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AN ECONOMETRIC STUDY OF THE
WORLD COPPER INDUSTRY

by
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A thesis submitted to the Faculty and Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Mineral Economics.

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ABSTRACT

An annual econometric model of the world copper industry is estimated incorporating geographically disaggregated equations of production capacity, primary supply and demand for the six largest producers and the ten most important consumers of fine copper. It also includes equations for secondary supply and refined copper price.

New contributions have been added to represent this market more suitably. Recent relevant consumers such as China, South Korea and Taiwan and also new important producers like Peru and Indonesia are added in the model to update previous studies. Mineral potential and investment climate variables are included as determinants of capacity investment. Innovative approaches have been developed to specify the equations of primary supply, demand and price. An improvement to the Rational Expectations Hypothesis is made to describe the demand for stocks due to speculative motives. Additionally, the simulation of future prospects is made stochastically while previous studies simulated the model deterministically.

An attempt is made to forecast copper price, supply and demand of copper, and analyze the effect of different scenarios in the most relevant aggregate variables, such as copper price.

The study demonstrates that stockpiling has a less significant influence over price than production cutbacks. As well, a decrease in the Chinese growth rate of industrial production strongly affects the level of total demand and copper price. In addition, different growth rates of production capacity can powerfully affect prices. Finally, price is also sensitive to changes in the dollar strength against other currencies. All these impacts are higher when the level of stocks is high and in turn prices are low.
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CHAPTER 1

INTRODUCTION

In the recent past, and specifically in the period 1998-2002, copper prices have been the lowest in history ranging from 70.7 to 82.3 ¢US/lb in nominal terms. These depressed prices have been the result of a prolonged economic situation that began with the “Asian crisis” and continued with a global recession. Nowadays, however we are looking at a strong recovery of copper prices, but we still do not know if it is going to be permanent or transitory. Moreover, if we take a look at a longer term, between 1980 and 2000 the nominal price of copper varied from a minimum of 62.3 ¢US/lb to a maximum of 133.2 ¢US/lb.

All this uncertainty in copper prices has enormous consequences for many countries worldwide. Copper is extremely important for the export earnings of several countries. As an example, copper represents approximately 70% of Zambian exports\(^1\), 40% of Peruvian exports\(^2\), 40% of Chilean exports\(^3\), 17% of Papua New Guinean exports\(^4\), and 50% of Democratic Republic of Congo’s (ex Zaire) exports\(^5\).

In addition, there are a large number of industrialized and developing countries that need huge amounts of copper to continue with their processes of growth and development. Among these economies we can highlight China, United States, Japan, Germany, South Korea, Italy, Taiwan, France, Mexico and Spain.

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\(^1\) Information found in [http://www.bized.ac.uk/virtual/dc/images/photos/00007.htm](http://www.bized.ac.uk/virtual/dc/images/photos/00007.htm)

\(^2\) Information found in [http://www.procobreperu.org/engimportance.htm](http://www.procobreperu.org/engimportance.htm)


It is because of the importance of copper prices for many countries that during the last forty years several applied studies have been conducted to analyze the behavior of the copper market and predict the evolution of future copper prices. These studies have also tried to simulate the effects of adjustments in supply, demand and prices. However, there exist various issues that are unresolved and need attention. This is in part because the last public econometric study of the world copper industry was done in 1989. As well, there are other key aspects that have appeared in the world copper market in the last years. As mentioned previously, in the last fifteen years new countries have become important participants of the consumption side in this market, for example, China, South Korea and Taiwan. Furthermore, production areas have changed to include new countries like Chile, Indonesia, Australia and Peru, which have captured most of the investment in the last decade. In addition, according to Cochilco (2003), some copper-producing companies (Codelco, BHP-Billiton, and Grupo Mexico) announced adjustments in their production for 2003, in addition to the cutbacks of 2002, as a form of controlling the excessive level of oversupply.

In summary, the industry has evolved, and a new econometric model is needed to characterize it. A better understanding of the world copper market behavior is crucial for improving governmental and firm planning in the producing and consuming countries.

The econometric model developed here incorporates equations of production capacity, primary supply, secondary supply, demand and price. Equations for production capacity and primary supply are estimated for Australia, Canada, Chile, Indonesia, Peru, United States, and the rest of the world. Similarly, demand equations are estimated for China, France, Germany, Italy, Japan, Mexico, South Korea, Spain, Taiwan, United States and the rest of the world.

The following characteristics of the model allow a better representation of the copper market:

- The incorporation of mineral potential and investment climate variables to see how they influence the development of production capacity.
• New specifications for the equations of primary supply, demand and price that describe more appropriately the working of the industry.

• The creation of a different model to represent the demand for stocks due to speculative motives.

The inclusion of these new elements allows one to assess several specific questions regarding the functioning of this market. For example, how do mineral potential and investment climate influence the development of production capacity in the world? Do inventory holdings by producers have any influence over copper price? How does the growth of industrial production affect the demand of a country and in turn copper price? What is the effect of a change in the production capacity growth rate of a country? How does the dollar's strength against other currencies impact copper price?

The study is organized in the following way: Chapter 2 examines previous econometric model of the world copper industry, and the most common specifications used to model metal markets. Chapter 3 presents the theoretical foundations for the proposed model. Chapter 4 reviews the estimation of the equations. Chapter 5 examines the estimated equations, and the performance of the model as a predictive tool. Chapter 6 provides a model simulation of future prospects and an analysis of different scenarios. Finally, chapter 7 highlights the most relevant findings and conclusions.
CHAPTER 2

LITERATURE REVIEW

Before developing an econometric model of the world copper industry it is necessary to analyze what has been done in the past. For that reason, in this section we firstly describe all the econometric studies of the world copper industry that have been developed formerly, beginning with the study of Fisher et al. (1972) and ending with the research of Vial (1989). Second, we analyze in more detail the more common specifications of demand, primary and secondary supply, and capacity equations utilized in these models and other base metal markets to determine the most significant deficiencies that need to be addressed in a new econometric model.

2.1. Econometric Models of the World Copper Industry

During the last forty years, some attempts of using an econometric model of the world copper industry to explain the behavior of the market and to forecast the main variables, especially copper price, have been developed. Among the most relevant studies, we can highlight Fisher et al. (1972), Richard (1978), Wagenhals (1984) and Vial (1989).

2.1.1. Main Models

Fisher et al. (1972) develop, in our opinion, the most influential econometric study of the world copper market. Because, it was the first econometric study of the world copper market, the posterior studies have many specifications in common with this study. They present a relatively disaggregated annual model, which includes primary supply
equations for the four most important producing countries and the rest of the world, demand equations for the United States, Europe, Japan and the rest of the world, scrap supply equations are done for the United States and the rest of the world, and price equations are estimated for the United States producer price and the London Metal Exchange (LME) price.

Richard (1978) develops a quarterly dynamic model of the world copper industry, specified in continuous time as a system of differential equations. The model includes equations for investment, supply, demand, price and stocks. There is no attempt to provide a disaggregated representation of supply and demand by geographical areas. The form of copper considered is refined copper, and all other forms (ore, concentrate, blister or scrap) are expressed in copper content. Supply for the United States and the rest of the world is separated into primary and secondary supply. Also, investment equations are specified to represent mine capacity behavior for the United States and the rest of the world.

Wagenhals (1984) also creates a very complete and disaggregated study of the copper market. He includes an analysis of the copper market structure, supply, production capacity, demand and price formation. Equations of primary supply are estimated for the eight most important producers of copper and for two regions considering the rest of the western world and the centrally planned countries. Mine capacities are estimated for the most important western copper producers and for the rest of the world. Total copper consumption and refined copper consumption equations are estimated for the Federal Republic of Germany, Italy, Japan, England, United States and the rest of the world. The author also develops stock equations for the LME, the Federal Republic of Germany, Japan, and the United States, and for the rest of the world. He includes secondary supply equations for the Federal Republic of Germany, Japan, the United States and the rest of the world. Finally, the model includes six equations of prices: LME cash, 3 months futures price, the Canadian and Chilean price, the US producers’ price and the scrap price.
Vial (1989) also creates a thorough model of the world copper industry. He takes advantage of past studies of metal markets to extract their most important features and includes some new ideas. One of the basic characteristics of the model is the disaggregation of the production in mineral ore, blister and refined copper.

For these three products, the author estimates short run supply functions including the main producers, and investment functions for the countries where the data allowed him to do it. He also adds two separate models of joint production and single production of mineral ore for Canada and Zaire. Additionally, he estimates consumption functions for the principal consumers of mineral ore, blister and refined copper in the world. Finally, he incorporates price equations for each of these three products.

Analyzing these relevant studies, we agree that an econometric study of the world copper industry must be geographically disaggregated to examine the most important producers and consumers of the world. On the contrary, the disaggregation in terms of product types such as concentrate, blister and refined copper could be interesting for some smelters or refiners, but in our point of view it is going too deep and is not worth the effort since can cause serious difficulties in the estimation, validation and simulation of the complete model because of the enormous amount of equations we could have. The copper industry can be very well described using only total copper. The same occurs for copper price. We think it is not necessary to estimate price equations for countries since they can be estimated multiplying the refined copper price with the exchange rate, so it could be even more useful to estimate equations for the behavior of exchange rates. Finally, we think that annual periods are adequate for the model, since it is very difficult to obtain data for shorter periods of time (for example, quarterly data of production or consumption).
2.1.2. Other Studies

There are other econometric studies of the copper industry that in our point of view are less important because they are not very disaggregated and analyze just some areas of the market, and not the industry as a whole. For example, Little (1976), creates a model of the US copper industry to analyze the impact of US government pollution abatement regulations on the US copper smelting industry. Taylor (1979) develops a quarterly model of the copper industry of the United States. In this study an attempt is made to estimate equations for refinery and scrap prices, total refined supply, refined consumption and employment. Hwa (1981 and 1985) creates a model for six commodities (including copper) that features the estimation of price, consumption and production equations at an aggregate world level.

Dammert et al. (1985) present a disaggregated mixed integer-linear programming approach to project investments in the copper industry including mining/milling, smelting, refining and semi-fabricating (wire, tubes and sheet semi-fabricating plants). The study does not present equations for supply, demand and price.

Ghosh et al. (1987) build a quarterly model of the world copper market. They disaggregate production in two geographical areas: the United States and the rest of the world, and by raw material origin: primary supply and secondary supply. They also disaggregate consumption by geographical area: the United States, Canada, Europe, Japan, and the rest of the world. Finally, they disaggregate stocks by ownership: speculative and merchants stocks, and geographical area: the United States, Japan, Great Britain, France, and Germany. One important feature of the speculative demand for copper stocks is the assumption of forward-looking rational expectations that make necessary the use of an auxiliary model of the world economy to analyze it would affect the future price. This makes the model extremely complicated.

Lewanika (1989) constructs an econometric model of the world copper industry that includes different functional forms for the supply equations of the most important world
copper producing countries. One aggregated equation is estimated for consumption, secondary supply, and change in inventory for the western world.

Finally, Intaraprawich (1989) and Labys (1989), develop an aggregated model of the world copper industry. The major contribution these authors made in their works was the incorporation of an equation for reserves, in addition to the equations for primary supply, production capacity, demand and price. However, the model is estimated at a world level.

Although, all the models of the previous section are valid and very valuable, we identify specifications in the equations we can improve to represent the copper industry in a more suitable way. Discussions of our concerns about the specification of the equations of primary and secondary supply, production capacity, demand, and price are provided more in depth in the section 2.2. The new features we include in our model are carefully explained in the section 3.2.

2.2. Revision of Model Specifications

This part of the literature review focuses on the most common model specifications utilized in econometric studies of base metals. This analysis is crucial for the development of our econometric model, since we try to determine the best specifications that researchers utilize for their equations of demand, capacity, primary and secondary supply, and price. When we say the best, we refer to factors such as reasoning behind the equations, variables used, etc. that are likely to be incorporated in our model. The review is divided in five main sections: supply, capacity, reserves, demand, and stock demand and price formation.

2.2.1. Supply

In this section, we examine the main contributions made in the past to specify primary and secondary supply equations.
2.2.1.1 Primary Supply

The theory behind econometric equations of primary supply has two origins: the partial adjustment model and the production function. Although, the majority of the authors divide their preferences in these two approaches, we also take a look at the adaptive expectations model that have not advanced enough to be as important as the previous.

2.2.1.1.1 Partial Adjustment Model

The partial adjustment model has been widely employed for supply models of metals. It assumes that reactions from producers to changes in product prices normally take several years until the capacity is adapted to the new features of the market.

If we make use of a simple model of long run supply, where $Q_t$ is the amount of copper supplied in year $t$, $P_t$ is the price of copper in year $t$, and $Q_t^r$ is the amount of copper that producers would supply in the long run (desired supply), then:

$$Q_t^r = \beta_0 + \beta_1 P_t$$  \hspace{1cm} (2.1)

Nevertheless, as we said before, producers cannot change some of their fixed factors in the short run. They only can adjust partially the production each year until they are able to provide the desired long run supply. If producers of copper can adjust their real supply from year $t-1$ to year $t$ (estimated as $Q - Q_{t-1}$) in a predetermined proportion $\lambda$ of the difference between desired supply ($Q_t^r$) and real supply during the preceding period ($Q_{t-1}$), we arrive at the following equation:

$$Q - Q_{t-1} = \lambda(Q_t^r - Q_{t-1}) \quad 0 \leq \lambda \leq 1$$  \hspace{1cm} (2.2)

If we substitute 2.1 into 2.2, we get:

$$Q = \beta_0 \lambda + \beta_1 \lambda P_t + (1 - \lambda)Q_{t-1}$$  \hspace{1cm} (2.3)
Banks (1974) and Fisher et al. (1972) agree this model represents the supply of copper. Alternatively, Mikesell (1979) argues that this theory has an important shortcoming as a supply theory because it is not related to the profitability conditions governing production decisions, in addition to costs and long run expected prices involved.

There are also authors that have included other explanatory variables to represent supply more properly. Ghosh et al. (1982) and Ghosh et al. (1987) combine a partial adjustment model with other explanatory variables that they believe must be in the equation. They argue that production of refined copper is a function of the production of the previous period, producers' stock of refined copper, cumulative excess supply, a price index and a time trend.

The reasoning behind the specification of our primary supply equations is different from that of the partial adjustment model. We recognize that normally there is a lag in the response of producers when price changes, and that this is because producers have fixed capacity in the short run. Therefore, primary supply is going to depend on current production capacity that is going to be a constraint. In the short run primary supply can be varied changing variable inputs and modifying capacity utilization. However, we think that the partial adjustment model is more applicable to the modeling of production capacity rather than primary supply.

2.2.1.1.2. Production Function Approach

This methodology has gained great popularity in the past, mainly because it is derived from microeconomic theory.

Supply of metals is normally assumed to depend on profit maximization subject to a certain production function. Profits commonly are determined by copper prices ($p$), quantity of copper produced by a mine ($q$), a vector of variable input prices ($c_v$), a group
of services used from variable inputs \((v)\), unit cost of capital \((c_k)\), and mine production capacity \((k)\).

Let us assume that a production function of a copper mining producer behaves as a Cobb-Douglas function. This is probably not very far from reality. Then:

\[
q(v) = \gamma v^\alpha k^\beta
\]

(2.4)

Where \(\alpha, \beta\) and \(\gamma\) are constants.

As we explained in the section of the partial adjustment model, producers are not able to change their capacities in the short run if any of the prevailing conditions of the market change. Because of this constraint, capacity is considered fixed in the short-run.

Profits \((\pi)\) will be given by:

\[
\pi = pq - c = \gamma v^\alpha k^\beta p - c
\]

(2.5)

Where \(p\) is the copper price and \(c\) is the total cost. If we assume that this is a competitive market, the first order condition for profit maximization will be:

\[
\partial \pi / \partial v = \alpha \gamma v^{\alpha - 1} k^\beta p - c_v = 0 \quad \text{or} \quad \alpha pq = c_v
\]

(2.6)

Where \(c_v\) denotes the unit cost of the collection of variables inputs. If we solve the equation for \(v\):

\[
v = c_v^{\gamma / (\alpha - 1)} k^{-\beta / (\alpha - 1)} \left(\alpha \gamma p\right)^{1 / (\alpha - 1)} \quad \text{or} \quad v = \left(p / c_v\right)^{1 / (\alpha - 1)} \left(\alpha \gamma\right)^{1 / (\alpha - 1)} k^{\beta / (\alpha - 1)}
\]

(2.7)

This last equation represents the factor demand function for profit maximizing. On the other hand, the restricted profit function is:

\[
\pi(p, c_v; k) = pq - c_v v - c_k k
\]

\[
= \gamma^{1 / (\alpha - 1)} \left(\alpha^{\alpha / (\alpha - 1)} - \alpha^{1 / (\alpha - 1)}\right) p^{1 / (\alpha - 1)} c_v^{\alpha / (\alpha - 1)} k^{\beta / (\alpha - 1)} - c_k k
\]

(2.8)

Where \(c_k\) is the cost of capital. Now, applying Hotelling’s lemma:

\[
q(p, c; k) = \partial \pi(p, c_v; k) / \partial p
\]

(2.9)

Then:

\[
q(p, c; k) = \left(1 / (1 - \alpha)\right) \gamma^{1 / (\alpha - 1)} \left(\alpha^{\alpha / (\alpha - 1)} - \alpha^{1 / (\alpha - 1)}\right) \left(p / c_v\right)^{\alpha / (\alpha - 1)} k^{\beta / (\alpha - 1)}
\]

(2.10)
And therefore:

$$Log_q = \beta_0 + \beta_1 Log\left(\frac{p}{c_r}\right) + \beta_2 Logk$$

(2.11)

Some authors like Adams et al. (1976a), Richard (1978), Vial (1989) have used similar approaches in their works. Wagenhals (1984) also supports this approach claiming that it has clear advantages over the partial adjustment model. He says that this approach is better in terms of higher determination coefficients and other statistics. Additionally, he states that the partial adjustment model is not based upon microeconomic theory and it also gives unrealistic high long run price elasticities.

Other authors, including Behrman (1978) and Adams (1978) support this hypothesis but they also add a time trend (t) that involves technological shifts in addition to increases of the reserves base. Hwa (1981 and 1985) uses a production function to characterize supply. He says that production depends on utilization rate of factor inputs, variable and fixed inputs, and technological changes. Since data for these variables are very difficult to acquire, he assumes a reduced form for variables and fixed inputs, determining that they depend mainly on relative prices and output. He also supposes that the utilization rate of factor inputs is a function of current and short term past real prices. The capital stock is a function of past investments that have been made as a result of profit maximization in the long run.

The production function approach is a better way of representing primary supply, given that is based upon microeconomic theory and that firms try to maximize profits (we assume that all the firms are profit maximizers independently of whether they are state-owned or private). In fact, this approach concludes that primary supply depends on the ratio unit price over unit variable costs and capacity. Basically, what we propose is very similar, but analyzed from another point of view.

We believe that primary supply is fundamentally a function of capacity and capacity utilization. In the short run, only capacity utilization can be modified to adjust production to changes in different variables such as copper price. In the long term, capacity of
production will be an important determinant and can be varied to adjust the production to a profit-maximizing level. For us, capacity utilization depends principally on the relation between price and variable costs. If price is greater than variable costs there exists an incentive to increase capacity utilization. If the contrary occurs there is an incentive to decrease production and in turn capacity utilization. More detail of this argument can be found in section 3.2.1.2.

2.2.1.1.3. Other Approaches

Another interesting model created by Cagan (1956) and Friedman (1957) that has not been used very much in the past, at least in metal markets, is the adaptive expectation model. In this model, we suppose that supply depends upon long run expected price \( P' \):

\[
Q = \beta_0 + \beta_1 P'
\]  
(2.12)

Suppose that price expectations are formed analyzing the relation between previous expected prices and actual prices. That is:

\[
P^*_t - P^*_{t-1} = \lambda \left( P_t - P^*_{t-1} \right) \quad 0 \leq \lambda \leq 1
\]  
(2.13)

So, this equation is equivalent to:

\[
P^*_t = \lambda P_t + (1-\lambda) P^*_{t-1} \quad 0 \leq \lambda \leq 1
\]  
(2.14)

Therefore, expected price is a weighted average of the last year expected price and actual price.

Then, the values for \( P^*_t, P^*_t, \ldots, P^*_t \) are:

\[
P^*_t = \lambda P_{t-2} + (1-\lambda) P^*_{t-1};
\]

\[
P^*_{t-2} = \lambda P_{t-3} + (1-\lambda) P^*_{t-2};
\]

\[
P^*_{t-n} = \lambda P_{t-n+1} + (1-\lambda) P^*_{t-n+1}
\]  
(2.15)

Now, substituting these terms into the equation of \( P^*_t \), we get the following equation:
\[ P_t^* = \lambda \sum_{i=0}^{\infty} (1 - \lambda)^i P_{t-i} \]  
\hspace{1cm} (2.16)

Therefore, expected price is a weighted average of present and past prices. However, the longer the lag on a price the less effect it will have on expected price. Finally, if (2.16) is plugged into (2.12), the supply equation is:

\[ Q_t = \beta_0 + \lambda \beta_1 \sum_{i=0}^{\infty} (1 - \lambda)^i P_{t-i} \]  
\hspace{1cm} (2.17)

We agree with Fisher et al. (1972) that the partial adjustment model is even more realistic for the copper industry than this approach, because changes in production normally take time, and additionally price expectations are probably not formed looking at past prices, but rather taking current and future prices more into account. Besides, this equation could have collinearity when estimated because of all the lagged prices.

2.2.1.2. Secondary Supply

Different from primary supply that comes from ore, a metal recovered from scrap is called secondary supply. Secondary supply can be separated into secondary supply from new and old scrap. New scrap is a material that is discarded from a manufacturing or processing operation and which cannot be directly used in the operation again. The treatment of new scrap involves sorting, cleaning and transporting before remelting, thus, it does not require a high level of associated costs. Almost all the new scrap is used in the same period that it is generated, and its production depends mainly on the copper consumption or the level of output in the copper using industries.

On the other hand, old scrap is a material derived from copper-containing products removed from the market because they ended their useful lifetimes. Processing of old scrap varies enormously, from high-grade scrap that needs only to be separated and can be reused without additional treatment, to low-grade scrap that has to be resmelting and refined. Consequently, the cost of metal recovery will depend on the form it is in when
the scrap is collected. Examples of old scrap containing copper are copper alloys, castings, electronic scrap, wires, tubes, etc.

For this research we only incorporate old scrap, given that new scrap produced in the stages after refining (semi-manufacturing and manufacturing) was once counted as refined copper production. If we include it as secondary supply we would be double counting.

Fisher et al. (1972) explain that the main determinants of secondary copper production from old scrap collection are the availability of old copper scrap for collection, the ease of collection and the price of old scrap. They assume that the change in available old copper scrap supply in a specific year is equal to primary production plus net imports of refined copper plus net imports of fabricated copper minus increases in stocks of copper. In this way, they can determine the availability of copper scrap for each year. This assumption does not make much sense since copper scrap takes a long time before being recovered at the end of its useful life. As an alternative for the difficulty of collection, they use the fraction of available scrap that was collected in the previous year.

Similarly, Mikesell (1979) affirms that secondary copper from old scrap depends on the cumulative stock of products containing recoverable copper, the cost of collection and the price of scrap that is related directly to the LME price. He states that some models use the amount of stock collected in the previous year as a measure of the cost of collection in the current year.

Slade (1979) develops an econometric model of the US secondary copper industry. It integrates microeconomic theory of production and costs to develop the model of copper scrap supply. One of the most interesting features that we have taken for our model is the representation of the scrap generation.⁶

According to Wagenhals (1984), copper produced from scrap is almost a perfect substitute of primary copper. However, he also argues that there are some differences

⁶ Details of the model are provided in section 3.2.1.3.
between the economics of both. Costs of producing secondary copper depend on the grade and quality of scrap input. Costs of collection for high grade and quality secondary copper should be lower than for primary copper. Also, energy requirements for recycling of copper scrap are smaller than for primary copper production. He affirms that the determinants for primary supply and secondary supply are very similar, but due to the availability of data, secondary supply has to be modeled in a different way. He assumes a partial adjustment model for secondary supply, although he recognizes that the speed of adjustment of this market is probably much quicker. This is a clear weakness of this model. Finally, the model he uses assumes that secondary supply depends on copper price and an index of activity for the copper using industries.

Ghosh et al. (1987) agree that secondary production responds very rapidly to changes in prices, distinct from primary production, and its long run response is constrained by the availability of scrap. According to the authors, secondary production depends on the difference between the forward refined copper price\(^7\) and the scrap price. This is explained by the fact that refiners are commonly using hedging. Old scrap supply also depends on the rate of recovery from sources such as obsolete machinery and equipment, and in turn, the rate of recovery will depend positively on the level of aggregate investment in new machinery and equipments and the scrap price, and negatively on the level of capacity utilization. Also they suppose that the scrap that is not recovered in one period is available for the next period.

