obtain the relative inventory coverage that will drive the price of jade per ton. Empirical evidence for the calculation of the relationship between inventory coverage and price is shown in Table 5.

YEAR	PRODUCTION (TONS)	CONSUMPTION (TONS)	NORMALIZED CONSUMPTION (TONS)	INVENTORY COVERAGE	DESIRED INVENTORY COVERAGE	RELATIVE COVERAGE	PRICE
2000	11,096	439	1,464	7.6	0.3	22.7	94,472
2001	8,174	615	2,050	4.0	0.3	12.0	31,707
2002	10,879	861	2,870	3.8	0.3	11.4	58,072
2003	10,755	426	1,418	7.6	0.3	22.7	36,036
2004	14,988	1,483	4,943	3.0	0.3	9.1	23,602
2005	20,390	2,029	6,765	3.0	0.3	9.0	37,943
2006	20,458	3,515	11,718	1.7	0.3	5.2	64,289
2007	20,235	5,935	19,783	1.0	0.3	3.1	62,342
2008	32,921	8,085	26,950	1.2	0.3	3.7	40,569
2009	25,795	6,899	22,995	1.1	0.3	3.4	45,155
2010	46,810	12,104	40,345	1.2	0.3	3.5	159,954
2011	70,000	18,529	61,762	1.1	0.3	3.4	151,119
2012	55,000	14,643	48,810	1.1	0.3	3.4	N/A

Table 5 Relative inventory coverage and price

Some of the coordinates for relative inventory coverage and price are shown in

Figure 30.

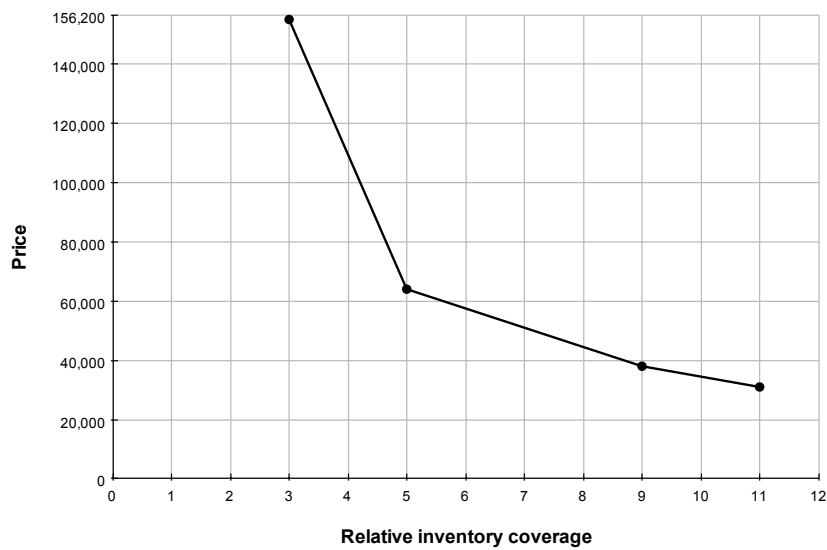


Figure 30 Empirical relationship between relative inventory coverage and price



The curve reveals prices increase with decreases in inventory coverage and vice versa. Although it is true that jade prices vary among producers, processors, distributors, and retailers, this model presents only one price under the assumption that where there are more than a few competitors, the prices at different levels are generally correlated (Meadows, 1970).

#### 6.3.5.4.2. Introduction to jade prices

Particular characteristics, namely “hue” (i.e. the position on the color wheel), “saturation” (i.e. intensity of color), and “tone” (i.e. lightness or darkness), determine the quality and consequently the price of jade (Hughes, et al., 2000) (Roskin, 2000). Besides offering a comprehensive review of the history and chemical characteristics of jade, Howard (2002) presents a color and quality classification that serves as a starting point at understanding the complexity involved in appraising both raw and processed jade (see Table 6).

GREEN	LAVANDER	OTHERS
EXTRA FINE GREEN	FINE LAVANDER	RED
FINE GREEN	GOOD LAVANDER	YELLOW
GOOD GREEN	COMMERCIAL LAVANDER	WHITE
COMMERCIAL GREEN		GREY

Table 6 Jade colors and qualities

Colors not only determine quality but also have a special spiritual meaning among jade’s biggest consumers: the Chinese. The value of a jade piece can dramatically decrease, for instance, when even a slight combination of lavender (i.e. “Chuan”) and green (i.e. “Chi”) color is encountered in the same jade boulder. The Chinese consider the color of jade as their energy or “Chi” and therefore the intensity of green in the stone is supremely important. In the presence of a mix, “Chuan” is believed to destroy the liveliness of “Chi” and therefore kill the spirit of jade consequently lowering the value of the stone (Naturaljade, 2007).

#### **6.3.5.4.2.1. A note on empirical findings**

Two emporium booklets provided by one of the mining firms allowed the calculation of average percentages for different jade qualities from a 4-month production period, which represents the accumulated production prior to each emporium show. Each booklet contained a picture, reserve price, sales price, and weight of each jade lot sold by this particular mining company during the emporium shows of October 2010 and July 2011. Additionally, the sales department at UMG was in possession of one complete government booklet, bought for around USD 700, that listed 7784 jade lots with their corresponding owner's name, buyer's name, weight, number of pieces, and finally the lot's sales price. Complete emporium reports are not only expensive but also difficult to obtain even when the interested party has the financial means to acquire them. The three booklets hereby mentioned were therefore the only ones used for analyzing the quality composition of jade lots in a 4-month jade mining period.

One can differentiate among four different categories of jade qualities: A=exceptional or extra fine, B=very good, C=good or commercial, and D=fair (Howard, 2002). One of the mining firms was instrumental in validating the realism of these four categories, which are based on reserve prices and the number pieces per lot. The latter represents a criterion for categorization since in the case of a lot offered at USD 100,000, for instance, the reserve price might have been calculated based on quality (e.g. one big jade stone of superior quality) or number of pieces (e.g. twenty five small stones of medium quality). Results from the analysis showed around 3 % of the production is quality A with a reserve price of USD 100,000 or higher, another 7% is jade quality B with a reserve price between USD 50,000 and USD 100,000, 20% jade quality C with reserve prices ranging between USD 10,000 and USD 50,000, and finally 70% jade quality D showing reserve prices lower than USD 10,000.

### 6.3.5.4.3. Prices in the jade model

“So as far as I’m aware, there’s no such thing as a “jade index,” just a more general impression of where the market stands.”

(Chovanec, 2011)

Different from ore, which has a fairly objective price based on weight and purity, it is now clear that every piece of jade is unique. Despite widespread concerns on the impossibility to determine the price of jade, this model introduces an attempt to do so by using aggregate data from gem emporium revenues and emporium sales transactions. Table 7 shows the average jade price per ton since 2000 until 2011 results from the division between total emporium revenues in USD millions and total emporium consumption in tons.

YEAR	EMPORIUM REVENUES*	EMPORIUM C TONS**	PRICE*** IN
2000	41.5	439	94,472
2001	19.5	615	31,707
2002	50.0	861	58,072
2003	23.0	426	54,054
2004	35.0	1483	23,602
2005	77.0	2029	37,943
2006	226.0	3515	64,289
2007	370.0	5935	62,342
2008	328.0	8085	40,569
2009	311.5	6899	45,155
2010	1936.0	12104	159,954
2011	2800.0	18529	151,119
2012	N/A	14643	N/A

Table 7 Emporium revenues, emporium sales, and estimated jade price

[Source\*: (Palagems, 2012) (Egreteau, 2011); Source\*\*: see Appendix 3;

Source\*\*\*: calculated by the author]

Emporium revenues are calculated as the sum of revenues from the 3 annual emporium shows described in section 6.3.5.3.1. Likewise, emporium sales in tons are calculated as the sum of all jade lots sold at the 3 annual emporium shows. Lots were converted into tons by estimating the average weight of each jade lot displayed at each of the emporium shows. This last measure was obtained by relying on 560 observations from the government sales booklet (about 8% of the universe), and complete data on lots from the two emporium booklets (i.e. “ES1” and “ES2”) provided by one of the mining companies. Results suggest that independently of the number of pieces per lot, each jade lot weights approximate 500 kg or the equivalent to 0.5 tons (see Table 8).

	JADE LOTS SHOWCASED	AVG WEIGHT PER LOT (KG)
SAMPLE GOVERNMENT	560	617
MINING COMPANY ES1	84	476
MINING COMPANY ES2	147	398
	AVG	497

Table 8 Estimation of weight in tons per jade lot

Figure 31 portrays the approximate evolution of jade prices since 2000 until 2011. As previously explained, the difficulty in stating an average selling price for raw jade arises from the many different combinations of features a certain piece can exhibit like color, cut, clarity, cracks, transparency, texture, and volume (Quimei, 2003). The green curve on the graph sketches the behavior described by most of the interviewees when asked about jade prices. Most agreed prices in 2010 increased at least four fold when compared to those in 2001. Although not accurately, Figure 31 seems to fit this description.

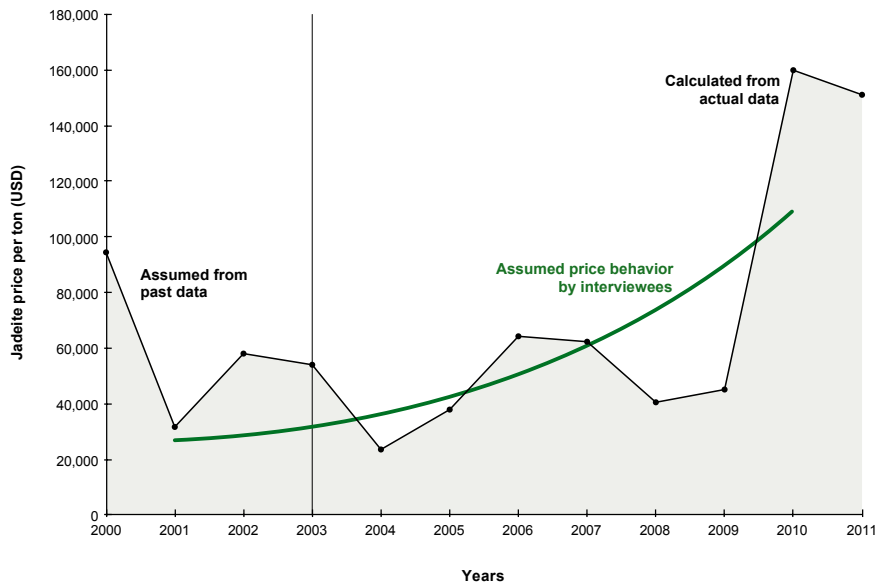


Figure 31 Jadeite prices per ton

### 6.3.6. Capacity utilization in the extraction phase

Exploitation or extraction is associated with the recovery of minerals from the earth. Once the mine is operating though, there are times when the mining firm decides to boost or slow down extraction. Differences in extraction choices are based on the relationship between price and operating costs. When the gap between the two is positive, there is an incentive to increase production using current resources and even expand it through the acquisition of more mining sites after some time. Conversely, when the gap is negative, more often as a result of a low price, production is discouraged and hence slowed down.

The function of capacity utilization in the model is given by the following relationship:

$$MRK \text{ Expected markup} = MRK$$

$$\text{Expected price short run} / \text{FIN Expected unit variable costs}$$

Where the expected price in the short run is modeled as a first order smoothing with a 1 month delay, and the expected variable cost is also modeled as expectations formations of the unit variable cost of production (see Figure 32).

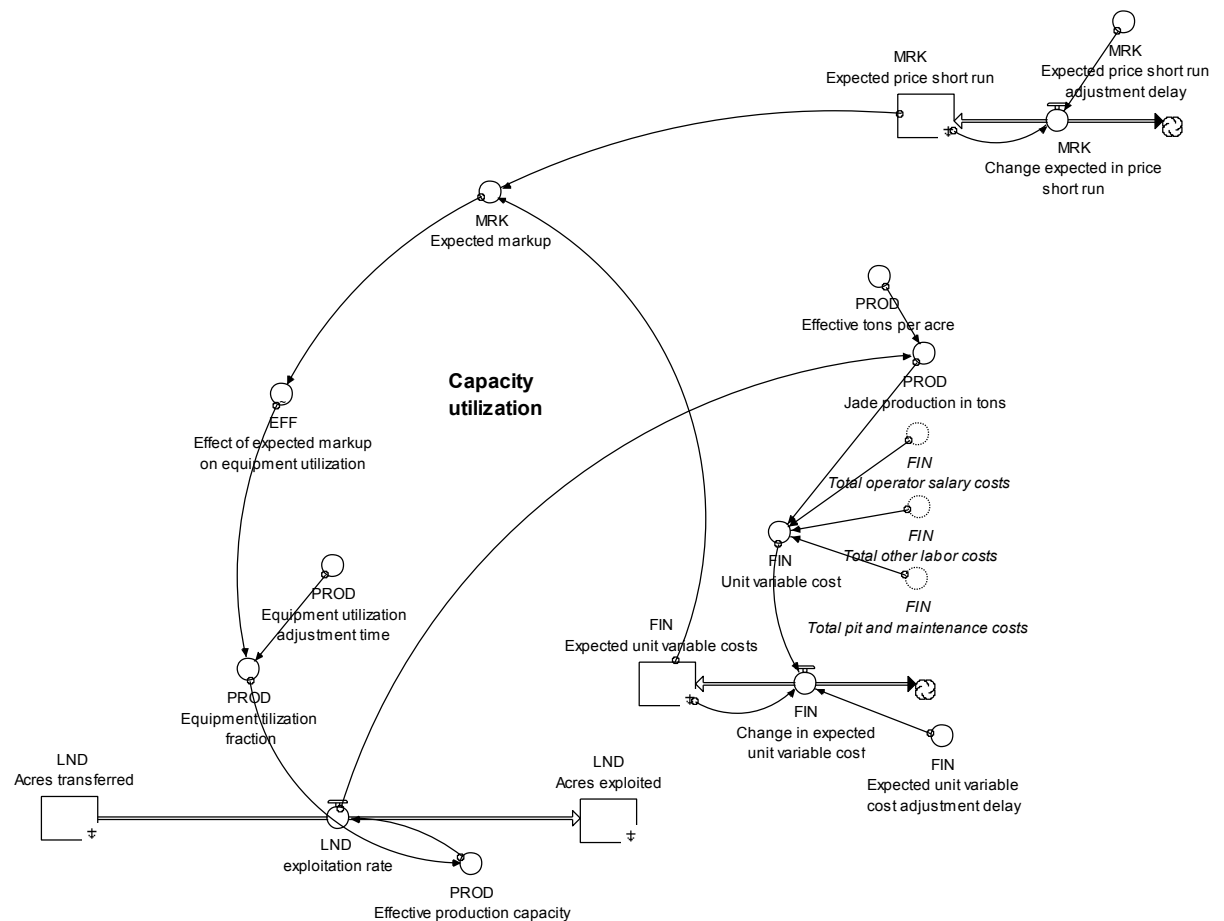


Figure 32 Stock and flow structure for capacity utilization

Different expected markup values feed the non-linear function that determines the multiplier of the actual production capacity. The graph function is one in which only few producers increase production in the advent of small positive markups and a more significant number fuels production further in the presence of greater positive markups. The upper boundary for the production multiplier has been set at 1.20 taking into account mining companies can only increase their daily schedules from 20 to 24 hours.

### 6.3.7. Financials

A financial sector has been included in the model to track the financial performance of the mining industry in an aggregate manner (see Figure 33).

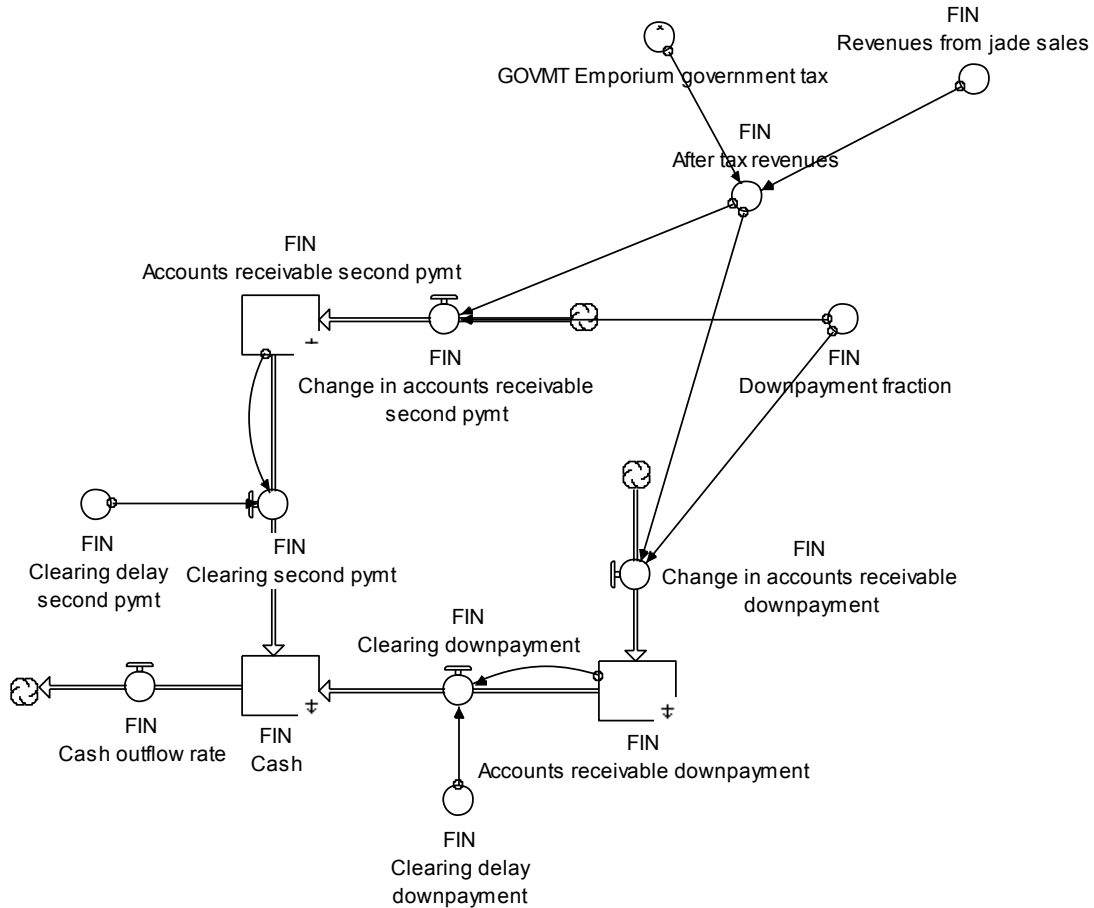


Figure 33 Stock and flow structure for the financial sector

Financial revenues are modeled as the product of jade sales and the effective jade price per ton while after-tax profits as the product of revenues and the emporium government tax set at 0.4.

*FIN Revenues from jade sales*

$$= MRK \text{ Jade sales rate} * MRK \text{ Effective jade price per ton}$$

Two types of payments feed the stock of cash, mostly in accordance with the payment delays involved in emporium transactions. Miners pointed out a down payment is first made after the sale transaction is completed or within a maximum

of 2 months, and a second and final payment is made after 5 months of the actual sale.

*FIN Clearing delay downpayment = 1 << month >>*

*FIN Clearing delay second pymt = 5 << months >>*

Expenses incurred during the mining operations represent the outflows from the cash stock. Such disbursements are in accordance with the expense categories listed in the discounted cash flow analysis in section 8.2.



## Chapter 7. Model behavior and analysis

### 7.1. Base case

Figure 34 displays the results of the base or “business as usual” run. Simulation results from different variables have been placed from left to right following a logical sequence starting with mining licenses. First note that at the beginning of the simulation, an increasing number of jade mining licenses granted allow the gradual escalation of acres transferred to mining companies, mining equipment orders, and jade production. As more land is given away, less remains available for further extraction, thus activating the balancing loop 1 described in detail in section 5.3.2. Through the land utilization fraction, licenses are gradually diminished as a result of “land crowding” even though the trend for mining licensing is going upwards (see the first 2 graphs in Figure 34). Assuming the non-linear function constraining the licenses is close to reality, the turning point in decreasing equipment orders and jade production lies around this year. Note the oscillations in both variables continue in a downward fashion given the decreasing amount of land left and therefore the less amount of land that can be granted to mining companies for jade extraction. In the base case, the final value of jade reserves is about 8% of the reserves at the beginning of the simulation.

Rows 3 and 4 from Figure 34 show the effects of production and inventory coverage on capacity utilization and jade supply. Although jade in production increases from the start of the simulation until 2011 or 2012, jade at warehouses is depleted during this period as a result of an equally high per-capita consumption. High consumption drains jade inventories so as to make the price of jade increase and foster greater consumption. The reinforcing loop 1, whereby higher prices trigger higher consumption, is at some point overwhelmed by an even higher increase in production that causes a price drops and makes consumption go down again.

Consumption is kept relatively low until a drop in production, resulting from the land depletion loop B1, causes inventories to drop and not be able to cope with demand. A drop in production and inventory coverage causes price and therefore consumption increases.

