EFFICIENCY ANALYSIS OF METAL MARKETS

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ABSTRACT

EFFICIENCY ANALYSIS OF METAL MARKETS

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This study analyzes the weak-form efficiency of global metal markets. We focus on both spot metal markets and three-month futures metal markets. To investigate the efficiency of spot metal markets, we examine the producer price index adjusted nominal prices of six base metals (copper, lead, aluminum, nickel, zinc, and tin) and three precious metals (gold, silver, and platinum). In the second chapter, we present a descriptive analysis, price dynamics, and an efficiency discussion about these metals. We apply two stationarity tests to quarterly data in the third chapter. One allows two sharp structural breaks while the other incorporates smooth breaks to the testing framework. Compared with the latter, the stationarity test with two sharp structural breaks captures the turning points better. A possible reason for such a result is the relative poor performance of the smooth break stationarity test in identifying the magnitude and timing of the sharp structural breaks. Except for gold and silver, we present evidence against the efficient market hypothesis with stationarity null accepted for almost all of the specifications considered in this study. Following the analysis of spot metal market efficiency, we concentrate on the futures market efficiency of the same six base metals in the London Metal Exchange in the fourth chapter. Our preliminary results indicate nonstationarity and no cointegration between futures and prompt prices for all six base metals. Therefore, we apply basis and forecast error-based regression approaches to analyze market efficiency. We present evidence against efficiency only for lead and zinc markets.

Keywords: Metals; Structural changes; Market efficiency; Stationarity tests; Futures

ÖZ

METAL PİYASALARININ VERİMLİLİK ANALİZİ

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Bu çalışma, küresel metal piyasalarının zayıf formda verimliliği analiz edilmektedir. Hem spot hem de üç ay vadeli işlem metal piyasalarına odaklanılmaktadır. Spot metal piyasaların verimliliğini analiz etmek için üretici fiyat endeksine göre düzeltilmiş altı ana metal (bakır, kurşun, alüminyum, nikel, çinko ve kalay) ve üç kıymetli metalin (altın, gümüş ve platinyum) nominal fiyatları incelenmiştir. İkinci bölümde söz konusu metallere ilişkin tanımlayıcı bir analiz, fiyat dinamikleri ve verimlilik üzerine bir tartışma sunuyoruz. Üçüncü bölümde çeyreklik veriye iki adet durağanlık testi uygulanmıştır. Bir test iki keskin yapısal kırılmaya izin verirken diğer test kademeli kırılmaları sınama çerçevesine dahil etmektedir. Sonraki teste kıyasla iki keskin yapısal kırılmalı test verideki dönüm noktalarını daha iyi yakalamaktadır. Böyle bir sonucun olası sebebi kademeli kırılmalı durağanlık testinin keskin yapısal kırılmaların büyüklük ve zamanını belirlemedeki görece düşük performansıdır. Altın ve gümüş dışında neredeyse tüm spesifikasyonlarda durağanlık sıfır hipotezinin kabul edilmesi suretiyle etkin piyasalar hipotezine karşı kanıt sunmaktayız. Spot metal piyasaları verimlilik analiz sonrasında dördüncü bölümde aynı altı ana metalin Londra Metal Borsasındaki vadeli işlem piyasalarının etkinliğine odaklandık. Ön hazırlık sonuçlarımız ana metal fiyatlarının hepsinin durağan olmadığı ve vadeli işlem ile vadedeki fiyat arasında eşgüdüm bulunmadığına işaret etmektedir. Bu yüzden bir varlığın gelecek fiyatı ile cari fiyatı arasındaki fark ve kestirim hatası temelli regresyon yaklaşımlarını kullandık. Sadece kurşun ve çinko piyasaları haricinde verimliliğe karşı kanıt sunuyoruz.

Anahtar Kelimeler: Metaller; Yapısal Kırılmalar; Piyasa Verimliliği; Durağanlık Testleri; Vadeli İşlemler

To my family

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LIST OF ABBREVIATIONS

ADF	Augmented Dickey and Fuller (1979)
AIC	Akaike Information Criteria
ARCH	Autoregressive Conditional Heterosedasticity
ARDL	Autoregressive Distributed Lag
ARMA	Autoregressive Moving Average
ARMAX	Autoregressive Moving Average with Distributed Lag
BIC	Bayesian Information Criteria
BM	Base Metals
CBOE	Chicago Board Options Exchange
CME	Chicago Merchantile Exchange
CPI	Consumer Price Index
DF	Dickey and Fuller (1979)
ECM	Error Correction Model
GARCH	Generalized Autoregressive Conditional Heteroscedasticity
GFC	Global Financial Crisis
HAC	Heteroscadasticity and Autocorrelation Consistent
ILZSG	International Lead and Zinc Study Group
ITC	International Tin Council
KPSS	Kwiatkowski et al. (1992)
KPSS-SPC	Kwiatkowski et al. (1992) Test with Sul et al. (2005)
LM	Lagrange Multiplier
LME	London Metal Exchange
LRV	Long-run Variance
MSE	Mean Squared Error
NYMEX	The New York Merchantile Exchange
OLS	Ordinary Least Squares
PM	Precious Metals
PP	Phillips and Perron (1988)

PPI	Producer Price Index
QS	Quadratic Spectral
ROW	Rest of the World
SHFE	Shanghai Futures Exchange
SPC	Sul et al. (2005)
SSR	Sum of Squared Residuals
USD	The United States Dollar
USGS	The United States Geological Surveys
VAR	Vector Autoregression

CHAPTER 1

INTRODUCTION

Metals are exhaustible or non-renewable commodities. As the classification suggests, their supply is limited in the Earth’s crust. Moreover, they are storable and do not disappear by a single use. The metals can be divided into two main categories. These categories are ferrous and nonferrous metals. Ferrous metals typically contain iron. On the other hand, nonferrous metals do not contain iron. We focus on non-ferrous metals. In particular, we concentrate on six base metals, namely copper, lead, aluminum, nickel, zinc, and tin, and three precious metals, namely gold, silver, and platinum.