Vial (1989) affirms that the decision of how much old scrap to recover depends on the expected profits rather than the availability of old scrap stock. Therefore, the recovery of old scrap must be a function of relative wages and energy prices (costs of production). Intarapravich (1989) also derives a secondary supply function from a profit maximizing condition, but assumes that the factors influencing it are scrap price, primary mineral price, economic activity, past demand and price of energy.

\(^7\) Rather than the spot price.
Labys (1989) says that for recycling there are certain features that must be considered before specifying the model. First, metal products are scrapped after a number of years of use. Second, the amount of scrap recovered and supplied depends on scrap prices. Third, primary and secondary productions are considered perfect substitutes. Following the suggestion of Radetzki et al. (1985), metal products available for recycling that are a proportion of past demand and secondary production will depend on the recoverable metal and on the ratio between scrap price and refined metal price.

We think the approach used by Vial (1989) and Intarapravich (1989), based upon profit maximization of secondary copper suppliers is interesting, but because of lack of data is complicated to estimate. They use wages and energy prices to represent production costs, but in our point of view the most important cost of copper production from old scrap is the collection cost. We also agree with Wagenhals (1984) who argues energy costs for secondary supply are not comparable with those for primary supply where they can be very important. Thus, we prefer to use the difficulty of collection as a measure of costs.

Additionally, although some authors underestimate the availability of scrap as a key variable for supply, we think it is extremely relevant and has to be included in the model, given that in the long run, the availability of scrap is clearly a constraint for secondary supply. On the other hand, as Wahgenhals (1984) explains, the adjustment speed of secondary supply is quicker than for primary supply, therefore, the partial adjustment model is not applicable.

Because copper price affects the sale price of copper produced from scrap and impacts the cost of old scrap as well, we think it has to be included in the model too.

Thus, the foundation of our model is based on a mix of the studies of Fisher et al. (1972) and Slade (1979). We utilize the same variables of Fisher et al.: available stocks of copper scrap, difficulty of collection and copper price. The principal change is in the

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8 If copper price increases, the price of old scrap increases too. Therefore, producers of secondary copper have to pay more for the cost of the old scrap they need. Both prices have a very high correlation (91%).
estimation of the availability of copper scrap where we use the more realistic model of Slade to represent it.⁹

2.2.2. Production Capacity

There are some econometric studies of primary commodity markets that have included the estimation of capacities or investments.

Richard (1978) argues that mine capacity could be established assuming that investors look for profit maximization. Because of the bad quality of data, he assumes that the rate of change of capacity is a function of the difference between actual and potential output, where potential output is equivalent to mine capacity. For us this does not seem clear. Nevertheless, he explains that non-US industry might not have a profit maximizing behavior, since nationalization of copper mining companies in some countries could have other objectives like maximization of export revenues or employment generation. However, he does not estimate a capacity equation.

Wagenhals (1984) postulates that the most relevant factors influencing copper production capacity are current and lagged copper prices, and the cost of capital, which in turn depends on the purchase price of capital, interest rate, depreciation rate, corporate tax rate for mining enterprises and depreciation method. Also, the author includes a variable of risk measured as a five-year variance of LME copper prices.

To develop the model he assumes that a copper producer determines the desired capacity that maximizes profits in the following way:

\[ K^*_t = f \left( \beta \left( \frac{P_t}{c_t} \right) Q_t, r_t \right) \tag{2.18} \]

Where \( K^*_t \) is the desired level of capacity, \( \beta \) is the constant elasticity of mine production with respect to capacity, \( P_t \) is the copper price, \( c_t \) is the user cost of capital, \( r_t \)

⁹ The description of the methodology can be found in section 3.2.2.2.
is the five-year variance of LME copper prices and $Q_t$ is the copper mine production. Then, Wagenhals uses a partial adjustment model to express capacity adjustments.

Intarapravich (1989) also assumes the partial adjustment model to represent the process of capacity adjustment, but the specification of the desired level of capacity is totally different. Intarapravich specifies desired capacity as a function of current price, expected price, primary production, economic activity and interest rate.

Labys (1989) prefers to specify changes in capacity as a function of economic activity, expected profits in current and previous periods and the ratio capacity/reserves.

Finally, Vial (1989) makes something very similar to what Richard (1978) and Labys (1989) mention. He applies forward looking expectations in the formulation of the capacity investment functions. Thus, he incorporates the present value of expected profits and the relative price of capital goods as main determinants. However, the results are rather poor from the point of view of the significance of the variables and the goodness of fit. The main difficulty with the model estimation is the determination of the expected profits.

We agree with Wagenhals (1984) and Intarapravich (1989) that the partial adjustment model describes the behavior of the copper production capacity adequately. Production capacity only can adjust partially to changes in prices each year until it reaches the desired capacity. We believe, nevertheless, that previous studies fail to include all the relevant variables that influence capacity formation. Two of the variables that should be incorporated are investment climate and mineral potential. We make an attempt to incorporate proxies of these variables since they do not inherently exist. We also take some variables of the previous studies such as the copper price, interest rate and technological changes as main determinants of desired capacity.
2.2.3. Reserves

There are only two studies of metal markets that include reserves. The reason for this is that there is a lack of good sources of data. The United States Geological Survey publishes some reserve data by country, but the majority of the reserves remain invariable in time or vary too little to justify the estimation of equations. Because of this, we decided to not estimate reserve equations, as originally planned.

Despite, we give a brief description of the two studies.

Labys (1989) argues that reserve additions depend on expected profitability of exploration, the ratio of capacity stock and reserve stock of the firm, and cumulative extraction. However, this study includes an equation for reserves at an aggregate level.

Intarapravich (1989), in an attempt to improve the work of Labys, assumes that reserve additions depend on the exploration done in the current and lagged periods, and on the copper price. To describe exploration he uses other variables such as expected price, an economic activity index and the ratio of capacity stock to reserve stock of the firm.

2.2.4. Demand

There are basically two types of models that have been utilized to explain demand of metals: the partial adjustment model, and linear or log-linear models without lagged demand as explanatory variable. We can find most of the studies classified in these two ways, however we also inspect two other models\(^\text{10}\) which are difficult to arrange in the previous two models and that have very different but interesting specifications.

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\(^{10}\)Ghosh et al. (1982 and 1987) and Figuerola-Ferreti et al. (2001)
2.2.4.1. Partial Adjustment model

The far response of consumers to a change in copper price normally takes a long period of time. This suggests that one form of representing the demand for copper could be a partial adjustment model.

If we have the following simple linear model of long run demand, where \( C_t \) is the amount of copper demanded in year \( t \) and \( P_t \) is the price of copper in year \( t \). The amount of copper that consumers are willing to demand is \( C_t^* \) (desired demand).

\[
C_t^* = \beta_0 + \beta_1 P_t
\]

(2.19)

However, because of technological limitations in the short run, consumers of copper are not able to move at once to \( C_t^* \). Consumers cannot immediately respond to a change in price, they can only adjust consumption partially until they reach the desired amount. If we assume that consumers of copper can only adjust their real demand from year \( t-1 \) to year \( t \) (estimated as \( C_t - C_{t-1} \)) in some predetermined proportion \( \lambda \) of the difference between desired demand and real demand during the preceding period (\( C_{t-1} \)), the new equation obtained is the following:

\[
C_t - C_{t-1} = \lambda \left( C_t^* - C_{t-1} \right) \quad 0 \leq \lambda \leq 1
\]

(2.20)

Now, we can bring together the last two equations, since it is not possible to observe desired demand.

\[
C_t = \beta_0 + \beta_1 P_t + (1 - \lambda) C_{t-1}
\]

(2.21)

Fisher et al. (1972) developed the first known econometric study of the world copper industry using the partial adjustment model. They argue that copper consumption in final end uses - measured by refined copper consumption adjusted for down stream stocks (estimated by using changes in durable goods inventories) - adjusts in the long term to changes in prices. This is a deviation of the classical assumption that only consumption is adjusted when prices change. Specifically, they assume that changes in copper
inventories in semi-finished and finished goods are linearly related to the total change in copper inventories. This argument does not seem very convincing since the level of copper stocks that consumers hold is related to the level of their own consumption. They also suggest that demand for copper depends mainly on variables such as industrial activity, its own price and the price of aluminum. Prices of copper and aluminum were used, lagged by one year, because short run adjustments in consumption are very difficult.

Although Banks (1974) does not estimate a model, he supports the work of Fisher et al., but tries to discuss some alternative price models like an “expectations model” (as he calls it), assuming that consumption can depend more on expected price than current price. For this purpose, he assumes consumers estimate the expected price as a function of actual price of the last year and a proportion of the difference between the current price and past prices. However, this seems to be not very realistic. Then, expected price is plugged into a partial adjustment model as suggested also by Witherwell (1967).

More recently, Pei (1996) and Pei et al. (1999) use the partial adjustment model and suggest that previous econometric analyses do not incorporate technological changes and consumer preferences in estimates of metals demand. This provokes an underestimation of the income elasticities for the developed countries. To avoid this problem they recommend the inclusion of a time variable characterizing technological changes and consumer preferences. Thus, they obtain higher income elasticities, improving previous studies.

We agree with Pei et al. (1999) that the partial adjustment model has an important shortcoming. It assumes that changes in prices and income affect demand more in the long run than in the short run. This seems correct for changes in prices but not for changes in income that have a greater impact in the short run. For this reason, we have decided not to use this approach.
2.2.4.2. Linear or Log-Linear Models without Lagged Demand as Explanatory Variable

Other types of models that are very common in the estimation of demand and that have been used extensively in econometric studies of primary commodity industries are simply linear or log-linear models that do not include lagged demand as explanatory variable. The most common representations of the demand equation are the followings:

\[ Q_t = \beta_0 + \beta_1 P_t + \beta_2 P_t^* + \beta_3 Y_t \] (Linear form) \hspace{1cm} (2.24)

\[ \log Q_t = \log \beta_0 + \beta_1 \log P_t + \beta_2 \log P_t^* + \beta_3 \log Y_t \] (Log-linear form) \hspace{1cm} (2.25)

Where \( P_t \) is the price of the product, \( P_t^* \) is a substitute price and \( Y_t \) is an index of economic activity.

Bozdogan et al. (1979) analyze these two forms. They state that independent of the initial price level, with a linear form, an absolute rise in price will cause an absolute decrease in the quantity demanded, and with a log-linear form we are accepting that independent of the price level, a proportional (percent) increase in price produces a proportional (percent) decrease in the quantity demanded (constant elasticity). Thus, if elasticities are not constant over the whole period of time a linear form should be chosen. However, if we have a big price variation over the period, the assumption of an unchanging absolute quantity response to an absolute price change cannot work. Another way of choosing the functional form might be with the Box-Cox test.

Finally, Bozdogan believes that copper consumption depends basically on the price of copper, the price of a substitute and the activity level, but states that if we want to specify the demand equation more correctly it is necessary to analyze the production function of copper users.

Taylor (1979) also agrees that consumption of refined copper depends positively on the production of end-use markets and changes in substitute prices, and negatively related to changes in the deflated copper price.
Wagenhals (1984) uses a simple model to describe the behavior of demand in the world copper market. He assumes that because normally in the industry consumers tend to have long-term contracts of supply, the adjustments in consumption are represented by lagged prices of copper and aluminum. He also employs a log-linear model to characterize the demand of copper.

Hwa (1981 and 1985) assumes that copper demand is a “derived” demand that depends on the demand for final goods, which use this input. He includes the real prices of copper and a substitute, real world income and a variable representing the sensitivity of the demand with respect to the cyclical changes of real income.

Gilbert (1995) also has a similar vision about metals demand. He develops a model of the world aluminum market and uses a linear structure. In the model he uses a lagged price of aluminum, a trend-modified industrial production index and a lagged OECD\(^{11}\) countries construction index.

Behrman (1976), Behrman (1978), Berhman et al. (1978), Adams (1978) and Richard (1978) use very similar specifications for their demand models.

Vial (1989 and 1992) also develops a log-linear model of copper consumption. He assumes that demand for copper is a function of production of final goods that employ copper as an input and the relative prices of each of the inputs with respect to the price of the final good. In addition, he considers that the use of price lags is necessary since a long period of time can elapse before the relative proportion of inputs in the final good changes due to a change in input prices. However, this specification can cause serious problems of collinearity since prices in different periods are normally correlated. Finally, he includes energy as an explanatory variable.

We agree with the variables used in most of the studies, but as we mentioned in the previous section 2.2.4.1., changes in demand due to changes in prices can normally take several years. For example, if copper price increases, producers of end use products

\(^{11}\) Organization for Economic Cooperation and Development
cannot switch immediately to other cheaper materials, since it would involve big changes in the processes of fabrication. This could take a long time, so consumers of copper will wait until they are sure the copper price will not go down again to incorporate new substitutes in the fabrication processes. However, the length of the lag in the response is not clear. We think the impact of prices on demand could take between 3 and 5 years. In section 3.2.3.2, we propose an approach that attempts to incorporate this feature in the model.

On the other hand, as Pei et al. (1999), we as well include a time variable to represent consumer preferences and technological changes.

2.2.4.3. Other Models

There are two models that escape from the two previous categorizations, although they could belong to the partial adjustment model, because of the lagged dependent variable. Ghosh et al. (1982 and 1987) utilize a one period lag on industrial production and a longer time lag of the copper price relative to the price of aluminum. The general form of the model for the consumer countries is as follow:

$$ C_t = \beta_0 + \beta_1 t + \beta_2 C_{t-1} + \sum_{i=0}^{\infty} \beta_{3i} IP_{t-i} - \sum_{i=1}^{\infty} \beta_{4i} (\ln LME_{t-i} - \ln ALPP_{t-i}) $$

(2.26)

Where $C_t$ is consumption of refined copper, $t$ is a time trend, $C_{t-1}$ is consumption of refined copper in the previous period, $IP$ is industrial production, $LME$ is LME settlement price (average over quarter), $ALPP$ is US aluminum producers price. The main deficiency of this model is the lag in industrial production since the effect of economic activity on demand is immediate, therefore lags are not necessary.

Figuerola-Ferreti et al. (2001) use a complex log-linear model to explain the demand for metals. Unfortunately, the fundamentals of this model are not explained in their paper. The equation is as follows:
\[ \ln C_t = \beta_0 + \beta_1 \text{trend}_t + \beta_2 \ln C_{t-1} + \beta_3 \Delta \ln P_t - \beta_4 \Delta \ln P_t - \beta_5 \left( \frac{Vol_{t-1} + Vol_{t-2}}{2} \right) \] (2.27)

Where \( C_t \) is the consumption of refined copper, \( \Delta \ln P_t \) is the change in industrial production, \( \text{trend}_t \) is a time trend, \( Vol_t \) is the intra-year daily price volatility, and \( \Delta \ln P_t \) is the change in copper price. However, we believe the volatility of prices is not a determinant in demand for metals, since the prices of almost all commodities are volatile. Contrarily, the level of prices is more important in causing substitution. In addition, most copper producers and consumers can use forward contracts to diminish this problem.

2.2.5. Demand for Stocks and Models of Price Formation

This is probably the most complex topic in the analysis of commodity markets, however it is also of great importance since one of the main objectives of commodity modeling is forecasting prices. Price determination has become a great challenge for academics and researchers who have not been able to represent the behavior of prices adequately. Therefore, the determination of prices continues to be an extremely interesting point still under discussion.

Upon analyzing the literature on competitive price models of storable commodities, it can be deduced that results are not very clear and conclusive.

2.2.5.1. Inverse Relationship Price-Stocks

Since the beginning of the seventies, authors already had in mind that there was a clear inverse relationship between metals prices and stocks level. However, the features of this relationship were not comprehensible for all the authors.

According to Labys (1973), there were basically three approaches describing price formation methods. These included a flow approach, a stock approach and a stock-flow approach:
a) \( P_t = f(\Delta S_t, Z_t) \) \hspace{1cm} (2.28)

b) \( P_t = f(S_t, Z_t) \) \hspace{1cm} (2.29)

c) \( P_t = f(S_t/C_t, S_t/Q_t, Z_t) \) \hspace{1cm} (2.30)

Where \( P_t \) represents the commodity price, \( S_t \) is the level of stocks at the end of the period, \( C_t \) is consumption, \( Q_t \) is production and \( Z_t \) corresponds to other variables influencing price. \( \Delta S_t \) symbolizes the first difference of \( S_t \), or the difference \( Q_t - C_t \).

The flow approach establishes that price depends on the excess supply measured by the difference between production and consumption; the stock approach considers the level of stock as the main determinant of price formation; and the stock-flow approach is a mix of both former approaches.

Fisher et al. (1972) argue that for the specification of the LME price the main effect over it is the change in the stocks-consumption ratio and not its level. Thus:

\[
P_{LME_t} = \beta_0 - \beta_1 \left[ (S_t/C_t) - (S_{t-1}/C_{t-1}) \right] + \beta_2 P_{LME_{t-1}}
\]

(2.31)

Where \( S_t \) is the level of stocks for the rest of the world, \( C_t \) is the consumption for the rest of the world.

Wagenhals (1984) says price depends on the level of stocks at the end of the period and consumption among other variables. However he does not realize that the level of stocks depends in turn on consumption, therefore, there is a possibility of collinearity.

Vial (1989) argues that price is a function of the ratio between the expected consumption – production imbalance and consumption, the real interest rate, the ratio between inventories at the end of the previous period and consumption, and the real exchange rate of the dollar against the German mark. However, he does not explain why real interest rates and the dollar strength against the German mark are included in the model.

We agree there is an inverse relationship between price and stocks level, but there is also an influence of what is the stakeholders’ perception of the relationship between
current level of demand and supply. These two aspects can influence metal prices. Since we use the level of stocks at the end of the previous period we could say that our position is more like a stock-flow approach.

Instead of the variables real interest rate and exchange rate of the dollar against the German mark, we propose the incorporation of an index of the dollar's strength against the most important currencies. This incorporates the effect of the relationship among interest rates all over the world.\footnote{More details are provided in section 3.2.4.4.}

Finally, we assume a partial adjustment model for price since if supply and demand take time to adjust the same occurs for price that tends to adjust slowly until it reaches the desired long term supply and demand.\footnote{More details are provided in section 3.2.4.5.}

2.2.5.2. Rational Expectations Hypothesis (REH) Approach

The rational expectations hypothesis is the principal approach used to describe the behavior of stocks demand and its relationship with price. As in the theory of money, there are three reasons why firms and individuals want to hold stocks: transactions, precautionary and speculative motives. Transactions demand for inventories indicates the need for holding inventory to satisfy the planned levels of production of a firm. As a consequence, the level of transactions demand for inventories will depend on the level of consumption of the firm. Thus, the greater the level of commodity consumption, the bigger the need for a large inventory. Precautionary demand is created by the need for holding inventory to defend against unexpected events. The inventories held by these two motives are totally independent of profit gain objectives. This means that consumers carry inventory because it is convenient for them for the reasons given before, or the stocks held gives them a "convenience yield".
On the other hand, and according to the majority of the authors that have done
research in the field of primary commodity models in the last forty years (Muth (1961),
(1990), Gilbert and Palaskas (1990), Gilbert (1995), and many more), the REH is central
in estimating models of speculative demand for stocks. According to them, the objective
of the speculative demand is to gain profits by buying at a low price and selling at a high
price. Kaldor (1961) and Kohn (1978) explain that the speculator will obtain profits only
if the expected price for the next period \( P_{t+1}^e \) is greater than the current price \( P_t \) plus
the storage cost \( (w_t) \) and plus the return \( ((i_t + r_t)P_t) \) he would obtain in another investment
with the same level of associated risk. The return is composed of the interest rate \( (i_t) \) and
the risk premium \( (r_t) \).

\[
P_t + w_t + (i_t + r_t)P_t \leq P_{t+1}^e \quad \text{or} \quad w_t + (1+i_t + r_t)P_t \leq P_{t+1}^e
\]  (2.32)

This formulation is based on the REH of prices, originally developed by Muth (1961).
This hypothesis establishes that agents are rational and they will base their decisions not
only on current information but also on anticipated estimations of the future (current
expectations of future market conditions are also called forward-looking expectations).

Following this approach, the majority of the researchers have used the REH to model
speculative demand. Therefore, they argue that speculative demand is going to be a
function of the difference between the expected future spot price and the current price
compounded by the interest rate. Unfortunately, because of the lack of data, it is assumed
that the storage cost and the risk premium are negligible or zero. Thus, the expression
generally assumed is:

\[
0 \leq P_{t+1}^e - (1+i_t)P_t
\]  (2.33)

On the other hand, when transactions, precautionary and speculative demand of
inventories are added, the stock demand function can be expressed in the following way:

\[
S_t = s\left(C_t, P_{t+1}^e - P_t, i_t\right)
\]  (2.34)
Because of the inverse relationship between price and the stocks level, this equation is typically inverted to determine price in terms of stocks. It helps also to make the process of model simulation easier.

\[ P_t = p^{-1}(S_t) \] (2.35)

The main problem that the stock equation 2.34 has to face is the estimation of the price expectations \( P_{t+1} \), because it is not observed. One obvious approximation for the expected price of a commodity traded in an exchange could be the use of its futures price. However, Gilbert (1995) argues that future contracts with more than six months of maturity are illiquid, meaning that prices from these contracts do not reflect with certainty the future market expectations.

So far, the difficulty on the expected future price estimation has caused the models of speculative demand of inventories based on the REH to have significant complications and deficiencies. Among the most important examples of stock demand estimation using REH, are the following:

Hwa (1981, 1985) develops a disequilibrium model for some commodity markets, assuming that transactions stocks are directly related to the level of consumption. In contrast, the speculative demand is related to profit-making behavior. He also argues that speculators will keep inventories until the expected price spread is greater than the storage cost of holding plus the interest cost and the risk premium associated with the uncertainties involved in predicting the price. Hwa replaces the difference between the expected future price and the current price by a dummy variable. This dummy variable is assumed to be one for the years where speculation has an important influence.

Ghosh et al. (1987) find evidence of this forward-looking behavior for the copper market. However, this behavior cannot be reproduced for cocoa, coffee, rubber, sugar and tin in the study of Gilbert et al. (1990), suggesting that it may be only a characteristic of the copper market. They also state that only very simple models can be used to
characterize commodity prices in terms of current and expected future market conditions. This is a clear limitation for this theory.

Ghosh et al. attempt to build a model of copper price based on the REH. They say that price depends on the interest rate, the US wholesale price index, the expected aggregate supply excess and a time trend. The expected aggregate supply excess is derived from a forward-simulation of the copper market. That is, the variable of expected aggregate excess supply replaces the expected future conditions of the market that are reflected in the expected future price. To estimate the expected aggregate excess supply they use an auxiliary model of the world economy to forecast the future conditions of the copper market. Thus, forecasts for industrial production by geographical area, the US wholesale price index, the US interest rate, and US energy prices are needed. Obviously, the estimation of the expected aggregate excess supply is of colossal complexity, and it adds a greater probability of error in the model of stock demand estimation.

Therefore, to address this difficulty in econometric models of metal industries normally no equations of stocks are estimated. On the contrary, researchers usually estimate the price equation as a function of stocks.

We think the REH is not completely applicable to the theory of stocks demand since speculators have nowadays more sophisticated techniques to make transactions. In section 3.2.4.1., we propose a more realistic model of stocks demand behavior; however, it is not estimated because of lack of information on future prices and more accurate information about interest rates. Thus, we just assume that prices are an inverse function of stocks.
CHAPTER 3

SUGGESTED ECONOMETRIC MODEL OF THE WORLD COPPER INDUSTRY

In this section we present the main features of our econometric model of the world copper industry that we are suggesting. First, we describe the theoretical foundation of this econometric model and then we explain the characteristics of the equations that we will try to estimate.

3.1. Background of the Suggested Econometric Model

This thesis presents a new econometric model of the world copper industry. The estimation of the model is based on the Standard Commodity Model (SCM)\(^{14}\).

The SCM explains the behavior of short and medium run equilibrium of flows and stocks utilizing five equations: consumption (\textit{constot}_t), production (\textit{tq}_t), production capacity (\textit{ktot}_t), price (\textit{p}_t) and an identity that clears the market. Thus, the basic system of simultaneous equations is:

\begin{align}
\text{constot}_t &= f(p_t, x_{c_t}) + u_t \quad (3.1) \\
\text{tq}_t &= q(p_t, x_{q_t}) + v_t \quad (3.2) \\
\text{ktot}_t &= k(x_{k_t}) + w_t \quad (3.3) \\
\text{p}_t &= h(s_t, x_{s_t}) + x_t \quad (3.4) \\
\text{s}_t &= s_{t-1} + t q_t - \text{constot}_t \quad (3.5)
\end{align}

The two first functions are represented by the commodity price (\textit{p}_t) and other significant variables (\textit{x}_{c_t}, \textit{x}_{q_t}), production capacity might depend on several variables

\(^{14}\) The SCM was developed by F. Gerard Adams and Jere Behrman in the 70s (Adams et al. (1976(b))).
(there is no unanimity) and the price equation is a function of the level of stocks ($s_t$) and other important variables ($xs_t$). $s_t$ is the level of stocks at the end of period $t$, which is going to be represented by the level of stocks at the end of the previous period plus the difference between supply and demand in the current period. The variables $xc_t, xq_t, xs_t$ are defined in detail in section 3.2.