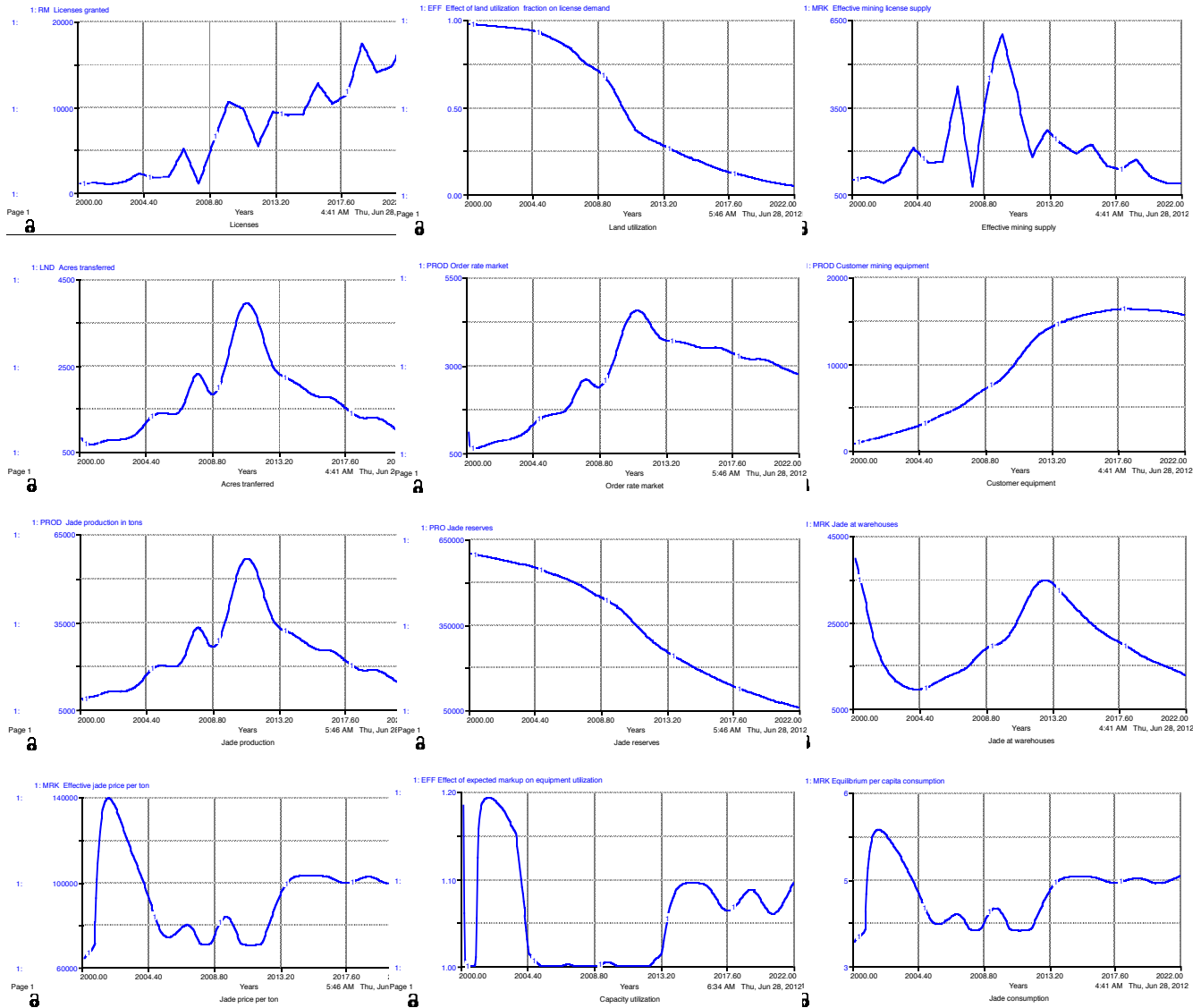


Figure 34 Base run simulation results

Regarding the supply side, capacity expansion is observed in the escalating amount of licenses granted as a result of high prices and the linked expectations of high future profitability. Finally, one of the minor model loops, the capacity utilization loop B4, is also operating by acting as a multiplier of current equipment

productivity when beliefs of short-term profitability are present. The effect of markup on capacity utilization can be seen in the graph before the last one in Figure 34.

## **7.2. Model validation**

Validation is the process by which the correspondence between the model system and the real system is systematically enhanced (Schwaninger & Groesser, 2009). Although different views on model validation exist, there seems to be the general consensus that, as advocated by Forrester and Senge (1980), there is no single test which serves to “validate” a system dynamics model, but rather only to build a gradual confidence on it. The process of model validation has then been described as iterative, gradual, semiformal, and conversational (Barlas, 1996), and one that is highly connected to the purpose of each particular model.

### **7.2.1. Behavior reproduction test**

The behavior reproduction test employs formal measures of “goodness-of-fit” to test the correspondence of model behavior with historical data. Because formal data at the industry-level is scarce for most of the major variables included in the model, only those variables backed up by time-series datasets have been subjected to this test.

After discussing why most used summary statistical measures to evaluate goodness-of-fit in econometric models (i.e.  $R^2$ ) do not serve their purpose for system dynamic models, Sterman (1984) proposes the use of (a) the mean square error (MSE), (b) the root mean square percent error (RMSPE), and (c) Theil statistics as measures of total error, normalized magnitude of the error, and a fractional decomposition of the error, respectively. Formulas for the each element are presented below:

$$MSE = \frac{1}{n} \sum_{t=1}^n (S_t - A_t)^2$$

$$RMSPE = \sqrt{\frac{1}{n} \sum_{t=1}^n \left[ \frac{(S_t - A_t)}{A_t} \right]^2}$$

Where  $n$  equals the total number of observations,  $S_t$  the simulated value at time  $t$ , and  $A_t$  the actual or reference value at time  $t$ .

Theil statistics yield three fractions that add to 100% of the MSE and that capture (a) bias ( $U^M$ ), (b) unequal variation ( $U^S$ ), and (c) unequal covariance ( $U^C$ ).

$$U^M = \frac{(\bar{S} - \bar{A})^2}{\frac{1}{n} \sum (S_t - A_t)^2}$$

$$U^S = \frac{(S_S - S_A)^2}{\frac{1}{n} \sum (S_t - A_t)^2}$$

$$U^C = \frac{2(1 - r)S_S S_A}{\frac{1}{n} \sum (S_t - A_t)^2}$$

Where  $\bar{S}$  and  $\bar{A}$  are the means of simulated (S) and actual values (A),  $S_S$  and  $S_A$  the standard deviations of S and A, and  $r$  the correlation coefficient between S and A.

VARIABLE	ROOT MEAN	MEAN	INEQUALITY STATISTICS		
	SQUARE PERCENT ERROR RMSPE (%)	SQUARE ERROR (MSE) (UNITS <sup>2</sup> )	U <sup>M</sup>	U <sup>S</sup>	U <sup>C</sup>
			(FRACTION OG MSE)		
PROD JADE PRODUCTION IN TONS (TONS/YEAR)	1.24%	3.5E+06	0.003	0.076	0.921
PROD SALES RATE UMG (EQUIPMENT/YEAR)	6.89%	5.8E+03	0.010	0.150	0.840
PROD ACCUMULATED SALES UMG (EQUIPMENT)	4.63%	9.1E+04	0.393	0.517	0.090

Table 9 MSE and Theil statistics for 3 selected variables

Table 9 shows how the mean square error and inequality statistics have been used to evaluate the fit to historical data of (a) jade production, (b) yearly equipment sales of UMG, and (c) accumulated sales or the total machine population of UMG. Starting the model in 2000 provides exactly 11 years of simulated data to compare against the real behavior of the jade industry. Note how the RMSPEs for all three variables are below 10% with the highest error of almost 7% corresponding to the sales rate. These results show the model adequately tracks all major system variables with a great deal of accuracy.

Below, quick descriptions expand on the statistical results for each of the three variables and graphs display a comparison between simulated and real data. *In all graphs, black lines denote reference times-series whereas green lines are used for simulation results. Complementary variables, if necessary, are presented in red.*

### 7.2.1.1. Simulated and actual jade production

Simulated and actual values for jade production are shown in Figure 35.

In accordance to real jade production, simulated results show periods of 3 years in an upwardly increasing trend. The error decomposition for this variable indicates less than 1% is attributed to bias, around 7% to unequal variation, and the vast majority (i.e. 92%) to unequal covariation, suggesting simulated production follows actual production almost perfectly in periods and amplitudes, but diverges point by point. In fact, most differences are noticeable at the beginning of the simulation and in the peak lying between 2006 and 2008. In spite of the small difference, results prove satisfactory and do not compromise by any means the validity of this study.



Figure 35 Simulated and actual jade production

### 7.2.1.2. Simulated and actual purchases to UMG

Figure 36 displays both simulated and actual results for mining equipment purchases to UMG, or sales of UMG, on a year-to-year basis. As in the actual situation, purchases of equipment in the simulation oscillate every 3 years and seem to grow from peak to peak.

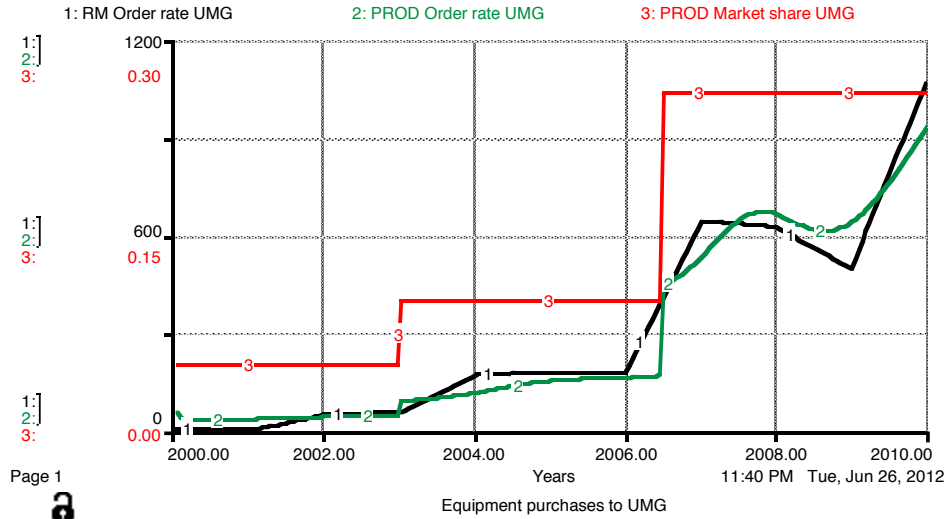


Figure 36 Simulated and actual equipment purchases to UMG

Because most variables in the model are at the industry level, purchases of mining equipment are reported as if the entire conglomerate of mining companies would purchase mining equipment from the entire group of equipment suppliers in Myanmar. Therefore, in order to derive UMG's yearly sales, a measure of market share was incorporated in the model as follows:

$$PROD\ Order\ rate\ UMG = PROD\ Order\ rate\ market * PROD\ Market\ share\ UMG$$

Where,

$$PROD\ Market\ share\ UMG = STEP(0.05,2000) + STEP(0.05,2003) + STEP(0.16,2006.5)$$

The market share fraction was first tested as a constant parameter of around 30%, but was later on adjusted to better emulate the real evolution of UMG market share over time. Hence, the market share fraction is set at 5% at the beginning of the simulation, increased by 5% in 2003, and finally increased by 16% in 2006 to reach a final total market share of about 25%. It is important to highlight UMG believes its market share to be around 50% today, and completely supports the existence of an evolutionary rather than linear and constant market share path since the company inception in 1998. Although simulation results certainly followed the actual behavior

mode of this variable at first, the introduction of a STEP function was necessary to explicitly reflect market share changes for the client firm.

It is crucial to have in mind that UMG equipment sales do not interact with the rest of the model per se but were rather calculated to report on the variable under study and check its fit with real-life observations. In practice, aggregated total equipment purchases is what, along with productivities per equipment, determines the total jade production in the model.

As in the previous case, Theil statistics show most of the 6.89% error between simulated and reference sales can be attributed to point-to-point mismatches and not bias or unequal variations.

### **7.2.1.3. UMG and its competitors**

Inter and intra-departmental discussions at UMG are generally centered on ensuring customer satisfaction through quality products, reliable processes, and speedy service (UMG Groups, 2012). Being the best implies no sale opportunity is lost, no customer relationship already gained is destroyed, and market share is always increasing. Market share figures are always a guess since not only estimates of total equipment requirements at the industry level are unknown, but also other measures to derive these estimates, such as the number of licenses granted, are subject to governmental secrecy. Given the pervasive uncertainty, the model serves as an appropriate tool to generate industry sales and graphically see the share of the market being taken by competitor firms in Myanmar.



Figure 37 shows this assertion by plotting simulated market sales parallel to sales for UMG. The existing gap throughout the reference period shows the amount of sales taken by competitor firms that in theory UMG could have taken advantage of.

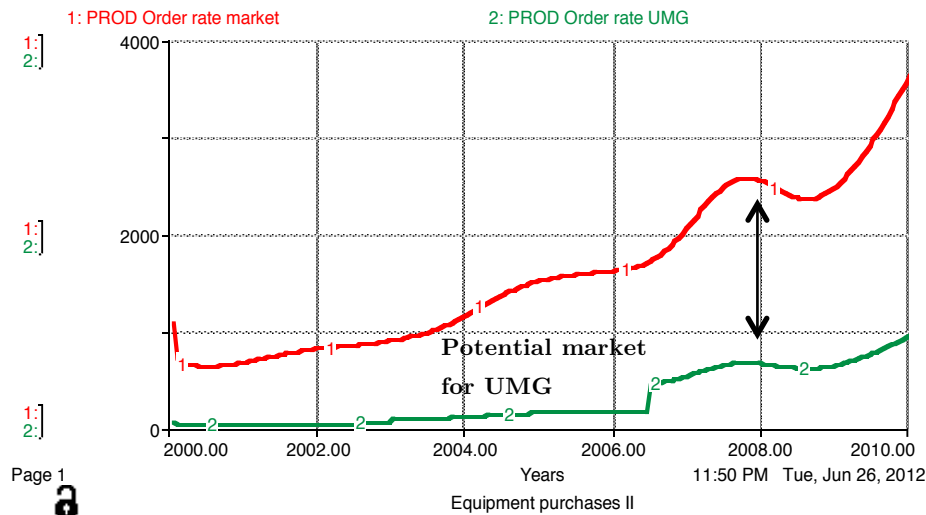


Figure 37 Simulated market sales vs. simulated UMG sales

#### 7.2.1.4. Simulated and actual accumulated sales

Although a measure of accumulated sales might seem unnecessary, as it is simply an accumulation of the sales rate, to UMG the evolution of yearly sales is as important as the accumulated equipment sales. The “machine population,” as UMG calls it, is an essential measure of the quantity of machines in operation technical personnel must provide support to. Technical support activities include, but are not restricted to, equipment repairs, equipment periodical maintenance checks, and changes in equipment spare parts when mandated by equipment manufacturers. Knowing the total number of sold machines serves also as a basis for UMG to plan ahead the number of mechanics that must trained (i.e. the complete mechanic development program at UMG lasts about 3 years) or the number of spare parts they must order to support potential customer needs (i.e. imports of spare parts take

an average of 5 months). It is within this context that accumulated UMG sales are also calculated in the model.

Figure 38 shows reference and simulated time-series for accumulated UMG sales. Again, looking at the compositions of the mean square error, 39% of the error shows up as bias and 51% as unequal variation. A large bias error is an indicator of systematic error in the presence of an equally large total error as reflected by the MSE, which in this case reaches only 4.63%. If an error is systematic, even if it is large, “it may still be acceptable provided it does not compromise the purpose of the model” (Stephan, 1992). In this case, nor the MSE is critically large, nor the purpose of the model is compromised by the results of this “indicator,” meaning the significance of a mildly large bias error is not worrying.

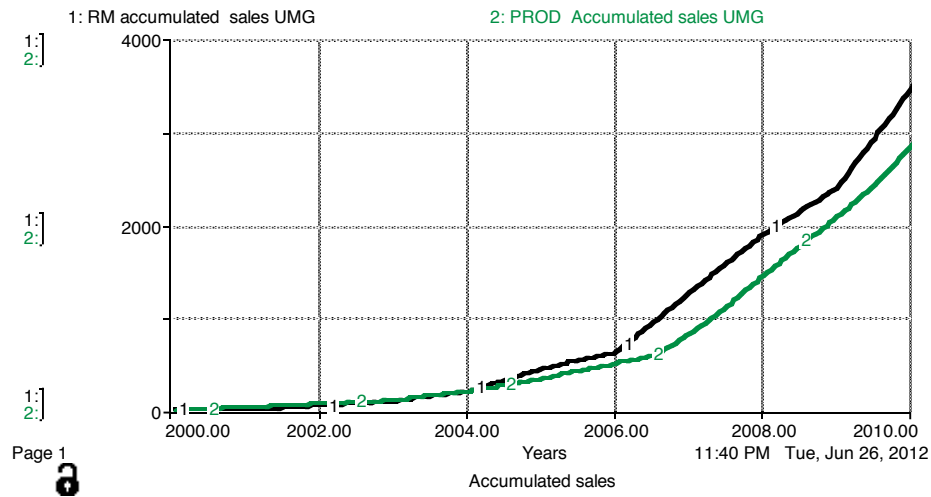


Figure 38 Simulated vs. actual accumulated UMG sales

The variance proportion  $U_S$ , equaling 51% for this variable, is a measure of how well simulated results match the degree of variability found in real values. In the case of accumulated sales, simulation results follow the rising trend of the real machine population (as expected from a stock with a single inflow), though they fail to follow the magnitude of actual values from 2006 onwards. A cause for this might be the arbitrary STEP fraction introduced in the rate that feeds this stock of accumulated sales (refer to Figure 36 again). As in the case of the sales rate though,

results of accumulated sales are not compromised given its small total error and its use in the model as only an indicator.

### **7.2.2. Scenario analysis**

This section presents the effects of two scenarios, run in parallel and combined, on critical model variables, namely (a) market sales rate of mining equipment, (b) jade production, (c) jade reserves, and (d) jade price per ton. Mining licensing and jade consumption have been chosen as inputs for the scenario analysis given they stand as the most relevant sources of uncertainty among UMG managers. The following lines briefly list the most common features of scenarios, as identified by Zhu, Bai, Xu, and Zhu (2011), and their correspondence with this study:

- *Scenarios describe processes in a broad time scale:* two sets of scenarios or alternative possible futures will be incorporated to the simulation model starting at 2012 and run throughout the rest of the simulation interval.
- *Scenarios are internally consistent and plausible alternative projections:* in the case of mining licenses, both lower and upper boundary scenarios can be considered realistic at this point in time. Given the drastic turnaround of Myanmar politics and laws, either the booming in mining licenses (following the opening of Myanmar's mining sector to foreign investment) as well as the decrease in mining licensing (upon reactions from the international community about Myanmar's environmental and human rights violations in the mine sites) are possible. In regards to tonnage per acre, chances are the best quality reserves have been depleted already or vice versa. How much jade can be found still remains a guess among producers and traders. This uncertainty, however, does not prevent the model form being tested under different hypothetical situations.
- *Scenario methods are uncertainty based both internal and external:* as pointed out in the introductory paragraph of this section, the amount of

jade mining licenses granted by government officials, as well as the consumption trends of Chinese consumers, are among the two biggest uncertainties decision makers at UMG face. These two prevent sales managers from making accurate predictions of how the market will behave and therefore how big their growth prospects in orders of equipment should be.

### 7.2.2.1. Mining licenses

Figure 39 shows how the reference mining license curve was adapted, through the use of different multipliers, to represent each scenario input.

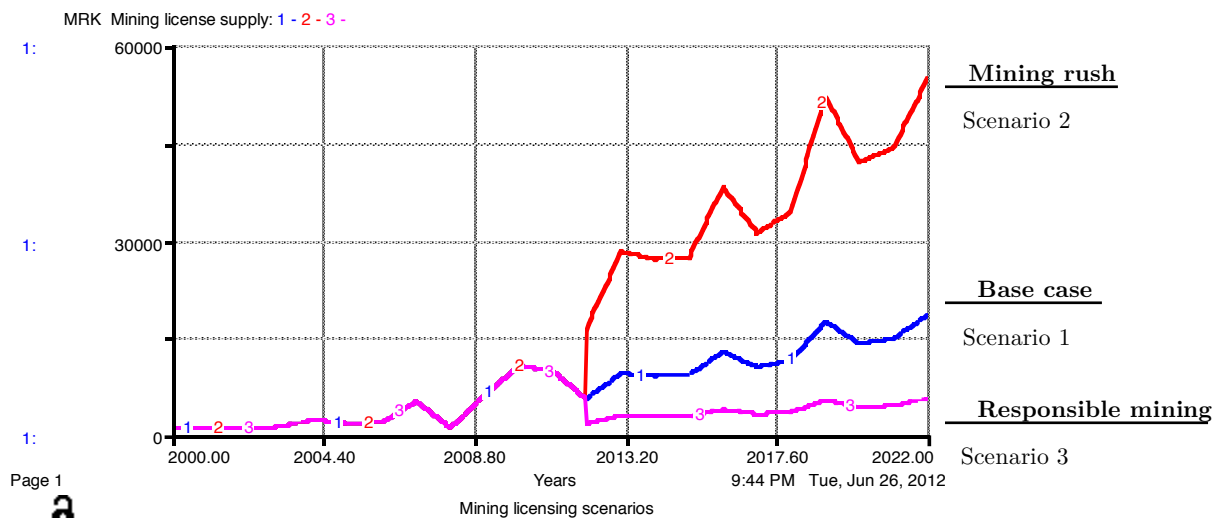


Figure 39 Paths in mining licensing

Table 10 displays a description of the first set of assumptions about the future of mining licenses tested in the model. Mining licenses in Myanmar are subject to government control and have therefore always been an “unknown” given for the different players in the industry. All three proposed situations are adjusted to represent a continuation (i.e. base case), an increase (i.e. mining rush), or a decrease (i.e. responsible mining) in the actual license-granting trend.