Based on their characteristics, metals are utilized for industrial and financial purposes. Due to their relative abundance and favorable technical properties, base metals are inputs in industrial production. For instance, copper is the best conductor of heat and electricity among base metals. This characteristic is why it is used in electrical and general engineering sectors. Another example would be aluminum. Aluminum is a lightweight metallic element. This lightweight characteristic encourages its consumption in the transportation industry. Although precious metals have some favorable technical properties, the investment motive generally plays a vital role in shaping the demand for precious metals. Aside from investment motive, safe haven or hedge role, store of value, and specie function typically contribute to the demand. Gold is the typical representative of precious metals. Jewelry production and retail investment compose the majority of the global gold market.

Due to the importance of metals in the macroeconomic framework, the investigation of price dynamics deserves particular emphasis. There has been a great effort to explain the price dynamics of metals. Hotelling’s Rule (Hotelling, 1931:141) argues that the net market price, which is defined as the market price net of the marginal cost of extracting it, should grow at the fixed interest rate under the assumption of free competition. On the other hand, the Prebisch and Singer Hypothesis (Prebisch (1950) and Singer (1950)) states that relative commodity prices, in other words, prices deflated by some type of producer price index, fall. This downward trend is commonly attributed to greater income elasticity demand for manufactured goods than natural resources. However, these are relatively early studies and focus on the expected trend. The price dynamics of metals have drawn more attention than the expected trend in recent studies. Recent studies support the argument that fundamental factors such as supply and demand shocks, either in the short-run or long-run, macroeconomic factors, and uncertainties regarding the demand and supply affect metal prices. Since metals are storable commodities, the level of the inventories has an either intensifying or moderating role on the effects of shocks. High level of metal inventories moderates the impact of shocks on prices (Carter et al., 2011), while low inventories intensify the impact, especially for base metals. In the case of precious metals, the inventory levels are not critical due to their scarcity, investment asset role, and low storage costs relative to their price.

Analyzing price behavior conveys significant information about the efficiency of the relevant resource markets. In essence, the price should reflect the efficiency structure of the market. There are three types of market efficiency, namely weak-form, semi-strong, and strong-form market efficiency. While the price in a strong form efficient market reflects all, either public or non-public, information, the price in a semi-strong form efficient market reflects all available public information. The price in a weak-form efficient market reflects only past prices. Econometrically, if the price series is integrated of order one, the relevant market can be claimed to be weak-form efficient. On the other hand, if it is reported to be stationary, the market can not be stated as a weak form efficient market. Shocks to prices are not short-lived in a weak-form efficient market. Therefore, returns can not be predicted. This condition implies that an investor can not earn abnormal profit by just analyzing the historical prices or implementing technical analysis. Moreover, there is a lack of market forces that equilibrate the market in the long run. However, if a market can not be claimed to be weak-form efficient, prices do not fully reflect past price information in the market. Therefore, incorporating any important nonpublic information may result in excessive profit. Furthermore, shocks to prices are short-lived, implying that there are market forces that bring the market into equilibrium and returns are predictable. It is worth noting that this argument is for spot market efficiency.

Knowledge of the stochastic properties of non-renewable resource prices is not only critical for the evaluation of the efficient market hypothesis, but it is also crucial for forecasting and forming firms’ long and short-term investment decisions and diversification strategies. The literature on the market efficiency of non-renewable resources is relatively thin. When examining the literature for the market efficiency of non-renewable resources, it appears that empirical evidence of earlier studies reveals non-stationary prices and therefore supports the efficient market hypothesis based on conventional augmented Dickey-Fuller (1979) (ADF) and Phillips and Perron (1988) (PP) tests. Recent studies (e.g., Presno et al., 2014) have attributed the nonstationarity finding of the earlier studies to the low power of traditional unit root tests in the presence of structural breaks. Since the seminal paper of Perron (1989), academia has acknowledged that the conventional unit root tests are biased towards falsely accepting the null hypothesis of a unit root when the time series is stationary around a break. However, a procedure that incorporates an exogenous break, as suggested by Perron (1989), may suffer from a pre-test bias. This argument motivates the application of test methods in which breaks are endogenously determined. In empirical work, results support the evidence that prices of the majority of commodities are stationary when the test includes endogenously determined breaks (e.g., Lee et al. (2006) and Presno et al. (2014)).

A futures contract is a standardized contract to buy or sell a particular asset of a predetermined quantity to be delivered at a specified future date. Regardless of the specific asset of the futures contract, e.g., a commodity or foreign currency, futures contracts furnish market participants with some understanding of future spot prices, i.e., price discovery function, and enable short/long hedgers to pass on their risk to speculators, i.e., risk transfer or hedge function. These features attract many researchers to study the efficiency of futures markets.

Analyzing futures market efficiency has been an important research subject since efficient markets do not allow profitable trading strategies between futures and spot markets. There are essential repercussions of futures market efficiency on hedgers, speculators, arbitrageurs, and regulators. In an inefficient futures market, hedgers can not hinge upon the risk transfer role of futures contracts. Therefore, they will be unwilling to buy/sell a futures contract. Thus, they forego lower transactions, faster execution of transactions, and short-selling opportunities in the futures market. Since a speculator is an economic agent who takes the risk of the hedger in exchange for a premium in a futures market, and the hedger is less likely to participate in an inefficient futures market, speculation activity also will fall. However, arbitrageurs will transact to earn riskless profits in an inefficient futures market. The return motive for a speculator and an arbitrageur is different. The speculator seeks a return in exchange for the hedger’s risk. The arbitrageur takes simultaneous market positions to earn profits without taking any risk. Even though regulators do not take any positions in futures or spot markets, they should intervene in the markets with regulations.