3.2. Description of the Econometric Model

In order to propose a new econometric model of the world copper industry, we attempt to incorporate new specifications for the equations of production capacity, primary supply, secondary supply, demand, and price. Thus, we try to improve the specifications of the equations made before by other researchers, either adding new variables not included in previous studies that we think should be in the equations or changing explanatory variables that in our point of view are not the best to explain the behavior of the dependent variables.

The proposed model is disaggregated by geographical area and considers the most important countries for each of the equations. The equations of this model are derived from an analysis of the models used in the past to explain the behavior of metal markets, as shown in the literature review section, microeconomic theory and several new contributions incorporated in the equations that should improve the results or, at least, characterize in a better way the functioning of this industry.

3.2.1. Supply

The supply of copper can be divided into primary supply ($pq_t$) and secondary supply ($sq_t$). Primary supply is the copper that comes from a mine, while secondary production represents the copper recovered from scrap. The sum of both gives us the total supply ($tq_t$):
\[ t_q = p_q + s_q, \quad (3.6) \]

### 3.2.1.1. Theory of Supply

Assuming that the copper industry is very close to a competitive market, a firm producing in this market does not have influence over copper price. The objective of this competitive firm is to maximize its profits:

\[
\text{max } pq - c(q)
\]

Where \( p \) is the market price of the product, \( q \) is the number of goods that are produced and \( c(q) \) is the total cost of production that is a function of the level of output.

The first order condition of maximization is:

\[
\frac{\partial (pq)}{\partial (q)} - \frac{\partial (c(q))}{\partial (q)} = 0 \quad (3.7)
\]

Therefore:

\[ p = MC \quad (3.8) \]

This means that the competitive firm chooses its level of production at the point where the marginal cost \( (MC) \) is exactly equal to the market price \( (p) \).

The second order condition must satisfy the following:

\[
\frac{\partial^2 (c(q))}{\partial (q)^2} \geq 0 \quad (3.9)
\]

This means that the marginal cost must be increasing.

Now analyzing figure 3.1, producer should produce exactly where price \( (P1) \) is equal to the marginal cost.

The short run supply curve of the firm coincides with the section of the marginal cost curve that is over the average variable cost curve. Although losing money, a firm has an incentive to keep producing when price is greater than \( P0 \) because it is covering its average variable costs. The reason behind this is that fixed costs (the difference between
average total costs (ATC) and average variable costs (AVC)) must be paid whether a firm produces or not, and losses are diminished by staying in the business.

Figure 3.1
Short run supply curve of a firm

3.2.1.2. Definition of Primary Supply Equations

Different from the two most common approaches, the partial adjustment model and the production function approach, developed in the past, we propose a new model. We certainly believe that primary supply is basically a function of capacity \( k_i \) and capacity utilization \( cu_i \). In the short run, only capacity utilization can be modified to adjust production to changes in different variables such as copper price or variable costs. In the long term, production capacity will be an important determinant and can be varied to adjust the production to a profit-maximizing level. Hence, the primary supply equation can be expressed as a function of these two variables:

\[ p q_i = f \left( cu_i, k_i \right) \]  

(3.10)
Capacity utilization depends (presumably among other things) on the relationship between price and average variable costs. If we assume that variable costs are very close to marginal costs (it can be seen in the previous figure), we could use variable costs instead of marginal costs given that are easier to get. Maybe the best way to represent this relationship is with a ratio of price to variable costs. If the ratio of price to variable costs grows, there is an incentive to increase production and in turn capacity utilization. If the opposite occurs, and the ratio of price to variable costs diminishes, the mine will try to decrease the capacity utilization. Normally, if the ratio is lower than one, a mine will have an incentive to shut down because price does not cover variable costs any more (supposing that we are including the associated shutdown costs in the analysis).

Unfortunately, there is a lack of information related to variable costs per country. At the beginning, we thought of using a wholesale or consumer price index to reflect the cost changes each year. However, these data suffer from the shortcoming that these indices probably do not show to a real magnitude the variation of production costs in the industry. Additionally, a price index is necessary to convert the nominal price of copper in a real one, so it would be already incorporated in the ratio.

We have two further possibilities that might be incorporated in the supply equations. One is the addition of a time variable to the equations of supply to reflect how technological changes have affected variable costs over time. The second option is to assume that solely price affects capacity utilization because it varies much more than variable costs from year to year. The first option appears more attractive since technological changes have been extremely important for improving productivity in the industry. For example, the development of the solvent extraction and electro-winning process that allows the treatment of copper oxides at a very low cost increased the productivity significantly in all the producing countries. Like this technology breakthrough, there are a lot more innovations that have helped the industry to decrease operation costs dramatically.

Therefore, the equation for capacity utilization can be expressed as:
\[ cu_i = g(p_i, t) \]  \hspace{1cm} (3.11)

And, if we plug 3.16 into 3.15, the supply function would be:

\[ pq_i = f(p_i, t, k_i) \]  \hspace{1cm} (3.12)

The final equation in linear form would be:\(^{15}\)

\[ pq_i = \beta_0 + \beta_1 p_i + \beta_2 k_i + \beta_3 t \]  \hspace{1cm} (3.13)

If this equation is expressed for each copper producer country \( i \), in national currency in real terms, we get:

\[ pq_{i,t} = \beta_0 + \beta_1 \left( p_{i,t} \times er_{i,t} / pi_{i,t} \right) + \beta_2 k_{i,t} + \beta_3 t \]  \hspace{1cm} (3.14)

Where, \( er_{i,t} \) is the exchange rate of each country (national currency/US dollar) and \( pi_{i,t} \) is a price index as the GDP deflator of each country.

If we add the primary copper production of each country and the rest of the world we obtain the total primary supply (\( pqtot_i \)):

\[ pqtot_i = \sum_{i=1}^{n} pq_{i,t} \]  \hspace{1cm} (3.15)

### 3.2.1.3. Definition of Secondary Supply Equation

Estimation of secondary supply is a complex issue, mainly because of problems related to collection, availability and reliability of data. Although, secondary supply normally is composed of new and old scrap, we have excluded the production of new scrap from the equation of secondary supply. The reason behind this is that new scrap supply is created in the process of production of manufactured and semi-manufactured products that are commonly used in the same period that was generated, therefore, if we include that output in the secondary production we would be double-counting it, because this copper was already produced and counted as primary supply. Thus, our task is

\(^{15}\) Although, it is not included in the equations, we assume that all the equations have an error term.
reduced now to develop an equation that includes only secondary production from old scrap.

The reasoning behind the specification of the secondary supply equation is mainly based on the studies of Fisher et al. (1972) and Slade (1979).

We use the same variables that Fisher et al. (1972) utilized, available stocks of copper scrap ($\Delta ss_t$), difficulty of collection ($\langle sq/ss \rangle_{t-1}$) and copper price ($p_t$). The principal problem appears when we want to get data for the availability of copper scrap stocks. Since, it does not exist we have to represent it by another variable.

Some researchers (Labys (1989), Intaraprvich (1989)) have used the consumption of copper in previous periods as an indicator of this variable. However, they assume very short lag periods for past consumption that in fact, are incompatible with average useful lifetimes of copper products that can range from 5 years to 30 years or even more. If we use the more realistic model of Slade (1979) that assumes that the mix of copper products does not vary over time and that each copper product has a constant average useful lifetime, then:

$$\Delta ss_t = \sum_{i=1}^{n} f_i constot_{t-t_i}$$

(3.16)

Where, $\Delta ss_t$ is the addition of old copper scrap to the stock in period $t$, $f_i$ is the fraction of metal consumption that goes into the final product $i$, $n$ is the number of final products, $t_i$ is the average useful lifetime of final product $i$, and $constot_{t-t_i}$ is total copper consumption in year $t-t_i$. The parameters used to calculate the available stocks of old copper scrap are presented in Table 3.1:
Table 3.1
Parameters used to calculate the available stocks of old copper scrap

<table>
<thead>
<tr>
<th>Final Product</th>
<th>Fraction of Consumption (%)</th>
<th>Average Lifetime of Product (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building and Construction</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>Transportation</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Consumer durables</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td>Electrical and electronic</td>
<td>23</td>
<td>30</td>
</tr>
<tr>
<td>Industrial Machinery</td>
<td>16</td>
<td>20</td>
</tr>
</tbody>
</table>

Source: Slade (1979)

Net additions to the stocks of scrap in year \( t \) are represented by additions minus production from old scrap in that year. Thus, scrap stocks can be expressed as:

\[
ss_t = ss_{t-1} + (\Delta ss_{t-1} - sq_{t-1}) \quad \text{or}
\]

\[
ss_t = ss_{t_0} + \sum (\Delta ss_{t-i} - sq_{t-i}) \tag{3.17}
\]

Where \( t_0 \) is the base year. For \( ss_{t_0} \), Slade uses a value that is approximately two times the value of total consumption of copper for that year. According to her, the estimates of the coefficients of the supply equation are not sensitive to the initial stocks. Therefore, we have decided to use two times the value of total consumption for \( ss_{t_0} \), and the base year \( t_0 \) is 1970.

On the other hand, because of the limited availability of cost data for the facilities producing old scrap, we use another measure of difficulty of collection. As a measure of the difficulty of collection, we will use the ratio of production of old scrap to the availability of copper old scrap in the previous period \((sq/ss)_{t-1}\). The justification is the fact that one should expect the easiest collection of copper first. Thus, if a great amount of old scrap was collected the previous year, it is going to be much more difficult to collect copper scrap the next year. This is the same assumption made by Fisher et al. (1972).
Price of copper is utilized as a proxy for price of copper scrap\textsuperscript{16}. Since they are much correlated, copper price will affect secondary supply in two different ways. First, as the price of the final product it impacts supply positively. Second, as it reflects also the price of one of the most important inputs, the effect should be negative. Finally, the coefficient accompanying this variable will show the net effect of these two impacts.

Therefore, the equation is the following:
\[ sq_t = \beta_0 + \beta_1 s_t + \beta_2 (sq/.ss)_{t-1} + \beta_3 p_t \] \hspace{1cm} (3.18)

3.2.2. Production Capacity

Supporting the works of Wagenhals (1984) and Intarapravich (1989), we think that a partial adjustment model\textsuperscript{17} features the behavior of the production capacity equations very well. This means that we assume the production capacity only can adjust partially each year until it reaches the desired capacity. From year \( t-1 \) to year \( t \) the adjustment of capacities for each country \( i \) (\( k_{id} - k_{id-1} \)) is a fixed proportion \( \lambda \) of the difference between desired capacity at the end of period \( t \) (\( k_{id}^* \)) and capacity at the end of period \( t-1 \) (\( k_{id-1} \)).

Therefore, we arrive to the following equation:
\[ k_{id} - k_{id-1} = \lambda (k_{id}^* - k_{id-1}) \] \hspace{1cm} (3.19)

In turn, the desired level of capacity (\( k_{id}^* \)) or the capacity towards which the industry is moving over the long run depends on the copper price of the previous year, interest rate of the previous year, investment climate and mineral potential of a country, and technological changes that affect investment in capacity. Thus, the desired capacity can be represented by the following function:

\textsuperscript{16} The correlation coefficient is 0.919 for the period 1971-2002. Price of copper scrap corresponds to No. 2 copper scrap refiners buying price.

\textsuperscript{17} The partial adjustment model is explained in more detail in the sections of supply and demand of the literature review.
\[ k_t^* = f(p_{t-1}, ir_{t-1}, (fdi / pop)_{t-1}, r_{t-1}, t) \]  \hspace{1cm} (3.20)

Where \( p_{t-1} \) is the copper price, \( ir_{t-1} \) is the risk-free annual interest rate in the previous period\(^{18} \), \( fdi_{t-1} \) is foreign direct investment in the previous period, \( pop_{t-1} \) is population in the previous period, \( r_t \) is reserves and \( t \) is a time trend that represents any improvement in productivity that is time-related. The causes of the increases in productivity can be for example, new managerial techniques, inclusion of new technology, etc. The \( fdi \) to \( pop \) ratio corresponds to the per capita foreign direct investment and represents the investment climate of a country. This variable which should include issues, like taxation, environmental regulations and country risk, might be represented adequately by the per capita foreign direct investment in the previous period \((fdi/pop)_{t-1}\).\(^{19} \) In addition, the amount of copper reserves \( r \) stands for the mineral potential of a country. This variable incorporates basically the firms’ perceptions of each country’s geology.

On the other hand, capacity should depend as well on the capital purchase price, depreciation method, interest rates and effective tax rates. However, due to the difficulty of their observations and the lack of data we have decided to include only the interest rate since it is more observable.

If a linear form of this function is applied, our equation would be:

\[ k_t^* = \beta_0 + \beta_1 p_{t-1} + \beta_2 ir_{t-1} + \beta_3 (fdi / pop)_{t-1} + \beta_4 r_t + \beta_5 t \]  \hspace{1cm} (3.21)

If we substitute (3.21) in (3.19) we obtain:

\[ k_t - k_{t-1} = \lambda(\beta_0 + \beta_1 p_{t-1} + \beta_2 ir_{t-1} + \beta_3 (fdi / pop)_{t-1} + \beta_4 r_t + \beta_5 t - k_{t-1}) \]  \hspace{1cm} (3.22)

Then,

\[ k_t - k_{t-1} = \lambda \beta_0 + \lambda \beta_1 p_{t-1} + \lambda \beta_2 ir_{t-1} + \lambda \beta_3 (fdi / pop)_{t-1} + \lambda \beta_4 r_t + \lambda \beta_5 t - \lambda k_{t-1} \]  \hspace{1cm} (3.23)

---

\(^{18}\) We are assuming that the risk-free interest rate of the United States is much correlated with the interest rate of the other producing countries. This assumption would imply that the risk premium of each country is very similar.

\(^{19}\) There are some sources of investment climate indicators data: the World Bank publication: “World Development Report 2005: A Better Investment Climate for Everyone” and the website World Bank’s Foreign Investment Advisory Service: [http://www.fias.net/investment_climate.html](http://www.fias.net/investment_climate.html)
If we express the equation in function of \( k_t \), then:

\[
k_t = \lambda \beta_0 + \lambda \beta_1 p_{t-1} + \lambda \beta_2 i_{t-1} + \lambda \beta_3 (fdi/\text{pop})_{t-1} + \lambda \beta_4 r_t + \lambda \beta_5 t + (1 - \lambda) k_{t-1}
\] (3.24)

And if we estimate the equation for each copper producer country \( i \), then:

\[
k_{i,t} = \alpha_0 + \alpha_1 (p_{i,t-1} / p_{i-1}) + \alpha_2 i_{i,t-1} + \alpha_3 (fdi/\text{pop})_{i,t-1} + \alpha_4 r_{i,t} + \alpha_5 t + \alpha_6 k_{i,t-1}
\] (3.25)

Where, \( er_{i,t} \) is the exchange rate of each country (national currency/US dollar) and \( pi_{i,t} \) is a price index as the GDP deflator of each country. The objective of these variables is to convert the nominal price into a real price in national currency.

Finally, total production capacity is expressed as:

\[
k_{tot,i} = \sum_{i=1}^{n} k_{i,t}
\] (3.26)

3.2.3. Demand

Again, in this section we attempt to propose an equation with a new specification to improve previous studies of the world copper industry.

3.2.3.1. Theory of Demand

Normally, we represent the preferences of consumers with the utility function \( u = u(x_1, x_2) \), where \( x_1 \) and \( x_2 \) are two different goods that a consumer can choose. The main objective of the consumer is to maximize his utility knowing that he has a constraint of income (budget). To solve this optimization problem, we can use differential calculus.

Thus:

\[
\max u(x_1, x_2) \text{, given that: } p_1 x_1 + p_2 x_2 = y
\]

Where \( p_1 \) is the unit price of good \( x_1 \), \( p_2 \) is the unit price of good \( x_2 \) and \( y \) is the income level of the consumer.

This problem can be solved using Lagrange multipliers. Thus, we define the auxiliary function called "Lagrangian".
\[ L = u(x_1, x_2) - \lambda(p_1x_1 + p_2x_2 - y) \quad (3.27) \]

where \( \lambda \) is known as the Lagrange multiplier. The Lagrange theorem says that for an optimal election \( (x_1^*, x_2^*) \) we have to satisfy the three conditions of first order.

\[
\begin{align*}
\frac{\partial L}{\partial x_1} &= \frac{\partial u(x_1^*, x_2^*)}{\partial x_1} - \lambda p_1 = 0 \\
\frac{\partial L}{\partial x_2} &= \frac{\partial u(x_1^*, x_2^*)}{\partial x_2} - \lambda p_2 = 0 \\
\frac{\partial L}{\partial \lambda} &= p_1x_1^* + p_2x_2^* - y = 0
\end{align*}
\quad (3.28)\]

Now, we have three equations with three unknown values. The goal is to obtain \( x_1 \) and \( x_2 \) in function of \( p_1, p_2 \) and \( y \). The Lagrange theorem is demonstrated in any advanced calculus book.

If we divide the first condition by the second condition, we have:

\[
\frac{\frac{\partial u(x_1^*, x_2^*)}{\partial x_1}}{\frac{\partial u(x_1^*, x_2^*)}{\partial x_2}} = \frac{p_1}{p_2} \quad (3.29)
\]

This result simply means that the ratio of marginal utilities of \( x_1 \) and \( x_2 \) must be equal to the ratio of their prices at the optimal point of maximization \( (x_1^*, x_2^*) \). This is the point where the slope of the indifference curves (different levels of utility) is equal to the slope of the income constraint (see figure 3.2). Naturally, the optimal point must as well satisfy the income constraint \( p_1x_1^* + p_2x_2^* = y \), so we have again 2 equations. From these equations we get the optimal values of \( x_1 \) and \( x_2 \) or the demand functions of \( x_1 \) and \( x_2 \).

\[
\begin{align*}
x_1 &= x_1(p_1, p_2, y) \\
x_2 &= x_2(p_1, p_2, y)
\end{align*}
\quad (3.30)
\]

The demand functions show the optimal amounts of each of the goods in function of prices and the income of the consumer. The demand of a normal good like copper is going to increase if its own price decreases; it increases if the other good's price increases; and it increases if income increases.
This explains why almost all the authors use these variables to explain the demand for copper.

Figure 3.2.
Optimal election of goods

\[ y = p_1 x_1 + p_2 x_2 \]

3.2.3.2. Definition of Demand Equations

We define our demand equations taking advantage of the theory of demand and the most relevant contributions of other authors.

It is commonly assumed that demand for metals (\( cons_i \)) depends on the metal’s own price (\( p_i \)), the price of a substitute (\( ps_i \)) and a measure of economic activity (\( y_i \)) such as the level of industrial production or the Gross Domestic Product (GDP). Because of the inelastic behavior of demand to changes in prices in the short run, one of the most used forms to explain the behavior of demand is the partial adjustment model. However, as Pei et al. (1999) explain, the partial adjustment model suffers from an important deficiency. It assumes that changes in prices and income affect demand more in the long run than in the short run. Certainly, this is correct for changes in prices but probable not for changes in
income that have a greater impact in the short run. Typically, when a country’s GDP or industrial production begins to grow, commodity consumption tends to increase immediately. As production of end use industries such as durable goods, transportation, construction, electricity, and so on expands, consumption of inputs like copper increases too.

This deficiency could be solved by using a model like this:

\[ cons_t = \beta_0 + \beta_1 p_t^* + \beta_2 px_t^* + \beta_3 y_t + \beta_4 t \]  

(3.31)

Where \( p_t^* \) (refined copper price) can be equal to \( 0.25p_t + 0.50p_{t-1} + 0.25p_{t-2} \) and \( px_t^* \) (price of the closest substitute, aluminum) can be equal to \( 0.25px_t + 0.50px_{t-1} + 0.25px_{t-2} \). This equation assumes that the total effect on demand of a change in the price of the metal occurs over three years. In addition, it assumes that 25% of the impact takes place in the period when the change in price occurs, 50% one period later, and 25% two periods later. However, this model might have some shortcomings such as the correct value of weights in the equations, and the number of lags that we should use to not cause mis-specification.

Another choice is to assume a certain number of lags for price, and allow the estimation of the model to pick up the weights. This has the disadvantage that if different period prices are correlated there is a serious possibility of collinearity.\(^{20}\) This was corroborated when we ran the demand equations and in all of them some coefficients of the lagged price variables got wrong signs.

Although, we know both approaches can have drawbacks, we have chosen the first one, since trying different pattern of weights (in next chapter we show in detail the patterns we try) can help us to determine which the best specifications for each country are and we get rid of problems of wrong signs.

In addition, we include a time trend to show the effect of technological changes and consumer preferences.

\(^{20}\) Vial (1989) assumes this approach.
If this equation is expressed for each of the most important consumer countries $i$ and the rest of the world:

$$cons_{i,t} = \beta_0 + \beta_1(p^*er / pi)_t^* + \beta_2(ps^*er / pi)_t^* + \beta_3y_{i,t} + \beta_4t$$ (3.32)

Where,

$$(p^*er / pi)_t^* = 0.25(p^*er / pi)_t + 0.50(p^*er / pi)_{t-1} + 0.25(p^*er / pi)_{t-2}$$ (3.33)

And,

$$(ps^*er / pi)_t^* = 0.25(ps^*er / pi)_t + 0.50(ps^*er / pi)_{t-1} + 0.25(ps^*er / pi)_{t-2}$$ (3.34)

The exchange rate $er_{i,t}$, and the price index $pi_{i,t}$ are included in the equation to express the price in constant terms and in the national currency. This shows in a more real way how much a consumer has to pay for one pound of copper.

Finally, total consumption is the sum of the demands of each country and the rest of the world:

$$constot_t = \sum_{i=1}^{n} cons_{i,t}$$ (3.35)

### 3.2.4. Price

There are various important issues that we have to discuss before specifying the price equation. First, we examine the theory that governs stock demand; second, we recall the relationship between stock demand and price; third, we analyze the importance of exchange rates in price determination; fourth, we explain the election of the partial adjustment model to characterize the behavior of copper price.

#### 3.2.4.1. Theory of Stock Demand

In this section we suggest an alternative model for the traditional stock demand theory based on the Rational Expectations Hypothesis that was explained previously in section 2.2.5.2. Our hypothesis is a more realistic treatment of how speculators make
transactions in the commodity markets. We also include an analysis of the transactions and precautionary demand for commodity stocks.

3.2.4.1.1. Speculators Demand for Stocks

An attempt is made to provide a hypothesis that explains in a more suitable way the behavior that motivates speculators to demand stocks of copper. It is necessary to say that we do not completely agree with the REH. We think that a stock demand function (equation 2.34) should not exclusively include the difference between the expected future price and the current price, because it is not the only way how speculators work. For commodities such as copper, that is a consumption asset rather than investment asset, the speculation argument needs to be reviewed carefully.\(^{21}\)

First of all, we explain how the speculators act in a market for investment assets like gold or silver. All that we need is to have a large number of investors holding the asset. Let us consider a future or forward contract on an investment asset of price \(p\) that provides no income, \(\tau\) is going to be the time of maturity, \(r\) is the risk-free interest rate, and \(f_0\) the future or forward price. \(f_0\) is related to \(p\) according to the following expression that assumes continuous compounding:

\[
f_0 = pe^{r\tau}
\]  \(\text{(3.36)}\)

This formula remains as an equality because if \(f_0 > pe^{r\tau}\), speculators will take advantage of the situation and will maintain the following strategy:

a) Borrow \(p\) dollars at an interest rate \(r\) for \(\tau\) months.

b) Buy on ounce of gold.

c) Short a forward contract on one ounce of gold.\(^{22}\)

\(^{21}\) The explanation of the hypothesis is based upon Hull (2000).

\(^{22}\) "A party with a short position on a forward contract has to sell the underlying asset at the maturity of the contract."
At time \( \tau \) one ounce of gold is sold for \( f_0 \) and an amount \( pe^{\tau} \) is paid to cancel the loan. Thus, the speculator makes a profit of \( f_0 - pe^{\tau} \).

Now, let us suppose that \( f_0 < pe^{\tau} \). In this situation, the speculators that hold an ounce of gold can:

a) Sell the gold for \( p \).

b) Invest the revenues at interest rate \( r \) for time \( \tau \).

c) Take a long position in a forward contract on one ounce of gold.\(^{23}\)

At time \( \tau \) the investment will be \( pe^{\tau} \). The gold can be repurchased for \( f_0 \) and the speculator will make a profit of \( pe^{\tau} - f_0 \).