MINING LICENSES SCENARIOS	DESCRIPTION	MULTIPLIERS (AS A FRACTION OF BASELINE VALUE)
BASE CASE	CONTINUATION OF PREVIOUS LICENSING TREND	1
MINING RUSH	INCREASE IN THE DESIRED LICENSING DUE TO THE INFLUX OF FOREIGN INVESTMENT IN MINING	3
RESPONSIBLE MINING	DECREASE IN THE DESIRED LICENSING DUE TO ENVIRONMENTAL AND SOCIAL CONCERNS	0.3

Table 10 Scenarios for mining licenses

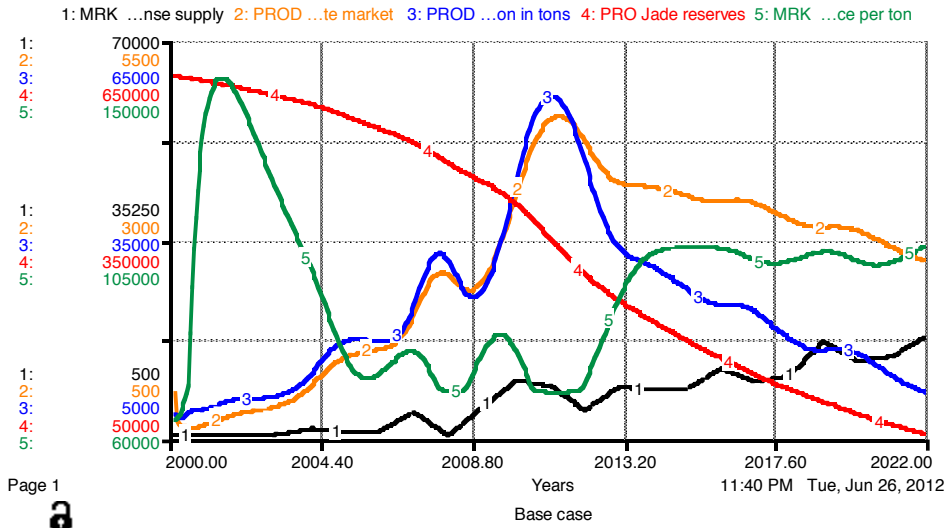
### 7.2.2.1.1. Results

Results from the three different scenarios in mining licenses on the five chosen output variables are displayed in Table 11 and Figure 40.

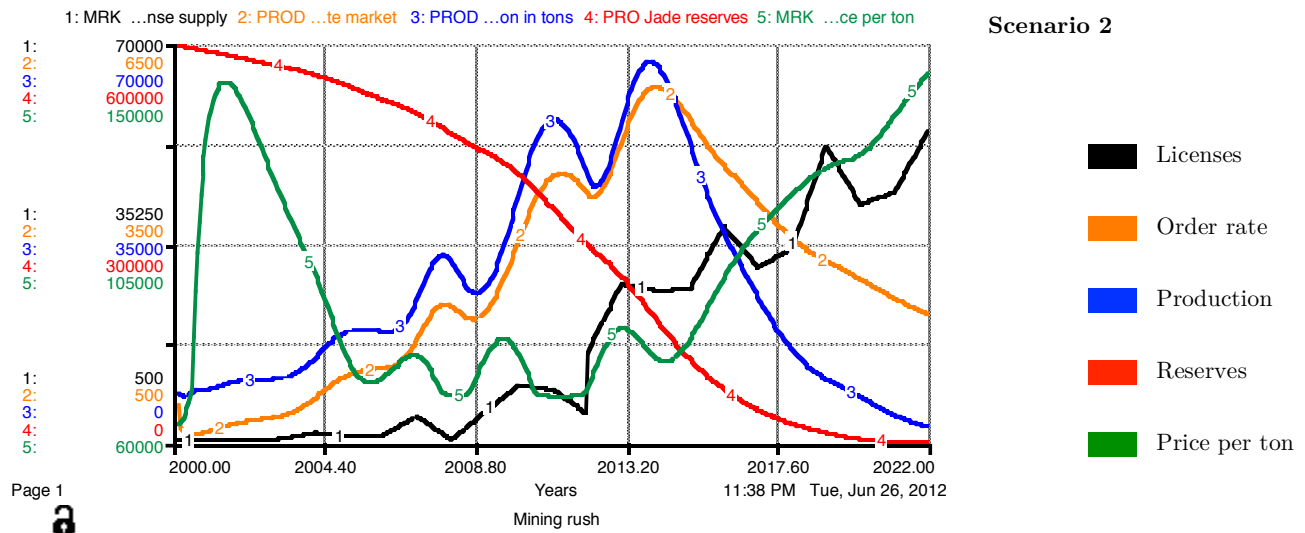
	BASE CASE			MINING RUSH			RESPONSIBLE MINING		
	2015	2018	2021	2015	2018	2021	2015	2018	2021
ORDER RATE	3,520	3,204	2,829	5,046	3,416	2,566	2,398	2,244	2,180
JADE PRODUCTION	25,349	18,403	12,000	37,113	11,240	2,790	10,131	10,345	10,413
JADE RESERVES	171,579	105,237	57,292	81,011	14,853	737	219,912	189,369	156,599
PRICE PER TON	103,245	102,512	103,785	97,305	122,366	144,046	124,043	100,099	91,732
MACHINE POPUL.	15,935	16,304	15,708	20,252	19,841	17,247	13,612	12,650	11,970

Table 11 Results from scenarios in mining licenses

Scenario 1



Scenario 2



Scenario 3

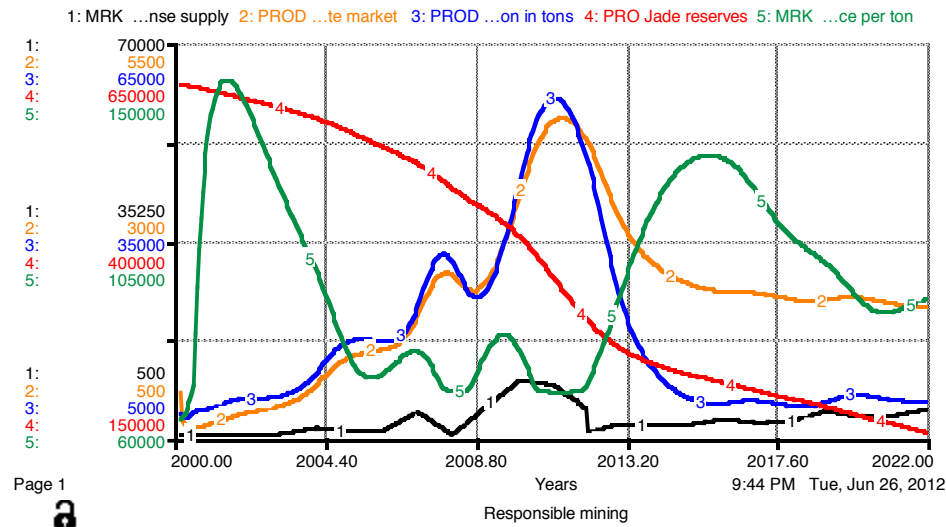


Figure 40 Results from scenarios in mining licenses II

For UMG, the most favorable scenario seems to be the one in which responsible mining prompts government authorities in Myanmar to slow down license granting for jade mining. Although orders or mining equipment (at the market level) are slightly less in scenario 3 than in the base case scenario or scenario 2, remaining reserves at the end of the simulation in scenario 3 make a difference in the future.

Note how in the first 2 scenarios, jade reserves are exhausted quickly and even get depleted in face of the “mining rush” scenario. When less licenses than usual are granted, the market keeps needing equipment for a longer time period, and the fact that reserves are not exhausted as quick, implies the sustainability or survival of UMG as a firm is not compromised as quick. In scenario 2, notice also how, in contrast to scenarios 1 and 3, jade production peaks once again around 2014 to then follow the imminent collapsing trend.

In terms of market prices per ton, the most obvious guess is to have rising prices when production starts to shrink and reserves get exhausted, stable prices when production is able to supply market needs, but also rising prices when productions drops, not because reserves cannot support further extraction but because government policies artificially diminish production. Although scenario 3 has the potential of benefiting the environment, the communities, and even UMG, the gain will be at the expense of diminished government revenues (see run 3 in Figure 41). Finally, it is uncertain the extent to which the best scenario is one UMG can exert influence on. Even though sustainable operations might be more desirable, government licenses continue to be government controlled and lie therefore beyond UMG’s immediate scope of control.

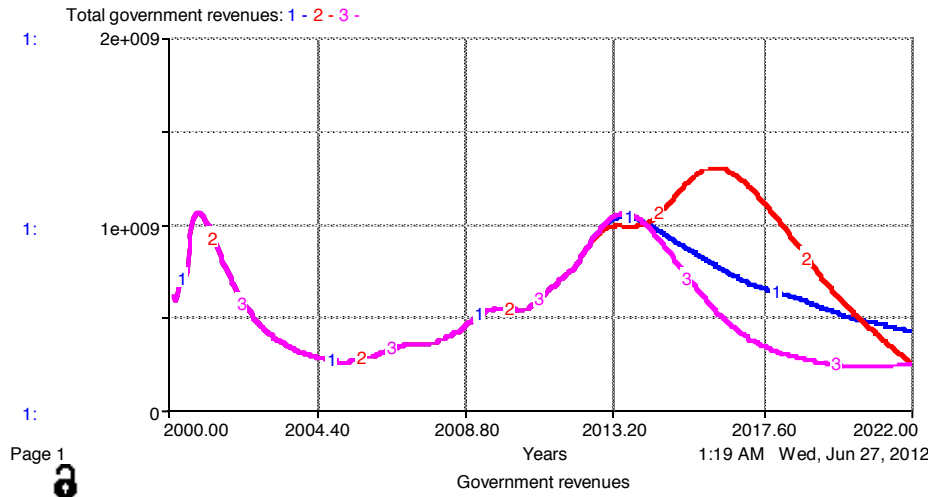


Figure 41 Government revenues under the 3 licensing scenarios

### 7.2.2.2. Tonnage per acre

Three scenarios for the parameter tonnage per acre were designed in order to evaluate its effects on the same 5 selected in section 7.2.2.1. The base case scenario refers to the default value of 12<<tons/acre>> first used the model. The second scenario, named “best is yet to come,” relates to the hypothetical idea that tonnage per acre doubles from 2012 onwards to reflect the fact that most of the best quality jade has not been extracted in the past. The last and third scenario, “best is gone,” is the exact opposite meaning all high quality jade has been mined and what remains is much less than expected (see Table 12 and Figure 42).

CONSUMPTION SCENARIOS	DESCRIPTION	MULTIPLIERS (AS A FRACTION OF BASELINE VALUE)
BASE CASE	AVERAGE TONS PER ACRE USED IN THE SIMULATION	1
BEST IS YET TO COME	TONNAGE PER ACRE INCREASE AS THE BEST JADE IS DISCOVERED	2
BEST IS GONE	TONNAGE PER ACRE DIMINISHES AS THE BEST JADE WAS ALREADY MINED	0.3

Table 12 Scenarios for tonnage per acre



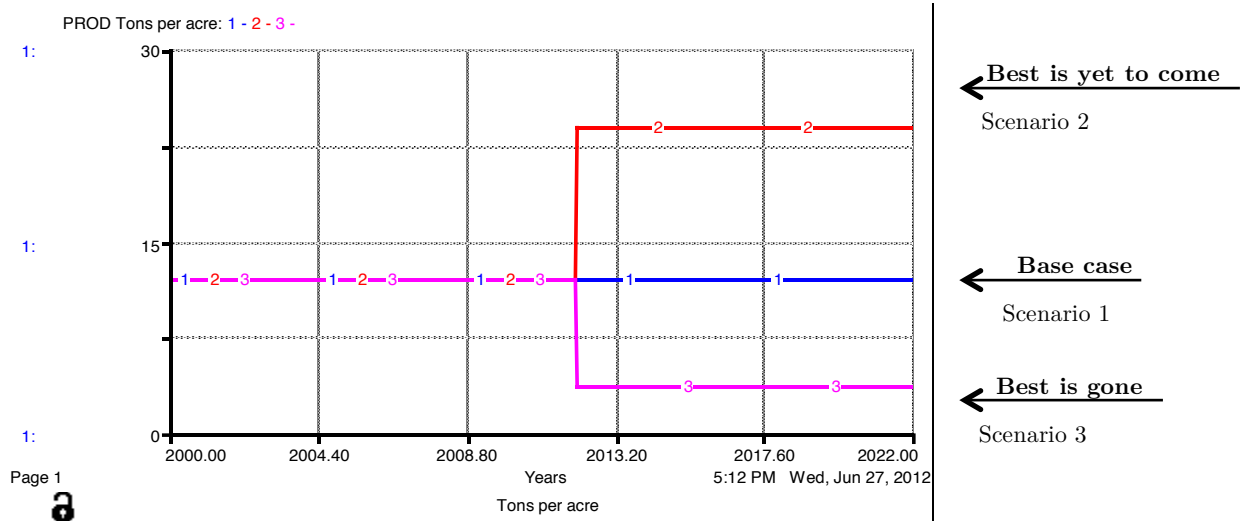
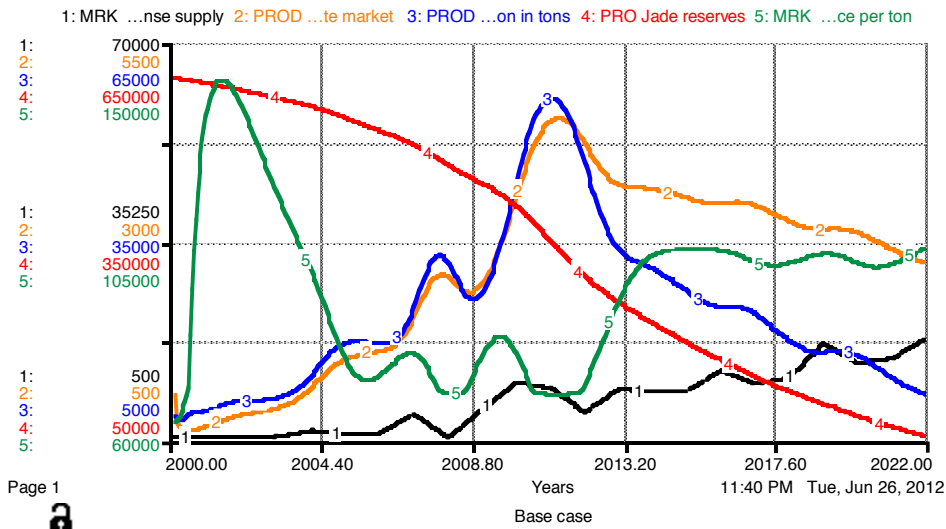


Figure 42 Paths in tons per acre

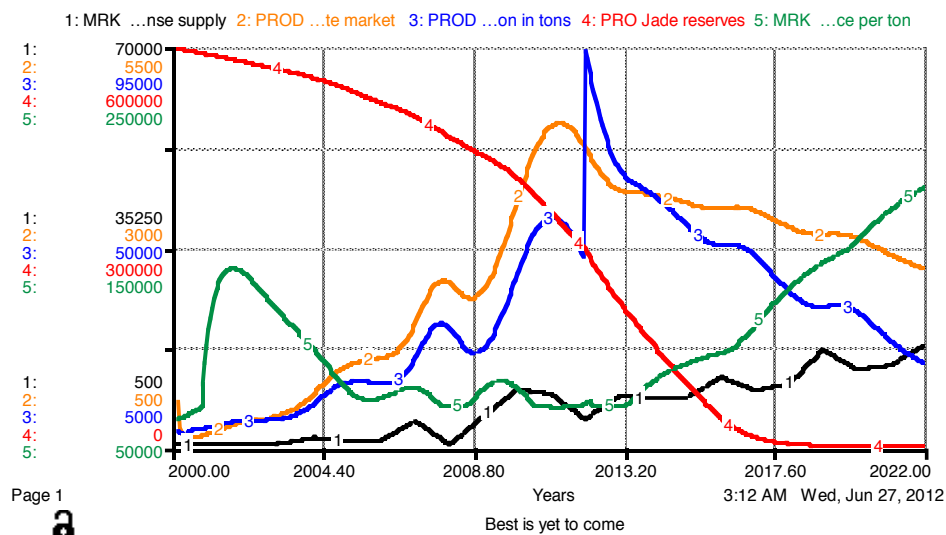
### 7.2.2.2.1. Results

As in the case of a booming in licenses, a booming in more and better “yield” per acre is counteracted by the inexorable depletion of jade reserves (see Table 13 and Figure 43). This means that a greater or a lesser amount of tons per acre does not alter the collapsing behavior of jade production or equipment purchases, what it does is simply to move such sales and production curves to upper or lower limits when compared to the base case scenario. This finding is of revealing nature when we consider the weight most players in Myanmar’s mining industry place on the uncertainty of deposit characteristics and how they it is the key unknown factor that prevents decision makers from planning strategically for the future.

As in the previous case, jade reserves are greater in scenario 3 but this time remaining deposits are of poor quality. Note also the initial value for the stock of jade reserves is set using the default tons/acre measure of 12 tons/acre. This contributes to having more reserves in all scenarios at the different simulation intervals.

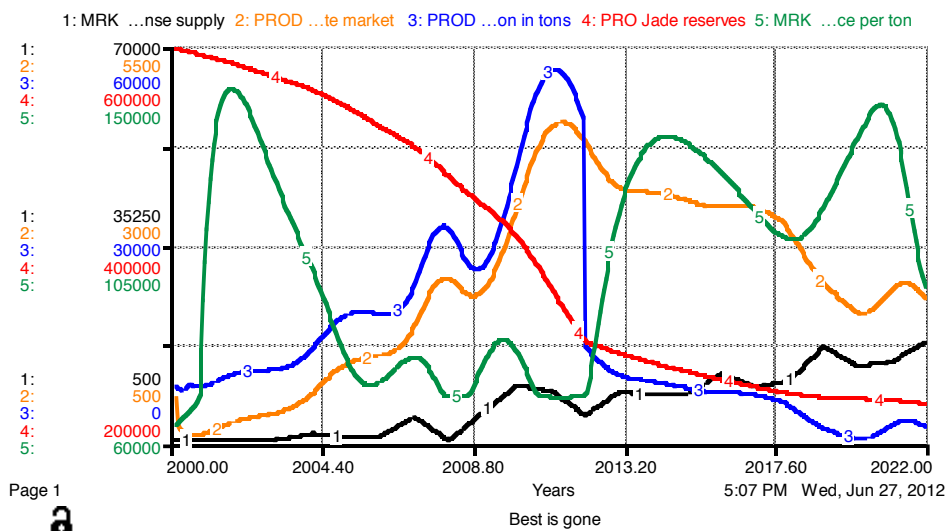


Scenario 1



Scenario 2

- Licenses
- Order rate
- Production
- Reserves
- Price per ton



Scenario 3

Figure 43 Results from scenarios in tonnage per acre

	BASE CASE			BEST IS YET TO COME			BEST IS GONE		
	2015	2018	2021	2015	2018	2021	2015	2018	2021
ORDER RATE	3,520	3,204	2,829	3,520	3,204	2,829	3,526	2,861	2,479
JADE PRODUCTION	25,349	18,403	12,000	50,698	36,806	24,000	7,615	2,308	2,620
JADE RESERVES	171,579	105,237	57,292	43,953	2,025	93	264,610	246,366	240,394
PRICE PER TON	103,245	102,512	103,785	97,162	142,736	180,713	121,714	113,722	95,591
MACHINE POPUL.	15,935	16,304	15,708	15,935	16,304	15,708	15,903	16,014	14,116

Table 13 Results from scenarios in tonnage per acre II

### 7.2.3. Sensitivity analysis

Sensitivity analysis serves as a vehicle to not only to determine the effects of parameter changes on different measures of model output but also to “develop intuition about model structure and guide data collection efforts” (Hekimoglu & Barlas, 2010; Sterman, 2000). This section relies on the use of sensitivity analysis to test how important the estimation of (a) tonnage per acre, (b) extension of the jade mining tract, and (a) government tax rate on jade sales, are for model behavior. A list of the chosen parameter inputs and their distributions is shown in Table 14.

INPUT	RANGE	DISTRIBUTION
PROD TONS PER ACRE	$[\bar{x} = 18; \sigma = 10; seed = 5]$	NORMAL
INIT INITIAL ACRES AVAILABLE	[30000-100000]	INCREMENTAL
GOVMT GOVERNMENT EMPORIUM TAX	[0.1-0.7]	INCREMENTAL

Table 14 Input specifications for sensitivity analysis

#### 7.2.3.1. Tons per acre

To simulate the changes in this parameter through time, the distributional sensitivity mode with a mean, a standard deviation, and a seed was chosen. Figure 44 shows the results of different input values of tonnage per acre on (a) equipment order rate (market), (b) jade production, (c) jade reserves, and (d) jade price per ton. Similar to the results in scenario analysis, changes in the number of jade tons that can be mined from an acre of land, do not change the behavior mode of the

chosen variables. In almost all cases, production peaks but then declines as reserves start approximating exhaustion.