The empirical investigation of futures metal market efficiency differs from the spot metal market efficiency. The metal futures market efficiency is commonly inspected by implementing methodologies using both spot and futures metal prices to argue whether futures price is an unbiased predictor of future spot price. The investigation method varies based on the existence of a unit root or cointegration, provided that both futures and prompt prices are non-stationary.

Some studies (Chowdhury (1991), Moore and Cullen (1995), Reichsfeld and Rauche (2011), Arouri et al. (2011, 2013), Cagli et al. (2019), and Kuruppuarachchi et al. (2019)) use cointegration methodologies due to the existence of a cointegrating vector. Moore and Cullen (1995), Reichsfeld and Rauche (2011), Cagli et al. (2019), and Kuruppuarachchi et al. (2019) report the efficiency of base metal futures markets subject to their research. On the other hand, the estimation of regressions in which metal’s futures and prompt price are used directly or indirectly in a single equation. Based on these single equation estimations, Otto (2011), Chinn and Coibion (2014), and Park and Lim (2018) point out the inefficiency of London Metal Exchange (LME) futures markets, while Canarella and Pollard (1986) report the efficiency of LME for copper, lead, tin, and zinc futures markets.

In our study, we focus on the weak-form efficiency of both spot metal markets and three-month futures metal markets. In analyzing spot metal markets, we aim to investigate whether quarterly real prices of copper, lead, tin, nickel, zinc, aluminum, gold, platinum, and silver can be characterized by the efficient market hypothesis or not throughout 1980Q1 and 2017Q1. Following the existing literature, real metal prices are selected to eliminate the potential cyclicality of the exchange rate. Methodologically, unlike most existing studies, we utilize two different stationarity tests, which are modified versions of the conventional KPSS (Kwiatkowski et al., 1992) test. Given that tests with the null of a unit root have low power with stationary but persistent data and cannot reject the null hypothesis of nonstationarity unless there is powerful evidence against it, the market efficiency can be more naturally tested under the null of stationarity, as in Presno et al. (2014). Moreover, following the proposal of Lee et al. (2006) that structural breaks and trends are essential considerations for analyzing stochastic properties of non-renewable natural resource prices, we adopt two different tests to incorporate gradual breaks and to identify sharp breaks in the price series. Given that misspecification of the functional form of the breaks could be as problematic as ignoring the breaks, we consider both smooth and instant breaks.

Following the analysis, we commence with the investigation of the futures markets of six base metals. In our study, we focus on the same six base metals (copper, lead, nickel, zinc, tin, and aluminum) non-overlapping price data to make inferences about the weak-form efficiency of related LME futures markets between the period January 1990 and April 2020. We follow the standard approach in the literature and apply ADF and PP tests. Moreover, the standard KPSS test with the Sul et al. (2005) (SPC) prewhitening procedure to make the test consistent is also applied. Then, we employ the autoregressive distributed lag (ARDL) bounds test of Pesaran et al. (2001), designed to investigate a cointegrating relationship between futures and spot prices. This testing procedure is robust to the integration of order and has some superior features in comparison with Engle and Granger (1987), Johansen (1988), and Johansen and Juselius (1990). Other than its robustness to the integration of order, this procedure does not mandate a large sample for validity, unlike the Johansen cointegration techniques. Furthermore, varying optimal autoregressive orders are allowed for each series in this method. Finally, based on test results, we commence with the examination of futures market efficiency.

The organization of the dissertation is as follows. In the following chapter, we provide details about the demand, supply, and price dynamics of metals and a simple efficiency discussion. Later, we present our analysis regarding the weak form efficiency of spot metal markets. In the fourth chapter, we examine the weak form efficiency of three-month futures metal markets. We end with a brief conclusion.

CHAPTER 2

A CLOSER LOOK AT THE BASE AND PRECIOUS METALS

The second chapter of the thesis aims to present detailed information regarding the main descriptive properties of both base and precious metals, metal price dynamics, and market efficiency, which is investigated by analyzing prices. Base metals are mostly used as industrial inputs for further production or construction rather than investment purposes. Like base metals, precious metals, which are also classified as non-ferrous (i.e., not containing iron) metals, have some industrial usage, for instance, platinum or palladium for autocatalysts. However, industrial usage is limited primarily due to the relatively scarce nature of the precious metals and, therefore, higher prices.

Due to its importance for industrial production, both price indices and individual metal prices have been analyzed empirically in the literature. It has been well documented that real metal prices, particularly base metal prices, are mainly affected by macroeconomic fundamentals such as industrial production, real interest rates, and real exchange rates. In the case of precious metals, due to their limited industrial use, especially gold, industrial production does not seem to be an influential direct factor as much as base metals. However, interest rates and exchange rates should still be emphasized due to the precious metals' financial investment role. There exists strong evidence underlining the nexus between precious metal prices and oil prices, inflation, or risk appetite/economic uncertainty.

Analyzing the price behavior conveys significant information about the efficiency of the relevant resource markets. There are three types of market efficiency, namely weak-form, semi-strong, and strong-form market efficiency. The fundamental distinction between these types is due to the information set available. While the price in a strong form efficient market reflects all, either public or non-public, information, the price in a semi-strong form efficient market reflects all available public information. The price in a weak-form efficient market reflects only past prices. Econometrically, if the price series is integrated of order one, the relevant market can be claimed to be weak-form efficient. On the other hand, if it is reported to be stationary, the market can not be stated as a weak-form efficient market.