As we said previously, for commodities this is a little different because they are storable goods. This means that we have to consider also the storage costs \( (u) \).

Let us suppose that we have:

\[
f_0 > (p+u)e^{\tau}
\]

(3.37)

The speculator will take advantage of this opportunity, undertaking the following strategy:

a) Borrow \( (p+u) \) at the risk-free rate and employ it to buy one unit of the commodity and to pay the storage costs.

b) Short a forward contract on one unit of the commodity.

With this strategy the speculator obtains a risk-free profit of \( f_0 - (p+u)e^{\tau} \) at time \( \tau \).

However, since there is a demand for the commodity and a supply of future contracts in the present, the price \( p \) will tend to increase and \( f_0 \) will tend to decrease. Thus, in the short run the equation (3.37) transforms into equality.

Let us suppose now that:

\[
f_0 < (p+u)e^{\tau}
\]

(3.38)

\(^{23}\) "A party with a long position on a forward contract has to buy the underlying asset at the maturity of the contract."
The speculator, again, will take advantage of this situation and will undertake the following strategy:

a) Sell the commodity and save the storage costs. Invest the revenues at the risk-free interest rate.

b) Long a future contract to buy in period $r$.

The strategy of the speculator leads to a risk-free profit of $(p+u)e^{r} - f_0$. However, because there is a supply of the commodity and a demand for future contracts in the present, the price $p$ will tend to decrease and $f_0$ will tend to increase. Again, in the short run the equation (3.38) transforms into equality.

This result is not that easy and obvious. This argument is not applicable to commodities that are mainly used for consumption and not for investment. Firms that have stocks for consumption objectives will be reluctant to have forward contracts, because they cannot be consumed. Therefore, equations (3.38) could persist or change into equality at any time. Thus, it can surely be affirmed that:

$$f_0 \leq (p+u)e^{r}$$  \hspace{1cm} (3.39)

The equality does not necessarily arise because firms that use a commodity for consumption think that there is a convenience for them to carry inventory. For example, a fabricator of copper wire will prefer to have a stock of copper to assure its production, rather than have a future contract of copper. This is independent of profit opportunities. This benefit from holding the inventory is known as the “convenience yield”. The convenience yield represents the consumers’ expectations about the availability of the commodity in the future. Thus, if there is a likelihood of high level of inventories in the market, the convenience yield will tend to be lower, and in contrast, if there is a possibility of inventories shortage, the convenience yield will tend to be higher. For investments assets the convenience yield will be zero, to eliminate the chances of arbitrage.
3.2.4.1.2. Transactions and Precautionary Demand for Stocks

Stock demand is compounded not only by speculative demand. We also need to add the transactions and precautionary demand for inventories. Transactions and precautionary demands can be divided into consumers, merchants and producers demand. Consumers and merchants demand for stocks are directly related to the level of total commodity consumption (constot). As an example, a company that sells copper wire will accumulate inventories depending on the level of sales it has, and in turn on its own amount of consumption to satisfy its customers.

On the other hand, producers demand for stocks is encouraged mainly when there is a desire to diminish production due to a large excess of supply (xs) that has a negative influence over prices. The purpose of this inventory accumulation is to try to decrease the excess of supply in the market and move the price upward.

As we mentioned before, speculative demand would depend on the spot price, the current future price at time of maturity \( \tau \) and the risk-free interest rate for the period of maturity. It will be assumed that storage costs are insignificant with respect to the total value of inventories that are stored. Speculators demand for stocks is a function of the difference \( f_0 - pe^\tau \). If the difference is positive, the strategy taken by the speculator will produce a demand for commodity inventories. Normally, this positive value will last a very short time until it comes back to equality. On the other hand, if that difference is negative the strategy taken by the speculator would lead to a supply of commodity inventories. Therefore, it is not necessary for speculators to have only an expected future price in mind; they can take a look at prices and interest rates to make transactions.

Therefore, the stock demand function \( (sd_i) \) can be specified in the following way:

\[
sd_i = s\left(\text{constot}_i, x_s, ep, (f_0 - pe^{\tau_i})\right)
\]

(3.41)
Where, \( ep_t \) is the expected price. This proposed formula seems more realistic than the equation 2.34 that was based on the REH, and represents in a better way how this market works.

It is important to state that we will not estimate a stock demand equation due to problems of data availability.

### 3.2.4.2. Relationship between Price and Stocks

Because one of our main objectives is to estimate a price equation to make forecasting and simulation easier, the stock level is normally expressed in terms of price, or price is an inverse function of the stocks level. This has been a common practice among authors of econometric models of storable commodities.

We prefer to use the variable lagged one period to show the level of inventories at the beginning of each period.

\[
p_t = p^{-1}(sd_{t-1})
\]

(3.42)

### 3.2.4.3. Relationship between Supply and Demand

The relationship between supply (\( tq_t \)) and demand (\( constot_t \)) has great importance in the determination of copper price. A change in the relationship between these two variables should have an immediate effect on price. For example, when supply of copper exceeds demand (oversupply) the price should tend to move downward, and when demand for copper is higher than supply (deficit) the price should tend to increase.

This matter necessitates including a variable that shows the impact of changes in the interaction between supply and demand. To illustrate this relationship we have two main ways. The first option might be to utilize the difference between these variables (\( tq_t - constot_t \)) that could stand for the addition of stocks (\( \Delta sd_t \)), and the second alternative might be to use a ratio between both variables such as \( tq_t / constot_t \) or \( constot_t / tq_t \). The
second option seems more reasonable to us since price is a function of $sd_{t-1}$ and the difference between supply and demand ($\Delta sd_t$) could be correlated with that variable producing collinearity. From the second alternative we have chosen $constot_{t}/tq_{t}$ for the price equation although in theory we could use any of these two ratios.

3.2.4.4. Importance of Exchange Rates

We think there are several reasons that justify the inclusion of the exchange rates effect over price. As we can see from figure 3.3, although imprecise because copper price is much more volatile, there exists a clear inverse relationship between copper price and the dollar strength against other currencies. It is likely that this inverse association comes mainly from two sources: a direct and indirect effect.

Figure 3.3
Relationship between copper price and dollar index

Traditionally, while some financial markets are moving up, others are moving down. A direct effect is produced when due to reigning economic conditions investors look to
move from one asset class to another. This relationship is extremely important in
economic cycles. When there is a recession, for example, in the case of the United States,
the weakness of the economy in the last years has encouraged the Federal Reserve to
decrease interest rates making dollars holding very unattractive. Maybe more important,
is the effect of the large trade deficit of the United States that has helped to maintain a
constant depreciation of the dollar against other currencies. This provokes a big
movement of flows from dollars to other assets, including commodities. This investment
switch can be particularly important in commodities like gold, but it might also be
significant for other commodities like copper and other non ferrous metals. To invest in
base metals it is no longer necessary to make physical transactions, given that
predominant operations are via future or forward contracts. This allows investors to
participate in commodity markets without having warehouses to keep big inventories, so
transactions are easier, encouraging the participation of more investors. Therefore, a
depreciation of the dollar produces an increase on the demand for other assets like
commodities. This in turn causes a rise in the price of them.

The indirect effect is given by the pressure of exchange rates over demand and supply
of copper. Because copper price is normally expressed in €US/Lb in the international
market, the exchange rate is going to have an impact on the demand and supply of
copper. Obviously, changes in demand or supply of copper produce consequences, in
turn, on prices. Let us see an example. In these past months, we have seen a big
depreciation of the US dollar against the Euro. When this occurs, European countries
increase the demand for copper given that for them a pound of copper is cheaper to buy
since they have to pay in euros. The growth of demand obviously provokes an increase in
the copper price offsetting the depreciation of the US dollar. The contrary occurs on the
supply side. For countries other than the United States, the depreciation of the dollar
makes much more unattractive the export of copper, because they receive lower revenues
in terms of their national currencies. However, this indirect effect has already been
accounted for by the equations of demand and supply where we have added exchange rates to convert copper price in dollars to countries' national currencies.

Consequently, we can justify the inclusion of a variable that shows the strength of the dollar against other currencies on the basis of the direct effect. This variable could be characterized by an index \((dollar\_index)\) that incorporates the relationship between the dollar and the major currencies. The Federal Reserve of the United States (2004) publishes monthly an index that includes these features. It is a weighted average of the foreign exchange values of the U.S. dollar against a set of currencies.\(^{24}\) We calculate it in a yearly basis as an average of the twelve months of a year. This index is published from 1973, so from 1971 to 1973, we estimate the missing values of the index with the variation of the G-10 index\(^{25}\) that reflects the value of the dollar against the currencies of the ten most important countries in terms of amount of trade.

Finally, the function of copper price could be incorporating the following variables:

\[
P_t = p^{-1}(sd_{t-1}, (\text{constot} / tq), \text{dollar\_index})
\]  
(3.43)

3.2.4.5. Partial Adjustment Model

As we explained in previous sections, supply and demand adjust slowly to changes in prices. This means that supply and demand vary in the short run but just partially and continue changing until they reach the desired magnitude (in the long run). For the desired values of supply and demand there exists also a long run price of copper that clears the market. This is also corroborated by Fisher et al. (1972). We think that the partial adjustment model might be a good way to characterize copper price behavior. Consequently, we assume that price only can adjust partially each year until it reaches the long run price. From year \(t-1\) to year \(t\) the adjustment of the price \((p_t - p_{t-1})\) is a fixed

\(^{24}\) For more detail see the article of Leady (1998)
\(^{25}\) Find it in http://www.federalreserve.gov/releases/H10/summary/indexgx_m.txt
proportion $\lambda$ of the difference between the desired price ($p_t^*$) and price during the preceding period ($p_{t-1}$). Therefore, we arrive to the following equation:

$$p_t - p_{t-1} = \lambda(p_t^* - p_{t-1})$$ (3.44)

In turn, the desired price ($p_t^*$) is going to be represented by the equation (3.43):

$$p_t^* = p(sd_{t-1}, (constot/tq)_t, dollar_index_t)$$ (3.45)

Therefore, the price equation is the following:

$$p_t = \beta_0 + \beta_1sd_{t-1} + \beta_2(constot/tq)_t + \beta_3dollar\_index_t + \beta_4p_{t-1}$$ (3.46)

### 3.2.5. Stock Supply

Only one more relationship remains to close the model. The definition of stock supply is extremely important for reaching this goal. Stock supply is going to be the remaining stocks in the previous period plus the change in inventories represented by the difference between total production and consumption in the current period. This is:

$$s_t = s_{t-1} + tq_t - constot_t$$ (3.47)

Normally, it is assumed that $s_t=sd_t$.

### 3.2.6. Complete Model

The complete model is a simultaneous system of the following ten equations:

$$k_{t,i} = \alpha_0 + \alpha_1(p_{t-1}*er_{t-1}/pi_{t-1}) + \alpha_2r_{t-1} + \alpha_3(fdii/pop)_{t-1} + \alpha_4q_{t,i} + \alpha_5t + \alpha_6k_{t-1,i}$$ (3.48)

$$k\_tot_t = \sum_{i=1}^{n} k_{t,i}$$ (3.49)

$$pq_{t,i} = \beta_0 + \beta_1(p_i*er_{i,t}/pi_{i,t}) + \beta_2k_{t,i} + \beta_3t$$ (3.50)

$$pq\_tot_t = \sum_{i=1}^{n} pq_{t,i}$$ (3.51)
\[ s_{q,t} = \beta_0 + \beta_1 s_{s,t} + \beta_2 (s_{q,s})_{t-1} + \beta_3 p_{t} \quad (3.52) \]
\[ t_{q,t} = p_{q,t} + s_{q,t} \quad (3.53) \]
\[ cons_{i,t} = \beta_0 + \beta_1 (p^* \text{er} / p_i)_{t}^* + \beta_2 (p^* \text{er} / p_i)_{t}^* + \beta_3 y_{i,t} + \beta_4 t \quad (3.54) \]
\[ constot = \sum_{i=1}^{n} cons_{i,t} \quad (3.55) \]
\[ p_{t} = \beta_0 + \beta_1 s_{d,t-1} + \beta_2 (constot / t_{q})_{t} + \beta_3 \text{dollar } \text{index}_{t} + \beta_4 p_{t-1} \quad (3.56) \]
\[ s_{t} = s_{t-1} + t_{q,t} - constot_{t} \quad (3.57) \]
\[ s_{t} = s_{d,t} \quad (3.58) \]

A summary with a description of the variables is provided in the following table:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k_{i,t} )</td>
<td>Per country capacity of copper production</td>
</tr>
<tr>
<td>( p_{t} )</td>
<td>LME price of grade A copper cathode</td>
</tr>
<tr>
<td>( er_{i,t} )</td>
<td>Per country exchange rate</td>
</tr>
<tr>
<td>( p_{i,t} )</td>
<td>Per country price index</td>
</tr>
<tr>
<td>( i_{r,t} )</td>
<td>Annual risk-free interest rate of US Treasury Bonds</td>
</tr>
<tr>
<td>( fdi_{i,t} )</td>
<td>Per country foreign direct investment</td>
</tr>
<tr>
<td>( pop_{i,t} )</td>
<td>Per country population</td>
</tr>
<tr>
<td>( r_{i,t} )</td>
<td>Per country copper reserves</td>
</tr>
<tr>
<td>( t )</td>
<td>Time trend</td>
</tr>
<tr>
<td>( k_{tot} )</td>
<td>Total capacity of production</td>
</tr>
<tr>
<td>( p_{q,t} )</td>
<td>Per country primary copper production</td>
</tr>
<tr>
<td>( p_{q,t} )</td>
<td>Total primary copper production</td>
</tr>
<tr>
<td>( s_{q,t} )</td>
<td>Secondary production or copper supply from scrap</td>
</tr>
<tr>
<td>( s_{s,t} )</td>
<td>Available stocks of old copper scrap</td>
</tr>
<tr>
<td>( t_{q,t} )</td>
<td>Total supply of copper</td>
</tr>
<tr>
<td>( cons_{i,t} )</td>
<td>Per country consumption of refined copper</td>
</tr>
<tr>
<td>( p_{s,t} )</td>
<td>LME price of higher grade aluminum</td>
</tr>
<tr>
<td>( y_{i,t} )</td>
<td>Per country index of economic activity</td>
</tr>
<tr>
<td>( constot_{t} )</td>
<td>Total refined copper consumption</td>
</tr>
<tr>
<td>( dollar_{index}_{t} )</td>
<td>Index that shows the strength of the dollar against other world currencies</td>
</tr>
<tr>
<td>( sd_{t} )</td>
<td>Total stocks demand at the end of the period</td>
</tr>
<tr>
<td>( s_{t} )</td>
<td>Total stocks supply (stock level)</td>
</tr>
</tbody>
</table>

Note: See appendix A for a full list of variables with a description of their units and their sources.
CHAPTER 4

ESTIMATION OF THE EQUATIONS

In this chapter we present a description of the methodology utilized for the estimation of the econometric model of the world copper industry, and then, we analyze the results obtained for the equations with the methodology previously explained.

4.1. Methodology for the Estimation

The approach used to estimate the model is the Ordinary Least Squares (OLS) method for the single equations and the Three Stages Least Squares (3SLS) method for the simultaneous equations. There are several variables such as demand, primary supply, secondary supply and price that are all jointly or simultaneously determined. This means that we have to treat these variables as a system of simultaneous equations rather than single equations.

What is the problem if we estimate this simultaneous equations system with the OLS method used to estimate single equations? According to Studenmund (2001), it can cause several troubles. To have the best linear unbiased estimator (BLUE) we need to satisfy the assumption that all explanatory variables must be uncorrelated with the error term. Unfortunately, this assumption is violated when we estimate simultaneous equations systems with the OLS method, and as a result bias is produced in the coefficients estimates. This in turn, causes inaccurate t-statistics that we cannot rely upon for testing objectives. To face this problem we can use the Two Stages Least Squares (2SLS) or the Three Stages Least Squares (3SLS) methods. The 3SLS method is the 2SLS method but it also includes a third stage called the Seemingly Unrelated Regression (SUR)
technique.\textsuperscript{26} If the disturbances of each equation are uncorrelated, that is, there is no relationship among equations, the technique of 2SLS is efficient, however, if the contrary occurs, asymptotically efficient estimates can be obtained with 3SLS. If the errors in different structural equations are uncorrelated, the 3SLS method would be the same as the 2SLS method.

We have chosen to use the 3SLS method to correct for a possible lack of efficiency due to correlation among the errors of different equations. However, we have to be very careful when there are errors of specification in the structure of the model, because they can be propagated throughout the system.

On the other hand, one of the most common problems in time-series estimation is serial correlation. The software Eviews solves this problem applying Generalized Least Squares (GLS). Eviews transforms a linear model into a non-linear model. For example, if we have a linear AR(1) model:

\begin{align*}
    y_t &= x_t \beta + u_t \\
    u_t &= \rho u_{t-1} + \varepsilon_t 
\end{align*}

(4.1)

is converted to the following non-linear model:

\begin{align*}
    y_t &= \rho y_{t-1} + (x_t - \rho x_{t-1}) \beta + \varepsilon_t 
\end{align*}

(4.2)

Normally, the GLS equations are not easy to estimate. Let us notice that we need to estimate the $\beta$s and $\rho$s, and since this is not a linear model we cannot use OLS for the estimation. According to Studenmund (2001), the most common approaches to estimate GLS equations are the Cochrane-Orcutt and the AR(1) method. Eviews uses the AR(1) technique that is solved by an optimization algorithm called Marquardt procedure to obtain the solutions for the $\beta$s and $\rho$s simultaneously. This technique has the advantage of being applicable to models containing endogenous right-hand side models, or models that

\textsuperscript{26} According to Pindyck et al. (1998), the SUR method consists of a series of equations that have a very close theoretical relationship and the error terms across these equations are correlated. If the errors were correlated, we would not obtain efficient estimates with the 2SLS method. However, estimating the system of equations with the SUR technique we could improve the efficiency.
have high orders of correlation among errors. This approach also has the advantage of being applicable to nonlinear equations. The GLS estimates are asymptotically efficient.

On the other hand, we wanted to know what form to use for expressing the equations in the best possible way. After applying a Box-Cox test to the equations we realized that the log-linear form was the best characterization for some of the countries and the linear form was the best for others. Hence, there was not unanimity. At the beginning, we tried the log-linear form for all the primary supply and demand equations. But finally, we chose linear equations for three main reasons. First, when we utilized the log-linear form for the simultaneous equations and we ran them with the 3SLS method, at least five out of the twenty equations got wrong signs for the price variables. When we did the same with the linear form, we only obtained wrong signs in two equations out of the twenty. This is a very important issue given that if there is an incorrect sign in the price variable we have to eliminate it and the equation would not be determined simultaneously anymore. Second, when we were making the stochastic forecasting with the equations in log-linear form, we found many problems when some variables became negative. Consequently, some logarithms were undetermined. Third, another complication appeared for the capacity equations (that are not in the simultaneous equation system), when we tried the linear and log-linear forms. The log-linear form was impossible to apply because for some countries in some periods the variable \((f/di/pop)_{h,1}\) was negative. So when we applied logarithms to these negative values the result was undetermined.

Therefore, our final decision was to utilize the linear form for all the equations. We think that this is likely not a big issue since all the variables that explain the behavior of the dependent variables remain in the equations. Although, one disadvantage of the linear form against the log-linear form could be the fact that elasticities are no longer constant.

Now, since all the equations are in linear form, the coefficients that we estimate show the absolute effects of an increase in one unit of any of the explanatory variables. That is, the coefficients show the slopes or the derivative of the dependent variable with respect to any of the independent variables.
Almost the majority of the variables in the equations present some degree of non-stationarity.\textsuperscript{27} This can cause spurious correlation that inflates $R^2$ and the t-statistics of the non-stationary variable. There are two major solutions: The first alternative to eliminate the non-stationarity is to take the first difference and use it instead of the original variable. The stationarity of these new variables can also be examined with the Phillip-Perron Test. According to Studenmund (2001)\textsuperscript{28}, this has some disadvantages. It can produce changes in the theoretical meanings of the variables and can eliminate information about the long-run trend in the variables. Consequently, this approach should not be used without taking into account the problems and benefits of the change. First differencing moreover can remove the variation in the data and variables can become insignificant.

The second option is to utilize cointegration instead of using first differences. This approach consists of canceling out the degree of non-stationarity of the variables in an equation to make the residuals of the equation stationary and to get rid of the spurious correlation. To determine if the non-stationarity of the variables in the equations is cointegrated, we can analyze the residuals of the equation with the Phillip-Perron test. If the residuals are stationary the first difference is not necessary.

The results of the Phillip-Perron test for examining cointegration (appendix G) suggest that all the residuals (except Indonesia) are stationary and therefore, the equations to which they belong would be cointegrated at a 95\% level of confidence.

It is also crucial to state that we are assuming that there are not big structural changes during the sample period. Therefore, we suppose the coefficients accompanying the explanatory variables are constant.

As well, there are several other important points that are necessary to clarify before discussing the results:

\textsuperscript{27} It was determined applying the Phillip-Perron test (results in appendix F).
\textsuperscript{28} Details can be found on page 427.
First, we include the explanatory variables that are not significant but have the correct signs. Second, in the few cases where we obtained wrong signs for the coefficients, contradicting economic theory or logic, we have not included them.

Finally, the t-statistic for each coefficient is presented in parenthesis below the estimated equations to show the significance of each variable included in the model.

4.2. Results of the Estimation

In this section we show and analyze the results of the production capacity, primary supply, secondary supply, demand and price equations estimations.

4.2.1. Primary Supply Equations

In this section we display the results of the primary supply equations that were estimated for Australia, Canada, Chile, Indonesia, Peru, United States and the rest of the world. We ran the equations for all the countries and the rest of the world with the original specification defined in the section 3.2.1.2. That is:

\[
pq_{i,t} = \beta_0 + \beta_1 \left( p_{i,t} \right) + \beta_2 k_{i,t} + \beta_3 t
\]  

(4.3)

Then, we removed any variables having coefficients with wrong signs and re-estimated the equations.

According to this, the estimated equations are:

Australia (1971-1998):

\[
pqaus_{i} = -50.34 + 1.04 kaus_{i} + 0.99t
\]

\[
(-2.82) (12.24) (0.81)
\]  

(4.4)

\[
R^2 = 0.978 \quad \rho 1 = 0.37
\]

\[
(1.97)
\]
Canada (1971-1998):

\[ pqcan_i = 340.93 + 0.43kcan_i + 2.52t - 44.62d1can_i \]

\[ (1.92) \quad (2.50) \quad (0.84) \quad (-1.00) \]

\[ R^2 = 0.489 \quad \rho 1 = 0.46 \quad \rho 2 = 0.28 \]

\[ d1can_i \text{is 1 for a strike in 1978 and 1979 and 0 otherwise.} \]

Chile (1971-1998):

\[ pqchi_i = -81.21 + 0.97kchi_i + 7.07t \]

\[ (-3.29) \quad (32.06) \quad (2.53) \]

\[ R^2 = 0.996 \quad DW = 1.47 \]

Indonesia (1971-1998):

\[ pqind_i = -17.19 + 0.001pind_i + 1.00kind_i + 0.40t \]

\[ (-3.25) \quad (1.63) \quad (91.48) \quad (1.22) \]

\[ R^2 = 0.999 \quad \rho 1 = 0.81 \quad \rho 2 = -0.35 \]

\[ Instruments: \; kind_i, \; pind_{i-1}, \; t, \; (erind/piind), \; dollar\_index, \; irb, \; (sd/constot)_{i-1}, \; (constot/tg)_{i-1} \]

Where

\[ pind = p*erind / piind \]

\[ pind_i \text{is the annual average LME price of grade A copper cathode in Indonesian currency and real terms.} \]

\[ \rho 1 \text{ and } \rho 2 \text{ are the first and second order correlation coefficients of the errors, respectively.} \]

\[ \text{Figures in parenthesis are the t-statistics.} \]
Peru (1971-1998):

\[ pper_i = -81.49 + 11.08 pper_i + 0.57 kper_i + 9.54t - 48.01d1per_i \]

\[ (-1.27) \quad (1.77) \quad (6.45) \quad (4.45) \quad (-2.36) \]

\[ R^2 = 0.883 \quad DW=1.59 \]

Instruments: \( kper_i, d1per_i, p_{t-1}, (eper/piper)_i, dollar\_index_i, ir_i, (sd/constot)_{t-1}, (constot/tq)_{t-1} \)

Where

\( pper = p \times erper / piper \)

\( pper_i \) is the annual average LME price of grade A copper cathode in Peruvian currency and real terms; \( d1per_i \) is 1 for the economic crisis in period 1988-1990 and 0 otherwise.