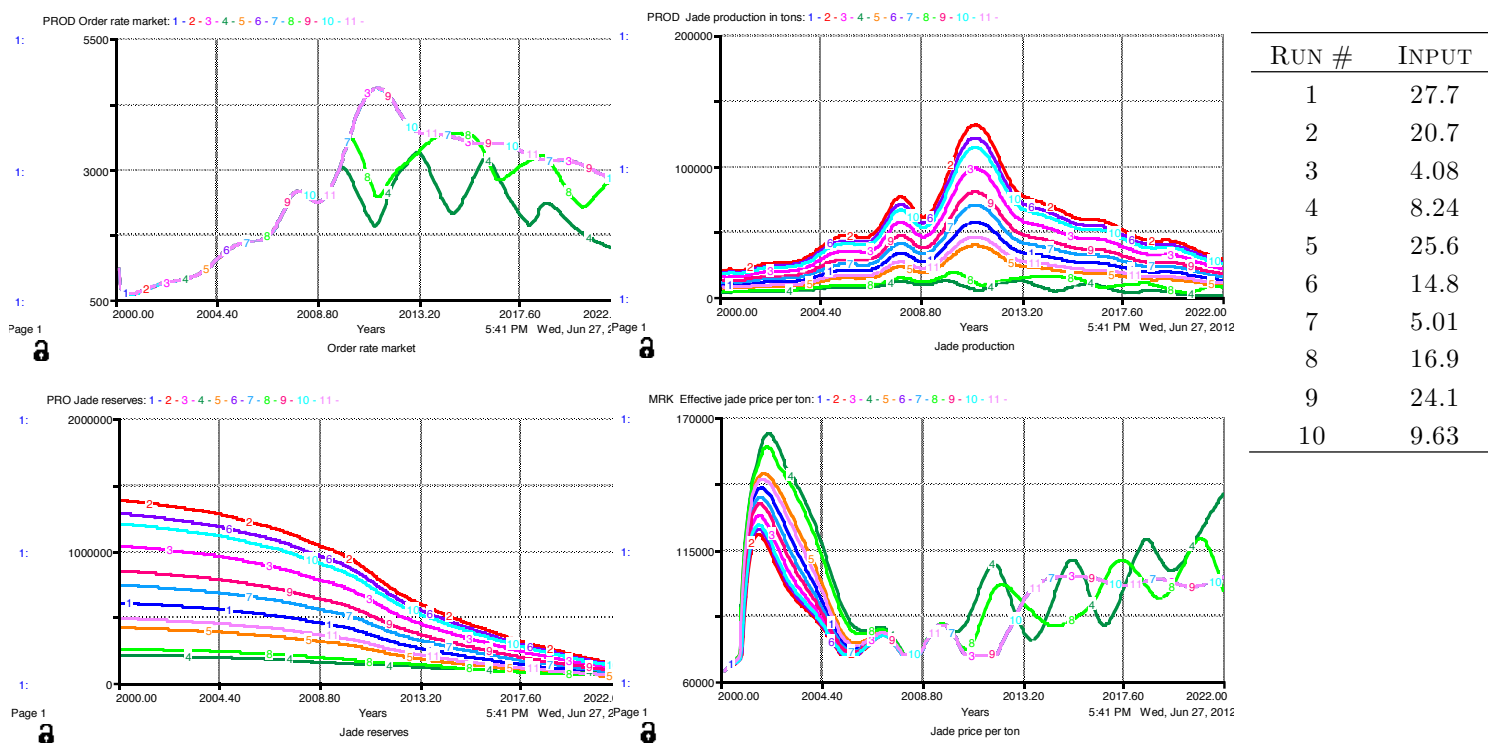


Figure 44 Sensitivity analysis results for changes in tons per acre

### 7.2.3.2. Jade mining area

Another often mentioned difficulty involved in forecasting the behavior of jade production, jade prices or equipment sales, is the question of how big Myanmar's jade mining area is. The few estimates that could be found are believed to be unreliable and therefore the doubt of whether new available figures on jade area could alter the development path of Myanmar's jade industry still remains.

Using an incremental distribution mode, the parameter for the initial value of acres available was subjected to a 10-run sensitivity test. Results shown in Figure 45 show that regardless the extension of the jade tract, the dynamics of the system prevail by not altering the decaying behavior mode of reserves and equipment orders. The fact that there might be more or less acres containing jade deposits in Myanmar only implies the horizon for extraction gets longer and that decay is inevitable. This

assertion is evident by looking at the last graph of Figure 45, “effect of land utilization on license demand.” The land utilization effect is a multiplier that constraints the inflow of mining licenses as jade reserves are gradually mined: the less the reserves, the smaller the land fraction multiplier and vice versa.

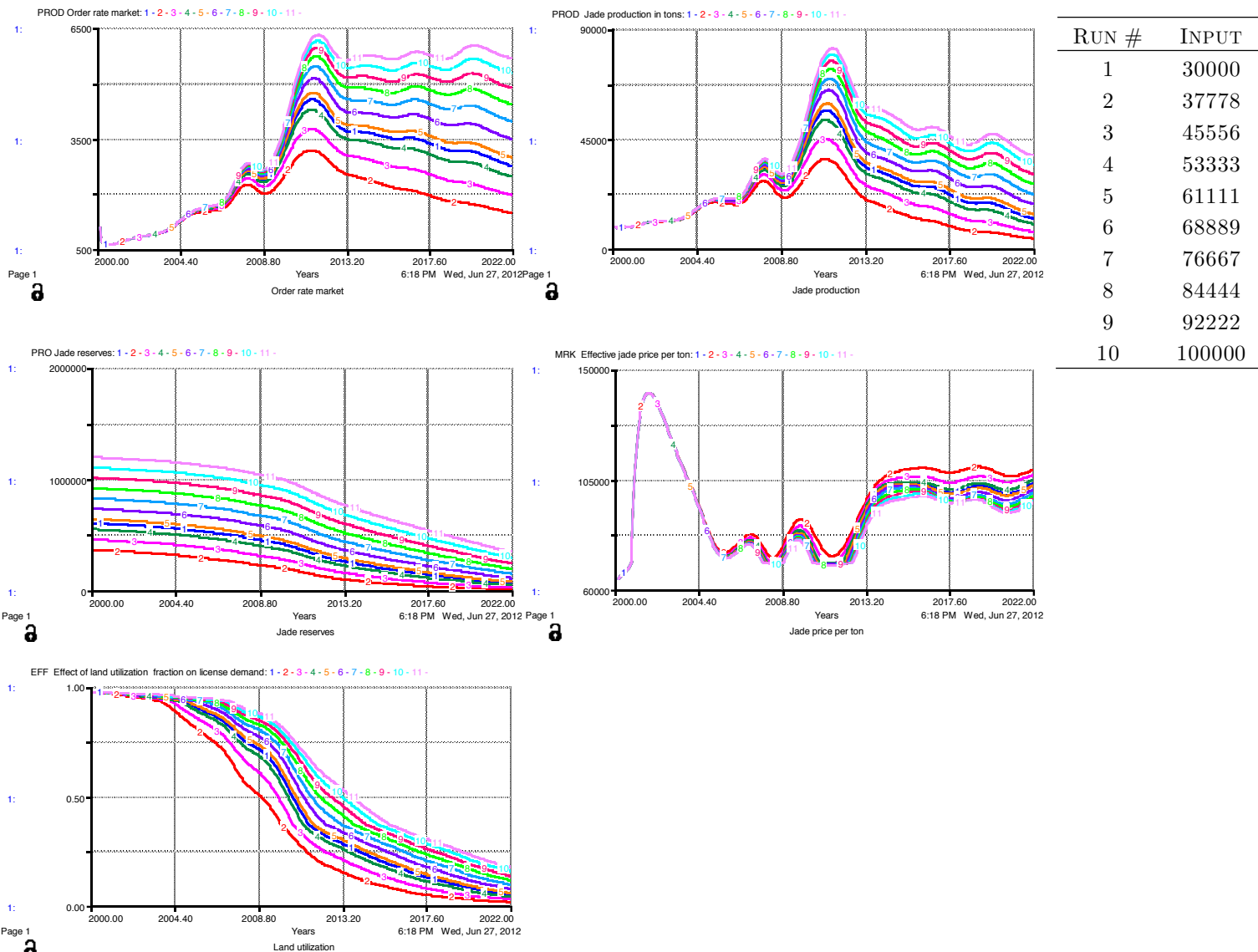


Figure 45 Sensitivity analysis results for changes in the jade mining area

In run 10, for instance, the area in acres is at its highest (i.e. 100,000) and therefore, the effect of land utilization is not as drastic as in run 2 where the area is significantly less, and even at a slower extraction pace, deposits they are exhausted faster. Going back to run 10, as the influx of licenses is not constrained as much as in run 2, production and equipment orders soar. Finally, and most interestingly, even

when the initial value for the mining area of runs 10 and 2 differ considerably, jade reserves at the end of the simulation are not that drastically different between both. In other words, in face of the existence of a bigger jade tract the behavior will still be the same with the difference that the decay of the industry will take longer.

### 7.2.3.3. Government emporium tax

Uncertainty in Myanmar’s mining industry also stems from government policies. Among those, taxation on profits from jade sales is of special concern. Although not all jade sales are consolidated through government sponsored auctions, more and more jade mining companies are finding it more appealing. Inputs for this sensitivity test range from the quasi removal of the tax mining companies must pay to the government under the “profit-sharing” scheme, to a maximum of 75% increase in such a tax.

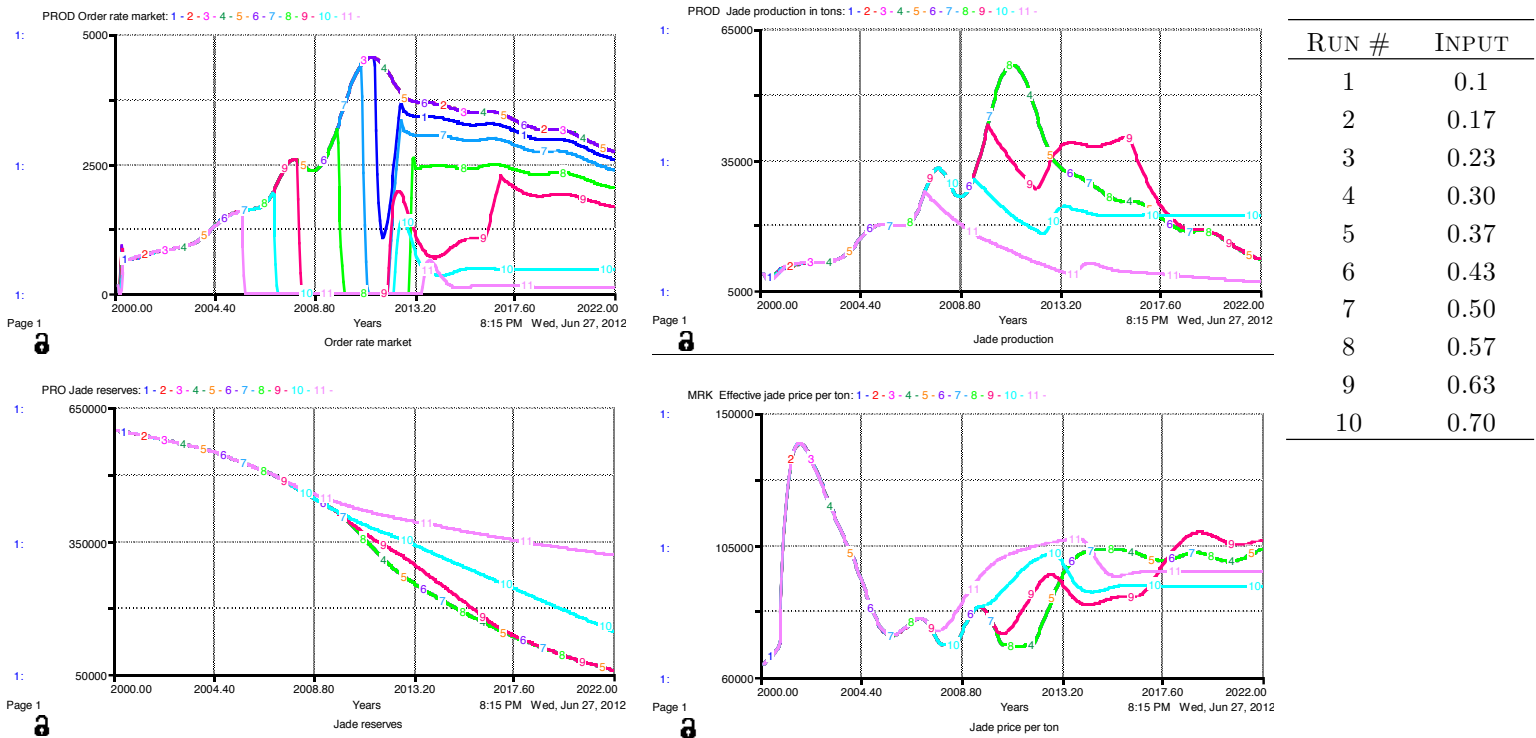


Figure 46 Sensitivity analysis results for changes in the government emporium tax

tax

Following the course of higher taxes, such as in runs 10 or 11, the results are evident: higher taxes pose bigger financial constraints to jade mining companies (i.e. they must now sustain all their costs with a smaller revenue portion) affecting also the purchases of equipment they can make even when high prices led these companies to buy more mining licenses and in theory need more equipment. The less the equipment, the less the production, and the less the production the higher the reserves and the price of jade. Prices increase temporarily until inflated gains from sales allow producers to buy equipment, fuel production again, and make prices go slightly down as a result of a greater inventory coverage.

## **Chapter 8. Financial policy for jade mining companies**

Except for the most obvious stages such as development and extraction, prospecting, exploration, and reclamation activities are virtually absent in Myanmar's mining industry nowadays. A financial analysis sector has therefore been included in the model to test whether differences in investment decisions could have arisen in the face of a formal financial analysis during the development stage of a mine.

The following sections provide an introduction of all the stages in the mine life to incorporate analyses that are new to the jade industry. Although mines are certainly not all the same, as they differ in geology, methods of mining, and so on, most of the general aspects of mining are common to all mines (Clough, et al., 1965). The general aspects or activities in the mine life are grouped below and are briefly discussed in the upcoming sections:

- Prospecting
- Exploration
- Development
- Extraction
- Reclamation

### **8.1. Prospecting and exploration**

Considered by some as two independent steps, prospecting and exploration are often combined to refer to the initial work undertaken to determine the size and value of an ore deposit (i.e. deposits of rocks from which a metal or mineral can be profitably extracted). During this first stage, geologists map the geology of rock outcrops (i.e. mapping) and take measurements of the selected exploration site (i.e. measuring). Also, representative samples are collected (i.e. sampling) to study the



potential tonnage and grade, or richness, of the ore deposit and therefore its value (Hartman & Mutmamsky, 2002).

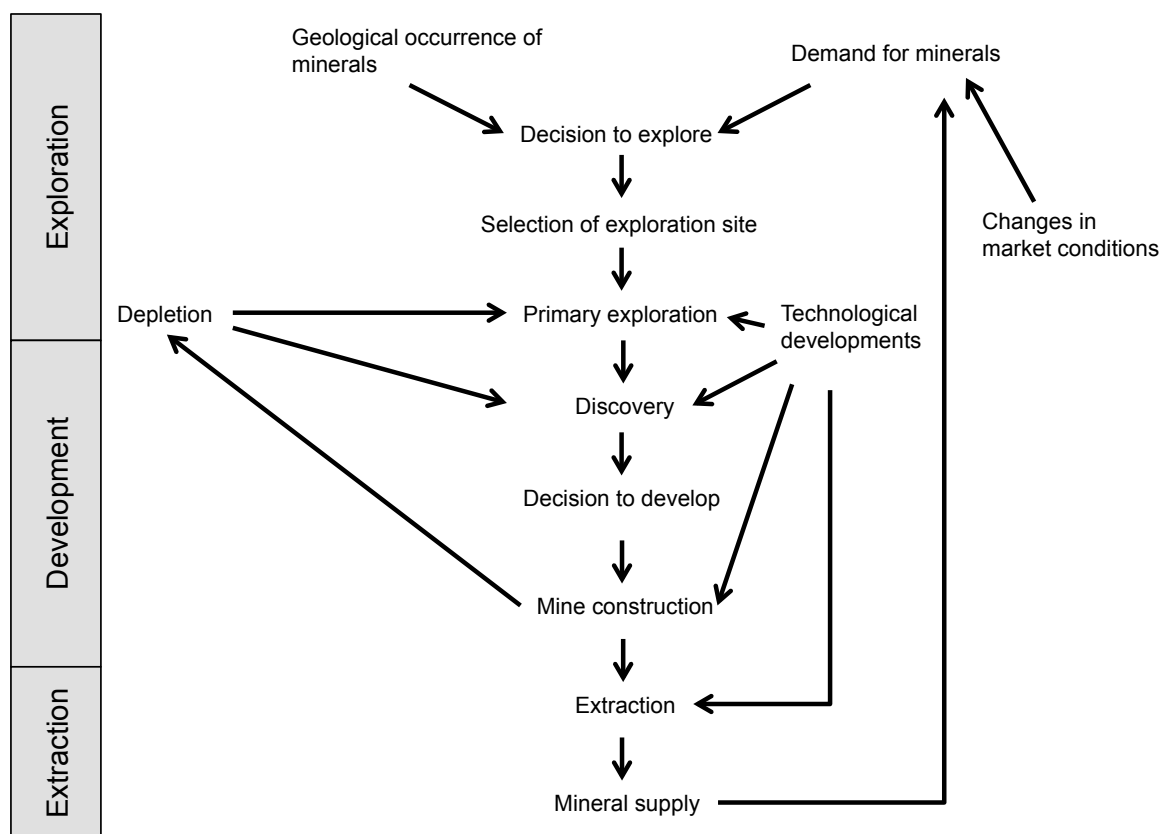


Figure 47 Stages in the life of a mine

Taken from O'Regan and Moles (2006), Figure 47 displays the five stages of the mining process (excluding reclamation) with mapping, measuring, and sampling being classified as “primary exploration” in the exploration phase.

In particular, jade sampling poses a great challenge to mining experts during the exploration stage. Sampling of jade dykes/boulders differs strikingly from traditional sampling methods in that it is almost impossible to take samples of jade for posterior chemical analyses without injuring the jade first (Win, 1968). It is then of no surprise that what Win (1968) reported more than 40 years ago still holds true in Myanmar’s mining landscape today. Most companies enter a mining venture, namely the acquisition of a mining license and the posterior development of the

mine, blindly depending entirely on their luck. Still today the choice of a site depends solely upon judgment, experience, and instinct and consists of a quick visit to the prospect site by one geologist, one mining engineer, and some locals.

Besides the geology of jade, other factors such as government regulations also impede the undertaking of exhaustive exploration studies in prospect sites. As previously mentioned, it is a state-owned enterprise the one in charge of the exploration, production (i.e. through joint ventures), and commercialization of jade in Myanmar. Hence, at least in the near future, the commissioning of exploration tasks to private companies is not expected to take place. Financial estimates for exploration will therefore be excluded from the model for now.

## 8.2. Development

Once a deposit has been identified, the work of opening a mineral deposit for exploitation begins (Hartman & Mutmanský, 2002). During this stage, a discounted cash flow analysis will be incorporated to the model to aid in the evaluation of the economic viability of mine development. Cash flow analysis involves simulating what is expected to happen in the mine over time in order to make informed decisions on whether to proceed or not with the development investment. Such an analysis is conducted by subtracting a project's initial investment ( $CF_0$ ) from the sum its cash inflows discounted at a rate equal to the firm's cost of capital (Mohapatra, 2009)

$$NPV = \sum_{t=1}^n \frac{CF_t}{(1+k)^t} - CF_0$$

Appendix 5 shows the different items included in the calculation of cash inflows and outflows throughout the license period. Cash inflows involve the recovery factor of the expected jade tonnage times the expected price, whereas cash outflows have been condensed into the following categories:

- Cash outflows at  $t_0$ 
  - Development costs

- Equipment costs
- Other equipment
- Civil works
- Miscellaneous development costs
- Cash outflows at t1, t2, t3, t4, and t5
  - Direct labor costs
  - Administration
  - Production
  - Engineering
  - Maintenance
  - Other personnel
  - Pit and maintenance services costs

Development costs at t0 relate mainly to equipment purchases and civil works (i.e. construction of roads or the installation of water or power facilities). From t1 onwards, labor and pit/maintenance service costs, strongly associated with the operation and maintenance of equipment respectively, comprise the main cash outflows of the mine operation (Mohapatra, 2009). Values for all costs have been derived from data provided by UMG and one of the interviewed mining companies.

### **8.2.1. The discount factor for the NPV analysis**

The discount factor for evaluating mining projects performs the same function as it does in the evaluation of any project: it accounts for the time value of money and project risk (Taheri, Irannajad, & Atae-pour, 2009). Among various other methods for estimating discount rates in mining, (a) calculating the WACC (i.e. weighted average cost of capital) and (b) summing up the discount rate components, stand out as the two most common. Because the latter fits the current financial structure of Myanmar's mining companies better, it has been used as a basis for

calculating the discount rate of mining projects in the model. Taheri, et al. (2009) describe the summing up discount rate method as follows:

$$d = R_F + R_P + R_C$$

Where  $d$  is the project-specific discount rate,  $R_F$  the risk-free long-term interest rate,  $R_P$  the risk portion of the project discount rate, and  $R_C$  the risk increment for country risk. In the model, the  $R_F$  component is represented by the normal discount rate whereas the last two elements are combined into a multiplier risk factor as follows:

$$\begin{aligned} & \text{NPV Adjusted for risk discount rate} = \\ & \text{NPV Normal discount rate} * \text{NPV Risk factor multiplier} \end{aligned}$$

The normal discount rate has been set at 10% whereas the risk factor multiplier is the product of the following three risk categories (see Figure 48):

- *Environmental and social*, namely environment-related obligations;
- *Regulatory*, namely security of tenure; and
- *Political*, namely national and political stability

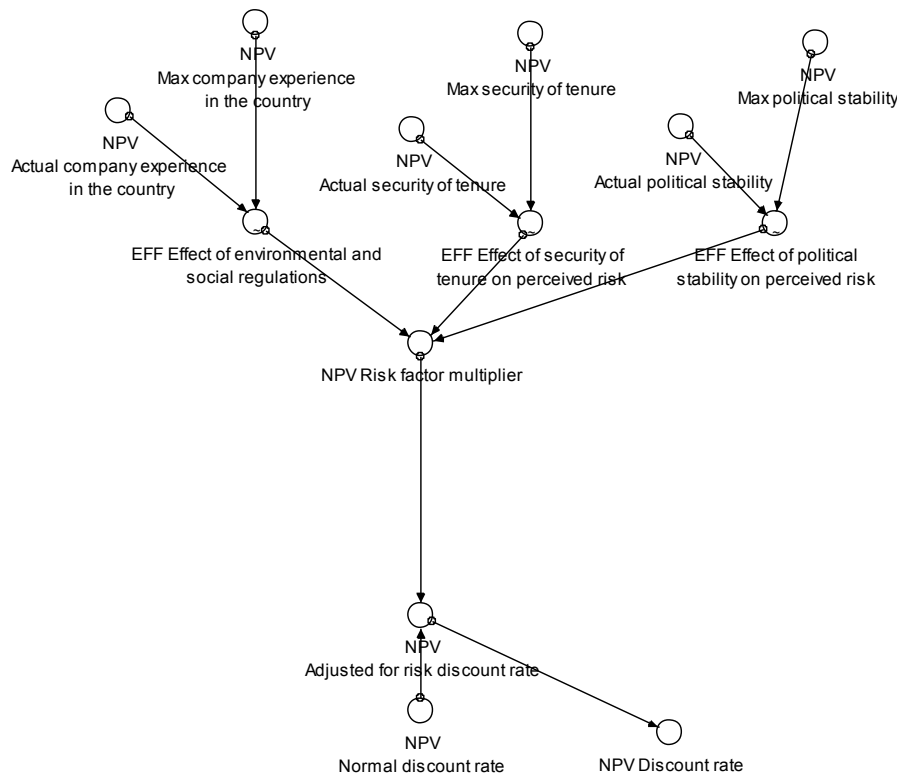


Figure 48 Adjusted discount rate

These three were considered to be the most appropriate for Myanmar’s current situation and were chosen among the nine key foreign investment criteria in mining listed by Vivoda (2011). Regulatory and political risks are of particular concern to jade miners who often see armed conflicts between government forces and rebel groups getting heated. In fact, during the last days of May this year, Myanmar’s authorities mandated the suspension of all mining activities in the northern Kachin state claiming “armed conflicts in the Pharkant area make it unsafe there” (Mizzima, 2012).