Early studies focus on other relatively simple methodologies to infer whether metal markets are efficient or not. Some of these methodologies are such as runs, autocorrelation, variance ratio tests, etc. Just like stationarity analysis, a runs test or a variance ratio test suggests serial dependence or predictability of a price or return series. In simple terms, serial dependence violates the efficiency of the relevant market. Furthermore, these tests have more limitations compared to stationary analysis. For instance, a runs test considers only the sign of deviation from the mean but not the magnitude. Unlike stationary or unit root tests, other tests mainly did not evolve in a way that included the possibility of structural changes such as smooth or sharp breaks.

The remainder of the chapter is organized as follows. The first section presents a descriptive analysis of some selected metals. The second section elaborates on the price dynamics of the metals. The penultimate section discusses the efficiency concepts. The last section concludes.

2.1. Descriptive Analysis of Selected Metals

Generally, unlike agricultural commodities, metals are classified as exhaustible or non-renewable commodities. Like any non-renewable resource, finite stocks of metals are present in the Earth’s crust. Moreover, on the contrary to fuel or energy commodities (e.g., oil, natural gas), they do not perish by a single use. In terms of storability, in contrast to commodities such as electricity, metals are storable commodities. There is a pronounced discrepancy between labor and capital manufactured by labor and non-renewable resources such as metals. This discrepancy originates from the limited supply of all metals existing in the Earth’s crust (Slade et al., 1993). This limited supply, storability, and technological advancements motivate the recycling or secondary production of metals, which saves energy compared to primary production or ore production.

It is common to divide metals into two groups, namely ferrous and non-ferrous metals. A typical ferrous metal (e.g., steel, cast iron) contains iron. Ferrous metals are quite abundant relative to non-ferrous metals. Expectedly, a generic non-ferrous metal does not contain iron. Moreover, non-ferrous metals can be categorized into three sub-groups, namely base metals (copper, lead, zinc, tin, nickel, aluminum), precious metals (gold, silver, platinum, palladium), and noble metals (gold, silver, osmium, iridium, rhodium). A distinctive feature of noble metals is their resistance to oxidation. On the other hand, base metals are relatively inexpensive and mostly used for industrial purposes. A typical precious metal has a much higher price due to its relative scarcity. Furthermore, those metals have investment, hedge, and safe haven functions in addition to limited industrial purposes. Although all metals’ price dynamics merit detailed study, we restrain our descriptive analysis to base metals, namely copper, lead, zinc, tin, nickel, aluminum, and some precious metals, gold, silver, and platinum, which are covered in the study.

2.1.1. Base Metals

Base metals, classified as non-ferrous metals, are mostly used as industrial inputs for further production rather than investment purposes. Some of these industrial purposes may be listed as construction, electrical equipment, and transportation vehicles (e.g., automobiles, airplanes, spaceships). The industrial use of a metal is highly dependent on the special features of that metal. Distinctive technical properties of a base metal have an important role in determining the industrial input function of that particular metal, which in turn affects the demand for the metal. Table 2.1 illustrates the three largest consumption sectors for six base metals based on their consumption shares as of 2008. The information regarding the content of Table 2.1 is obtained from Cuddington and Jerrett (2008:559). Except for aluminum and tin, the largest end-use consumption sectors can be argued to be unique to that base metal and quite concentrated. From an industrial perspective, one metal may be a complement or substitute for another metal to some extent. However, none of these base metals seem to overlap any other in significant amounts.

Base metals have experienced major changes in terms of supply shares after the mid-2000s due to China's fast-growth economic model. Particularly, China has constantly increased both its mine and smelter/ refinery production share of lead, zinc, and tin, especially after the 2000s, and has become the major producer. On the other hand, for nickel, aluminum, and copper, the same development has occurred only for smelter/refinery production. Moreover, China can be labeled as the leading consumer country for all of these base metals. As a result of its consumer role, while metal imports constituted 11 percent of China's merchandise imports, metal exports formed only 1.2 percent of merchandise exports as of 2018. Thus, the fast growth model of China justifies its significant dominance in both demand and supply for base metals to a great extent.

Table 2. 1. The Three Largest Consumption Sectors of Base Metals

Base Metal	**Sectors**
Copper	Building (48%), Electrical (17%), and General Engineering (16%)
Lead	Batteries (71%), Pigments (12%), and Rolled Products (7%)
Aluminum	Transportation (26%), Packaging (22%), and Construction (22%)
Zinc	Galvanizing (47%), Brasse and Bronze (19%), and Zinc Alloying (14%)
Tin	Solders (32%), Tin Plate (27%), and Other (17%)
Nickel	Stainless Steel (65%), Nonferrous Alloys (12%), and Other Alloys (10%)

2.1.1.1. Copper

Copper has been utilized in various uses due to its advantageous features. Some of these features can be listed as being the best conductor of heat and electricity among base metals, antimicrobial, ductility, malleability, and resistance to corrosion. These properties provide an extensive commercial ability to the metal such as automobiles, construction, heat exchangers, electronic products, consumer products, industrial machinery and equipment, transportation equipment, etc. As a result, copper ranks third after iron and aluminum in terms of industrial usage (U.S. Geological Survey, 2013:45).

Specifically, a quite large portion of produced copper is demanded by electrical industries while copper alloys constitute the remaining part (Encyclopaedia Britannica, 2019a). Furthermore, environmental regulations like reducing carbon emissions also contributed to the consumption of copper in the automobile industry, namely in electrical vehicle production (International Copper Study Group hereafter ICSG, 2019). Copper production can be investigated in three phases: mine production, smelter production, and refined metal production. In terms of mine production, there has been a regional shift from North America to Latin America, namely Chile and Peru, depicted in Figure 2.1 and Figure 2.2. On the other hand, Asia, mostly China, has dominance both in smelting and refined copper production after the 2000s (Figure 2.3, 2.4, and 2.5) based on the data from ICSG.