United States (1971-1998):

\[ ppus_i = -373.73 + 322.78 pus\_1 + 0.62 kus_i + 25.25t - 367.87 d2us_i - 182.09 d3us_i \]

\[ (-1.59) \quad (5.55) \quad (4.88) \quad (7.39) \quad (-7.14) \quad (-3.83) \]

\[ R^2 = 0.901 \quad \rho = 0.35 \]

\[ (2.55) \]

Instruments: \( kus_i, d1us_i, d2us_i, d3us_i, (p/pius)_{t-1}, ir_i, dollar\_index_i, (constot/tq)_{t-1}, 1/ppius_i, (sd/constot)_{t-1} \)

Where

\( pus\_1 = p / pius \)

\( pus\_1 \) is the annual average LME price of grade A copper cathode in US dollars and real terms; \( d1us_i \) is 1 for the strikes in 1975 and 0 otherwise; \( d2us_i \) is 1 for the strikes in 1979 and 1989 and 0 otherwise; \( d3us_i \) is 1 for the strikes in the period 1982-1984 and 0 otherwise.

\[ pqrw_i = 2618.91 + 98.03 prw_{-1} + 0.26 kw_i + 11.97 t \]

\[ (6.75) \quad (1.85) \quad (4.21) \quad (1.64) \]

\[ R^2 = 0.893 \quad \rho_1 = 0.86 \quad \rho_4 = -0.24 \]

\[ (8.70) \quad (-2.54) \]

Instruments: \( kw_i, ppiu, i, dollar\_index, ir, (sd/constot)_{t-1}, (constot/tq)_{t-1}, yspa, eraus \)
Where

\( prw_{-1} = p / pius \)

\( prw_{-1} \) is the annual average LME price of grade A copper cathode in US dollars and real terms. \( \rho_1 \) and \( \rho_4 \) are the first and fourth order correlation coefficients of the errors, respectively. Figures in parenthesis are the t-statistics.

With the exception of Canada, the equations show a very good fit that varies from 88.3% for Peru to 99.9% for Indonesia.

One common factor for all the equations is the huge importance of the production capacity variable. This shows that production capacity is the main determinant of primary supply for all the countries. As well, the price variable is significant for Peru, United States and the rest of the world, and it could be also important for Indonesia given that the t-statistics are very close to two. The exceptions are Australia, Canada and Chile which have incorrect signs. Overall, it seems that production capacity is more important than prices. This is not very surprising since in the short run it is not that easy to adjust production to changes in prices once output approaches full capacity. Normally, to justify a modification of the production plan a price change has to remain for a longer period of time.

The coefficients of the capacity variables for Australia, Chile and Indonesia are very close to one confirming that the capacity utilization has been around 100%.
Finally, the inclusion of dummy variables representing different strikes that occurred in the United States in the years 1979-1980 and 1982-1983, and in Peru for the big economic crisis at the end of the 1980s, is clearly justified by the t-statistics. Nevertheless, for Canada, it seems that the strike that occurred in the period 1978-1979, was not very important. Unfortunately, the results do not explain very well the upward and downward movements that Canadian copper production has taken in the sample period.

4.2.2. Secondary Supply Equation

In the case of the secondary supply equation, we obtained very good results. The variables included in the equation explained 88.6% of the dependent variable, and almost all the variables were significant and with correct signs.

World secondary supply (1971-1998)

\[
sq_t = 999.76 + 265.48 \, p_t + 0.009 \, ss_t - 3237.44 \, (sq/ ss)_{t-1}
\]

(4.23) (2.97) (2.57) (-1.28)

\[
R^2 = 0.886 \quad \rho_1 = 0.53
\]

(3.60)

Instruments: \( ss_t, (sq/ ss)_{t-1}, p_{t-1}, (sd/constot)_{t-1}, dollar\_index_t, ir_t, t, (constot/tq)_{t-1} \)

According to the figures, the most significant determinant of secondary supply is the copper price \( p_t \), which affects positively the production of copper from scrap. The availability of scrap \( ss_t \) also influences the secondary production of copper notably. Consequently, increases in these two variables generate a growth in the production of secondary supply. In contrast, if the difficulty of collection \( ((sq/ ss)_{t-1}) \) becomes more intense, secondary supply will tend to diminish.
4.2.3. Capacity Equations

In this section we present the results of the estimates of the capacity equations for Australia, Canada, Chile, Indonesia, Peru, United States and the rest of the world using the sample period 1971-1998.

There are three important points that we need to mention before showing the equations. First, the variable \((fdi/pop)_{t-1}\) representing the investment climate of a country was only evaluated for the equations of the three developing countries, Chile, Indonesia and Peru, since the other three countries, the United States, Canada and Australia are developed countries and we are assuming they do not have a very high level of political risk to discourage investment in mining, although we recognize that environmental constraints can affect negatively investment.

Second, to represent geological potential we tried different variables, but we did not get good results for all the countries. Thus, we finally decided to use the countries current reserves \((r_t)\) for Chile and Canada, and a one period lag of the same variable \((r_{t-1})\) for Indonesia, Peru, United States and the rest of the world. This assumption gave us better results.

Third, we ran the equations for all the countries and the rest of the world with the original specification defined in the section 3.2.2. That is:

\[
k_{it} = \alpha_0 + \alpha_1 (p_{t-1} \ast r_{t-1} / p_{t-1}) + \alpha_2 r_{t-1} + \alpha_3 (fdi/pop)_{t-1} + \alpha_4 r_{t-1} + \alpha_5 t + \alpha_6 k_{i,t-1} \quad (4.12)
\]

Nevertheless, we removed the variables having coefficients with wrong signs (that do not comply logic) and re-estimated the equations.

According to this, the estimated equations are:
Australia (1971-1998):

\[ k_{aus} = -53.56 - 2.12t_{r_{-1}} + 3215.27(p^{*} eraus/picaus)_{t_{-1}} + 0.92k_{aus}_{t_{-1}} + 3.16t \]

\[ (-1.29) \quad (-1.82) \quad (2.00) \quad (9.77) \quad (1.50) \]  

\( R^2 = 0.933 \) 

Canada (1971-1998):

\[ k_{can} = 172.31 - 8.58t_{r_{-1}} + 0.80k_{can}_{t_{-1}} + 0.002r_{can} \]

\[ (2.17) \quad (-1.41) \quad (6.58) \quad (0.75) \]  

\( R^2 = 0.665 \) 

Chile (1971-1998):

\[ k_{chi} = 216.68 - 10.48t_{r_{-1}} + 0.003r_{chi} + 0.62k_{chi}_{t_{-1}} + 2.36 \left( \frac{f_{ichi}}{popchi} \right)_{t_{-1}} + 6.12t \]

\[ (1.04) \quad (-2.57) \quad (1.11) \quad (2.25) \quad (1.91) \quad (0.59) \]  

\( R^2 = 0.985 \) 

Indonesia (1971-1998):

\[ \Delta k_{ind} = -23.74 - 0.97t_{r_{-1}} + 0.005t_{ind} + 0.22((p^{*} erind)/piind)_{t_{-1}} + 1.92t \]

\[ (-1.39) \quad (-1.02) \quad (1.73) \quad (2.48) \quad (2.54) \]  

\( R^2 = 0.521 \)

\( \Delta k_{ind} \) is the change in capacity from one period to another. It was used for reasons explained below.
Peru (1971-1998):

\[ k_{\text{per}_t} = 7.20 + 0.67k_{\text{per}_{t-1}} + 0.0044r_{\text{per}_{t-1}} + 0.60 \left( \frac{fdiper}{popper} \right)_{t-1} - 46.64d_{\text{per}_t} + 0.18t \]

\begin{align*}
(0.24) & 	(7.22) &  (2.60) &  (2.85) &  (-2.73) &  (0.28) \\
\end{align*}

\[ R^2 = 0.880 \]

United States (1971-1998):

\[ k_{us_t} = -346.43 - 18.32r_{t-1} + 9123.66(\frac{p}{pius})_{t-1} + 0.68k_{us_{t-1}} + 0.010r_{us_{t-1}} + 2.41t \]

\begin{align*}
(-1.09) &  (-2.25) &  (2.02) &  (6.54) &  (2.25) &  (1.15) \\
\end{align*}

\[ R^2 = 0.782 \]


\[ k_{rw_t} = -242.37 + 27682.30(\frac{p}{pirw})_{t-1} + 0.97k_{rw_{t-1}} \]

\begin{align*}
(-0.80) &  (4.32) &  (16.71) \\
\end{align*}

\[ R^2 = 0.908 \]

The partial adjustment model was applied to all the equations except Indonesia. After doing the Augmented Dickey-Fuller test we realized that the variables had serious problems of non-stationarity (appendix G), and moreover the equation was also not cointegrated. This caused that the speed of adjustment had no economic sense given that the variable \( k_{\text{ind}_{t-1}} \) had a coefficient greater than 1. To face this difficulty we ran the regression as the first difference of the capacity production, although we are losing some of the theoretical meaning of the production capacity variable.
On the other hand, all the equations exhibited some level of heteroskedasticity that was not fixed because it is almost impossible to know what the source of it is\textsuperscript{29}. This problem can produce a loss of efficiency for the OLS estimates and a misestimate of the coefficient standard errors. However, we can obtain consistent estimates of the standard errors and t-statistics without changing the estimates of the coefficients. This is made with the heteroskedasticity-consistent standard errors and covariance method, introduced by White (1980).

The results show that the production capacity equations for Chile, Australia and the rest of the world behave very well, having determination coefficients ($R^2$) greater than 90%. Peru also performs well and has a little lower $R^2$ of 88%. For the United States the $R^2$ explains approximately 78% of the production capacity variable. Canada and Indonesia have the worst performance showing fits of almost 67% and 51%, respectively. However, the $R^2$ for Indonesia shows how much of the variation in $\Delta \text{kind}_t$ is explained by the explanatory variables, so a lower $R^2$ is not surprising.

If we examine the equations in detail, we can see that the variable $K_{t-1}$ has the correct sign and it is significant for all the countries. The price variable ($(p_{t-1}^* e_{t-1}^* )/p_{i,t-1}^*$) is significant for Australia, Indonesia, United States and the rest of the world, and it is not included in the equations of Chile, Peru and Canada since it has the wrong sign and is not significant. The interest rate variable ($i_{t-1}$) is included in all the equations but Peru and the rest of the world and it is significant only for Chile and the United States, but it is very important for Australia as well. The variable representing geological potential ($r_t$ and $r_{t-1}$) was not utilized in the equation of Australia because of its incorrect sign, and was significant only for the United States, although, we think that it could be also considered important for Indonesia and Peru since the t-statistics are close to two. If we examine the investment climate variable ($((fdi/pop),_{t-1}$) we could conclude that it is one of the most important determinants that explain the huge growth in capacity production for

\textsuperscript{29}The White test was used to determine if the equations had heteroskedasticity.
Chile and Peru. Something totally different occurs with Indonesia where this growth occurs more because of its geological potential. Finally, if we look at the time trend, it should be positive for all the countries as increases in productivity have produced a decrease in costs over time and this, in turn, has generated an increase in capacity of production. Advance in productivity should be relatively similar in all the countries given that productivity improvements spread very quickly. Obviously, this is going to depend in some extent on the specific features of a mine (ore type, grade, etc.). This variable works very well for all the countries but Canada and the rest of the world. In addition, we include a dummy variable in the equation of Peru to represent the huge economic crisis that affected production capacity heavily at the end of the 1980s.

On the other hand, the adjustment coefficient \( \lambda \) for the capacity equations varies from 0.03 for the rest of the world to 0.38 for Chile. This means that the change in production capacity between any two periods \((t \text{ and } t-1)\) will be in the range of 3% to 38% of the difference between the production capacity in the long-run and the production capacity of the previous period \(t-1\). Obviously, the greater the adjustment coefficient the faster is the speed of adjustment.

4.2.4. Demand Equations

In this section we present the results of the estimates of the demand equations for China, United States, Germany, France, Italy, Spain, Japan, South Korea, Taiwan, Mexico and the rest of the world. We ran the equations for all the main consumer countries and the rest of the world with the original specification defined in the section 3.2.3.2. That is:

\[
\text{cons}_{i,t} = \beta_0 + \beta_1 (p \ast er / pi)^\ast_t + \beta_2 (ps \ast er / pi)^\ast_t + \beta_3 y_{i,t} + \beta_4 t
\]  

(4.20)

Again, we removed the variables having coefficients with wrong signs and re-estimated the equations.
We also tried to include the price of aluminum in the equations, because we thought that this was the main substitute of copper. However, the result was not satisfactory because there were some problems with the signs of the coefficients accompanying the aluminum price. Thus, we obtained negative signs for more than half of the equations, being contrary to the logic that indicates they should be positive. This difficulty could suggest that aluminum maybe is not the most important substitute of copper or there exist other substitutes of copper such as plastic in construction (e.g. tubing) and optic fiber in telecommunications that we are not considering and that could be significant too. Another argument could be that aluminum price simply does not affect consumption of copper in the short term, and it might be a determinant in the long run where substitution has a more important role.

On the other hand, one of the major contributions of this econometric model is the inclusion of formulas of price adjustments different from the classical partial adjustment model, which improves the copper demand models made so far. Six different lag structures were tried for each of the demand equations:

1. \[ p_t^* = 0.25*p_t + 0.25*p_{t-1} + 0.5*p_{t-2}; \]  
2. \[ p_t^* = 0.25*p_t + 0.5*p_{t-1} + 0.25*p_{t-2}; \]  
3. \[ p_t^* = 0.5*p_t + 0.25*p_{t-1} + 0.25*p_{t-2}; \]  
4. \[ p_t^* = 0.33*p_t + 0.33*p_{t-1} + 0.33*p_{t-2}; \]  
5. \[ p_t^* = 0.2*p_t + 0.3*p_{t-1} + 0.3*p_{t-2} + 0.2*p_{t-3}; \]  
6. \[ p_t^* = 0.1*p_t + 0.2*p_{t-1} + 0.4*p_{t-2} + 0.2*p_{t-3} + 0.1*p_{t-4}; \]

To define the best lag structure, we ran the equation for each country and compared the coefficient of determination (R^2) of each of the regressions. Finally, we chose the lag structure that provides the largest R^2 to the country's demand equation. All the equations showed the best results when we included lag structures of three periods. This suggests
that all or almost all of the effect on demand of a change in copper price occurs within three years.

Thus, the estimated equations are the following:

China (1978-1991):

\[ \text{conschn}_t = 120.31 - 11.31 \text{pchn}_t + 10.54 \text{ychn}_t \]
\[ (2.20) \quad (1.30) \quad (16.29) \]
\[ R^2 = 0.948 \quad DW = 1.65 \]

Instruments: \text{ychn}_b, \text{t}, \text{pichn}_b, \text{dollar} \_\text{index}_b, (sd/\text{constot})_b, \text{pchn}_{t-1}

Where

\[ \text{pchn}_t = 0.25 \left( \left( \frac{p_t \times \text{erchn}_t}{\text{pchn}_t} \right) + 0.25 \left( \left( \frac{p_{t-1} \times \text{erchn}_{t-1}}{\text{pchn}_{t-1}} \right) + 0.5 \left( \left( \frac{p_{t-2} \times \text{erchn}_{t-2}}{\text{pchn}_{t-2}} \right) \right) \right) \]

\text{pchn}_t \] is a weighted average of the annual average LME price of grade A copper cathode in Chinese currency and real terms.


\[ \text{consfra}_t = -105.02 + 5.41 \text{yfra}_t + 2.49t \]
\[ (-0.66) \quad (2.79) \quad (0.80) \]

\[ R^2 = 0.882 \quad \rho_1 = 0.75 \]
\[ (5.68) \]

Germany (1971-1998):

\[ \text{consger}_t = -319.73 - 30.79 \text{pger}_t + 14.24 \text{yger}_t - 2.62t \]
\[ (-1.43) \quad (-0.94) \quad (6.23) \quad (0.57) \]

\[ R^2 = 0.906 \quad \rho_1 = 0.58 \]
\[ (4.27) \]
Instruments: $yger_t$, $t$, $pger_{t-1}$, $\frac{\text{erger/piger}}{\text{b}}$, $\text{dollar\_index}_b$, $\text{ir}_b$, $(\text{sd/constot})_{t-1}$, $(\text{constot/tq})_{t-1}$

Where

$$pger_t = 0.25\left(\frac{p_t \cdot \text{erger}_t}{\text{piger}}\right) + 0.25\left(\frac{p_{t-1} \cdot \text{erger}_{t-1}}{\text{piger}_{t-1}}\right) + 0.5\left(\frac{p_{t-2} \cdot \text{erger}_{t-2}}{\text{piger}_{t-2}}\right)$$

$pger_t$ is a weighted average of the annual average LME price of grade A copper cathode in German currency and real terms.

Italy (1971-1998):

$$\text{consita}_t = -55.72 - 0.01pita_t + 5.26\text{vita}_t + 3.63t$$

$$(-0.80) (-1.76) \quad (6.01) \quad (1.17)$$

$R^2 = 0.971 \quad \rho_1 = 0.79$ \hspace{1cm} (4.30)

Instruments: $yita_t$, $t$, $p_{t-1}$, $\frac{\text{erita/piita}}{\text{b}}$, $\text{dollar\_index}_b$, $(\text{sd/constot})_{t-1}$

Where

$$pita_t = 0.5\left(\frac{p_t \cdot \text{erita}_t}{\text{piita}}\right) + 0.25\left(\frac{p_{t-1} \cdot \text{erita}_{t-1}}{\text{piita}_{t-1}}\right) + 0.25\left(\frac{p_{t-2} \cdot \text{erita}_{t-2}}{\text{piita}_{t-2}}\right)$$

$pita_t$ is a weighted average of the annual average LME price of grade A copper cathode in Italian currency and real terms.


$$\text{consjap}_t = 583.94 - 1.21pjap_t + 17.91yjap_t - 35.12t$$

$$\quad (3.13) \quad (-3.01) \quad (7.83) \quad (-4.96)$$

$R^2 = 0.862 \quad \rho_1 = 0.32$ \hspace{1cm} (4.31)

Instruments: $yjap_t$, $t$, $pjap_{t-1}$, $\frac{\text{erjap/pijap}}{\text{b}}$, $\text{dollar\_index}_b$, $\text{ir}_b$, $(\text{sd/constot})_{t-1}$

Where
\[ p_{ijap_t} = 0.25 \left( \frac{(p_t \cdot erjap_t)}{pijap_t} \right) + 0.5 \left( \frac{(p_{t-1} \cdot erjap_{t-1})}{pijap_{t-1}} \right) + 0.25 \left( \frac{(p_{t-2} \cdot erjap_{t-2})}{pijap_{t-2}} \right) \]

\( pijap_t \) is a weighted average of the annual average LME price of grade A copper cathode in Japanese currency and real terms.

Mexico (1971-1998):

\[ consmex_t = -261.88 - 2.69 \, pmex_t + 4.05 \, ymex_t + 3.40 \, t \]

\( (-1.19) \quad (-1.17) \quad (4.76) \quad (0.37) \)

\[ R^2 = 0.908 \quad \rho l = 0.86 \]

(7.31)

**Instruments:** \( ymex_t, t, pmex_{t-1}, (ermex/pimex)_t, dollar_index_t, ir_t, (sd/constot)_{t-1} \)

Where

\[ pmex_t = 0.25 \left( \frac{(p_t \cdot ermex_t)}{pimex_t} \right) + 0.25 \left( \frac{(p_{t-1} \cdot ermex_{t-1})}{pimex_{t-1}} \right) + 0.5 \left( \frac{(p_{t-2} \cdot ermex_{t-2})}{pimex_{t-2}} \right) \]

\( pmex_t \) is a weighted average of the annual average LME price of grade A copper cathode in Mexican currency and real terms.

South Korea (1971-1998):

\[ conskor_t = 39.24 - 0.03 \, pkor_t + 5.64 \, ykor_t - 1.83 \, t \]

\( (0.55) \quad (-1.94) \quad (6.08) \quad (-0.34) \)

\[ R^2 = 0.989 \quad \rho l = 0.79 \]

(7.18)

**Instruments:** \( ykor_t, t, pkor_{t-1}, (erkor/pikor)_t, dollar_index_t, (sd/constot)_{t-1}, ir_t \)

Where

\[ pkor_t = 0.5 \left( \frac{(p_t \cdot erkor_t)}{pikor_t} \right) + 0.25 \left( \frac{(p_{t-1} \cdot erkor_{t-1})}{pikor_{t-1}} \right) + 0.25 \left( \frac{(p_{t-2} \cdot erkor_{t-2})}{pikor_{t-2}} \right) \]

\( pkor_t \) is a weighted average of the annual average LME price of grade A copper cathode in South Korean currency and real terms.
Spain (1971-1998):

\[ consspa_t = -584.81 - 0.12 pspa_t + 1.86 yspa_t + 15.51 t \]

\[ (-1.00) \quad (-4.61) \quad (7.70) \quad (1.48) \]

\( R^2 = 0.944 \quad \rho 3 = 0.62 \)

\( (11.93) \)

**Instruments:** \( yspa_b, t, pspa_{t-1}, ir_b \) \((sd/constot)_{t-1}\)

Where

\[ pspa_t = 0.25 \times \left( \left( p_t \times erspa_t / pspa_t \right) + 0.25 \times \left( \left( p_{t-1} \times erspa_{t-1} / pspa_{t-1} \right) \right) + 0.5 \times \left( \left( p_{t-2} \times erspa_{t-2} / pspa_{t-2} \right) \right) \]

\( pspa_t \) is a weighted average of the annual average LME price of grade A copper cathode in Spanish currency and real terms. \( \rho 3 \) is the third order correlation coefficient of the errors, respectively. Figure in parenthesis is the t-statistic.

Taiwan (1981-1998):

\[ constwn_t = -347.92 - 1.88 ptwn_t + 7.84 ytwn_t \]

\[ (-2.85) \quad (-0.47) \quad (10.49) \]

\( R^2 = 0.955 \quad \rho 1 = 0.51 \)

\( (3.65) \)

**Instruments:** \( ytwn_b, t, ptwn_{t-1}, pitwn_b, dollar\_index_b, ir_b \) \((sd/constot)_{t-1}\)

Where

\[ ptwn_t = 0.25 \times \left( \left( p_t \times ertwn_t / ptwn_t \right) + 0.25 \times \left( \left( p_{t-1} \times ertwn_{t-1} / ptwn_{t-1} \right) \right) + 0.5 \times \left( \left( p_{t-2} \times ertwn_{t-2} / ptwn_{t-2} \right) \right) \]

\( ptwn_t \) is a weighted average of the annual average LME price of grade A copper cathode in Taiwanese currency and real terms.
United States (1971-1998):

\[ \text{conus}_t = 234.19 - 210.35 \text{pus}_2t + 37.03 \text{yus}_t - 47.45t \]

\[
\begin{array}{ccc}
(0.95) & (-2.76) & (9.48) & (-5.48)
\end{array}
\]

\( R^2 = 0.850 \quad \text{DW} = 1.85 \)

Instruments: \( \text{yus}_t, \text{time}, \text{pus}_2t, (1/\text{pius})_t, \text{dollar\_index}_t, \text{ir}_t, (\text{sd/constot})_{t-1}, (\text{constot}/\text{tq})_{t-1} \)

Where

\[ \text{pus}_2t = 0.25*(p_t/\text{pius}_t) + 0.25*(p_{t-1}/\text{pius}_{t-1}) + 0.5*(p_{t-2}/\text{pius}_{t-2}) \]

\( \text{pus}_2t \) is a weighted average of the annual average LME price of grade A copper cathode in US dollars and real terms.


\[ \text{conrwr}_t = 2872.18 - 171.07 \text{pw}_2t + 29.73 \text{yrw}_t - 60.44t \]

\[
\begin{array}{ccc}
(4.02) & (-1.06) & (2.35) & (-2.58)
\end{array}
\]

\( R^2 = 0.863 \quad \rho_1 = 0.86 \quad \rho_4 = -0.26 \)

\[
\begin{array}{ccc}
(7.91) & (-2.90)
\end{array}
\]

Instruments: \( \text{yrw}_t, \text{time}, \text{pw}_2t, \text{dollar\_index}_t, \text{ir}_t, (\text{sd/constot})_{t-1}, \text{pius}_t, \text{yger}_t \)

Where

\[ \text{pw}_2t = 0.25*(p_t/\text{pirw}_t) + 0.25*(p_{t-1}/\text{pirw}_{t-1}) + 0.5*(p_{t-2}/\text{pirw}_{t-2}) \]

\( \text{pw}_2t \) is a weighted average of the annual average LME price of grade A copper cathode in US dollars and real terms. \( \rho_1 \) and \( \rho_4 \) are the first and fourth order correlation coefficients of the errors, respectively. Figures in parenthesis are the t-statistics.