### 8.2.2. Calculating the discount factor

The 10% base discount rate “d” increases between  $7\% \leq d \leq 11\%$  depending on whether the risk factor is high (i.e. 0) or low (i.e. 1). As shown next, this adjustment is done by using the formula for a straight line  $y = mx + c$ , where:

- $m = \text{slope of the line} = \frac{y_2 - y_1}{x_2 - x_1}$

- $c$  = point at which it cuts the y-axis
- $x$  = risk factor

Assuming,

- 11% ( $y_1$ ) applies to complete risk or 0 ( $x_1$ ), and
- 7% ( $y_2$ ) applies to no risk or 1 ( $x_2$ )

It follows,

$$m = \frac{7 - 11}{1 - 0} = \frac{-4}{1} = -4$$

Finally,

$$y = mx + c$$

$$y = (-4 * risk\ factor) + 11$$

When there is no risk the discount factor will reach the normal long-term loan interest rate in Myanmar, that is 17% (10% base rate + 7% at low risk) (The World Bank, 2012b), whereas when risk starts increasing, the discount rate can go beyond 17% up to 21% (10% base rate + 11% at high risk). The smoothed formula for the adjusted discount rate is presented below:

$$NPV\ Adjusted\ for\ risk\ discount\ rate = NPV\ Normal\ discount\ rate + ((-4 * SMTH1(NPV\ Risk\ factor\ multiplier, 6/12 + 11)/100)$$

### 8.3. Exploitation

To review the financial dynamics of extraction or exploration refer to section 6.3.6.

### 8.4. Reclamation

Reclamation refers to the process of closing a mine, recountouring, revegetating, and restoring the water and land value of a mined area (Hartman & Mutmansky, 2002). Although Myanmar's mining law (1994) does discuss the duties of small and large scale mining companies to "arrange backfill, revegetation or reclaim the land in the areas already mined out to the satisfaction of the Ministry"

(Images Asia & Pan Kachin Development Society, 2004), there are no enforcement mechanisms in place to ensure this duty is carried out in practice. Reclamation activities have been therefore left out from the model as, besides from not being performed, they do not bring about any relevant dynamic to subject matter being investigated.

## **8.5. Implementing the NPV policy**

A detailed financial analysis structure was added to the model in order to test the impact of formal financial assessments on the demand for mining licenses. The goal is to understand how prices and costs interact and produce positive or negative NPV results, thus encouraging or discouraging applications for further mining licenses. As mentioned previously, mining companies in Myanmar rely only on instinct at the moment of acquiring licenses. No formal evaluation is made on the premise that the market is so uncertain, complex, and fragmented that any assessment will most likely result in a futile endeavor.

For UMG it becomes particularly important to be aware of how a possible switch in the financial mindset of mining companies could feedback to purchases of mining equipment in the future. Figure 50 recycles the scenarios introduced in section 7.2.2.1 to test the impact of active and inactive NPV assessments at the moment of evaluating mining development projects. The rest of model parameters described in the stock-and-flow section remain the same.

### **8.5.1. Runs 1 and 2**

Results suggest that in the case of runs 1 and 2, where licenses are set to their base case, discounted cash flow analyses do not make a striking difference in equipment purchases since revenues always exceed costs throughout the complete simulation and, in the presence of a continuous positive NPV, no development proposal is rejected. The rejection measure of projects is given by the third variable

in the second column of Figure 50 named “MRK analysis negative output rate.” The negative output rate is an outflow from the licenses under analysis stock that discards license proposals, after an analysis delay, when their NPV is negative (see Figure 49). In contrast to scenarios 1 and 2, the presence or absence of an NPV analysis does make a difference in scenarios 3 and 4, especially in regards to equipment ordering and production. The following two sections present an analysis of each run.

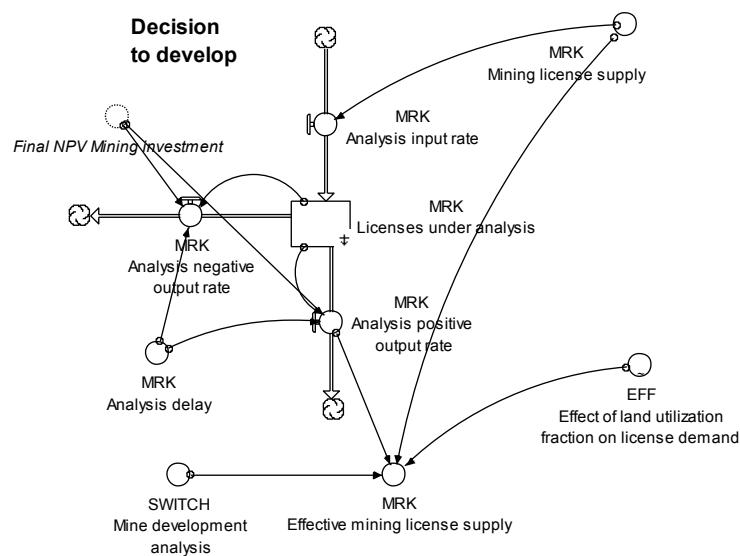


Figure 49 Structure for the evaluation of licenses

### 8.5.2.Run 3: booming mining licenses and no financial analysis

In the presence of an aggressive licensing campaign and the absence of a due financial analysis in run 3, equipment orders and jade production increase much more than in the remaining 3 scenarios, even though increases in the “negative output rate,” or the measure of investment rejection in the model, would have advised mining investments during this period not to be undertaken. A negative NPV results from jade prices not being able to keep up with the vast amount of new machinery a boom in mining licenses requires. In this framework, costs exceed prospect revenues and a negative NPV follows.



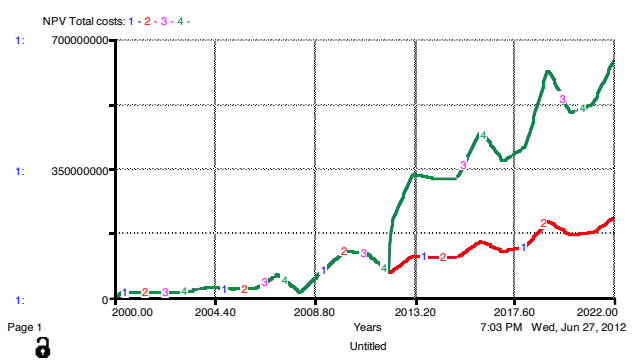
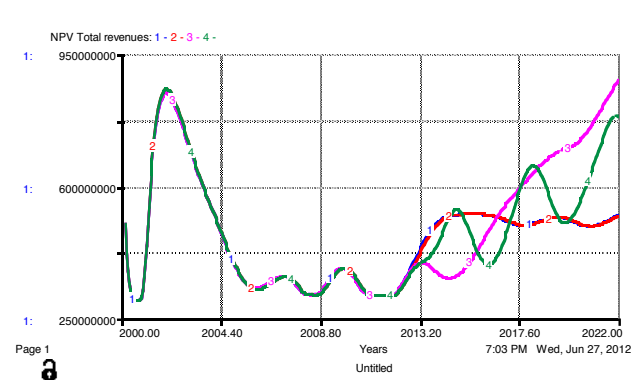
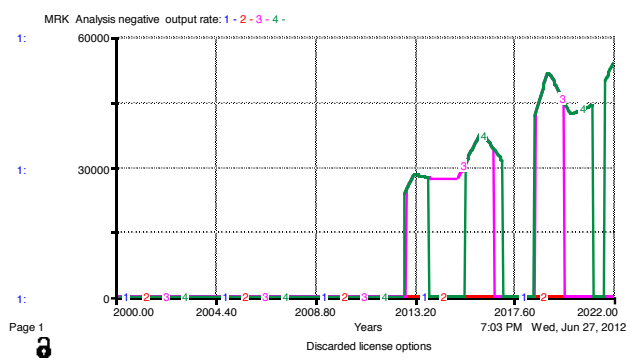
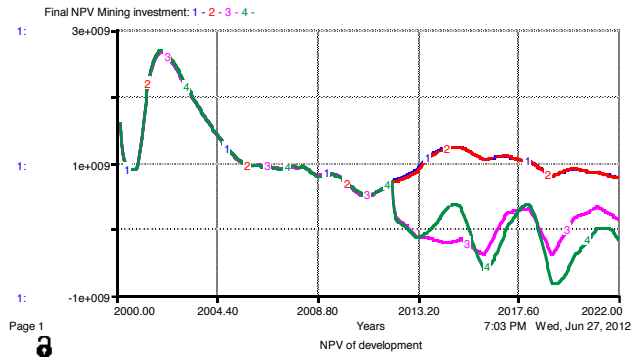
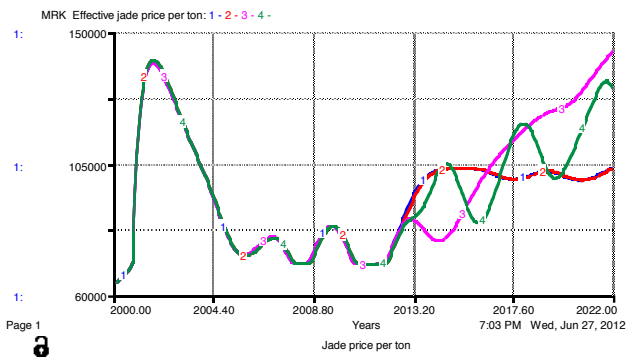
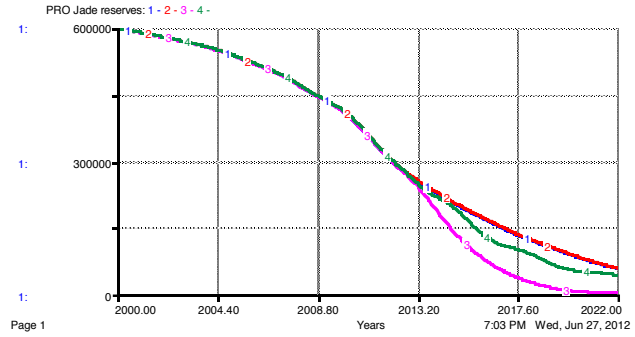
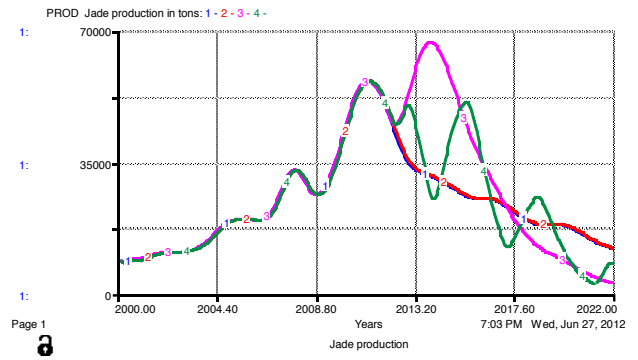
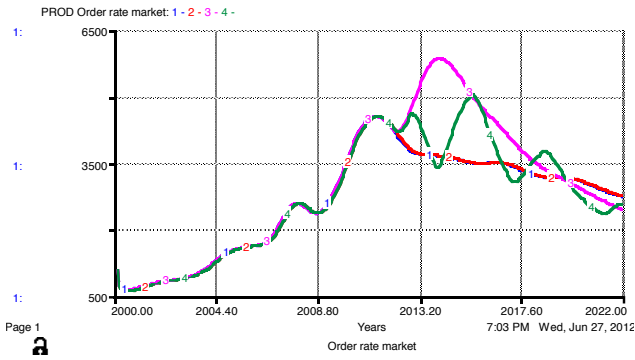
In the absence of a financial analysis, orders of equipment are made, production climbs, inventories increase, and price drops until despite the increasing trend in license demand, equipment orders and production start falling as land and reserves begin to deplete and the government begins to grant less and less concessions. When reserves start decreasing, price rises, and again despite the willingness to keep investing in licensing, there is simply less and less available for further exploitation.

### **8.5.3.Run 4: booming mining licenses and the presence of financial analysis**

When the switch for NPV analysis is activated, mining companies refrain from investing in further mining licenses in the advent of negative NPV results. In the face of no new land, orders drop at around 2014, and so does production. The decrease in production causes a drop in the inventory coverage, which in turn raises the jade price. The expansion loop kicks off as prospects of high profitability have now arisen. Positive NPVs (backed up by a higher jade price) prompt the further application of licenses, the jump in production and in inventory coverage, and the subsequent drop in price. This cycle will repeat once again, until the exhaustion of land and reserves prevent further extraction from taking place.

## **8.6. Policy insights**

Runs 3 and 4 are especially valuable in portraying how different risk profiles in mining investment have not isolated effects but rather feedback into production and therefore into prices, as shown by the simulation results. Also, though until now jade prices have exceeded all the costs involved in mining operations, there might come times when regardless the nature of the jade deposit prospected, investing in mining licenses might result in financial losses. If this is the case and a due financial analysis is performed, the impact on UMG will be simply decreased sales.



RUN	LICENSES	NPV SWITCH
1	BASE CASE	OFF
2	BASE CASE	ON
3	MINING RUSH	OFF
4	MINING RUSH	ON

Figure 50 Four scenarios for a hypothetical switch in mining financial analysis

## Chapter 9. Conclusions

Myanmar's jade mining industry has proved to be a system whose behavior is determined by the dynamics of its underlying structure. This thesis has answered the main research question related to cause of the oscillatory or cyclical nature of purchases of jade mining equipment and has shed light on the future of the industry as a whole and how this future feedbacks to UMG and its customers.

Given the interconnected dynamics of all the elements in the jade system, it is rather difficult to suggest an investment scheme that could stabilize equipment purchases either for UMG customers or for the aggregate of mining companies in the industry. Model results, though, serve as a fundamental to start considering industry dynamics during the preparation of sales forecasts of mining equipment.

Regarding the growth objective of UMG, it is advised the client firm must reshape its growth strategy to better fit industry prospects which show the imminent collapsing trend of mineable land, reserves, and with that a gradual decay in equipment purchases.

Furthermore, despite the uncertainty lying behind most of the model parameters and the complexity inherent to the jade itself, this model proved insensitive to parameter changes and being able to provide, backed up by empirical data, a hypothesis of industry behavior. This evidences how many insights can result even in the presence of imperfect or scarce information.

*Jorgen Tessman: "About the future! My God, we know nothing about it."*

*Eilert Lovborg: "No, but there are things to be said about it"*

Henrik Ibsen in his play Hedda Gabler

## **Chapter 10. Limitations**

Health hazards to workers and other sharp environmental degradation issues that are widespread in Myanmar's mining locations have not been included in the model.

Upgrades in mining technology have been excluded as well. Although major technological innovations have improved operations in the energy sector for example, technological changes in mining have not been as radical as to induce significant shakeout in their own right (Bartos, 2007 ).

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## **Appendix 1. A note on building reference modes**

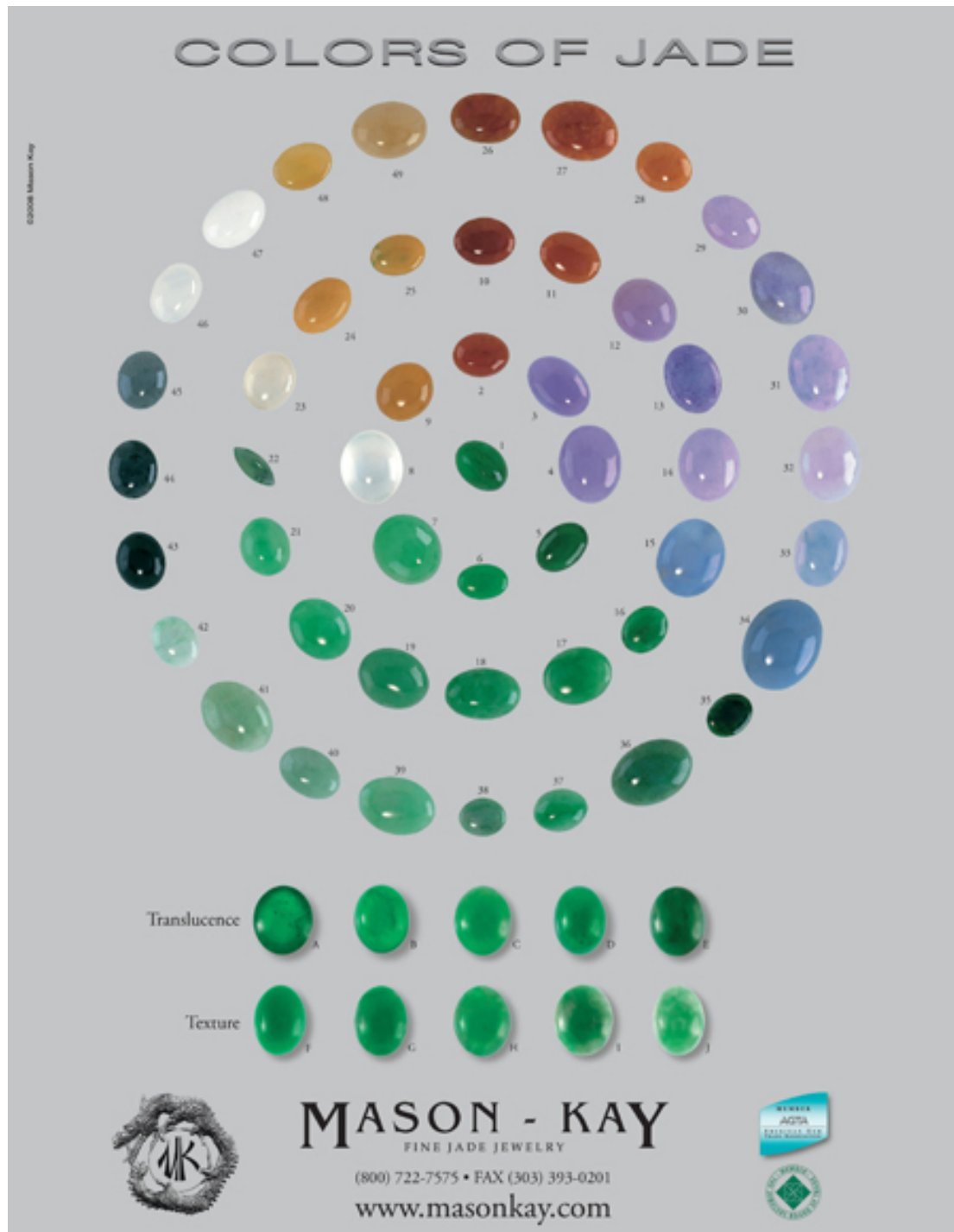
At the moment of starting this project, I was provided with an exceptionally vague and quick description (not resulting from lack of willingness but rather from lack of time from the “problem owner”) of the problem I was commissioned to investigate. After a couple of days of data gathering and analysis, the first reference mode displayed in Figure 7 emerged, causing a shocking surprise to UMG’s general and sales manager respectively. What to me seemed a mere graphic representation taken from their everyday data, to them it was a depiction they had not been confronted to in the past. The reason for this resides in UMG’s performance measurement system, which uses key performance indicators or KPIs to measure performance across the entire organization.

KPIs are mostly used for “measuring the degree of accomplishment of the defined objectives based on expected results” (Rodriguez, Alfaro, & Ortiz, 2009). As in many other organizations today, the need for dealing with increasingly expanding and complex operations prompted UMG to adopt a standard tool to define and measure progress quantitatively. Aided by performance indicators, variations between desired and actual results across the different units and departments at UMG are reported on a month-to-month basis contrasting them only to last year’s results and thus failing to recognize important trends that might be developing over time. This is the reason why when confronted with a graph that plotted perhaps one of their most critical indicators (i.e. sales of equipment units) over time, both the general and sales manager reacted with such astonishment.

The presence of an overwhelming quantity of KPIs also hinders the ability of top managers at UMG to concentrate in the understanding what really matters. Indeed =, a poor understanding of the dynamic drivers in the mining industry is reflected in the way equipment orders are raised by UMG to their principals today. Currently, orders are made on the basis of (a) expectations of random political or

ethnic outrages in the mining sites, and (b) prospects of sales growth set by upper management and salesmen themselves. Equipment orders are therefore assembled in a way that entirely disregards industry dynamics and how they influence purchases of mining equipment.