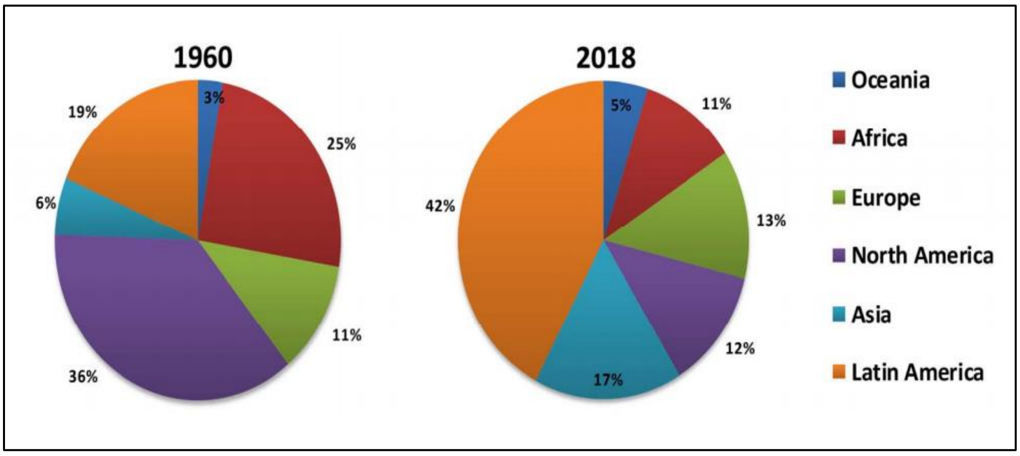

Figure 2. 1. Copper Mine Production by Region

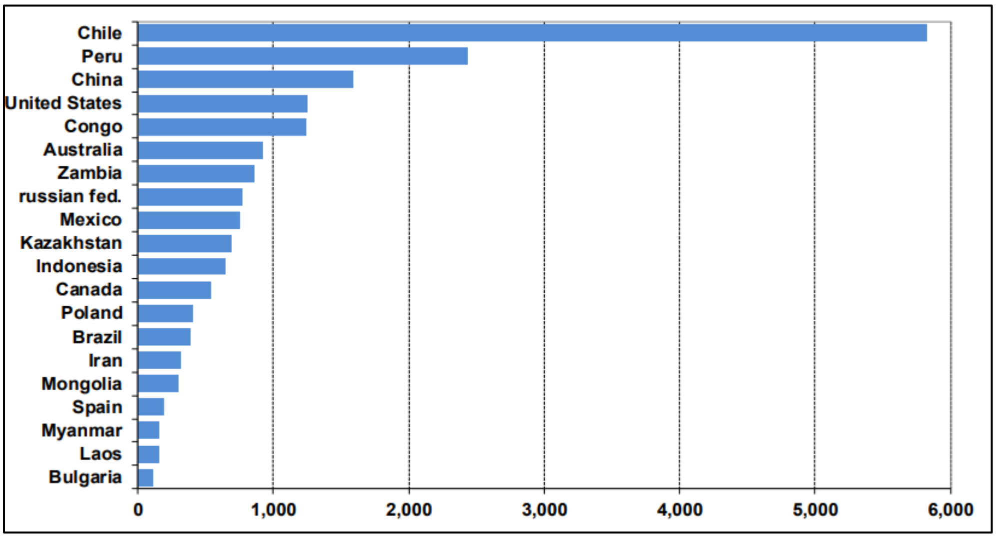

Figure 2. 2. Copper Mine Production by Country as of 2018 (Thousand Metric Tonne)

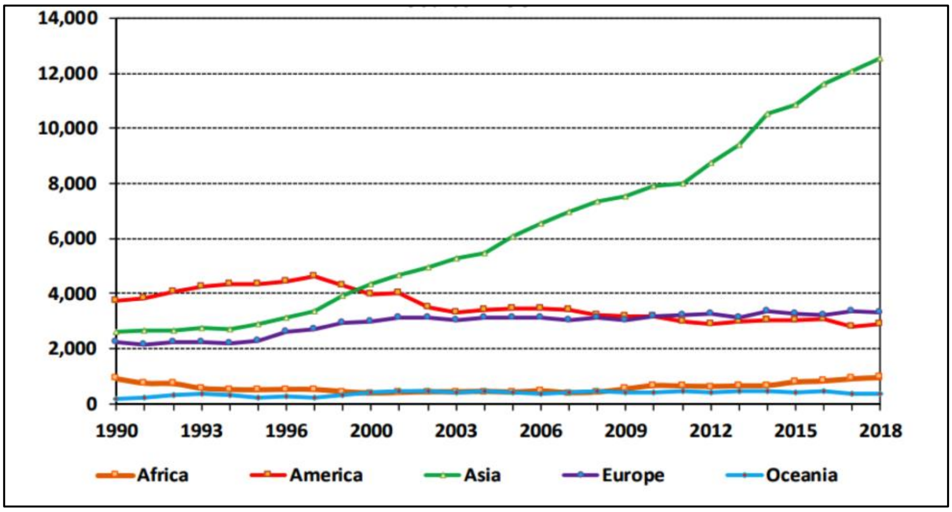

Figure 2. 3. Copper Smelter Production by Region (Thousand Metric Tonne)