Overall, the equations have very good fits ranging their \( R^2 \) from 85% for the United States to 99% for South Korea. A problem that appeared when we ran the equations of China and Taiwan was collinearity. To solve this complication we dropped the time variable \((t)\) since it was highly correlated with the industrial production variable \((y_t)\). So
for these equations the estimated coefficients on industrial production variable reflect the net influence of industrial production and all the other variables correlated with time.

In addition, most of the equations also suffered from serial correlation, which was corrected by applying the GLS method.

The speed of adjustment of demand to changes in copper price varied among countries. For the majority of the countries the speed of adjustment is relatively slow, having 50% of the full impact on demand in the third period, 25% in the first period and 25% in the second period. However, there are also some exceptions, like Italy and South Korea, where 50% of the adjustment in copper demand due to changes in prices occurs in the first year. The rest of the adjustment takes place in the same proportion in the second and third year. For Japan, the most important adjustment of demand (50%) occurs in the second year.

On the other hand, if we analyze the performance of the variables in more detail, we can see that industrial production is the most important determinant of copper consumption. This variable is significant for all the countries and the rest of the world. Additionally, the price variable is a very important determinant of consumption for Japan, South Korea, Spain, United States and the rest of the world, and with somewhat less significance for China, Italy and Mexico. France was the only country with a wrong sign on the price variable, so we omitted it. Fortunately, the t-statistic was not significant. As well, the time variable was significant only for Japan, United States and the rest of the world, and the coefficients were negative for Germany, Japan, South Korea, United States and the rest of the world suggesting that copper demand tends to diminish each year in these countries as a result of changes in technology and consumer preferences. This phenomenon is very pronounced in Japan and the United States where the consumption would decrease 35,120 and 47,450 tons each year, respectively, due to this factor. On the contrary, the time variable is positive for France, Italy, Mexico and Spain meaning that copper demand tends to grow each year due to changes in technology and consumer preferences.
4.2.5. Price Equation

In this section we examine the results of the estimates of the price equation. The equation is as follows:

\[
p_t = 1.70 - 0.0002sd_{t-1} + 2.99(constot / tq)_t - 0.006dollar_{index_t} + 0.33p_{t-1}
\]

\[
(-3.32) (-3.91) \quad (6.70) \quad (-3.15) \quad (3.25) \quad (4.38)
\]

\[R^2 = 0.779\]

Instruments: dollar_{index}, p(-1), (ir/4), sd_{constot(-1)}, constot_{tq(-1)}, kchi, yger, yus, c

Overall, we think the results obtained are very good, and the variables included in the model explain almost 78% of the price variable. As well, all the coefficients are highly significant.

On the other hand, the adjustment coefficient \( \lambda \) for the equation is 0.67. This means that the change in price between any two periods (\( t \) and \( t-1 \)) will be 67% of the difference between the price in the long-run and the price of the previous period \( t-1 \). This shows that prices adjust very quickly to changes in any of the variables.
CHAPTER 5

VALIDATION OF THE MODEL

In this chapter we analyze the reliability of the model. Although, individual equations can work very well, have correct specifications, highly significant t-statistics and very good fits, this does not assure that the model as a whole will work well when all the equations are interacting. Normally, simulation methods are utilized to evaluate the complete model. The most common techniques are the ex-post simulation in and out of the sample period.

The ex-post simulation in the sample period consists of simulating the model over the historical period where the equations were already estimated, and then comparing the solved values of the endogenous variables with actual data. As a result, we can measure the simulation error, and also estimate other indicators that we can utilize to assess the simulation accuracy. The ex-post simulation out of the sample period also compares the actual and solved values of the simulation but for the periods not included in the estimation of the model. This procedure is generally applied for two or three years forward and, although is not a definitive test, it helps to indicate how the model is in reality working and validate the ability of it to predict the future.

5.1. Performance of the Model in the Sample period

In this section we evaluate the performance of the model in the sample period, developing a simulation that is deterministic and dynamic. This means that values of the endogenous variables in the sample period are estimated using only the estimated equations. This is the correct method when we want to simulate various values into the future, or when we want to know how the model would have performed historically. The
ex-post simulation within the sample period is probably not the best way to measure the ability of a model to predict the future, since the simulation is executed in the same period in which the equations were estimated, however it can be very helpful and give us an insight of what is happening, and how each of the equations are working.

The analysis is carried out during the period 1983-1998 to avoid problems in the solution due to missing values from our data. Let us remember that we ran the equation of Taiwan for the sample period 1981-1998, because we could not get data from 1971 to 1980. We are also giving up two more years backward to allow for lagged variables.

As it follows, some results of the dynamic simulation are shown graphically. A summary of the results for the aggregate variables graphs of the model is shown in this section, while a complete display of all the other variables graphs can be found in the appendix C.

The aggregate variables of the model are total production capacity (ktot), total primary supply (pqtot), total supply (tq), \(^{30}\) total demand (constot) and price (p).

In general, we can see that the simulation of all the variables, excepting total production capacity, perform really well. The baseline or dynamic simulation of ktot is always far from the actual values, and it has a very dissimilar trend (figure 5.1.a). The path of the baseline of p follows the trend of the actual values suitably, but it is much smoother and it cannot recognize the peaks very accurately in some years (figure 5.1.c). The reason behind this is not very clear, but we guess that probably in periods of big copper price variations or changes in the business cycle (for example, passing from a recession to a strong economic growth in the world), there is a lot of speculation that can drive prices very high or very low. Another alternative might be that there are too many factors driving prices that we are not including in our equation.

If we examine the graphs of all the individual variables, we can see that some simulations are not working very well. The most significant deficiencies can be found in

\(^{30}\)It includes the sum of primary and secondary supply.
the variables \(kcan, \ krw, \ pqcan, \ pqper, \ pqus, \ pqrw\) and \(consrw\). For \(krw, \ pqrw\) and \(consrw\), the simulated baseline is unsuccessful in following the trend of the actual values. For \(kcan\) and \(pqcan\) the baseline keeps the trend of the actual values curve in some way, but does not recognize the big peaks and troughs. For \(pqus\) the baseline curve is flatter than the actual curve, and for \(pqper\) the baseline curve is lower than the actual curve.

Figure 5.1.a
Total Production Capacity
(Thousand tons)

KTOT

--- Actual \quad \cdots \quad KTOT \ (Baseline)
Figure 5.1.b
Total Primary Production
(Thousand tons)

PQTOT
Figure 5.1.c
Total Primary and Secondary Production
(Thousand tons)

TQ

14000
13000
12000
11000
10000
9000


Actual  TQ (Baseline)
Figure 5.1.d
Total Demand
(Thousand tons)

CONSTOT

--- Actual --- CONSTOT (Baseline)
Figure 5.1.e
Price of Refined Copper
(US$/Lb, Grade A Cathode, London Metal Exchange)
We can also measure the goodness of the ex-post simulation in the sample with some indicators. The tools utilized for the evaluation of the model simulation are the correlation coefficient (r), root mean square error (RMSE), Theil inequality coefficient (U), and a decomposition of this last coefficient to determine the origin of the differences between the actual and the solved values. In general, these variations come from a bias proportion ($u_1$), which explains how far the mean of the simulation is from the mean of the actual values, a variation proportion ($u_2$), which tells us how far is the variation of the simulation from the variation of the actual values, and the covariance proportion ($u_3$) that measures the unsystematic (residual) errors of the simulation. According to Su (1996), the sum of these last three terms has to be 1, and a very good fit is obtained when $u_3$ is close to 1, and the other two terms $u_2$ and $u_3$ are close to zero. As well, the closer to zero is U better the performance of the simulation is.

Table 5.1 shows the result of the calculation of these indicators for all the endogenous variables. In general, the results are notably good, with the exception of some particular variables. The correlation coefficients between the actual and simulated values of all the variables are really high. The exceptions are $kean$ and $pqcan$ where r behaves very badly. The Theil Inequality Coefficient (U) is also very close to zero for all the equations showing that the simulation is fairly accurate. If we take a look at the decomposition of U, it is possible to realize that the term $u_3$ (the unsystematic part) is very variable but, in general, it is the most important explanation of the simulation. However, the results are not completely satisfactory since we have some problems with the variables $kus$, $krw$, $ktot$, $pqus$, $pqrw$, $pqtot$, $consspa$ and $consrw$ that present an unsystematic proportion that is lower than 50%.
<table>
<thead>
<tr>
<th>Variables</th>
<th>r</th>
<th>RMSE</th>
<th>U</th>
<th>u₁</th>
<th>u₂</th>
<th>u₃</th>
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<td>kaus</td>
<td>0.949</td>
<td>36.32</td>
<td>0.097</td>
<td>0.071</td>
<td>0.000</td>
<td>0.929</td>
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<td>0.403</td>
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<td>0.512</td>
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<td>0.007</td>
<td>0.215</td>
<td>0.777</td>
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<td>kind</td>
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<td>0.125</td>
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<td>0.530</td>
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<td>0.959</td>
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<td>0.854</td>
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<td>0.053</td>
<td>0.015</td>
<td>0.330</td>
<td>0.655</td>
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<td>0.212</td>
<td>0.135</td>
<td>0.653</td>
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<td>paper</td>
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<td>25.59</td>
<td>0.067</td>
<td>0.000</td>
<td>0.018</td>
<td>0.982</td>
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<td>pqs</td>
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<td>119.16</td>
<td>0.078</td>
<td>0.005</td>
<td>0.519</td>
<td>0.475</td>
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<td>0.208</td>
<td>0.713</td>
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<td>0.030</td>
<td>0.457</td>
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<td>0.145</td>
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<td>0.155</td>
<td>0.001</td>
<td>0.844</td>
</tr>
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<td>consjap</td>
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<td>0.120</td>
<td>0.074</td>
<td>0.806</td>
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<td>27.28</td>
<td>0.072</td>
<td>0.077</td>
<td>0.046</td>
<td>0.876</td>
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<td>consmex</td>
<td>0.918</td>
<td>29.57</td>
<td>0.179</td>
<td>0.026</td>
<td>0.088</td>
<td>0.885</td>
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<tr>
<td>consspa</td>
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<td>9.03</td>
<td>0.059</td>
<td>0.476</td>
<td>0.068</td>
<td>0.455</td>
</tr>
<tr>
<td>constwn</td>
<td>0.963</td>
<td>49.27</td>
<td>0.129</td>
<td>0.001</td>
<td>0.082</td>
<td>0.918</td>
</tr>
<tr>
<td>consus</td>
<td>0.934</td>
<td>104.27</td>
<td>0.046</td>
<td>0.013</td>
<td>0.025</td>
<td>0.962</td>
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<tr>
<td>consrw</td>
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<td>287.28</td>
<td>0.079</td>
<td>0.001</td>
<td>0.893</td>
<td>0.106</td>
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<td>constot</td>
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<td>0.017</td>
<td>0.270</td>
<td>0.015</td>
<td>0.716</td>
</tr>
<tr>
<td>p</td>
<td>0.882</td>
<td>0.12</td>
<td>0.131</td>
<td>0.160</td>
<td>0.258</td>
<td>0.582</td>
</tr>
<tr>
<td>sq</td>
<td>0.823</td>
<td>78.30</td>
<td>0.055</td>
<td>0.035</td>
<td>0.000</td>
<td>0.969</td>
</tr>
<tr>
<td>tq</td>
<td>0.985</td>
<td>300.02</td>
<td>0.028</td>
<td>0.333</td>
<td>0.076</td>
<td>0.591</td>
</tr>
</tbody>
</table>
5.2. Performance of the Model out of the Sample Period

In this section, we evaluate the performance of the model out of the sample period, using a simulation that is dynamic and stochastic. A stochastic simulation out of the sample period is a great advance compared to the last studies of Wagenhals (1984) and Vial (1989), which only used a deterministic simulation.

The ex-post simulation out of the sample period is much more helpful about the reliability of the model, because it compares future periods that were not included in the estimation of the equations.

Let us recall that for the ex-post simulation in the sample period we obtained only point estimates, however these point estimates are only one value of a big amount of such estimates that could have been obtained from different independent variables or coefficients. Those estimates can be improved if we also have an idea of the variability of the simulation. The measure of variability most commonly used is the confidence interval, which could be defined as the range of values within which the actual value of the item being estimated is likely to fall some percentage of the time.\textsuperscript{31}

The stochastic ex-post simulation out of the sample period is done in two different ways to see the influence of including the production capacity equations in the estimation. The original plan was to examine the model with all the equations including production capacities. Nonetheless, due to big differences between the actual values and the simulated values for these equations we ran another simulation excluding the capacity equations but incorporating instead the actual values for the capacity variables, to compare them. The period of time utilized to do the ex-post simulation out of the sample is 1998-2001.

In our case, we assume that the model is linear and the errors are normal, therefore, the endogenous variables follow a normal distribution, and the mean and standard deviation are sufficient to describe their distributions completely. For a normal

\textsuperscript{31} Definition obtained from Studenmund (2001), section 5.2.4.
distribution the mean always shows the deterministic solution of the model. To simulate the distributions, Eviews employs a Monte Carlo approach, solving the model many times with random numbers that replace the errors at each repetition. This method gives us only approximate results, but the more repetitions we use the more accurate they are.

The results of the stochastic simulation are showed graphically. A summary of the results of the aggregate variables of the model is showed with graphs, while a complete presentation of the graphs of all the other variables can be found in the appendix C (with the inclusion of the capacity equations) and the appendix D (without the inclusion of the capacity equations). The 95% confidence interval that is shown in the graphs is approximately twice the value of the standard deviation of the simulation.

The aggregate variables of the model are, as in the previous section, total production capacity (ktot), total primary production (pqtot), total primary and secondary production (tq), total demand (constot) and price (p).

5.2.1. Inclusion of Capacity Equations

When we ran the ex-post simulation out of the sample period including the capacity equations, the results were not very satisfactory. If we take a look at the following graphs of the aggregate variables, we can see that although the actual values are within the confidence interval, the trend of the solved values strongly differ from the path of the actual values and they cannot recognize the direction of the actual curves. The only aggregate curve that works very well is the total demand curve. The actual curve is within the confidence interval and it is very close to the mean of the simulation. Besides, it follows exactly the same trend showing great accuracy.

The poor result of the simulation on all the aggregate variables (excepting total demand) is due to the individual capacity equations, which are very deficient in predicting the future values. In addition, the capacity equations also produce a negative
effect over the primary production equations, which in turn influence the total production equation that impacts the price equation as well.

Figure 5.2.a
Total Production Capacity
(Thousand tons)

KTOT ± 2 S.E.
Figure 5.2.b
Total Primary Production
(Thousand tons)

PQTOT ± 2 S.E.

--- Actual  --- PQTOT (Baseline Mean)
Figure 5.2.c
Total Primary and Secondary Production
(Thousand tons)

TQ ± 2 S.E.
Figure 5.2.d
Total Demand
(Thousand tons)

CONSTOT ± 2 S.E.
Figure 5.2.e
Price of Refined Copper
(US$/Lb, Grade A Cathode, London Metal Exchange)

\[ P \pm 2 \text{ S.E.} \]
If we analyze the disaggregate graphs (appendix C) we find the reason behind the problems mentioned before. All the capacity equations show very disappointing results in the simulations, and some of the actual values are even out of the confidence interval.

These problems of prediction accuracy in the capacity equations cause in turn problems in the individual results of all the other equations. Therefore, the simulation is not close to actual values and it would be difficult to rely on the results of a posterior forecasting for a longer period of time into the future.

Some individual demand equations also have some deficiencies in forecasting the actual values. That is the case for China, which in 2000 and 2001, experienced a bigger rate of growth in copper consumption than forecasted. The same occurred with Italy, where the consumption increased strongly while its industrial production index was almost stagnant and even in 2001 decreased. For the same period 1999-2001, the opposite occurred for the United States and Taiwan. While the simulation produced higher values mainly because of the expansion in the economy, the actual consumption of copper was almost flat. Nevertheless, as we mentioned before the total demand curve -the sum of all the individual demands- is an excellent approach to the actual one, so we do not have to worry too much about this problem.

5.2.2. Exclusion of Capacity Equations

Due to the problems in the simulation of the capacity equations in the previous section we decided to run also a stochastic simulation of the whole model for the same period but without including the capacity equations, that is incorporating the production capacity of all the countries as exogenous variables. The objective is to determine if there is any improvement in the results of the past simulation that helps us to make a decision about whether or not to include the capacity equations for a future simulation. In case we decide to exclude the capacity equations from the model, the Chilean Copper Commission (Cochilco) has some estimates of the production capacity per mine and per
country until 2010. Cochilco is relatively accurate since mining investments are announced with a lot of anticipation.

The following four graphs of the aggregate variables show much better results.

Figure 5.3.a
Total Primary Production
(Thousand tons)

PQTOT ± 2 S.E.
Figure 5.3.b
Total Supply
(Thousand tons)

\[ TQ \pm 2 \text{ S.E.} \]
Figure 5.3.c
Total Demand
(Thousand tons)

CONSTOT ± 2 S.E.

--- Actual  --- CONSTOT (Baseline Mean)
Figure 5.3.d
Price of Refined Copper
(US$/Lb, Grade A Cathode, London Metal Exchange)

\[ P \pm 2 \text{ S.E.} \]
We can see that the total primary supply ($pq_{tot}$) and total supply ($tq$) curves of the solved values are slightly overestimated but there is an important improvement in the new simulation. The baselines of these variables follow the same trend of the actual values.

The results for the total demand ($constot$) again perform splendidly and they are very close to the actual curve. The price ($p$) simulated curve also is much better than the previous one, and the baseline maintains almost the same path as the actual values. However, the baseline mean of the simulation is slightly underestimated, but this is principally due to the overestimation of secondary supply ($sq$) that in turn causes an overestimation in the total supply variable ($tq$). Let us recall that the price equation has the variable $constot/tq$ (with a positive sign) that shows the relationship between total demand and total supply. Hence, if $tq$ is overestimated, the ratio is going to be lower than the real value and in turn the estimated price is going to be lower than the real price. We think the worst problem is $sq$ that was roughly 400 thousand tons over the actual value in 2001. Unfortunately, secondary production is highly variable and it is very difficult to forecast the peaks and troughs as we could see in appendix C with a longer period of time.

Difficulties still continue for the demand simulations of some countries such as in the previous section when we included the capacity equations, but fortunately they do not affect negatively the results of the total demand variable ($constot$).

Overall, we think that the model works considerably well, and it can be used to analyze future prospects and evaluate different scenarios of the world copper industry.
CHAPTER 6

SIMULATION AND ANALYSIS OF DIFFERENT SCENARIOS

In this final section, we run a model simulation to analyze future prospects of the world copper industry and also to examine the effect of different scenarios in the assumptions of the exogenous variables.

As in any forecast, the assumptions about the future values of the exogenous variables are fundamental for the results. Therefore, it would be complicated to compare the forecasts of different models, because they normally depend on different assumptions. In our case, we have made projections for some variables such as production capacities, industrial production indices, exchange rates and price indices for all the countries included in the model. Other critical variables that we assume as exogenous are the availability of scrap, dollar strength against other currencies, the level of stocks, etc.

After obtaining the model forecast, we simulate changes in different exogenous variables to see the impact of different events on some endogenous variables, such as copper price. We emphasize production cutbacks and stockpiling, different growth rates of industrial production (mainly for China that is the major world consumer), several growth rates of production capacity (mainly for Chile that is the largest world producer) and various dollar strengths.

6.1. Main Assumptions for the Model

Mainly, to take advantage of the existing information, we have initialized the forecast in 2004, updating all the equations to include all the relevant information for the period
1999-2003 not incorporated previously in the equations. The simulation is performed during the period 2004-2010, since a longer term involves greater uncertainty and the forecast is much less reliable.

In order to have a more realistic forecast we have tried to use consistent information from different sources. In year 2004, the estimations of Bloomsbury Mineral Economics (2004) are used for exchange rates and industrial production growth rates (table 6.1.a). The GDP deflators are obtained directly from the estimation of the participant countries’ central banks. In the case of the production capacity of the producer countries, the data were collected from Cochilco and it was based upon market information acquired in year 2003.

For the period 2005-2010, the projections of the variables were determined with different criterias. For example, for variables that had clear long term trends (some exchange rates) we estimated an average growth rate. For less apparent trends we used the average of the last three, four or five years (when big structural changes occurred in the past that do not allow for inclusion of older data) depending on which was the best period to describe the behavior of the last years. When a trend was difficult to recognize, we employed the same value of 2004.

---

32 All the updated equations appear in the appendix E.
Table 6.1.a
Assumptions for the Forecast (2004-2010)
(All the exogenous variables except capacity)

<table>
<thead>
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<th>Exogenous Variable</th>
<th>Value of year 2004</th>
<th>Percentage of change per year (2005-2010)</th>
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<td>dollar_index</td>
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<td>erchn</td>
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<td>0%</td>
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<td>erfra</td>
<td>-4.55%</td>
<td>0%</td>
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<tr>
<td>erger</td>
<td>-4.55%</td>
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<td>0%</td>
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<td>pispa</td>
<td>3.50%</td>
<td>3.50%</td>
</tr>
<tr>
<td>pitwm</td>
<td>0.70%</td>
<td>0.70%</td>
</tr>
<tr>
<td>pius</td>
<td>1.90%</td>
<td>1.90%</td>
</tr>
<tr>
<td>ppius</td>
<td>1.90%</td>
<td>1.90%</td>
</tr>
<tr>
<td>ychn</td>
<td>12.5%</td>
<td>12.5%</td>
</tr>
<tr>
<td>yfra</td>
<td>2.60%</td>
<td>2.60%</td>
</tr>
<tr>
<td>yger</td>
<td>2.70%</td>
<td>2.70%</td>
</tr>
<tr>
<td>yita</td>
<td>-0.40%</td>
<td>-0.40%</td>
</tr>
<tr>
<td>yjap</td>
<td>5.70%</td>
<td>5.70%</td>
</tr>
<tr>
<td>ykor</td>
<td>11.0%</td>
<td>11.0%</td>
</tr>
<tr>
<td>ymex</td>
<td>4.30%</td>
<td>4.30%</td>
</tr>
<tr>
<td>yrw</td>
<td>9.70%</td>
<td>9.70%</td>
</tr>
<tr>
<td>yspa</td>
<td>3.10%</td>
<td>3.10%</td>
</tr>
<tr>
<td>ytwm</td>
<td>10.10%</td>
<td>10.10%</td>
</tr>
<tr>
<td>yus</td>
<td>4.80%</td>
<td>4.80%</td>
</tr>
</tbody>
</table>
Table 6.1.b
Capacity variables, stock level (sd) and changes in copper scrap availability (delta_ss) (2004-2010)\textsuperscript{33}
(thousand tons)

<table>
<thead>
<tr>
<th>Variable</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>kaus\textsubscript{i}</td>
<td>911</td>
<td>924</td>
<td>989</td>
<td>1,056</td>
<td>1,036</td>
<td>968</td>
<td>934</td>
</tr>
<tr>
<td>kcan\textsubscript{i}</td>
<td>555</td>
<td>542</td>
<td>524</td>
<td>516</td>
<td>421</td>
<td>398</td>
<td>264</td>
</tr>
<tr>
<td>kchi\textsubscript{i}</td>
<td>5,514</td>
<td>5,594</td>
<td>6,017</td>
<td>6,399</td>
<td>6,548</td>
<td>6,876</td>
<td>6,936</td>
</tr>
<tr>
<td>kind\textsubscript{i}</td>
<td>1,036</td>
<td>1,036</td>
<td>1,002</td>
<td>963</td>
<td>943</td>
<td>935</td>
<td>883</td>
</tr>
<tr>
<td>kper\textsubscript{i}</td>
<td>938</td>
<td>969</td>
<td>1,062</td>
<td>1,404</td>
<td>1,597</td>
<td>1,593</td>
<td>1,687</td>
</tr>
<tr>
<td>krw\textsubscript{i}</td>
<td>4,569</td>
<td>4,803</td>
<td>4,942</td>
<td>5,099</td>
<td>5,364</td>
<td>5,815</td>
<td>6,251</td>
</tr>
<tr>
<td>kus\textsubscript{i}</td>
<td>1,180</td>
<td>1,200</td>
<td>1,216</td>
<td>1,256</td>
<td>1,324</td>
<td>1,424</td>
<td>1,424</td>
</tr>
<tr>
<td>sd\textsubscript{i}</td>
<td>1,197</td>
<td>1,197</td>
<td>1,197</td>
<td>1,197</td>
<td>1,197</td>
<td>1,197</td>
<td>1,197</td>
</tr>
<tr>
<td>delta\textsubscript{ss}</td>
<td>10,040</td>
<td>9,891</td>
<td>10,449</td>
<td>10,768</td>
<td>7,646</td>
<td>7,902</td>
<td>7,660</td>
</tr>
</tbody>
</table>

Additionally, a dummy is included in the equation of China to incorporate a structural change that incremented the intensity of copper use from year 2000 onward. After 2000, the consumption of China grew faster than in previous years, despite it had similar growth rates of industrial production. It is probable that new sectors, more intensive in the use of copper are appearing in these years.