## Appendix 2. Jade color wheel



Source: Mason-Kay (2012)

## Appendix 3. Myanmar's jade emporium data

							Average per year							
SOURCE	EDITION	MONTH / YEAR	TOTAL VISITORS	FOREIGN VISITORS	JADE LOTS OFFERED	JADE LOTS SOLD	TOTAL VISITORS	% CHANGE	FOREIGN VISITORS	% CHANGE	JADE LOTS OFFERED	% CHANGE	JADE LOTS SOLD	% CHANGE
1	40TH	MARCH 2003	1270	635	1254	503								
	12TH	OCTOBER 2003	914	457	1042	348	1092		546		1148		426	
2, 2.1	41ST	MARCH 2004	1200	600	-	-								
	1ST	JULY 2004	-	-	-	-								
	13TH	OCTOBER 2004	-	-	1412	989	1200	10%	600	10%	1412	23%	989	132%
3, 3.1, 3.2	42ND	MARCH 2005	1220	792	1711	1198								
	2ND	JULY 2005	-	-	-	-								
	14th	October 2005	1436	737	2154	1508	1328	11%	765	27%	1933	37%	1353	37%
4, 4.1, 2.1	43rd	March 2006	2359	1000	2459	1721								
	3rd	July 2006	-	-	-	-								
	15th	October 2006	2000	1000	4237	2966	2180	64%	1000	31%	3348	73%	2344	73%
5, 5.1, 5.2, 5.3, 5.4	44th	March 2007	3419	2068	5217	3652								
	4th	July 2007	4000	2200	5880	4600								
	16th	November 2007	3616	2300	5500	3618	3678	69%	2189	119%	5532	65%	3957	69%
6	45th	March 2008	6000	3000	7700	5390								
	5th	July 2008	-	-	-	-								
	17th	November 2008	-	-	-	-	6000	63%	3000	37%	7700	39%	5390	36%
7, 7.1, 7.2, 7.3	46th	March 2009	4600	2300	5000	3500								
	6th	June 2009	6000	3000	-	-								
	18th	October 2009	4000	2000	8140	5698	4867	-19%	2433	-19%	6570	-15%	4599	-15%
8, 8.1, 8.2	47th	March 2010	6000	3000	10000	7000								
	7th	July 2010	-	-	11500	8050								
	19th	November 2010	6700	4000	13081	9157	6350	30%	3500	44%	11527	75%	8069	75%
9, 9.1, 9.2, 9.3	48th	March 2011	8700	4719	20000	13608								
	8th	July 2011	9366	5000	22317	15149								
	20th	December 2011	5300	1600	12000	8300	7789	23%	3773	8%	18106	57%	12352	53%
10, 10.1	49th	March 2012	6000	3000	16697	9762								
	9th	July 2012	N/A	N/A	N/A	N/A								
	21st	December 2012	N/A	N/A	N/A	N/A	6000	-23%	3000	-20%	16697	-8%	9762	-21%

## Appendix 4. Sources of Myanmar's gem emporium data

- 1 [http://www.myanmargems.com/jade\\_remains\\_yardstick\\_for\\_gemindustry.htm](http://www.myanmargems.com/jade_remains_yardstick_for_gemindustry.htm)
- 2 <http://www.burmanet.org/news/2005/03/09/xinhua-myanmar-to-hold-gems-emporium/>
- 2.1 [http://english.peopledaily.com.cn/200610/19/eng20061019\\_313505.html](http://english.peopledaily.com.cn/200610/19/eng20061019_313505.html)
- 3 [http://missions.itu.int/~myanmar/e-com/050403\\_jade/gems.htm](http://missions.itu.int/~myanmar/e-com/050403_jade/gems.htm)
- 3.1 <http://www.myanemb-sa.net/news/previous%20news/october/06-10-05.htm>
- 3.2 <http://www.myanemb-sa.net/news/previous%20news/october/08-10-05.htm>
- 4 [http://www.myanmargems.com/43myanma\\_gems\\_emporium.htm](http://www.myanmargems.com/43myanma_gems_emporium.htm)
- 4.1 [http://www.kaladanpress.org/v3/index.php?option=com\\_content&view=article&id=27:burma-gems-corporation-display-more-jade-at-gems-emporium&catid=53:march-2006&Itemid=2](http://www.kaladanpress.org/v3/index.php?option=com_content&view=article&id=27:burma-gems-corporation-display-more-jade-at-gems-emporium&catid=53:march-2006&Itemid=2)
- 5 [http://www.myanmargems.com/myanmargems\\_emporium\\_biggestever.htm](http://www.myanmargems.com/myanmargems_emporium_biggestever.htm)
- 5.1 [www.unhcr.org/refworld/docid/4896c48d1e.html](http://www.unhcr.org/refworld/docid/4896c48d1e.html)
- 5.2 [http://news.xinhuanet.com/english/2008-02/10/content\\_7585414.htm](http://news.xinhuanet.com/english/2008-02/10/content_7585414.htm)
- 5.3 <http://www.mmtimes.com/no389/b007.htm>
- 5.4 <http://www.minesandcommunities.org/article.php?a=8316&l=1>
- 6 [http://news.xinhuanet.com/english/2008-08/27/content\\_9721366.htm](http://news.xinhuanet.com/english/2008-08/27/content_9721366.htm)
- 7 [http://news.xinhuanet.com/english/2009-08/23/content\\_11930018.htm](http://news.xinhuanet.com/english/2009-08/23/content_11930018.htm)
- 7.1 [http://news.xinhuanet.com/english/2009-09/13/content\\_12045884.htm](http://news.xinhuanet.com/english/2009-09/13/content_12045884.htm)
- 7.2 <http://www.bbtrv.com/2010/0328/2022.html>
- 7.3 <http://www.burmanet.org/news/2009/03/24/associated-press-gem-sales-earn-myanmar-191-million/>
- 8 [http://news.xinhuanet.com/english2010/business/2011-03/10/c\\_13770779.htm](http://news.xinhuanet.com/english2010/business/2011-03/10/c_13770779.htm)
- 8.1 [http://news.xinhuanet.com/english2010/business/2010-06/28/c\\_13373777.htm](http://news.xinhuanet.com/english2010/business/2010-06/28/c_13373777.htm)
- 8.2 <http://english.peopledaily.com.cn/90001/90777/7287472.html>
- 9 <http://www.mmtimes.com/2011/business/577/biz57701.html>
- 9.1 <http://www.mmtimes.com/2011/business/584/biz58403.html>
- 9.2 <http://www.visit2burma.com/news-events/gems-emporium/>
- 9.3 <http://www.mmtimes.com/2012/business/609/biz60904.html>
- 10 [http://news.xinhuanet.com/english/world/2012-03/09/c\\_131457034.htm](http://news.xinhuanet.com/english/world/2012-03/09/c_131457034.htm)
- 10.1 <http://www.bullionstreet.com/news/recovering-myanmar-hit-by-sharp-dips-in-gem-sales/1>



## Appendix 5. Net present value analysis

	YEAR					
	0	1	2	3	4	5
CASH INFLOWS						
JADEITE PRODUCTION (TONS)						
PRICE PER TON						
TOTAL REVENUES						
CASH OUTFLOWS						
DEVELOPMENT COSTS						
1. EQUIPMENT COSTS						
EXCAVATORS						
TRUCKS						
DRILLING MACHINES						
DOZERS						
TOTAL EQUIPMENT COSTS						
2. OTHER EQUIPMENT						
REPAIR EQUIPMENT						
CUTTING EQUIPMENT						
LIGHT VEHICLES						
TOTAL OTHER EQUIPMENT COSTS						
3. CIVIL WORKS						
HOUSING						
ROADS						
WATER SUPPLY						
TOTAL CIVIL WORKS COST						
4. MISCELLANEOUS DEVELOPMENT COSTS						
LAND PURCHASE						
EXPLOSIVES						
TOTAL DEVELOPMENT COSTS						

LABOR COSTS  
 1. ADMINISTRATION  
     GENERAL MANAGER  
     PROCUREMENT  
     FINANCE & ACCOUNTING  
 TOTAL ADMINISTRATION LABOR COSTS  
 2. PRODUCTION  
     2.1 OPERATORS  
         EXCAVATOR DRIVER  
         TRUCK DRIVER  
         DRILLING MACHINE DRIVER  
         DOZER DRIVER  
     2.2 OTHERS  
         STONEFINDER CREW  
 TOTAL PRODUCTION LABOR COST  
 3. ENGINEERING  
     MINING ENGINEER  
 TOTAL ENGINEERING LABOR COSTS  
 4. MAINTENANCE  
     WORKSHOP SUPERVISOR  
     MECHANICS  
 TOTAL MAINTENANCE LABOR COSTS  
 5. PERSONNEL  
     OTHERS  
 TOTAL OTHER PERSONNEL LABOR COSTS  
 TOTAL LABOR COSTS  
 INDIRECT COSTS  
 1. PIT AND MAINTENANCE SERVICES  
     FUEL EXCAVATORS  
     FUEL TRUCKS  
     FUEL DRILLING MACHINES  
     FUEL DOZERS  
     SPARE PARTS EXCAVATORS  
     SPARE PARTS TRUCKS  
     SPARE PARTS DRILLING MACHINES  
     SPARE PARTS DOZERS  
 TOTAL PIT AND MAINTENANCE SERVICES  
 COSTS  
 TOTAL INDIRECT COSTS  
 GOVERNMENT CHARGES  
     ROYALTY TAX ON SALES  
 TOTAL GOVERNMENT CHARGES

## Appendix 6. Equation list

$$\text{FIN\_Cash}(t) = \text{FIN\_Cash}(t - dt) + (\text{FIN\_Clearing\_second\_pymt} +$$

$$\text{FIN\_Clearing\_downpayment} - \text{FIN\_Cash\_outflow\_rate}) * dt$$

$$\text{INIT FIN\_Cash} = 0$$

INFLOWS:

$$\text{FIN\_Clearing\_second\_pymt} =$$

$$\text{FIN\_Accounts\_receivable\_second\_pymt}/\text{FIN\_Clearing\_delay\_second\_pymt}$$

$$\text{FIN\_Clearing\_downpayment} =$$

$$\text{FIN\_Accounts\_receivable\_downpayment}/\text{FIN\_Clearing\_delay\_downpayment}$$

OUTFLOWS:

$$\text{FIN\_Cash\_outflow\_rate} =$$

$$\text{FIN\_Total\_cashflows\_t0} + \text{FIN\_Total\_operator\_salary\_costs} + \text{FIN\_Total\_other\_labor\_costs} + \text{FIN\_Cost\_of\_equipment\_purchased} + \text{FIN\_Total\_pit\_and\_maintenance\_costs} + \text{GOVMT\_Tax\_pymts\_on\_raw\_production}$$

$$\text{FIN\_Expected\_unit\_variable\_costs}(t) = \text{FIN\_Expected\_unit\_variable\_costs}(t - dt) +$$

$$(\text{FIN\_Change\_in\_expected\_unit\_variable\_cost}) * dt$$

$$\text{INIT FIN\_Expected\_unit\_variable\_costs} = 15000$$

INFLOWS:

$$\text{FIN\_Change\_in\_expected\_unit\_variable\_cost} = (\text{FIN\_Unit\_variable\_cost} -$$

$$\text{FIN\_Expected\_unit\_variable\_costs})/\text{FIN\_Expected\_unit\_variable\_cost\_adjustment\_delay}$$

$$\text{FIN\_Accounts\_receivable\_downpayment}(t) = \text{FIN\_Accounts\_receivable\_downpayment}(t - dt)$$

$$+ (\text{FIN\_Change\_in\_accounts\_receivable\_downpayment} - \text{FIN\_Clearing\_downpayment}) * dt$$

$$\text{INIT FIN\_Accounts\_receivable\_downpayment} = 0$$

INFLOWS:

$$\text{FIN\_Change\_in\_accounts\_receivable\_downpayment} =$$

$$\text{FIN\_After\_tax\_revenues} * \text{FIN\_Downpayment\_fraction}$$

OUTFLOWS:

$$\text{FIN\_Clearing\_downpayment} =$$

$$\text{FIN\_Accounts\_receivable\_downpayment}/\text{FIN\_Clearing\_delay\_downpayment}$$

$$\text{FIN\_Accounts\_receivable\_second\_pymt}(t) = \text{FIN\_Accounts\_receivable\_second\_pymt}(t - dt) + (\text{FIN\_Change\_in\_accounts\_receivable\_second\_pymt} - \text{FIN\_Clearing\_second\_pymt}) * dt$$

INIT FIN\_\_Accounts\_receivable\_second\_pymt = 0

INFLOWS:

$$\text{FIN\_Change\_in\_accounts\_receivable\_second\_pymt} = \text{FIN\_After\_tax\_revenues} * (1 - \text{FIN\_Downpayment\_fraction})$$

OUTFLOWS:

FIN\_\_Clearing\_second\_pymt =

$$\text{FIN\_Accounts\_receivable\_second\_pymt} / \text{FIN\_Clearing\_delay\_second\_pymt}$$

$$\text{LND\_Acres\_exploited}(t) = \text{LND\_Acres\_exploited}(t - dt) + (\text{LND\_exploitation\_rate}) * dt$$

INIT LND\_\_Acres\_exploited = 0

INFLOWS:

LND\_\_exploitation\_rate =

$$(\text{PROD\_Effective\_production\_capacity} * \text{EFF\_Effect\_of\_acres\_availability\_on\_exploitation}) * 1$$

$$\text{LND\_Acres\_transferred}(t) = \text{LND\_Acres\_transferred}(t - dt) +$$

$$(\text{LND\_Acres\_transferring\_rate} - \text{LND\_exploitation\_rate}) * dt$$

INIT LND\_\_Acres\_transferred = 800

INFLOWS:

$$\text{LND\_Acres\_transferring\_rate} = \text{MRK\_License\_approval\_rate} * \text{LND\_Acres\_per\_license}$$

OUTFLOWS:

LND\_\_exploitation\_rate =

$$(\text{PROD\_Effective\_production\_capacity} * \text{EFF\_Effect\_of\_acres\_availability\_on\_exploitation}) * 1$$

$$\text{LND\_Proven\_reserves\_in\_acres}(t) = \text{LND\_Proven\_reserves\_in\_acres}(t - dt) + (-$$

$$\text{LND\_Acres\_transferring\_rate}) * dt$$

INIT LND\_\_Proven\_reserves\_in\_acres = LND\_\_Initial\_acres\_available

OUTFLOWS:

$$\text{LND\_Acres\_transferring\_rate} = \text{MRK\_License\_approval\_rate} * \text{LND\_Acres\_per\_license}$$

$$\text{MRK\_Expected\_price\_by\_miners}(t) = \text{MRK\_Expected\_price\_by\_miners}(t - dt) +$$

$$(\text{MRK\_Change\_in\_expected\_price\_by\_miners}) * dt$$

INIT MRK\_\_Expected\_price\_by\_miners = 100000

INFLOWS:

MRK\_Change\_in\_expected\_price\_by\_miners = (MRK\_Effective\_jade\_price\_per\_ton - MRK\_Expected\_price\_by\_miners) / MRK\_Expected\_price\_long\_run\_adjustment\_delay

MRK\_Expected\_sales\_rate(t) = MRK\_Expected\_sales\_rate(t - dt) + (MRK\_Change\_in\_expected\_sales\_rate) \* dt

INIT MRK\_Expected\_sales\_rate =

MRK\_Population\_of\_consumers \* MRK\_Per\_capita\_consumption\_requirements

INFLOWS:

MRK\_Change\_in\_expected\_sales\_rate = (MRK\_Jade\_sales\_rate - MRK\_Expected\_sales\_rate) / MRK\_Expected\_sales\_rate\_adjustment\_delay

MRK\_Jade\_at\_warehouses(t) = MRK\_Jade\_at\_warehouses(t - dt) + (PRO\_Jade\_transportation\_rate - MRK\_Jade\_sales\_rate) \* dt

INIT MRK\_Jade\_at\_warehouses = 40000

INFLOWS:

PRO\_Jade\_transportation\_rate = ((PRO\_Jade\_extracted \* (1 - PRO\_Dillution\_fraction)) \* 1)

OUTFLOWS:

MRK\_Jade\_sales\_rate =

MIN(MRK\_Max\_jade\_sales\_rate, ((MRK\_Population\_of\_consumers \* MRK\_Effective\_per\_capita\_consumption\_requirements)))

MRK\_Licenses\_approved(t) = MRK\_Licenses\_approved(t - dt) + (MRK\_License\_approval\_rate) \* dt

INIT MRK\_Licenses\_approved = 0

INFLOWS:

MRK\_License\_approval\_rate = MRK\_Licenses\_available / LND\_License\_approval\_delay

MRK\_Licenses\_available(t) = MRK\_Licenses\_available(t - dt) + (MRK\_License\_application\_rate - MRK\_License\_approval\_rate) \* dt

INIT MRK\_Licenses\_available = 50

INFLOWS:

MRK\_License\_application\_rate = MRK\_Effective\_mining\_license\_supply

OUTFLOWS:

MRK\_License\_approval\_rate = MRK\_Licenses\_available / LND\_License\_approval\_delay

```

MRK_Population_of__consumers(t) = MRK_Population_of__consumers(t - dt) +
(MRK_Change_in_population__of_consumers) * dt
INIT MRK_Population_of__consumers = 6000
INFLOWS:
MRK_Change_in_population__of_consumers = IF SWITCH__Population_growth=1 THEN
MRK_Population_of__consumers*MRK_Percentage_change_in_population ELSE 0
MRK__Expected_price_short_run(t) = MRK__Expected_price_short_run(t - dt) +
(MRK_Change_expected_in_price__short_run) * dt
INIT MRK__Expected_price_short_run = 100000
INFLOWS:
MRK_Change_expected_in_price__short_run = (MRK__Effective_jade_price_per_ton-
MRK__Expected_price_short_run)/MRK_Expected_price_short_run__adjustment_delay
MRK__Jade_sold(t) = MRK__Jade_sold(t - dt) + (MRK_Jade_sales_rate) * dt
INIT MRK__Jade_sold = 0
INFLOWS:
MRK_Jade_sales_rate =
MIN(MRK__Max_jade_sales__rate,(((MRK_Population_of__consumers*MRK__Effective_per_c
apita_consumption_requirements)))
MRK__Licenses_under_analysis(t) = MRK__Licenses_under_analysis(t - dt) +
(MRK__Analysis_input_rate - MRK__Analysis_positive__output_rate -
MRK__Analysis_negative__output_rate) * dt
INIT MRK__Licenses_under_analysis = 1
INFLOWS:
MRK__Analysis_input_rate = MRK__Mining_license_supply
OUTFLOWS:
MRK__Analysis_positive__output_rate = IF Final_NPV_Mining_investment>0 THEN
MRK__Licenses_under_analysis/MRK__Analysis_delay ELSE 0
MRK__Analysis_negative__output_rate = IF Final_NPV_Mining_investment<0 THEN
MRK__Licenses_under_analysis/MRK__Analysis_delay ELSE 0

```

```

MRK__Per_capita_consumption__requirements(t) =
MRK__Per_capita_consumption__requirements(t - dt) +
(MRK__Change_in_per_capita_consumption_requirements) * dt
INIT MRK__Per_capita_consumption__requirements = 5
INFLOWS:
MRK__Change_in_per_capita_consumption_requirements =
(MRK_Equilibrium_per_capita_consumption-
MRK__Per_capita_consumption__requirements)/MRK_Consumption_requirements__adjustment
__delay
NOISE__Pink_noise(t) = NOISE__Pink_noise(t - dt) + (NOISE_Change_in_pink_noise) * dt
INIT NOISE__Pink_noise = 1
INFLOWS:
NOISE_Change_in_pink_noise = (NOISE__White_noise-
NOISE__Pink_noise)/NOISE_Adjustment_delay
PROD_Customer_mining_equipment(t) = PROD_Customer_mining_equipment(t - dt) +
(PROD_Mining_equipment__delivery_rate - PROD__Mining_equipment__scrapping_rate) * dt
INIT PROD_Customer_mining_equipment = 750
INFLOWS:
PROD_Mining_equipment__delivery_rate =
PROD_Desired_delivery_rate*PROD_Order_fulfillment__ratio
OUTFLOWS:
PROD__Mining_equipment__scrapping_rate =
(PROD_Customer_mining_equipment/PROD__Scrapping_delay)*1
PROD__Accumulated_sales_UMG(t) = PROD__Accumulated_sales_UMG(t - dt) +
(PROD__Change_in_accumulated__sales_UMG) * dt
INIT PROD__Accumulated_sales_UMG = 0
INFLOWS:
PROD__Change_in_accumulated__sales_UMG = PROD_Order_rate_UMG
PROD__Order_backlog(t) = PROD__Order_backlog(t - dt) + (PROD_Order_rate_market -
PROD__Order_fulfillment__rate) * dt
INIT PROD__Order_backlog = 1

```





$Final\_NPV\_Mining\_investment =$   
 $(NPV\_Discounted\_cash\_flow\_yr\_1+NPV\_Discounted\_cash\_flow\_yr\_2+NPV\_Discounted\_cash\_flow\_yr\_3+NPV\_Discounted\_cash\_flow\_yr\_4+NPV\_Discounted\_cash\_flow\_yr\_5)-$   
 $NPV\_t0\_Total\_cash\_outflows$   
 $FIN\_Average\_yearly\_fuel\_req = 54900$   
 $FIN\_Budget\_for\_equipment = FIN\_Cash/NPV\_Average\_equipment\_cost$   
 $FIN\_Expected\_unit\_variable\_cost\_adjustment\_delay = 6/12$   
 $FIN\_Land\_cost = LND\_Acres\_transferring\_rate*NPV\_t0\_Acre\_cost$   
 $FIN\_Total\_cashflows\_t0 = FIN\_Total\_civil\_works\_costs+FIN\_Total\_development\_costs$   
 $FIN\_Total\_operator\_salary\_costs =$   
 $NPV\_Average\_operator\_salary*PRO\_Equipment\_used\_per\_year*NPV\_Average\_driver\_req\_per\_equipment$   
 $FIN\_Total\_other\_labor\_costs =$   
 $(PRO\_Equipment\_used\_per\_year*NPV\_t0\_Stone\_finders\_per\_equipment*NPV\_PROD\_Stone\_finder\_crew\_yearly\_salary)+$   
 $(PRO\_Equipment\_used\_per\_year*NPV\_mechanics\_per\_equipment*NPV\_MAINT\_Mechanics\_yearly\_salary)$   
 $FIN\_After\_tax\_revenues = FIN\_Revenues\_from\_jade\_sales*(1-GOVMT\_Emporium\_government\_tax)$   
 $FIN\_Clearing\_delay\_downpayment = 1/12$   
 $FIN\_Clearing\_delay\_second\_pymt = 5/12$   
 $FIN\_Cost\_of\_equipment\_purchased =$   
 $PROD\_Order\_fulfillment\_rate*NPV\_Average\_equipment\_cost$   
 $FIN\_Downpayment\_fraction = 0.5$   
 $FIN\_Explosives\_cost = FIN\_Explosive\_units*NPV\_t0\_Explosive\_cost$   
 $FIN\_Explosive\_units = LND\_Acres\_transferring\_rate*NPV\_Explosives\_per\_acre$   
 $FIN\_Revenues\_from\_jade\_sales =$   
 $MRK\_Jade\_sales\_rate*MRK\_Effective\_jade\_price\_per\_ton$   
 $FIN\_Total\_civil\_works\_costs =$   
 $FIN\_Total\_housing\_costs+FIN\_Total\_power\_supply\_costs+FIN\_Total\_road\_costs+FIN\_Total\_water\_supply\_costs$