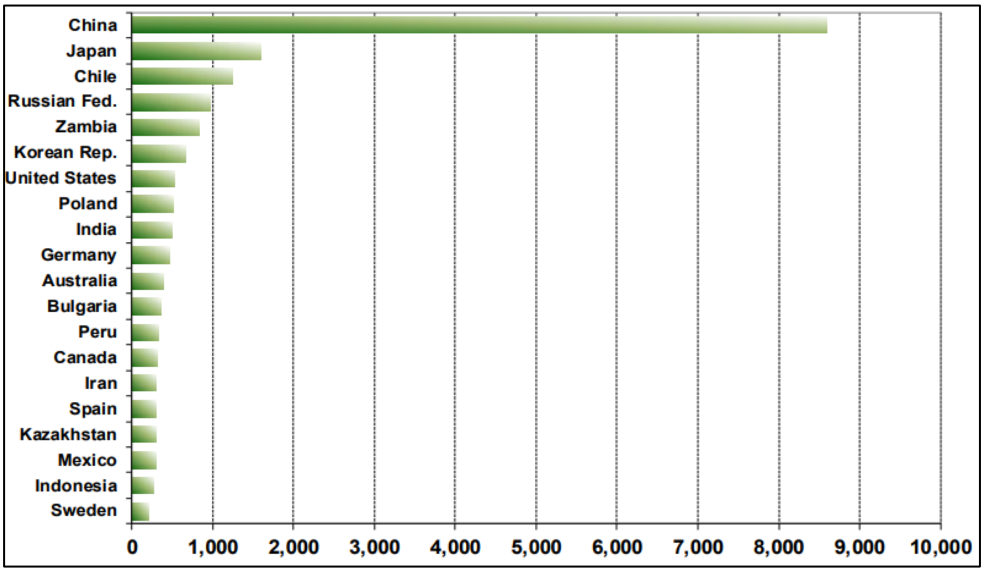

Figure 2. 4. Copper Smelter Production by Country: Top 20 Countries in 2018 (Thousand Metric Tonne)

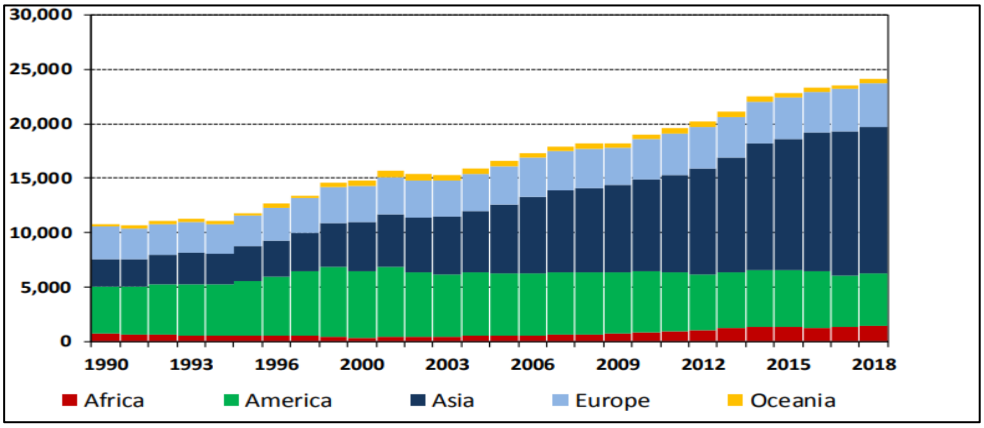

Figure 2. 5. Refined Copper Production by Region (Thousand Metric Tonne)

2.1.1.2. Lead

Similar to copper, lead is also a malleable, ductile, and corosion-resistant non-ferrous metal. However, this dense metal is a poor conductor of electricity. The production of storage batteries has the lion’s share of lead consumption. These storage batteries include vehicle (either electrical or conventional) batteries and emergency power supply batteries. Moreover, its ability to absorb electromagnetic radiation of short wavelengths promotes the usage of the metal as a protective shield around nuclear reactors, particle accelerators, X-ray equipment, and containers used for transporting and storing radioactive materials (Encyclopaedia Britannica, 2019b). These usage areas are mostly related to its feature of being dense. According to the International Lead and Zinc Study Group (ILZSG), the average end use of lead for the last five years is highly concentrated (about 80 percent) on batteries (Figure 2.6).

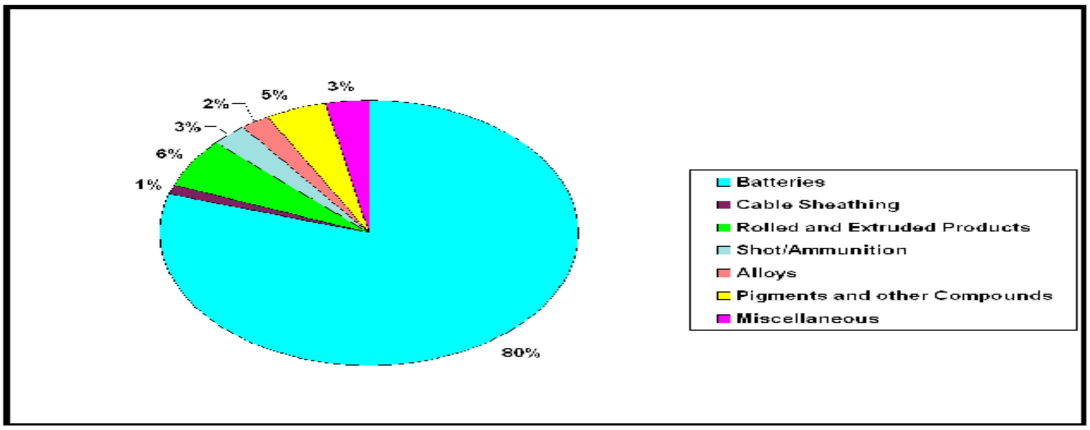

Figure 2. 6. Average End Use of Lead Over Last Five Years

Global mine production experienced a shift after the early 2000s, which was spurred by China, as displayed in Figure 2.7 from the data obtained from the United States Geological Survey (USGS). This is due to the fast growth model of China, depending on the metal-intensive industries. On the other hand, production gradually decreases as a result of China’s new smart growth model. This smart growth model entails shifting from energy-intensive and high-polluting industries to high technology, green energy, and services (Congressional Research Service, 2019:8). Consistently, a similar picture is depicted at the refinery production front (Figure 2.8).