Finally, it is really important to mention that the published inventory data are probably not very reliable because they do not match with the calculated data from the equation \( s_t = s_{t-1} + tq_t - constot_t \). In addition, when the equation is used and some deficits are accumulated (when demand is greater than supply over several periods in time) we can even get negative values for the level of inventories (not logical). Consequently, we prefer to suppose that the level of stocks is fixed to avoid these problems.

6.2. Simulation Results

The most important results of the forecast are illustrated in the following table and graphs. The main feature that we can identify is the strong growth of all the aggregate

\textsuperscript{33}Information about estimated capacities was provided by the Chilean Copper Commission (Cochilco). Delta\_ss was calculated by ourselves.
variables. For example, the model predicts that in 2004 the price of copper would increase from 0.807 US$/Lb to 1.01 US$/Lb. This represents an increment of 25%. In turn, for copper demand and supply, the growth rate would be around 10.0% and 9.1%, respectively.

<table>
<thead>
<tr>
<th>Variable</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_t$</td>
<td>1.01</td>
<td>1.17</td>
<td>1.29</td>
<td>1.39</td>
<td>1.56</td>
<td>1.75</td>
<td>2.00</td>
</tr>
<tr>
<td>$constot_i$</td>
<td>17,162</td>
<td>18,259</td>
<td>19,506</td>
<td>20,908</td>
<td>22,477</td>
<td>24,207</td>
<td>26,094</td>
</tr>
<tr>
<td>$pqtot_i$</td>
<td>14,695</td>
<td>15,075</td>
<td>15,734</td>
<td>16,573</td>
<td>17,030</td>
<td>17,594</td>
<td>17,860</td>
</tr>
<tr>
<td>$tq_i$</td>
<td>16,032</td>
<td>16,577</td>
<td>17,359</td>
<td>18,293</td>
<td>18,857</td>
<td>19,525</td>
<td>19,918</td>
</tr>
</tbody>
</table>

*Price is in $US/Lb and the other variables are in thousand tons.

The results of the simulation show that demand would continue being higher than supply in the next years, and therefore, this would provoke a rise in copper price, although at lower growth rates than, in the posterior years. It is necessary to highlight that figures for price, demand and supply for 2008, 2009 and 2010 seem unrealistic, and the main reason behind this is the low growth speed of production capacity that we are projecting. This causes that in year 2010 the price reaches the 2 $US/Lb. It is likely that high prices in years 2006 and 2007 encourage copper producers to increase output or invest in new capacity. This would reduce the gap between demand and supply and would compel prices to decrease. Therefore, simulation results should be treated very cautiously since projections so far into the future are extremely uncertain.

At this point, we must emphasize that one of the most important determinants of the success of a forecast is the reliability of the exogenous variables projection. Since projections from reliable sources of information like the Consensus Forecast or others publish data only for one or two years forward, it is very complicated to make long-term forecasts. In general, we should not trust in forecasts of more than two years into the
future as the exogenous variables are extremely uncertain. Even, the companies that make projections of variables such as exchange rates or industrial production can change them several times in a year.

Because of that, we need to be very alert to check constantly the projection of exogenous variables. A continuous monitoring and analysis would allow us to update the values of the exogenous variables and therefore the results of the simulation. In summary, the projection of exogenous variables are often more important for forecasting than the model simulation itself.
Figure 6.1.a
Total Primary Production
(Thousand tons)

PQTOT ± 2 S.E.
Figure 6.1.b
Total Supply
(Thousand tons)

TQ ± 2 S.E.
Figure 6.1.c
Total Demand
(Thousand tons)

CONSTOT ± 2 S.E.
Figure 6.1.d
Price of Refined Copper
(US$/Lb, Grade A Cathode, London Metal Exchange)

$P \pm 2 \text{ S.E.}$
On the other hand, if we compare the actual copper prices in 2003 and 2004, we could see that they have grown from an average of 80.7 $US/lb to an average of 1.30 $US/Lb. This value is much higher than the price of 1.01 $US/lb that the model estimates for 2004. This difference is not very surprising as we said before, because the price baseline simulation, although follows the same trend, has some difficulties in tracking the peaks of the actual values. As we said before, in section 5.1., this phenomenon is particularly noticeable in periods of big changes in the business cycle. (In this case, passing from a recession to strong global economic growth), with a lot of speculation and copper prices rising more than 50% in one year. Another alternative might be that there are too many factors driving prices that we are not including in our equation.

6.3. Analysis of Different Scenarios

Since there is always uncertainty in the exogenous variables, it is important to examine different ways in which one variable might move in the future. It is crucial for a decision maker to know how the most important variables (price, supply and demand) might react to changes in exogenous variables. Because of time constraints, we have chosen only the four most interesting cases (in our point of view), although we know that there is an inestimable number of analysis alternatives that could be considered in a future study. But mainly, the objective of this analysis is to visualize the impact on copper price.

In brief, as we mentioned before, we attempt to simulate four distinct scenarios:

1. The consequences of production cutbacks and stockpiling, focusing primarily on Chile;
2. Different growth rates of industrial production, concentrating the analysis on China;
3. Several growth rates of production capacity, again with an analysis of Chile;
4. And various levels of dollar strength, emphasizing the effect of a possible appreciation of it.

The analysis of scenarios is performed in year 2004 at two different levels of stocks: a low level of stock defined as the lowest level of stocks in history (522 thousand tons), and the highest level of stocks in history (2,047 thousand tons). The objective is to analyze the effect of the decisions at different levels of prices since obviously when there is a low level of stocks, price is normally very high, and when the contrary occurs the price is generally very low. All the other exogenous variables are left without changes (ceteris paribus).

6.3.1. Effect of production cutbacks or stockpiling

Due to the low prices of the recent past years, several firms made the decision of reducing their outputs. Among them, for example, the world largest producer, Codelco, began to stockpile part of its production and the price started to rise very quickly. However, the origin of this strong price recovery is not completely clear given that world economy was also improving rapidly. In this section, we try to measure the real influence of stockpiling and production cutbacks on price to clarify this doubt.

The difference between these two terms is that when a company is stockpiling, it is producing the same amount, so it is not reducing the output, however the company is keeping some part of it as inventory that can be sold whenever it wants. On the other hand, a cutback is an output reduction, and it is typically done upon exploiting the areas of lower grades in the mine. Another way of doing this could be also to shut down the mine, but this requires much more analysis given the large costs involved. The analysis of the impact of cutbacks and stockpiling are made using the case of Chile, the world largest copper producer.
6.3.1.1. Production Cutbacks

The value of the Chilean primary supply \((pqchi)\) for the year 2004 is obtained from the baseline forecast done in the previous chapter (5,497.3 thousand tons). We start from this value called “normal” assuming that all the exogenous variables are the same of the baseline forecast. Then, we simulate two alternatives for production reductions: 100 and 300 thousand tons. and we run the whole model. The only change in the simulation is the variation in production, so the result is compared with the baseline simulation to see how prices vary.

According to the following tables, production cutbacks have a clear influence over price. The largest impact (in percentage) is made when the stocks level is high or at the same time, the price is relatively lower. Therefore, for a decrease of 100 thousand tons, the price would tend to rise between 0.89% and 1.88%, and for a decrease of 300 thousand tons, the price would tend to increase between 4.03% and 5.16% in the same year.

<table>
<thead>
<tr>
<th>(pqchi)</th>
<th>Normal</th>
<th>Normal (-100)</th>
<th>Normal (-300)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price ($US/Lb)</td>
<td>1.125</td>
<td>1.135</td>
<td>1.170</td>
</tr>
<tr>
<td>Change</td>
<td>0.89%</td>
<td>4.03%</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.3.b
Production Cutbacks at a High Level of Stocks

<table>
<thead>
<tr>
<th>(pqchi)</th>
<th>Normal</th>
<th>Normal (-100)</th>
<th>Normal (-300)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price ($US/Lb)</td>
<td>0.904</td>
<td>0.921</td>
<td>0.951</td>
</tr>
<tr>
<td>Change</td>
<td>1.88%</td>
<td>5.16%</td>
<td></td>
</tr>
</tbody>
</table>

If price increases, capacity will tend to rise too. In the long run, this will produce a decrease in price.
6.3.1.2. Stockpiling

For the analysis of the effect of stockpiling on price we again use Chile. The main difference with the previous case is that when primary production is reduced in year 2004, the level of stocks is also increased by the same amount. But because the equation of price contains the level of inventories at the beginning of each year, the impact can be better visualized in year 2005. Again, the value of the Chilean primary supply ($pqchi$) in 2005 (5,581.2 thousand tons) is determined with the baseline forecast of the previous chapter. In addition, it is necessary to explain that the reason behind the higher prices of the tables 6.3.a and 6.3.b compared to the tables 6.4.a and 6.4.b is the bigger difference between demand and supply of 2005.

<table>
<thead>
<tr>
<th>$pqchi$</th>
<th>Normal</th>
<th>Normal (-100)</th>
<th>Normal (-300)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p$ ($US/Lb)</td>
<td>1.322</td>
<td>1.326</td>
<td>1.335</td>
</tr>
<tr>
<td>Change</td>
<td>0%</td>
<td>0.35%</td>
<td>1.05%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$pqchi$</th>
<th>Normal</th>
<th>Normal (-100)</th>
<th>Normal (-300)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p$ ($US/Lb)</td>
<td>1.039</td>
<td>1.049</td>
<td>1.064</td>
</tr>
<tr>
<td>Change</td>
<td>0%</td>
<td>0.98%</td>
<td>2.38%</td>
</tr>
</tbody>
</table>

The results show that stockpiling also influences prices but in a smaller amount than when there is a production cutback. The explanation behind this is that an increase in the level of inventories produces a negative effect on price that is offset by the lower primary supply that influences price positively. The largest impact is again produced when the level of inventories is high and in turn the price is low. In summary, when there is a stockpiling of 100 thousand tons, the price would tend to rise between 0.35% and 0.98%,
and for a decrease of 300 thousand tons, the price would tend to increase between 1.05% and 2.38% in the same year.

If price increases, companies will try to sell their copper stocks. In the long run, this increase of copper supply (copper stocks plus copper production) will decrease price again.

6.3.2. Effect of Different Growth Rates of Industrial Production

Another interesting issue is the impact that different growth rates of industrial production could have on the level of consumption of a country and in turn on copper price. In this case, we have chosen China because of its huge importance as a consumer country, and because any decrease in the level of growth of its economy could affect this market very strongly.

The following tables show that a reduction in the growth rate of industrial production strongly affects the level of demand and price. This is almost independent of the level of stocks, given that the results are very similar. Thus, if for example, the growth rate of industrial production is 10% instead of 12.5% (normal), the Chinese demand would decrease in a range between 2.33% and 2.40% and the price would decrease between 1.58% and 1.41%. In the case where the growth rate of industrial production is 2.5% instead of 12.5%, the demand of China would decrease in a range between 8.69% and 8.91% and the price would decrease between 4.0% and 4.27%.

<table>
<thead>
<tr>
<th>$ychn$</th>
<th>Normal</th>
<th>Normal-2.5%</th>
<th>Normal-5.0%</th>
<th>Normal-7.5%</th>
<th>Normal-10.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$conschn$</td>
<td>0%</td>
<td>-2.33%</td>
<td>-4.41%</td>
<td>-6.74%</td>
<td>-8.69%</td>
</tr>
<tr>
<td>$p$</td>
<td>0%</td>
<td>-1.58%</td>
<td>-2.56%</td>
<td>-3.74%</td>
<td>-4.27%</td>
</tr>
</tbody>
</table>

34 This value is also going to depend on the value of the quotient total consumption/total supply.
Table 6.5.b  
Impact of Different Growth Rates of the Chinese Industrial Production  
at a low level of stocks

<table>
<thead>
<tr>
<th>$ychn$</th>
<th>Normal</th>
<th>Normal-2.5%</th>
<th>Normal-5.0%</th>
<th>Normal-7.5%</th>
<th>Normal-10.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$consch_n$</td>
<td>0%</td>
<td>-2.40%</td>
<td>-4.68%</td>
<td>-6.64%</td>
<td>-8.91%</td>
</tr>
<tr>
<td>$p$</td>
<td>0%</td>
<td>-1.41%</td>
<td>-2.05%</td>
<td>-2.79%</td>
<td>-4.00%</td>
</tr>
</tbody>
</table>

The changes in industrial production generate immediate effects on consumption and in turn in price. However, the extent of this impact is not clear, and we assume that in the long run the rise in price will encourage increases in production capacity and the price will go down again.

6.3.3. Effect of Different Growth Rates of Production Capacity

This scenario is very similar to the previous case but it is analyzed from the point of view of the producers. As well, the growth rate of production capacity in a country such as Chile can affect powerfully copper price.

As we can see in the following tables, if the growth rate of the Chilean production capacity is 2.5% more than the value obtained in the baseline forecast (5,514 thousand tons), the supply of Chile would increase in a range between 2.33% and 2.44% and the price would decrease between 0.89% and 1.65%. In case, the growth rate of the Chilean production capacity is 10.0% more than the value of the baseline forecast, the supply of Chile would increase in a range between 9.54% and 9.62% and the price would decrease between 6.46% and 8.54%.

Table 6.6.a  
Impact of Different Growth Rates of the Chilean Production Capacity  
at a high level of stocks

<table>
<thead>
<tr>
<th>$kch_i$</th>
<th>Normal</th>
<th>Normal +2.5%</th>
<th>Normal +5%</th>
<th>Normal +7.5%</th>
<th>Normal +10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_{qch_i}$</td>
<td>0% 2.44%</td>
<td>4.80%</td>
<td>7.22%</td>
<td>9.62%</td>
<td></td>
</tr>
<tr>
<td>$p$</td>
<td>0%</td>
<td>-0.89%</td>
<td>-2.75%</td>
<td>-5.03%</td>
<td>-6.46%</td>
</tr>
</tbody>
</table>
Table 6.6.b
Impact of Different Growth Rates of the Chilean Production Capacity at a low level of stocks

<table>
<thead>
<tr>
<th>$k_{chi}$</th>
<th>Normal</th>
<th>Normal +2.5%</th>
<th>Normal +5%</th>
<th>Normal +7.5%</th>
<th>Normal +10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pq_{chi}$</td>
<td>0%</td>
<td>2.33%</td>
<td>4.79%</td>
<td>7.21%</td>
<td>9.54%</td>
</tr>
<tr>
<td>$p$</td>
<td>0%</td>
<td>-1.65%</td>
<td>-4.87%</td>
<td>-6.16%</td>
<td>-8.54%</td>
</tr>
</tbody>
</table>

The figures show that in the short run the larger production capacity growth causes a decrease in price. In the long run, this decrease will encourage a reduction in capacity and a rise in price.

6.3.4. Effect of Dollar Strength

Finally, we examine the influence of dollar strength on copper price. For its significance in the price equation, we think it is worthy to determine how sensitive the copper price is to changes in the value of the American dollar.

From the tables, we can observe that if the dollar index appreciates 5% more than the value used in the baseline forecast (86.6), the price would decrease between 1.0% and 2.6%. In case, the dollar index appreciates 10% more than the value of the baseline forecast, the price would decrease between 2.9% and 4.0%.

Table 6.7.a
Impact of Different Dollar Index Growth Rate at a low level of stocks

<table>
<thead>
<tr>
<th>Dollar_index</th>
<th>Normal</th>
<th>Normal+5%</th>
<th>Normal+10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p$</td>
<td>0%</td>
<td>-1.0%</td>
<td>-2.9%</td>
</tr>
</tbody>
</table>

Table 6.7.b
Impact of Different Dollar Index Growth Rate at a high level of stocks

<table>
<thead>
<tr>
<th>Dollar Index</th>
<th>Normal</th>
<th>Normal+5%</th>
<th>Normal+10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p$</td>
<td>0%</td>
<td>-2.6%</td>
<td>-4.0%</td>
</tr>
</tbody>
</table>
Therefore, we can conclude that copper price is really sensitive to movements of the dollar strength against other currencies. These changes are mainly produced in the short term, and the duration of them is not clear. In the long term, the decrease in price would encourage a decrease in production capacity and eventually a rise in the copper price.
CHAPTER 7

CONCLUSIONS AND FINAL COMMENTS

This econometric model of the world copper industry incorporates new contributions that improve upon earlier work. Among the most important advances of the model we can highlight the incorporation of mineral potential and investment climate variables in the production capacity equations. There are also new specifications for the equations of supply, demand and price that we believe describe more appropriately the working of the industry: Primary supply depends on a variable (the ratio of price to variable costs) determining adjustment in the short run and a variable (capacity) representing a constraint in the short run that show a more realistic behavior of copper producers. The demand equations incorporate a lag structure with advantages over previous models that used the partial adjustment model to explain lagged responses of consumption to changes in price. The price equation includes a variable representing the strength of the dollar against other currencies. This reflects the effect on copper price of investors' decisions to switch from one asset to another. Additionally, an alternative model of stock demand due to speculative motives is proposed adding new features of how speculators make transactions.

Among the most interesting findings we can highlight that investment climate has been a very important factor for the growth of production capacity in Chile and Peru. Mineral potential is also very significant for Peru, but less so for Chile and Indonesia. Results also suggest that improvements in productivity have not been a determinant in the increase of production capacity.

The estimation of the primary supply equations illustrate that production capacity is the most important factor influencing the output in Australia, Chile and Indonesia. These
countries have been producing copper at almost full capacity in the past, and prices are not a big determinant of the output level. On the contrary, Canada and the United States are swing producers. This means that they produce closer to full capacity when prices increase. The results also show that increases in productivity are a key factor in the supply additions of Chile, Peru and the United States.

The demand equations of all the countries (except France) suggest that consumption is affected by prices in the short and long run. This means that the full effect on demand of a change in copper price would occur normally in three years. The main impact of price is produced in the third year for the majority of the countries (except Italy, Japan and Korea). Income represented by an index of industrial production is the most important determinant of consumption for all the countries. Figures also insinuate that intensity of copper use has tended to decrease in countries such as Japan, Germany, South Korea and the United States\textsuperscript{35} due to technological changes and consumer preferences. In contrast, France, Italy, Mexico and Spain are raising their intensities of copper use from these same motifs.

The price equation shows as well that the stock level, the relationship between demand and supply, and the dollar strength are all significant for the determination of copper price.

The validation of the model exhibits some problems with the capacity equations. The troubles are related to the ability of the model to predict the actual values of production capacity for the involved countries. This ends up affecting negatively the whole model. Accordingly, we decide to use the production capacities as exogenous variables instead of utilizing the estimated equations to have a more accurate simulation.

In general, the baseline simulation follows the actual trend of the main aggregate variables (total demand and total supply); simulated price is much smoother than the actual price curve, however it fails in recognizing some of the peaks of the actual values.

\textsuperscript{35} According to Prof. John Tilton, intensity of copper use declined in the United States until the 1990s, however after that year it began to increase again.
It is likely that there are other factors influencing price in some periods of time. For example, when there are rapid changes in the growth of the world economy, prices rise extremely fast suggesting that speculation may have an important role in price determination.

The analysis of the simulation of future prospects shows that the main determinant of the model predictive power is the information about the exogenous variables. Because, normally information about economic variables (for example, industrial production, price indices and exchange rates) can be acquired with only one or two years of anticipation, a simulation of a longer term it is not very reliable. Therefore, it is necessary to be very alert to changes in economy and in other variables like production capacity. If changes in the exogenous variables are predicted, we should run the simulation again. Thus the simulation should be dynamic with constant updates rather than static where we run the model once and we forget about it forever.

As we said before, in years of rapid economic growth like 2004, prices increase very quickly (from 0.80 US/Lb in 2003 to 1.30 US/Lb in 2004), and the model fails to reach the peaks of the actual prices. Nevertheless, as we observe in the validation of the model in the sample period 1999-2001, where we have more stable prices, the simulated price behaves much better and follows the real values very closely. We strongly recommend in 2005 to run the simulation again, when we already have the real values of the endogenous variables and we know with more certainty the more probable values for the exogenous variables.

In our opinion, more interesting than the predictive power of the model, are the conclusions that we can obtain from the analysis of different scenarios simulation. Four alternatives are examined: Consequences of production cutbacks and stockpiling in Chile; different growth rates of Chinese industrial production; several growth rates of production capacity in Chile; and various levels of dollar strength, emphasizing a possible appreciation of it.
The analysis of the first issue demonstrates that stockpiling influences prices less than production cutbacks. When there is a stockpiling of 100 thousand tons, the price would tend to rise between 0.35% and 0.98%, and for a decrease of 300 thousand tons, the price would tend to increase between 1.05% and 2.38% in the same year. For a production cutback of 100 thousand tons, the price would tend to rise between 0.89% and 1.88%, and for a decrease of 300 thousand tons, the price would tend to increase between 4.03% and 5.16%. For both, the largest impact is produced when the level of inventories is high and in turn the price is low.

As well, a decrease in the Chinese growth rate of industrial production strongly affects the level of total demand and price. For instance, if the growth rate of industrial production is 10% instead of 12.5%, the demand of China would decrease in a range between 2.33% and 2.40% and the price could decrease between 1.58% and 1.41%.

In addition, the growth rate of the Chilean production capacity can affect powerfully copper prices. With another example, if the growth rate is 2.5% more than the value obtained in the baseline forecast (5,514 thousand tons), the supply of Chile would increase in a range between 2.33% and 2.44% and the price would decrease between 0.89% and 1.65%.