$FIN\_Total\_development\_costs = FIN\_Land\_cost + FIN\_Explosives\_cost$   
 $FIN\_Total\_fuel\_costs =$   
 $FIN\_Average\_yearly\_fuel\_req * NPV\_Fuel\_cost\_per\_gallon * PRO\_Equipment\_used\_per\_year$   
 $FIN\_Total\_housing\_costs =$   
 $LND\_Acres\_transferring\_rate * NPV\_t0\_Housing\_cost * NPV\_t0\_Housing\_req\_per\_acre$   
 $FIN\_Total\_pit\_and\_maintenance\_costs =$   
 $FIN\_Total\_fuel\_costs + FIN\_Total\_spare\_parts\_cost$   
 $FIN\_Total\_power\_supply\_costs =$   
 $LND\_Acres\_transferring\_rate * NPV\_t0\_Power\_supply\_cost * NPV\_t0\_Power\_supply\_req\_per\_acre$   
 $FIN\_Total\_road\_costs =$   
 $LND\_Acres\_transferring\_rate * NPV\_t0\_Road\_cost * NPV\_t0\_Road\_req\_per\_acre$   
 $FIN\_Total\_spare\_parts\_cost =$   
 $NPV\_EOC\_Average\_spare\_parts\_cost * PRO\_Equipment\_used\_per\_year * NPV\_EOC\_avg\_spare\_parts\_per\_equipment$   
 $FIN\_Total\_water\_supply\_costs =$   
 $LND\_Acres\_transferring\_rate * NPV\_t0\_Water\_supply\_cost * NPV\_t0\_Water\_supply\_req\_per\_acre$   
 $FIN\_Unit\_variable\_cost =$   
 $(FIN\_Total\_operator\_salary\_costs + FIN\_Total\_other\_labor\_costs + FIN\_Total\_pit\_and\_maintenance\_costs) / PROD\_Jade\_production\_in\_tons$   
 $GOVMT\_Desired\_government\_revenue = 2000000000$   
 $GOVMT\_Effective\_price\_per\_ton\_on\_appraisal =$   
 $MRK\_Expected\_price\_by\_miners * GOVMT\_Fraction\_of\_price\_on\_appraisal$   
 $GOVMT\_Emporium\_government\_tax = 0.4$   
 $GOVMT\_Fraction\_of\_price\_on\_appraisal = 0.1$   
 $GOVMT\_Tax\_fraction\_on\_raw\_production = 0.2$   
 $GOVMT\_Tax\_pymts\_on\_raw\_production =$   
 $(PROD\_Jade\_production\_in\_tons * GOVMT\_Effective\_price\_per\_ton\_on\_appraisal) * GOVMT\_Tax\_fraction\_on\_raw\_production$

GOVMT\_\_Gap\_ratio =  
 GOVMT\_\_Government\_revenue\_gap/GOVMT\_\_Desired\_government\_\_revenue  
 GOVMT\_\_Government\_reporting\_\_delay = 1/12  
 GOVMT\_\_Government\_revenues\_from\_jade\_sales\_and\_licenses =  
 FIN\_\_Revenues\_from\_jade\_sales-FIN\_\_After\_tax\_revenues+FIN\_\_Land\_cost  
 GOVMT\_\_Government\_revenue\_gap = SMTH1(GOVMT\_\_Desired\_government\_\_revenue-  
 GOVMT\_\_Government\_revenues\_from\_jade\_sales\_and\_licenses,GOVMT\_\_Government\_reporti  
 ng\_\_delay)  
 LDN\_\_Land\_utilization\_fraction =  
 (LND\_\_Proven\_reserves\_\_in\_acres/LND\_\_Initial\_acres\_\_available)\*1  
 LND\_\_Max\_acres\_\_exploitation\_rate = LND\_\_Acres\_transferred/LND\_\_Min\_exploitation\_time  
 LND\_\_Min\_exploitation\_time = 10/12  
 LND\_\_Acres\_per\_license = 1  
 LND\_\_Initial\_acres\_\_available = 50000\*1+30000\*0  
 LND\_\_License\_approval\_delay = 6/12  
 Max\_equipment\_\_utilization\_Cutting\_equipment = 10  
 Max\_equipment\_\_utilization\_Light\_vehicle = 20  
 Max\_equipment\_\_utilization\_Repair\_equipment = 8  
 MRK\_\_Consumption\_requirements\_\_adjustment\_delay = 4/12  
 MRK\_\_Desired\_inventory\_\_coverage = 4/12  
 MRK\_\_Expected\_price\_long\_run\_\_adjustment\_delay = 2/12  
 MRK\_\_Expected\_price\_short\_run\_\_adjustment\_delay = 1/12  
 MRK\_\_Expected\_sales\_rate\_adjustment\_delay = 4/12  
 MRK\_\_Inventory\_coverage = MRK\_\_Jade\_at\_warehouses/MRK\_\_Expected\_sales\_rate  
 MRK\_\_Percentage\_change\_in\_population = 0.35  
 MRK\_\_Relative\_inventory\_\_coverage =  
 MRK\_\_Inventory\_coverage/MRK\_\_Desired\_inventory\_\_coverage  
 MRK\_\_Analysis\_delay = 1/12  
 MRK\_\_Effective\_mining\_\_license\_supply = (IF SWITCH\_\_Mine\_development\_\_analysis=1  
 THEN  
 MRK\_\_Analysis\_positive\_\_output\_rate\*EFF\_\_Effect\_of\_land\_utilization\_\_fraction\_on\_license

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_demand ELSE
MRK__Mining_license_supply*EFF__Effect_of_land_utilization__fraction_on_license_demand)
MRK__Effective_per_capita_consumption_requirements = IF SWITCH_Noise=1 THEN
MRK__Per_capita_consumption__requirements*NOISE__Pink_noise ELSE
MRK__Per_capita_consumption__requirements
MRK__Expected_markup =
MRK__Expected_price_short_run/FIN__Expected_unit_variable_costs
MRK__Max_jade_sales__rate = MRK__Jade_at_warehouses/MRK__Min_time__to_sell
MRK__Mining_license_supply =
(MRK__Desired_mining_licenses)*0+(RM__Licenses_granted)*1+(IF
SWITCH_SCE_Licenses_1=1 THEN SCE_1__Mining_rush ELSE SCE_2__Responsible_mining)*0
MRK__Min_time__to_sell = 1
NOISE__Adjustment_delay = 1
NOISE__Random = RANDOM(0.1,5,5)
NOISE__SD = 0.03
NOISE__DT = DT
NOISE__Mean = 0.7
NOISE__White_noise =
NOISE__Mean+NOISE__SD*((24*NOISE__Adjustment_delay/NOISE__DT)^0.5)*NOISE__Rando
m
NPV__Actual_company_experience__in_the_country = 1
NPV__Actual_political_stability = 1
NPV__Actual_security_of_tenure = 1
NPV__ADM_Finance_&_accounting =
NPV__ADM_Finance_&_accounting_yearly_salary*NPV__ADM_Finance_&_accounting_req
NPV__ADM_Finance_&_accounting_req = 1
NPV__ADM_Finance_&_accounting_yearly_salary = 36000
NPV__ADM_General_manager =
NPV__ADM_General_manager_yearly_salary*NPV__ADM_General_manager_req
NPV__ADM_General_manager_req = 1
NPV__ADM_General_manager_yearly_salary = 60000

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$NPV\_ADM\_Procurement =$   
 $NPV\_ADM\_Procurement\_yearly\_salary * NPV\_ADM\_Procurement\_req$   
 $NPV\_ADM\_Procurement\_req = 1$   
 $NPV\_ADM\_Procurement\_yearly\_salary = 36000$   
 $NPV\_After\_tax\_profit\_yr1 = NPV\_Pre\_tax\_profit * (1 - NPV\_Taxes\_rate)$   
 $NPV\_After\_tax\_profit\_yr\_2 = NPV\_Pre\_tax\_profit * (1 - NPV\_Taxes\_rate)$   
 $NPV\_After\_tax\_profit\_yr\_3 = NPV\_Pre\_tax\_profit * (1 - NPV\_Taxes\_rate)$   
 $NPV\_After\_tax\_profit\_yr\_4 = NPV\_Pre\_tax\_profit * (1 - NPV\_Taxes\_rate)$   
 $NPV\_After\_tax\_profit\_yr\_5 = NPV\_Pre\_tax\_profit * (1 - NPV\_Taxes\_rate)$   
 $NPV\_Average\_driver\_req\_per\_equipment =$   
 $(NPV\_dozer\_drivers\_per\_equipment + NPV\_drilling\_machine\_drivers\_per\_equipment + NPV\_excavator\_drivers\_per\_equipment + NPV\_truck\_drivers\_per\_equipment) / 4$   
 $NPV\_Average\_equipment\_cost =$   
 $(NPV\_t0\_Dozer\_cost + NPV\_t0\_Drilling\_machine\_cost + NPV\_t0\_Excavator\_cost + NPV\_t0\_Truck\_cost) / 4$   
 $NPV\_Average\_operator\_salary =$   
 $(NPV\_PROD\_Dozer\_driver\_yearly\_salary + NPV\_PROD\_Drilling\_machine\_driver\_yearly\_salary + NPV\_PROD\_Excavator\_driver\_yearly\_salary + NPV\_PROD\_Truck\_driver\_yearly\_salary) / 4$   
 $NPV\_Average\_penetration\_in\_acres\_per\_hour =$   
 $PROD\_Max\_acres\_handled\_per\_mining\_equipment\_per\_month / (PROD\_Days\_in\_a\_month * PROD\_Operating\_hours\_per\_day)$   
 $NPV\_Discounted\_cash\_flow\_yr\_1 =$   
 $(NPV\_After\_tax\_profit\_yr1 / ((1 + NPV\_Discount\_rate)^{NPV\_Power\_yr\_1}))$   
 $NPV\_Discounted\_cash\_flow\_yr\_2 =$   
 $(NPV\_After\_tax\_profit\_yr\_2 / ((1 + NPV\_Discount\_rate)^{NPV\_Power\_yr\_2}))$   
 $NPV\_Discounted\_cash\_flow\_yr\_3 =$   
 $(NPV\_After\_tax\_profit\_yr\_3 / ((1 + NPV\_Discount\_rate)^{NPV\_Power\_yr\_3}))$   
 $NPV\_Discounted\_cash\_flow\_yr\_4 =$   
 $(NPV\_After\_tax\_profit\_yr\_4 / ((1 + NPV\_Discount\_rate)^{NPV\_Power\_yr\_4}))$   
 $NPV\_Discounted\_cash\_flow\_yr\_5 =$   
 $(NPV\_After\_tax\_profit\_yr\_5 / ((1 + NPV\_Discount\_rate)^{NPV\_Power\_yr\_5}))$

$NPV\_Discount\_rate = NPV\_Adjusted\_for\_risk\_discount\_rate$   
 $NPV\_dozer\_drivers\_per\_equipment = 2$   
 $NPV\_drilling\_machine\_drivers\_per\_equipment = 4$   
 $NPV\_Effective\_price\_on\_appraisal =$   
 $MRK\_Expected\_price\_by\_miners*GOVMT\_Fraction\_of\_price\_on\_appraisal$   
 $NPV\_ENG\_Mining\_engineer =$   
 $NPV\_ENG\_Mining\_engineer\_yearly\_salary*NPV\_ENG\_Mining\_engineer\_req$   
 $NPV\_ENG\_Mining\_engineer\_req = 1$   
 $NPV\_ENG\_Mining\_engineer\_yearly\_salary = 18000$   
 $NPV\_EOC\_Average\_spare\_parts\_cost =$   
 $(NPV\_EOC\_Spare\_parts\_dozers\_cost+NPV\_EOC\_Spare\_parts\_drilling\_machines\_cost+NPV\_EOC\_Spare\_parts\_excavators\_cost+NPV\_EOC\_Spare\_parts\_trucks\_cost)/4$   
 $NPV\_EOC\_Fuel\_dozers =$   
 $NPV\_EOC\_Fuel\_dozers\_yearly\_req*NPV\_Fuel\_cost\_per\_gallon*NPV\_t0\_Dozer\_units$   
 $NPV\_EOC\_Fuel\_dozers\_yearly\_req = 72000$   
 $NPV\_EOC\_Fuel\_drilling\_machines =$   
 $NPV\_EOC\_Fuel\_drilling\_machines\_yearly\_req*NPV\_Fuel\_cost\_per\_gallon*NPV\_t0\_Drilling\_machine\_units$   
 $NPV\_EOC\_Fuel\_drilling\_machines\_yearly\_req = 28800$   
 $NPV\_EOC\_Fuel\_excavators =$   
 $NPV\_EOC\_Fuel\_excavators\_yearly\_req*NPV\_Fuel\_cost\_per\_gallon*NPV\_t0\_Excavator\_units$   
 $NPV\_EOC\_Fuel\_excavators\_yearly\_req = 64800$   
 $NPV\_EOC\_Fuel\_trucks =$   
 $NPV\_EOC\_Fuel\_trucks\_yearly\_req*NPV\_Fuel\_cost\_per\_gallon*NPV\_t0\_Truck\_units$   
 $NPV\_EOC\_Fuel\_trucks\_yearly\_req = 54000$   
 $NPV\_EOC\_Spare\_parts\_dozers =$   
 $NPV\_EOC\_Spare\_parts\_dozers\_cost*NPV\_EOC\_Spare\_parts\_dozers\_req$   
 $NPV\_EOC\_Spare\_parts\_dozers\_cost = 300$   
 $NPV\_EOC\_Spare\_parts\_dozers\_req =$   
 $NPV\_EOC\_avg\_spare\_parts\_per\_equipment*NPV\_t0\_Dozer\_units$

NPV\_EOC\_Spare\_parts\_drilling\_machines =  
 NPV\_EOC\_Spare\_parts\_drilling\_machines\_cost\*NPV\_EOC\_Spare\_parts\_drilling\_machines\_req  
 NPV\_EOC\_Spare\_parts\_drilling\_machines\_cost = 300  
 NPV\_EOC\_Spare\_parts\_drilling\_machines\_req =  
 NPV\_t0\_Drilling\_machine\_units\*NPV\_EOC\_avg\_spare\_parts\_per\_equipment  
 NPV\_EOC\_Spare\_parts\_excavators =  
 NPV\_EOC\_Spare\_parts\_excavators\_cost\*NPV\_EOC\_Spare\_parts\_excavators\_req  
 NPV\_EOC\_Spare\_parts\_excavators\_cost = 300  
 NPV\_EOC\_Spare\_parts\_excavators\_req =  
 NPV\_t0\_Excavator\_units\*NPV\_EOC\_avg\_spare\_parts\_per\_equipment  
 NPV\_EOC\_Spare\_parts\_trucks =  
 NPV\_EOC\_Spare\_parts\_trucks\_cost\*NPV\_EOC\_Spare\_parts\_trucks\_req  
 NPV\_EOC\_Spare\_parts\_trucks\_cost = 300  
 NPV\_EOC\_Spare\_parts\_trucks\_req =  
 NPV\_t0\_Truck\_units\*NPV\_EOC\_avg\_spare\_parts\_per\_equipment  
 NPV\_excavator\_drivers\_per\_equipment = 4  
 NPV\_Expected\_tonnage =  
 LND\_Acres\_per\_license\*PROD\_Effective\_tons\_per\_acre\*MRK\_Desired\_mining\_licenses  
 NPV\_Exploixives\_per\_acre = 10  
 NPV\_Fuel\_cost\_per\_gallon = 3  
 NPV\_MAINT\_Mechanics =  
 NPV\_MAINT\_Mechanics\_yearly\_salary\*NPV\_MAINT\_Mechanics\_req  
 NPV\_MAINT\_Mechanics\_req = NPV\_mechanics\_per\_equipment\*NPV\_t0\_Excavator\_units  
 NPV\_MAINT\_Mechanics\_yearly\_salary = 3600  
 NPV\_MAINT\_Workshop\_supervisor =  
 NPV\_MAINT\_Workshop\_supervisor\_yearly\_salary\*NPV\_MAINT\_Workshop\_supervisor\_req  
 NPV\_MAINT\_Workshop\_supervisor\_req = 1  
 NPV\_MAINT\_Workshop\_supervisor\_yearly\_salary = 6600  
 NPV\_Max\_company\_experience\_in\_the\_country = 1  
 NPV\_Max\_political\_stability = 1  
 NPV\_Max\_security\_of\_tenure = 1

$NPV\_mechanics\_per\_equipment = 0.066$   
 $NPV\_Operating\_hours\_per\_year =$   
 $PROD\_Operating\_days\_per\_year * PROD\_Operating\_hours\_per\_day$   
 $NPV\_Operating\_shifts\_per\_year =$   
 $(NPV\_Required\_shifts\_per\_year / NPV\_Scheduled\_shifts\_per\_year)$   
 $NPV\_others\_per\_equipment = 0.2$   
 $NPV\_Penetration\_rate\_in\_acres\_per\_shift =$   
 $PROD\_Hours\_per\_shift * NPV\_Average\_penetration\_in\_acres\_per\_hour$   
 $NPV\_PER\_Others = NPV\_PER\_Others\_yearly\_salary * NPV\_PER\_Others\_req$   
 $NPV\_PER\_Others\_req = NPV\_others\_per\_equipment * NPV\_t0\_Excavator\_units$   
 $NPV\_PER\_Others\_yearly\_salary = 960$   
 $NPV\_Pit\_area\_per\_year =$   
 $(MRK\_Licenses\_under\_analysis * LND\_Acres\_per\_license) / PROD\_Mine\_life$   
 $NPV\_Power\_yr\_1 = 1$   
 $NPV\_Power\_yr\_2 = 2$   
 $NPV\_Power\_yr\_3 = 3$   
 $NPV\_Power\_yr\_4 = 4$   
 $NPV\_Power\_yr\_5 = 5$   
 $NPV\_Pre\_tax\_profit = NPV\_Total\_revenues - NPV\_Total\_costs$   
 $NPV\_PROD\_Dozer\_driver =$   
 $NPV\_PROD\_Dozer\_driver\_yearly\_salary * NPV\_PROD\_Dozer\_driver\_req$   
 $NPV\_PROD\_Dozer\_driver\_req = NPV\_dozer\_drivers\_per\_equipment * NPV\_t0\_Dozer\_units$   
 $NPV\_PROD\_Dozer\_driver\_yearly\_salary = 4800$   
 $NPV\_PROD\_Drilling\_machine\_driver =$   
 $NPV\_PROD\_Drilling\_machine\_driver\_yearly\_salary * NPV\_PROD\_Drilling\_machine\_driver\_req$   
 $NPV\_PROD\_Drilling\_machine\_driver\_req =$   
 $NPV\_drilling\_machine\_drivers\_per\_equipment * NPV\_t0\_Drilling\_machine\_units$   
 $NPV\_PROD\_Drilling\_machine\_driver\_yearly\_salary = 4200$   
 $NPV\_PROD\_Excavator\_driver =$   
 $NPV\_PROD\_Excavator\_driver\_yearly\_salary * NPV\_PROD\_Excavator\_driver\_req$



$NPV\_PROD\_Excavator\_driver\_req =$   
 $NPV\_excavator\_drivers\_per\_equipment * NPV\_t0\_Excavator\_units$   
 $NPV\_PROD\_Excavator\_driver\_yearly\_salary = 4800$   
 $NPV\_PROD\_Stone\_finder\_crew =$   
 $NPV\_PROD\_Stone\_finder\_crew\_yearly\_salary * NPV\_PROD\_Stone\_finder\_crew\_req$   
 $NPV\_PROD\_Stone\_finder\_crew\_req =$   
 $NPV\_t0\_Excavator\_units * NPV\_t0\_Stone\_finders\_per\_equipment$   
 $NPV\_PROD\_Stone\_finder\_crew\_yearly\_salary = 1200$   
 $NPV\_PROD\_Truck\_driver =$   
 $NPV\_PROD\_Truck\_driver\_yearly\_salary * NPV\_PROD\_Truck\_driver\_requirement$   
 $NPV\_PROD\_Truck\_driver\_requirement =$   
 $NPV\_t0\_Truck\_units * NPV\_truck\_drivers\_per\_equipment$   
 $NPV\_PROD\_Truck\_driver\_yearly\_salary = 4200$   
 $NPV\_Required\_shifts\_per\_year =$   
 $NPV\_Pit\_area\_per\_year / NPV\_Penetration\_rate\_in\_acres\_per\_shift$   
 $NPV\_Risk\_factor\_multiplier =$   
 $(EFF\_Effect\_of\_environmental\_and\_social\_regulations * EFF\_Effect\_of\_political\_stability\_on\_pe$   
 $ceived\_risk * EFF\_Effect\_of\_security\_of\_tenure\_on\_perceived\_risk)$   
 $NPV\_Scheduled\_shifts\_per\_year = NPV\_Operating\_hours\_per\_year / PROD\_Hours\_per\_shift$   
 $NPV\_t0\_Acre\_cost = 1000$   
 $NPV\_t0\_Cutting\_equipment =$   
 $(NPV\_t0\_Cutting\_equipment\_cost * NPV\_t0\_Cutting\_equipment\_units) / NPV\_Customer\_acqui$   
 $sition\_delay\_1\_year$   
 $NPV\_t0\_Cutting\_equipment\_cost = 30000$   
 $NPV\_t0\_Cutting\_equipment\_units =$   
 $(NPV\_Operating\_shifts\_per\_year / Max\_equipment\_utilization\_Cutting\_equipment)$   
 $NPV\_t0\_Dozer\_cost = 127000$   
 $NPV\_t0\_Dozer\_units = (NPV\_Operating\_shifts\_per\_year / PROD\_Equipment\_utilization)$   
 $NPV\_t0\_Drilling\_machines =$   
 $(NPV\_t0\_Drilling\_machine\_cost * NPV\_t0\_Drilling\_machine\_units) / NPV\_Customer\_acquisition$   
 $\_delay\_1\_year$