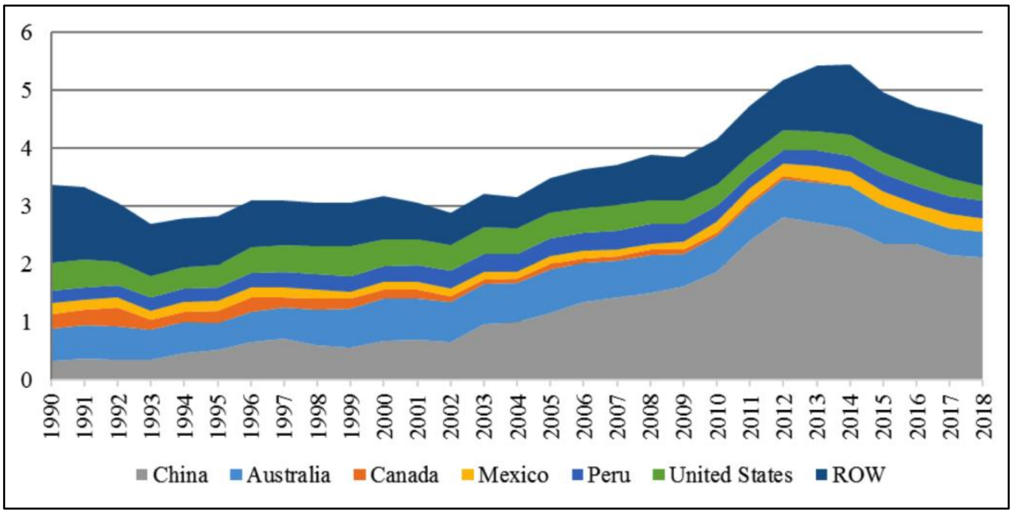

Figure 2. 7. Global Lead Mine Production by Country (Million Tonne)

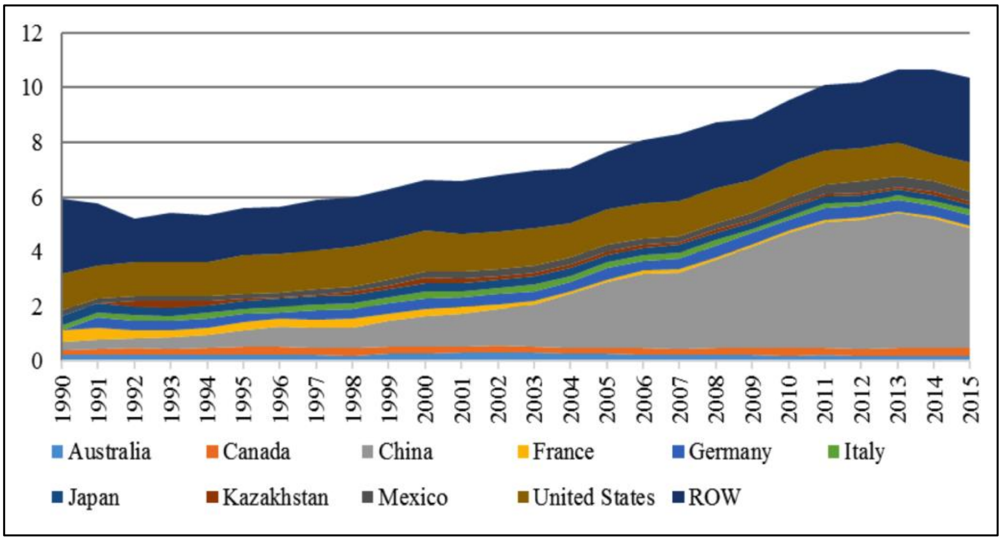

Figure 2. 8. Global Lead Refinery Production by Country (Million Tonne)

2.1.1.3. Aluminum

Among the non-ferrous metals, aluminum has the highest industrial usage in terms of quantity consumed. This high level of industrial usage, especially in transportation and construction, is a result of the special features of aluminum. Other than being the most abundant metallic element in Earth’s crust, aluminum is a lightweight metallic element, which is also an excellent conductor of heat and electricity. Moreover, its density is only about one-third of iron or copper. It is also malleable, ductile, and corrosion-resistant. Aluminum is commercially utilized for aircraft construction, construction, consumer durables, electrical conductors, and chemical and food processing equipment (Encyclopaedia Britannica, 2019c). Its property of being light attracts the automotive industry due to lower fuel consumption and greenhouse gas emissions. Aluminum is never present in metallic form due to its chemical activity. The principal aluminum ore in nature is a mixture of hydrated aluminum oxides, namely bauxite. After bauxite is refined into alumina, aluminum is produced from alumina. Thus, aluminum production should be considered in three stages: bauxite, alumina, and aluminum production. Especially in the refining process, electricity is used intensively. For lower electricity costs, refining facilities are located in places where electricity is relatively cheap. Furthermore, this condition pinpoints the importance of aluminum recycling due to lower energy consumption during the recycling process (Arezki and Matsumoto, 2017). In all three stages, China seemed to shift the production amount to a higher level and became the leading producer based on USGS data (Figures 2.9, 2.10, and 2.11).