Price is sensitive to changes in the dollar strength against other currencies. If the dollar index appreciates 10% more than the value of the baseline forecast, the price would decrease between 2.9% and 4.0%.
Finally, it is necessary to highlight that there are issues, such as the behavior of stock demand and capacity of production that are potential areas for future research. A better understanding of stock demand is crucial before this exogenous variable can be converted into an endogenous variable. On the other hand, we have realized that there are still troubles in modeling production capacity adequately. Although, we obtained good fits when we ran the equations, the validation showed problems in predicting the actual values, demonstrating that this field needs much more research to really improve the representation of production capacity behavior.
CHAPTER 8

REFERENCES CITED


CHAPTER 9
APPENDICES
### APPENDIX A

#### Table A.1

**Definition of Variables**

<table>
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<tr>
<th>Variable</th>
<th>Definition</th>
<th>Units</th>
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<td>conshn&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Copper demand of China</td>
<td>Thousand tons</td>
<td>Metal Statistics (Metallgesellschaft) (1992-2002 issue, and previous issues)</td>
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<td>Thousand tons</td>
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<td>1 for consumption change in period 1999-2010; 0 otherwise</td>
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<td>1 for strikes in 1979 and 1989; 0 otherwise</td>
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<td>1 for strikes in the period 1982-1984; 0 otherwise</td>
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<td>dollar&lt;sub&gt;index&lt;/sub&gt;&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Major currencies index. It is a weighted average of the foreign exchange values of the U.S. dollar against a set of currencies.</td>
<td>Index (March, 1973=100)</td>
<td>Federal Reserve of the United States (2004)</td>
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<td>Australian Dollars per US dollar</td>
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<td>Canadian Dollars per US Dollar</td>
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<td>Pesos per US Dollar</td>
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<td>Symbol</td>
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<td>Yuans per US Dollar</td>
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<td>Exchange rate of France</td>
<td>Francs per US Dollar</td>
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<td>Deutsche Mark per US Dollar</td>
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<td>Rupiahs per US Dollar</td>
<td>IFS (2003) from IMF</td>
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<td>Exchange rate of Italy</td>
<td>Liras per US Dollar</td>
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<td>Yens per US Dollar</td>
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<td>Canadian Dollars per US Dollar</td>
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<td>Production capacity of Australia</td>
<td>Thousand tons</td>
<td>1971-1984 from Lewanika (1989); 1985-1989 estimated by trend through peaks method; 1990-2001, from Chilean Copper Commission</td>
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<td>Production capacity of Canada</td>
<td>Thousand tons</td>
<td>1971-1984 from Lewanika (1989); 1985-1989 estimated by trend through peaks method; 1990-2001, from Chilean Copper Commission</td>
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<td>Annual average LME price of grade A copper cathode in Australian currency and real terms</td>
<td>Australian dollars/Lb</td>
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<td>Annual average LME price of grade A copper cathode in Canadian currency and real terms</td>
<td>Canadian dollars/Lb</td>
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<td>Consumer price index of Canada</td>
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<td>Wons/Lb</td>
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<td>Million people</td>
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<td></td>
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<td>issues)</td>
</tr>
<tr>
<td>$pqper_t$</td>
<td>Primary production of Peru</td>
<td>Thousand tons</td>
<td>Metal Statistics (Metallgesellschaft) (1992-2002 issue, and previous</td>
</tr>
<tr>
<td></td>
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<td>issues)</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
<td>Unit</td>
<td>Source</td>
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<td>---------</td>
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</tr>
<tr>
<td>$pq_{rw_i}$</td>
<td>Primary production of the rest of the world</td>
<td>Thousand tons</td>
<td>Metal Statistics (Metallgesellschaft) (1992-2002 issue, and previous issues)</td>
</tr>
<tr>
<td>$pq_{tot_i}$</td>
<td>Total primary production</td>
<td>Thousand tons</td>
<td>Metal Statistics (Metallgesellschaft) (1992-2002 issue, and previous issues)</td>
</tr>
<tr>
<td>$pq_{us_i}$</td>
<td>Primary production of the United States</td>
<td>Thousand tons</td>
<td>Metal Statistics (Metallgesellschaft) (1992-2002 issue, and previous issues)</td>
</tr>
<tr>
<td>$prw_{-1_i}$</td>
<td>Annual average LME price of grade A copper cathode in US dollars and real terms</td>
<td>US$/Lb</td>
<td>Own calculations</td>
</tr>
<tr>
<td>$prw_{-2_i}$</td>
<td>Weighted average of the last three annual average LME price of grade A copper cathode in US dollars and real terms</td>
<td>US$/Lb</td>
<td>Own calculations</td>
</tr>
<tr>
<td>$pspa_i$</td>
<td>Weighted average of the last three annual average LME price of grade A copper cathode in Spanish currency and real terms</td>
<td>Pesetas/Lb</td>
<td>Own calculations</td>
</tr>
<tr>
<td>$ptwn_i$</td>
<td>Weighted average of the last three annual average LME price of grade A copper cathode in Taiwanese currency and real terms</td>
<td>New Taiwan dollars/Lb</td>
<td>Own calculations</td>
</tr>
<tr>
<td>$pus_{-1_i}$</td>
<td>Annual average LME price of grade A copper cathode in US dollars and real terms</td>
<td>US$/Lb</td>
<td>Own calculations</td>
</tr>
<tr>
<td>$pus_{-2_i}$</td>
<td>Weighted average of the last three annual average LME price of grade A copper cathode in US</td>
<td>US$/Lb</td>
<td>Own calculations</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
<td>Unit</td>
<td>Source</td>
</tr>
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<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>$r_{can_t}$</td>
<td>Copper reserves of Canada</td>
<td>Thousand tons</td>
<td>Mineral Commodity Summaries 1971-1992 from United States Bureau of Mines (USBM); Mineral Commodity Summaries 1993-2002 from United States Geological Survey (USGS)</td>
</tr>
<tr>
<td>$r_{chi_t}$</td>
<td>Copper reserves of Chile</td>
<td>Thousand tons</td>
<td>Mineral Commodity Summaries 1971-1992 from USBM; Mineral Commodity Summaries 1993-2002 from USGS</td>
</tr>
<tr>
<td>$r_{ind_{t-1}}$</td>
<td>Copper reserves of Indonesia in the previous period</td>
<td>Thousand tons</td>
<td>Mineral Commodity Summaries 1971-1992 from USBM; Mineral Commodity Summaries 1993-2002 from USGS</td>
</tr>
<tr>
<td>$r_{per_{t-1}}$</td>
<td>Copper reserves of Peru in the previous period</td>
<td>Thousand tons</td>
<td>Mineral Commodity Summaries 1971-1992 from USBM; Mineral Commodity Summaries 1993-2002 from USGS</td>
</tr>
<tr>
<td>$r_{rw_{t-1}}$</td>
<td>Copper reserves of the rest of the world in the previous period</td>
<td>Thousand tons</td>
<td>Mineral Commodity Summaries 1971-1992 from USBM; Mineral Commodity Summaries 1993-2002 from USGS</td>
</tr>
<tr>
<td>$r_{us_{t-1}}$</td>
<td>Copper reserves of the United States in the previous period</td>
<td>Thousand tons</td>
<td>Mineral Commodity Summaries 1971-1992 from USBM; Mineral Commodity Summaries 1993-2002 from USGS</td>
</tr>
<tr>
<td>$s_{d_{t-1}}$</td>
<td>Stock demand (level of inventories at the end of the previous period)</td>
<td>Thousand tons</td>
<td>World Metal Statistics (2003 and previous issues)</td>
</tr>
<tr>
<td>$s_{g_{t}}$</td>
<td>Western world secondary production</td>
<td>Thousand tons</td>
<td>Metal Statistics (Metallgesellschaft) (1992-2002 issue, and previous issues)</td>
</tr>
<tr>
<td>Variable</td>
<td>Description</td>
<td>Units</td>
<td>Source Information</td>
</tr>
<tr>
<td>----------</td>
<td>--------------------------------------------------</td>
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<td>-----------------------------------------------------------------------------------</td>
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<tr>
<td>( ss_t )</td>
<td>Availability of copper scrap</td>
<td>Thousand tons</td>
<td>Own calculations</td>
</tr>
<tr>
<td>( time )</td>
<td>Time trend</td>
<td></td>
<td>1 for 1971, 2 for 1972, ... , 31 for 2001</td>
</tr>
<tr>
<td>( tq_t )</td>
<td>Total primary and secondary production</td>
<td>Thousand tons</td>
<td>Metal Statistics (Metallgesellschaft) (1992-2002 issue, and previous issues)</td>
</tr>
<tr>
<td>( ychn_t )</td>
<td>Industrial production index of China</td>
<td>Index (year 1995=100)</td>
<td>IFS (2003) from IMF</td>
</tr>
<tr>
<td>( yfraf_t )</td>
<td>Industrial production index of France</td>
<td>Index (year 1995=100)</td>
<td>IFS (2003) from IMF</td>
</tr>
<tr>
<td>( yger_t )</td>
<td>Industrial production index of Germany</td>
<td>Index (year 1995=100)</td>
<td>IFS (2003) from IMF</td>
</tr>
<tr>
<td>( yita_t )</td>
<td>Industrial production index of Italy</td>
<td>Index (year 1995=100)</td>
<td>IFS (2003) from IMF</td>
</tr>
<tr>
<td>( yjap_t )</td>
<td>Industrial production index of Japan</td>
<td>Index (year 1995=100)</td>
<td>IFS (2003) from IMF</td>
</tr>
<tr>
<td>( ykor_t )</td>
<td>Industrial production index of South Korea</td>
<td>Index (year 1995=100)</td>
<td>IFS (2003) from IMF</td>
</tr>
<tr>
<td>( ymex_t )</td>
<td>Industrial production index of Mexico</td>
<td>Index (year 1995=100)</td>
<td>IFS (2003) from IMF</td>
</tr>
<tr>
<td>( yrw_t )</td>
<td>Industrial production index of the rest of the world</td>
<td>Index (year 1995=100)</td>
<td>IFS (2003) from IMF</td>
</tr>
<tr>
<td>( yspa_t )</td>
<td>Industrial production index of Spain</td>
<td>Index (year 1995=100)</td>
<td>IFS (2003) from IMF</td>
</tr>
<tr>
<td>( ytwn_t )</td>
<td>Industrial production index of Taiwan</td>
<td>Index (year 1995=100)</td>
<td>IFS (2003) from IMF</td>
</tr>
<tr>
<td>( yus_t )</td>
<td>Industrial production index of the United States</td>
<td>Index (year 1995=100)</td>
<td>IFS (2003) from IMF</td>
</tr>
</tbody>
</table>
APPENDIX B

Results of the Deterministic Dynamic Simulation for Period 1982-1998

Figure B.1
Production Capacity of Australia

KAUS

--- Actual --- KAUS (Baseline)
Figure B.2
Production Capacity of Canada

Figure B.3
Production Capacity of Chile
Figure B.4
Production Capacity of Indonesia
KIND

Figure B.5
Production Capacity of Peru
KPER
Figure B.6
Production Capacity of the United States
KUS

Figure B.7
Production Capacity of the Rest of the World
KRW
Figure B.8
Mine Production of Australia

PQAUS

Figure B.9
Mine Production of Canada

PQCAN

--- Actual  --- PQAUS (Baseline)

--- Actual  --- PQCAN (Baseline)
Figure B.10
Mine Production of Chile

Figure B.11
Mine Production of Indonesia
Figure B.12
Mine Production of Peru

PQPER

Figure B.13
Mine Production of the United States

PQUS
Figure B.14
Mine Production of the Rest of the World
PQRW

Figure B.15
Production of Copper from Old Scrap
SQ
Figure B.16
Demand of China
CONSCHN

Figure B.17
Demand of France
CONSFRA
Figure B.20
Demand of Japan

CONSJAP

Figure B.21
Demand of South Korea

CONSKOR
Figure B.22
Demand of Mexico
CONSMEX

Figure B.23
Demand of Spain
CONSSPA
Figure B.24
Demand of Taiwan

CONSTWN

Figure B.25
Demand of the United States

CONSUS
Figure B.26
Demand of the Rest of the World

CONSRW

Figure B.27
Price of Refined Copper
(Grade A Cathode, London Metal Exchange)

$P$
APPENDIX C

Results of the Stochastic Simulation for the Period 1999-2001
Including the Production Capacity Equations

Figure C.1
Production Capacity of Australia
KAUS ± 2 S.E.
Figure C.2
Production Capacity of Canada
KCAN ± 2 S.E.

Figure C.3
Production Capacity of Chile
KCHI ± 2 S.E.
Figure C.4
Production Capacity of Indonesia
KIND ± 2 S.E.

Figure C.5
Production Capacity of Peru
KPER ± 2 S.E.
Figure C.6
Production Capacity of the United States

KUS ± 2 S.E.

--- Actual --- KUS (Baseline Mean)

Figure C.7
Production Capacity of the Rest of the World

KRW ± 2 S.E.

--- Actual --- KRW (Baseline Mean)
Figure C.8
Mine Production of Australia
PQAUS ± 2 S.E.

Figure C.9
Mine Production of Canada
PQCAN ± 2 S.E.
Figure C.10
Mine Production of Chile
PQCHI ± 2 S.E.

Figure C.11
Mine Production of Indonesia
PQIND ± 2 S.E.
Figure C.12
Mine Production of Peru
PQPER ± 2 S.E.

Figure C.13
Mine Production of the United States
PQUS ± 2 S.E.
Figure C.14
Mine Production of the Rest of the World
PQRW ± 2 S.E.

Figure C.15
Production of Copper from Old Scrap
SQ ± 2 S.E.
Figure C.16
Demand of China
CONSCHN ± 2 S.E.

Figure C.17
Demand of France
CONSFRAN ± 2 S.E.
Figure C.18
Demand of Germany
CONSGER ± 2 S.E.

Figure C.19
Demand of Italy
CONSITA ± 2 S.E.
Figure C.20
Demand of Japan
CONSJAP ± 2 S.E.

Figure C.21
Demand of South Korea
CONSKOR ± 2 S.E.
Figure C.22
Demand of Mexico
CONSMEX ± 2 S.E.

Figure C.23
Demand of Spain
CONSSPA ± 2 S.E.
Figure C.24
Demand of Taiwan

CONSTWN ± 2 S.E.

Actual \hspace{1cm} CONSTWN (Baseline Mean)

Figure C.25
Demand of the United States

CONSUS ± 2 S.E.

Actual \hspace{1cm} CONSUS (Baseline Mean)
Figure C.26
Demand of the Rest of the World
CONSRW ± 2 S.E.

Figure C.27
Price of Refined Copper
(Grade A Cathode, London Metal Exchange)
P ± 2 S.E.
APPENDIX D

Results of the Stochastic Simulation for the Period 1999-2001
Without Including the Production Capacity Equations

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Mine Production of Australia
PQAUS ± 2 S.E.
Figure D.2
Mine Production of Canada
PQCAN ± 2 S.E.

Figure D.3
Mine Production of Chile
PQCHI ± 2 S.E.
Figure D.4
Mine Production of Indonesia
PQIND ± 2 S.E.

Figure D.5
Mine Production of Peru
PQPHER ± 2 S.E.
Figure D.6
Mine Production of the United States
PQUS ± 2 S.E.

Figure D.7
Mine Production of the Rest of the World
PQRW ± 2 S.E.
Figure D.8
Production of Copper from Old Scrap
SQ ± 2 S.E.

Figure D.9
Demand of China
CONSCHN ± 2 S.E.
Figure D.12
Demand of Italy
CONSITA ± 2 S.E.

Figure D.13
Demand of Japan
CONSJAP ± 2 S.E.
Figure D.14
Demand of South Korea
CONSKOR ± 2 S.E.

Figure D.15
Demand of Mexico
CONSMEX ± 2 S.E.
Figure D.18
Demand of the United States

CONUS ± 2 S.E.

Figure D.19
Demand of the Rest of the World

CONSRW ± 2 S.E.
Figure D.20
Price of Refined Copper
(Grade A Cathode, London Metal Exchange)

$P \pm 2 \text{ S.E.}$

---

Actual

P (Baseline Mean)
APPENDIX E

Update of the Econometric Model of the World Copper Industry

a) Primary Supply

Australia:

\[ pqaus_t = -51.64 + 1.05kaus_t + 0.83t \]

\[ (-4.99) (24.99) (0.85) \]

\[ R^2 = 0.994 \quad \rho_1 = 0.31 \]

\[ (1.81) \]

Canada:

\[ pqcan_t = 311.87 + 0.49kcan_t + 0.87t - 119.03d1can_t \]

\[ (1.84) (3.10) (0.28) (-3.18) \]

\[ R^2 = 0.648 \quad \rho_1 = 0.57 \]

\[ (3.33) \]

Chile:

\[ pqchi_t = -74.76 + 0.96kchi_t + 7.65t \]

\[ (-3.05) (67.80) (3.09) \]

\[ R^2 = 0.999 \quad DW = 1.43 \]
Indonesia:

\[ pqind_t = -16.62 + 0.0008 \text{pind}_t + 1.02 \text{kind}_t \]
\[ (-3.03) \quad (1.44) \quad (171.18) \]

\[ R^2 = 0.999 \quad \rho_1 = 0.38 \]
\[ (2.19) \]

Instruments: \text{kind}, \text{pind}(-1), \text{time}, (\text{erind/piind}), \text{dollar\_index}, \text{ir}, (\text{sd}(-1)/\text{constot}(-1)),
(\text{constot}(-1)/\text{tq}(-1)), c

Where
\[ \text{pind} = p \ast \text{erind} / \text{piind} \]

Peru:

\[ pqper_t = -162.65 + 11.67 \text{pper}_t + 0.79 \text{kper}_t + 9.12t - 39.95d1\text{per}_t \]
\[ (-2.90) \quad (1.93) \quad (13.31) \quad (4.40) \quad (-1.90) \]

\[ R^2 = 0.972 \quad \rho_1 = 0.17 \]
\[ (1.13) \]

Instruments: \text{kper}, \text{d1per}, \text{p}(-1), (\text{erper/piper}), \text{dollar\_index}, \text{ir}, (\text{sd}(-1)/\text{constot}(-1)),
(\text{constot}(-1)/\text{tq}(-1)), c

Where
\[ \text{pper} = p \ast \text{erper} / \text{piper} \]
United States:

\[ pqus_t = -626.89 + 383.52 pus_{-1} + 0.73 kus_t + 24.60 t - 352.86 d2us_t - 135.41 d3us_t, \]

\[ (-3.10) \quad (6.35) \quad (7.06) \quad (8.64) \quad (-6.17) \quad (-2.60) \]

\[ R^2 = 0.884 \quad \rho_1 = 0.30 \]

\[ (2.26) \]

Instruments: \( kus, d1us, d2us, d3us, ((p/pius)(-1)), ir, dollar_index, (constot(-1)/tq(-1)), \]

\( (V/pius), (sd(-1)/constot(-1)), c \)

Where

\( pus_{-1} = p / pius \)

Rest of the World:

\[ pqrw_t = 2424.36 + 84.21 prw_{-1} + 0.30 krw_t + 13.22 t \]

\[ (5.94) \quad (1.50) \quad (4.59) \quad (2.01) \]

\[ R^2 = 0.880 \quad \rho_1 = 0.80 \quad \rho_4 = -0.17 \]

\[ (8.22) \quad (-1.85) \]

Instruments: \( krw, ppius, time, dollar_index, ir, (sd(-1)/constot(-1)), (constot(-1)/tq(-1)) \)

\( yrsa, eraus, c \)
b) Secondary Production

\[ s_{t} = 1224.94 + 381.94p_{t} + 0.0005ss_{t} - 4486.10(sq / ss)_{t-1} \]

(3.87) (3.87) (0.10) (-1.48)

\[ R^{2} = 0.850 \quad \rho 1=0.72 \]

(5.16)

Instruments: ss, (sq(-1)/ss(-1)), p(-1), (sd(-1)/constot(-1)), dollar_index, ir, t, (constot(-
1)/tq(-1)), c

c) Demand

China:

\[ conschn_{t} = 400.09 - 76.83pchn_{t} + 14.68ychn_{t} + 0.23(d1chn * ychn) \]

(2.04) (-3.36) (12.49) (0.28)

\[ R^{2} = 0.977 \quad \rho 1=0.62 \]

(4.29)

Instruments: ychn, time, pchn, dollar_index, (sd(-1)/constot(-1)), pchn(-1), c

Where

\[ pchn_{t} = 0.25 \times ((p_{t} * erchn_{t}) / pichn_{t}) + 0.25 \times ((p_{t-1} * erchn_{t-1}) / pichn_{t-1}) + 0.5 \times ((p_{t-2} * erchn_{t-2}) / pichn_{t-2}) \]
France:

\[ consfra_t = -25.76 + 4.67 \text{yfra}_t + 1.72t \]

(-0.18) (2.58) (0.64)

\[ R^2 = 0.909 \quad \rho 1=0.72 \]

(5.62)

Germany:

\[ consger_t = -435.75 + 14.44 \text{yger}_t - 1.78t \]

(-1.66) (4.01) (-0.36)

\[ R^2 = 0.908 \quad \rho 1=0.54 \]

(3.27)

Instruments: \text{yger, t, pger(-1), (eger/piger), dollar_index, ir, (sd(-1)/constot(-1)), (constot(-1)/tq(-1)), c}

Where

\[ pger_t = 0.25*\left(\frac{P_t \times eger_t}{piger_t}\right) + 0.25*\left(\frac{P_{t-1} \times eger_{t-1}}{piger_{t-1}}\right) + 0.5*\left(\frac{P_{t-2} \times eger_{t-2}}{piger_{t-2}}\right) \]

Italy:

\[ consita_t = -247.54 - 0.02 \text{pita}_t + 5.24 \text{yita}_t + 11.24t \]

(-1.03) (-1.86) (5.33) (1.78)

\[ R^2 = 0.986 \quad \rho 1=0.91 \]

(15.13)
Instruments: \( yita, t, p(-1), (erita/piita), dollar\_index, (sd(-1)/constot(-1)), c \)

Where

\[
pita_i = 0.5\left( \frac{p_i * erita_i}{piita_i} \right) + 0.25\left( \frac{p_{i-1} * erita_{i-1}}{piita_{i-1}} \right) + 0.25\left( \frac{p_{i-2} * erita_{i-2}}{piita_{i-2}} \right)
\]

Japan:

\[\text{consjap}_i = 684.00 - 1.20 \text{pjap}_i + 15.94 \text{yjap}_i - 31.04 t\]

\[
\begin{array}{ccc}
(3.75) & (-3.15) & (8.33) & (-5.93)
\end{array}
\]

\[R^2 = 0.860 \quad \rho_1 = 0.28\]

Mexico:

\[\text{consmex}_i = -437.24 - 3.15 \text{pmex}_i + 4.21 \text{ymex}_i + 8.98 t\]

\[
\begin{array}{ccc}
(-1.11) & (-1.53) & (5.96) & (0.82)
\end{array}
\]

\[R^2 = 0.970 \quad \rho_1 = 0.91\]

Instruments: \( ymex, t, pmex(-1), (ermex/pimex), dollar\_index, ir, (sd(-1)/constot(-1)), c \)

Where
\[ p_{mex_i} = 0.25\left(\frac{p_i \cdot ermex_i}{pimex_i}\right) + 0.25\left(\frac{p_{i-1} \cdot ermex_{i-1}}{pimex_{i-1}}\right) + 0.5\left(\frac{p_{i-2} \cdot ermex_{i-2}}{pimex_{i-2}}\right) \]

South Korea:

\[ conskor_i = 83.92 - 0.03 pko_i + 6.78 yko_i - 8.40 t \]

\[ (1.43) \quad (-1.61) \quad (10.98) \quad (-2.15) \]

\[ R^2 = 0.992 \quad \rho_1 = 0.62 \]

\[ (4.39) \]

Instruments: \( yko, t, pko(-1), (erko/piko), dollar\_index, (sd(-1)/cons\_stot(-1)), ir, c \)

Where

\[ pko_i = 0.5\left(\frac{p_i \cdot erko_i}{piko_i}\right) + 0.25\left(\frac{p_{i-1} \cdot erko_{i-1}}{piko_{i-1}}\right) + 0.25\left(\frac{p_{i-2} \cdot erko_{i-2}}{piko_{i-2}}\right) \]

Spain:

\[ constspa_i = -647.64 - 0.12 pspa_i + 1.81 yspa_i - 33.93 t \]

\[ (-0.20) \quad (-1.87) \quad (4.36) \quad (-0.57) \]

\[ R^2 = 0.972 \quad \rho_1 = 0.54 \quad \rho_2 = 0.50 \]

\[ (3.75) \quad (3.20) \]

Instruments: \( yspa, t, pspa(-1), ir, (sd(-1)/cons\_stot(-1)), c \)

Where

\[ pspa_i = 0.25\left(\frac{p_i \cdot erspa_i}{pspa_i}\right) + 0.25\left(\frac{p_{i-1} \cdot erspa_{i-1}}{pspa_{i-1}}\right) + 0.5\left(\frac{p_{i-2} \cdot erspa_{i-2}}{pspa_{i-2}}\right) \]
Taiwan:

\[ constwn_t = -196.73 + 5.54ytn_t \]

\[ (-1.32) \quad (4.57) \]

\[ R^2 = 0.949 \quad \rho_1 = 0.75 \]

\[ (4.31) \]

Instruments: \( ytn \) \( time \) \( ptwn(-1) \) \( pitwn \) \( dollar\_index \) \( ir \) \( (sd(-1)/constot(-1)) \)

Where

\[ ptwn_t = 0.25*\left(\frac{p_t \cdot ytn_t}{ptwn_t}\right) + 0.25*\left(\frac{p_{t-1} \cdot ytn_{t-1}}{ptwn_{t-1}}\right) + 0.5*\left(\frac{p_{t-2} \cdot ytn_{t-2}}{ptwn_{t-2}}\right) \]

United States:

\[ consus_t = 631.81 - 84.33pus_t + 25.57yus_t - 26.17t \]

\[ (2.40) \quad (-0.91) \quad (7.36) \quad (-2.98) \]

\[ R^2 = 0.843 \quad DW = 1.53 \]

Instruments: \( yus \) \( time \) \( pus\_2(-1) \) \( (1/pius) \) \( dollar\_index \) \( ir \) \( (sd(-1)/constot(-1)) \),

\( (constot(-1)/tq(-1)) \), \( c \)

Where

\[ pus\_2_t = 0.25*\left(\frac{p_t \cdot pius_t}{pitws_t}\right) + 0.25*\left(\frac{p_{t-1} \cdot pius_{t-1}}{pitws_{t-1}}\right) + 0.5*\left(\frac{p_{t-2} \cdot pius_{t-2}}{pitws_{t-2}}\right) \]
Rest of the World:

\[ consrw_i = 2608.65 - 87.08 prw_{-2} + 29.41 yrw_i - 49.02 t \]

\( (4.12) \quad (-0.57) \quad (2.84) \quad (-2.61) \)

\[ R^2 = 0.851 \quad \rho_1 = 0.94 \quad \rho_4 = -0.29 \]

\( (9.65) \quad (-3.57) \)

Instruments: yrw, time, prw_2(-1), dollar_index, ir, (sd(-1)/constot(-1)), pius, yger, c

Where

\[ prw_{-2} = 0.25*(p_i / pirw_i) + 0.25*(p_{i-1} / pirw_{i-1}) + 0.5*(p_{i-2} / pirw_{i-2}) \]

d) Price

\[ p_i = -1.55 - 0.0002 sd_i + 2.70 (constot / tq)_i - 0.005 dollar\_index_i + 0.38 p_{i-1} \]

\( (-2.88) \quad (-3.30) \quad (5.80) \quad (-2.60) \quad (3.46) \)

\[ R^2 = 0.776 \]

Instruments: dollar_index, p(-1), (ir/4), sd_constot(-1), constot_tq(-1), kchi, yger, yus, c
## APPENDIX F

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## APPENDIX G

### Table G.1
Results of the Phillip-Perron Test for Cointegration

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