$NPV\_t0\_Drilling\_machine\_cost = 300000$   
 $NPV\_t0\_Drilling\_machine\_units =$   
 $(NPV\_Operating\_shifts\_per\_year/PROD\_Equipment\_utilization)$   
 $NPV\_t0\_Excavators =$   
 $(NPV\_t0\_Excavator\_cost*NPV\_t0\_Excavator\_units)/NPV\_Customer\_acquisition\_delay\_1\_year$   
 $NPV\_t0\_Excavator\_cost = 140000$   
 $NPV\_t0\_Excavator\_units = (NPV\_Operating\_shifts\_per\_year/PROD\_Equipment\_utilization)$   
 $NPV\_t0\_Explosives = NPV\_t0\_Explosive\_cost*NPV\_t0\_Explosive\_units$   
 $NPV\_t0\_Explosive\_cost = 50$   
 $NPV\_t0\_Explosive\_units = NPV\_Explosives\_per\_acre*NPV\_t0\_Land\_in\_acres$   
 $NPV\_t0\_Housing = NPV\_t0\_Housing\_cost*NPV\_t0\_Housing\_units$   
 $NPV\_t0\_Housing\_cost = 8000$   
 $NPV\_t0\_Housing\_req\_per\_acre = 1/1000$   
 $NPV\_t0\_Housing\_units = NPV\_t0\_Housing\_req\_per\_acre*NPV\_t0\_Land\_in\_acres$   
 $NPV\_t0\_Land\_in\_acres = LND\_Acres\_per\_license*MRK\_Desired\_mining\_licenses$   
 $NPV\_t0\_Land\_purchase = NPV\_t0\_Land\_in\_acres*NPV\_t0\_Acre\_cost$   
 $NPV\_t0\_Light\_vehicles =$   
 $(NPV\_t0\_Light\_vehicle\_cost*NPV\_t0\_Light\_vehicle\_units)/NPV\_Customer\_acquisition\_delay\_1\_year$   
 $NPV\_t0\_Light\_vehicle\_cost = 20000$   
 $NPV\_t0\_Light\_vehicle\_units =$   
 $(NPV\_Operating\_shifts\_per\_year/Max\_equipment\_utilization\_Light\_vehicle)$   
 $NPV\_t0\_Power\_supply = NPV\_t0\_Power\_supply\_cost*NPV\_t0\_Power\_supply\_units$   
 $NPV\_t0\_Power\_supply\_cost = 5000$   
 $NPV\_t0\_Power\_supply\_units =$   
 $NPV\_t0\_Land\_in\_acres*NPV\_t0\_Power\_supply\_req\_per\_acre$   
 $NPV\_t0\_Power\_supply\_req\_per\_acre = 1/300$   
 $NPV\_t0\_Repair\_equipment =$   
 $(NPV\_t0\_Repair\_equipment\_cost*NPV\_t0\_Repair\_equipment\_units)/NPV\_Customer\_acquisition\_delay\_1\_year$

$NPV\_t0\_Repair\_equipment\_cost = 30000$   
 $NPV\_t0\_Repair\_equipment\_units =$   
 $(NPV\_Operating\_shifts\_per\_year/Max\_equipment\_utilization\_Repair\_equipment)$   
 $NPV\_t0\_Roads = NPV\_t0\_Road\_cost*NPV\_t0\_Road\_units$   
 $NPV\_t0\_Road\_cost = 5000$   
 $NPV\_t0\_Road\_req\_per\_acre = 2/500$   
 $NPV\_t0\_Road\_units = NPV\_t0\_Land\_in\_acres*NPV\_t0\_Road\_req\_per\_acre$   
 $NPV\_t0\_Stone\_finders\_per\_equipment = 7$   
 $NPV\_t0\_Total\_cash\_outflows =$   
 $NPV\_t0\_Total\_civil\_works\_cost+NPV\_t0\_Total\_development\_costs+NPV\_t0\_Total\_equipmen$   
 $t\_costs+NPV\_t0\_Total\_other\_equipment\_costs$   
 $NPV\_t0\_Total\_civil\_works\_cost =$   
 $NPV\_t0\_Housing+NPV\_t0\_Power\_supply+NPV\_t0\_Roads+NPV\_t0\_Water\_supply$   
 $NPV\_t0\_Total\_development\_costs = NPV\_t0\_Explosives+NPV\_t0\_Land\_purchase$   
 $NPV\_t0\_Total\_equipment\_costs =$   
 $NPV\_t0\_Dozers+NPV\_t0\_Drilling\_machines+NPV\_t0\_Excavators+NPV\_t0\_Trucks$   
 $NPV\_t0\_Total\_other\_equipment\_costs =$   
 $NPV\_t0\_Cutting\_equipment+NPV\_t0\_Light\_vehicles+NPV\_t0\_Repair\_equipment$   
 $NPV\_t0\_Trucks =$   
 $(NPV\_t0\_Truck\_cost*NPV\_t0\_Truck\_units)/NPV\_Customer\_acquisition\_delay\_1\_year$   
 $NPV\_t0\_Truck\_cost = 140000$   
 $NPV\_t0\_Truck\_units = (NPV\_Operating\_shifts\_per\_year/PROD\_Equipment\_utilization)$   
 $NPV\_t0\_Water\_supply = NPV\_t0\_Water\_supply\_cost*NPV\_t0\_Water\_supply\_units$   
 $NPV\_t0\_Water\_supply\_cost = 5000$   
 $NPV\_t0\_Water\_supply\_units =$   
 $NPV\_t0\_Land\_in\_acres*NPV\_t0\_Water\_supply\_req\_per\_acre$   
 $NPV\_t0\_Water\_supply\_req\_per\_acre = 1/300$   
 $NPV\_Taxes\_rate = 0$   
 $NPV\_Tax\_pymts\_on\_raw\_production =$   
 $(NPV\_Expected\_tonnage*NPV\_Effective\_price\_on\_appraisal)*GOVMT\_Tax\_fraction\_on\_raw\_production$

$NPV\_Total\_administration\_labor\_costs =$   
 $NPV\_ADM\_Finance\ \&\ accounting + NPV\_ADM\_General\_manager + NPV\_ADM\_Procurement$   
 $NPV\_Total\_costs = NPV\_Total\_indirect\_costs + NPV\_Total\_labor\_costs$   
 $NPV\_Total\_engineering\_labor\_costs = NPV\_ENG\_Mining\_engineer$   
 $NPV\_Total\_indirect\_costs = NPV\_Total\_pit\_and\_maintenance\_costs$   
 $NPV\_Total\_labor\_costs =$   
 $NPV\_Total\_administration\_labor\_costs + NPV\_Total\_engineering\_labor\_costs + NPV\_Total\_main$   
 $tenance\_labor\_costs + NPV\_Total\_other\_personnel\_labor\_costs + NPV\_Total\_production\_labor\_c$   
 $osts$   
 $NPV\_Total\_maintenance\_labor\_costs =$   
 $NPV\_MAINT\_Mechanics + NPV\_MAINT\_Workshop\_supervisor$   
 $NPV\_Total\_other\_personnel\_labor\_costs = NPV\_PER\_Others$   
 $NPV\_Total\_pit\_and\_maintenance\_costs =$   
 $NPV\_EOC\_Fuel\_dozers + NPV\_EOC\_Fuel\_drilling\_machines + NPV\_EOC\_Fuel\_excavators + NP$   
 $V\_EOC\_Fuel\_trucks + NPV\_EOC\_Spare\_parts\_dozers + NPV\_EOC\_Spare\_parts\_drilling\_machi$   
 $nes + NPV\_EOC\_Spare\_parts\_excavators + NPV\_EOC\_Spare\_parts\_trucks$   
 $NPV\_Total\_production\_labor\_costs =$   
 $NPV\_PROD\_Dozer\_driver + NPV\_PROD\_Drilling\_machine\_driver + NPV\_PROD\_Excavator\_dri$   
 $ver + NPV\_PROD\_Stone\_finder\_crew + NPV\_PROD\_Truck\_driver$   
 $NPV\_Total\_revenues = NPV\_Total\_revenues\_before\_emporium\_tax * (1 -$   
 $GOVMT\_Emporium\_government\_tax)$   
 $NPV\_Total\_revenues\_before\_emporium\_tax = NPV\_Expected\_revenue$   
 $NPV\_truck\_drivers\_per\_equipment = 2$   
 $NPV\_Adjusted\_for\_risk\_discount\_rate = NPV\_Normal\_discount\_rate + ((-$   
 $4 * SMTH1(NPV\_Risk\_factor\_multiplier, 6/12) + 11) / 100)$   
 $NPV\_Customer\_acquisition\_delay\_1\_year = 1$   
 $NPV\_EOC\_avg\_spare\_parts\_per\_equipment = 5$   
 $NPV\_Expected\_revenue = (MRK\_Expected\_price\_by\_miners * NPV\_Expected\_tonnage) -$   
 $NPV\_Tax\_pymts\_on\_raw\_production$   
 $NPV\_Normal\_discount\_rate = 0.1$

NPV\_\_t0\_Dozers =  
 (NPV\_\_t0\_Dozer\_cost\*NPV\_\_t0\_Dozer\_units)/NPV\_\_Customer\_acquisition\_delay\_1\_year  
 PROD\_Actual\_equipment\_\_order =  
 (PROD\_\_Backlog\_gap/PROD\_\_Customer\_acquisition\_delay)+PROD\_\_Mining\_equipment\_\_sr  
 apping\_rate  
 PROD\_Desired\_delivery\_rate = PROD\_\_Order\_backlog/PROD\_\_Target\_\_delivery\_delay  
 PROD\_Effective\_production\_capacity =  
 (PROD\_Equipment\_tilization\_\_fraction\*PROD\_\_Max\_producion\_\_capacity)\*1  
 PROD\_Effective\_tons\_per\_acre = (PROD\_\_Normal\_tons\_\_per\_acre)\*1+(IF  
 SWITCH\_SCE\_\_Tonnage\_1=1 THEN  
 PROD\_\_Normal\_tons\_\_per\_acre\*SCE\_1\_Best\_is\_\_yet\_to\_come ELSE  
 PROD\_\_Normal\_tons\_\_per\_acre\*SCE\_1\_Best\_is\_gone)\*0  
 PROD\_Equipment\_tilization\_\_fraction =  
 SMTH1(EFF\_Effect\_of\_expected\_markup\_on\_equipment\_utilization,PROD\_Equipment\_utilizati  
 on\_\_adjustment\_time)  
 PROD\_Equipment\_utilization\_\_adjustment\_time = 1/12  
 PROD\_Hours\_per\_\_shift = 7  
 PROD\_Market\_share\_UMG = STEP(0.05,2000)+STEP(0.05,2003)+STEP(0.16,2006.5)  
 PROD\_Max\_acres\_handled\_\_per\_mining\_equipment\_per\_month = 0.1  
 PROD\_Mine\_life = 8  
 PROD\_Min\_order\_processing\_time = 6/12  
 PROD\_Operating\_hours\_\_per\_year =  
 PROD\_\_Operating\_days\_per\_year\*PROD\_\_Operating\_hours\_per\_day  
 PROD\_Operating\_shifts\_per\_year =  
 (PROD\_Required\_shifts\_\_per\_year/PROD\_Scheduled\_shifts\_per\_year)  
 PROD\_Order\_rate\_UMG = PROD\_Order\_rate\_market\*PROD\_Market\_share\_UMG  
 PROD\_Penetration\_rate\_in\_acres\_per\_shift =  
 PROD\_Hours\_per\_\_shift\*PROD\_\_Average\_penetration\_in\_acres\_\_per\_hour  
 PROD\_Pit\_area\_per\_\_year = LND\_\_Acres\_transferred/PROD\_Mine\_life  
 PROD\_Required\_shifts\_\_per\_year =  
 PROD\_Pit\_area\_per\_\_year/PROD\_Penetration\_rate\_in\_acres\_per\_shift

PROD\_Scheduled\_shifts\_per\_year =  
 PROD\_Operating\_hours\_per\_year/PROD\_Hours\_per\_shift  
 PROD\_Target\_delivery\_delay = 1/12  
 PROD\_Average\_penetration\_in\_acres\_per\_hour =  
 PROD\_Max\_acres\_handled\_per\_mining\_equipment\_per\_month/(PROD\_Operating\_hours\_per\_day\*PROD\_Days\_in\_a\_month)  
 PROD\_Backlog\_gap = PROD\_Equipment\_to\_be\_purchased-PROD\_Order\_backlog  
 PROD\_Customer\_acquisition\_delay = 2/12  
 PROD\_Days\_in\_a\_month = 30  
 PROD\_Desired\_fleet = PROD\_Operating\_shifts\_per\_year/PROD\_Equipement\_utilization  
 PROD\_Equipment\_to\_be\_purchased = IF SWITCH\_Financial\_restrictions=1 THEN  
 MIN(PROD\_Desired\_fleet,FIN\_Budget\_for\_equipment) ELSE PROD\_Desired\_fleet  
 PROD\_Equipement\_utilization = 0.8  
 PROD\_Jade\_production\_in\_tons = LND\_exploitation\_rate\*PROD\_Effective\_tons\_per\_acre  
 PROD\_Max\_acres\_handled\_per\_mining\_equipment\_per\_year =  
 PROD\_Max\_acres\_handled\_per\_mining\_equipment\_per\_month\*PROD\_Working\_months\_per\_year  
 PROD\_Max\_delivery\_rate =  
 PROD\_UMG\_mining\_equipment\_inventory/PROD\_Min\_order\_processing\_time  
 PROD\_Max\_production\_capacity =  
 PROD\_Customer\_mining\_equipment\*PROD\_Max\_acres\_handled\_per\_mining\_equipment\_per\_year  
 PROD\_Normal\_tons\_per\_acre = 12  
 PROD\_Operating\_days\_per\_year = IF SWITCH\_Seasonality=1 THEN 240 ELSE 360  
 PROD\_Operating\_hours\_per\_day = 20  
 PROD\_Scrapping\_delay = 5  
 PROD\_Working\_months\_per\_year = IF SWITCH\_Seasonality=1 THEN 8 ELSE 12  
 PRO\_Min\_time\_for\_depletion = 1  
 PRO\_Dillution\_fraction = 0.25  
 PRO\_Equipment\_used\_per\_year =  
 LND\_exploitation\_rate/PROD\_Max\_acres\_handled\_per\_mining\_equipment\_per\_year

SCE\_1\_Best\_is\_gone = SCE\_Tonnage\_\_input\_2  
SCE\_1\_Best\_is\_\_yet\_to\_come = SCE\_Tonnage\_\_input\_1  
SCE\_1\_Mining\_rush = SCE\_Licenses\_input\_1\*RM\_\_Licenses\_granted  
SCE\_2\_Responsible\_mining = SCE\_Licenses\_input\_2\*RM\_\_Licenses\_granted  
SCE\_Licenses\_input\_1 = 1+STEP(2,2012)  
SCE\_Licenses\_input\_2 = 1-STEP(0.7,2012)  
SCE\_Tonnage\_\_input\_1 = 1+step(1,2012)  
SCE\_Tonnage\_\_input\_2 = 1-step(0.7,2012)  
SWITCH\_Noise = 0  
SWITCH\_SCE\_Licenses\_1 = 1  
SWITCH\_SCE\_\_Tonnage\_1 = 0  
SWITCH\_\_Financial\_restrictions = 0  
SWITCH\_\_Mine\_development\_\_analysis = 0  
SWITCH\_\_Population\_growth = 1  
SWITCH\_\_Seasonality = 1  
EFF\_Effect\_of\_acres\_availability\_\_on\_exploitation =  
GRAPH(LND\_Max\_acres\_\_exploitation\_rate/PROD\_Effective\_production\_capacity)  
(0.00, 0.00), (0.2, 0.2), (0.4, 0.4), (0.6, 0.6), (0.8, 0.8), (1.00, 1.00), (1.20, 1.00), (1.40, 1.00), (1.60,  
1.00), (1.80, 1.00), (2.00, 1.00)  
EFF\_Effect\_of\_environmental\_and\_social\_regulations =  
GRAPH(NPV\_Actual\_company\_experience\_\_in\_the\_country/NPV\_Max\_company\_experience\_  
\_in\_the\_country)  
(0.00, 0.05), (0.2, 0.42), (0.4, 0.68), (0.6, 0.865), (0.8, 0.985), (1.00, 1.00)  
EFF\_Effect\_of\_expected\_markup\_on\_equipment\_utilization =  
GRAPH(MRK\_\_Expected\_markup)  
(0.00, 1.00), (0.8, 1.00), (1.60, 1.00), (2.40, 1.00), (3.20, 1.00), (4.00, 1.00), (4.80, 1.01), (5.60, 1.15),  
(6.40, 1.18), (7.20, 1.20), (8.00, 1.20)  
EFF\_Effect\_of\_political\_stability\_on\_perceived\_risk =  
GRAPH(NPV\_Actual\_political\_stability/NPV\_Max\_political\_stability)  
(0.00, 0.05), (0.2, 0.42), (0.4, 0.68), (0.6, 0.865), (0.8, 0.985), (1.00, 1.00)

EFF\_Effect\_of\_security\_of\_tenure\_on\_perceived\_risk =  
 GRAPH(NPV\_Actual\_security\_of\_tenure/NPV\_Max\_security\_of\_tenure)  
 (0.00, 0.05), (0.2, 0.42), (0.4, 0.68), (0.6, 0.865), (0.8, 0.985), (1.00, 1.00)

EFF\_Effect\_of\_land\_utilization\_fraction\_on\_license\_demand =  
 GRAPH(LDN\_Land\_utilization\_fraction)  
 (0.00, 0.00), (0.1, 0.05), (0.2, 0.12), (0.3, 0.2), (0.4, 0.285), (0.5, 0.37), (0.6, 0.52), (0.7, 0.68), (0.8,  
 0.815), (0.9, 0.94), (1, 0.98)

MRK\_Equilibrium\_per\_capita\_consumption =  
 GRAPH((MRK\_Effective\_jade\_price\_per\_ton)\*1)  
 (12000, 1.95), (47273, 2.92), (82545, 3.97), (117818, 4.95), (153091, 5.63), (188364, 6.75), (223636,  
 7.88), (258909, 8.55), (294182, 9.67), (329455, 11.0), (364727, 12.6), (400000, 14.4)

MRK\_Desired\_mining\_licenses = GRAPH(MRK\_Expected\_price\_by\_miners)  
 (12000, 455), (50800, 578), (89600, 665), (128400, 823), (167200, 980), (206000, 1155), (244800, 2223),  
 (283600, 2730), (322400, 3010), (361200, 3290), (400000, 3325)

MRK\_Effective\_jade\_price\_per\_ton = GRAPH(MRK\_Relative\_inventory\_coverage)  
 (0.00, 400000), (0.8, 384000), (1.60, 350000), (2.40, 150000), (3.20, 71000), (4.00, 64000), (4.80,  
 49000), (5.60, 42000), (6.40, 41000), (7.20, 38000), (8.00, 34000), (8.80, 31500), (9.60, 27000), (10.4,  
 21000), (11.2, 17000), (12.0, 12000)

PROD\_Order\_fulfillment\_ratio =  
 GRAPH(PROD\_Max\_delivery\_rate/PROD\_Desired\_delivery\_rate)  
 (0.00, 0.00), (0.5, 0.3), (1.00, 0.8), (1.50, 1.00), (2.00, 1.00), (2.50, 1.00), (3.00, 1.00), (3.50, 1.00),  
 (4.00, 1.00), (4.50, 1.00), (5.00, 1.00)

RM\_accumulated\_sales\_UMG = GRAPH(TIME)  
 (2000, 1.00), (2001, 1.00), (2002, 51.0), (2003, 105), (2004, 207), (2005, 456), (2006, 634), (2007, 1282),  
 (2008, 1910), (2009, 2409), (2010, 3479), (2011, 4679)

RM\_emporium\_revenues\_per\_year = GRAPH(TIME)  
 (2000, 4.2e+007), (2001, 2e+007), (2002, 5e+007), (2003, 2.3e+007), (2004, 3.5e+007), (2005,  
 7.7e+007), (2007, 2.3e+008), (2008, 3.7e+008), (2009, 3.3e+008), (2010, 3.1e+008), (2011, 1.9e+009)

RM\_jade\_production\_in\_tons = GRAPH(TIME)  
 (2000, 11096), (2001, 8174), (2002, 10879), (2003, 10755), (2004, 14988), (2005, 20390), (2006, 20458),  
 (2007, 20235), (2008, 32921), (2009, 25795), (2010, 46810), (2011, 46810)



RM\_Order\_rate\_UMG = GRAPH(TIME)

(2000, 1.00), (2001, 0.00), (2002, 50.0), (2003, 54.0), (2004, 171), (2005, 180), (2006, 178), (2007, 648),  
(2008, 628), (2009, 499), (2010, 1070), (2011, 1200)

RM\_\_Licenses\_\_granted = GRAPH(TIME)

(2000, 1000), (2001, 1100), (2002, 900), (2003, 1200), (2004, 2200), (2005, 1700), (2006, 1800), (2007,  
5100), (2008, 1000), (2009, 5900), (2010, 10600), (2011, 9800), (2012, 5450), (2013, 9450), (2014,  
9050), (2015, 9100), (2016, 12800), (2017, 10400), (2018, 11500), (2019, 17500), (2020, 14100), (2021,  
14800), (2022, 18400)