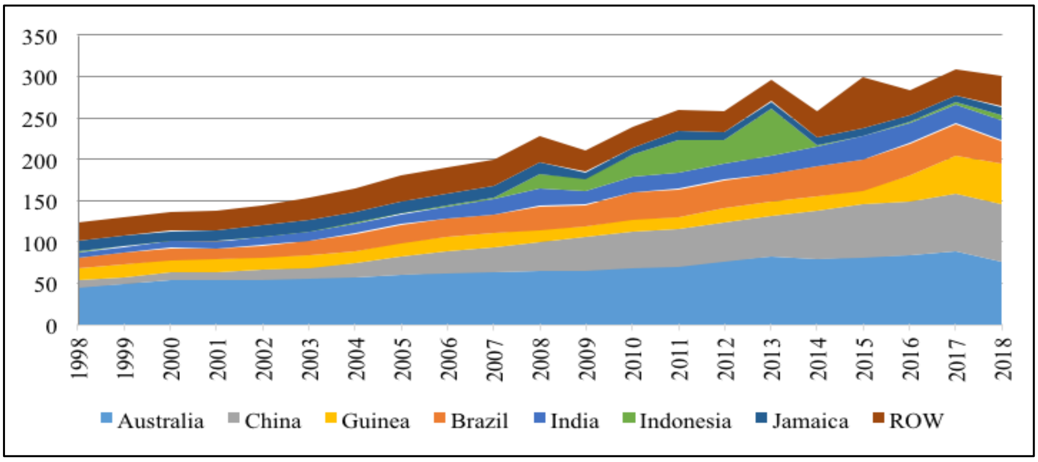

Figure 2. 9. Global Bauxite Production by Country (Million Metric Tonne)

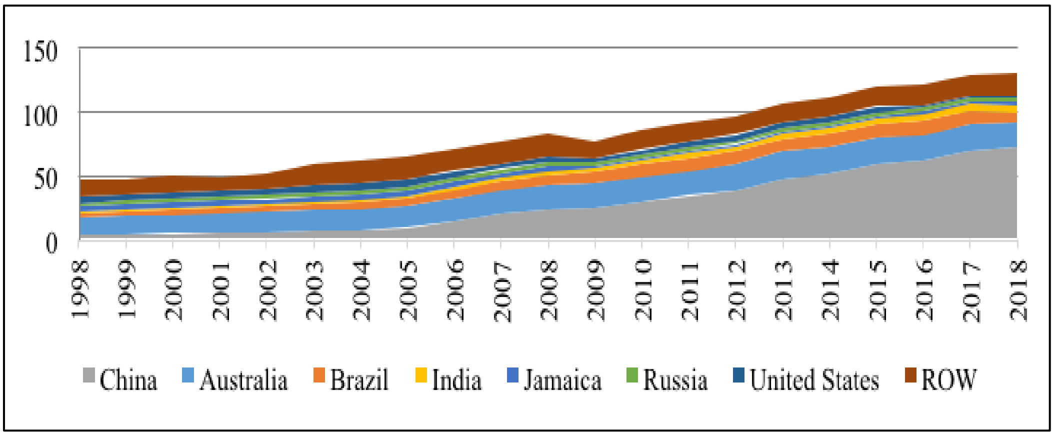

Figure 2. 10. Global Alumina Production by Country (Million Metric Tonne)

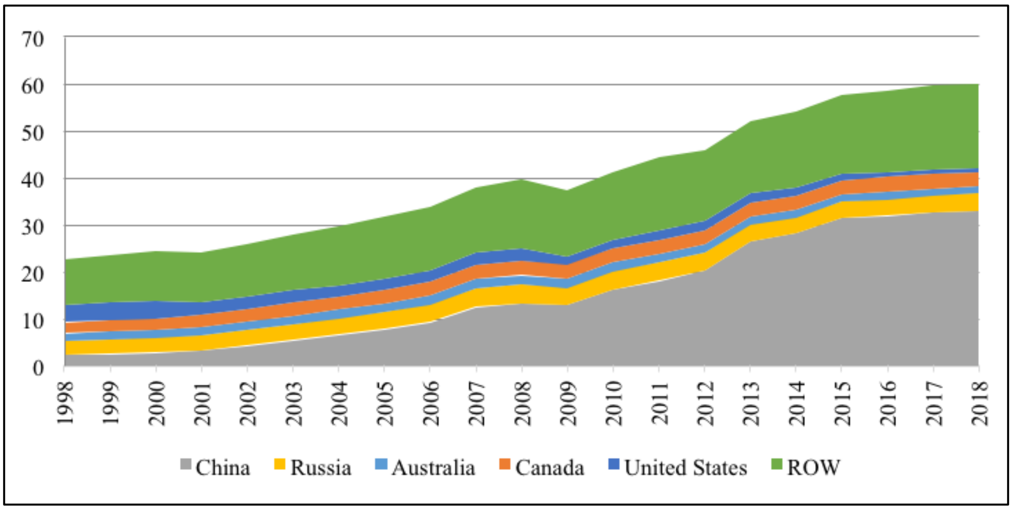

Figure 2. 11. Global Aluminum Production by Country (Million Metric Tonne)

2.1.1.4. Zinc

Zinc has a low melting point. This property eases the galvanizing of iron and steel with zinc. The galvanizing process protects iron and steel against corrosion (Encyclopaedia Britannica, 2019d). Half of the commercial use or demand of zinc is composed of galvanizing purposes, as depicted in Figure 2.12, which is obtained from the ILZSG website. Furthermore, alloys and brass, which share the second rank in commercial use, are utilized in die-casting. Before zinc smelting technology has been discovered, zinc compounds have been produced by smelting copper and lead (USGS, 2012:197).

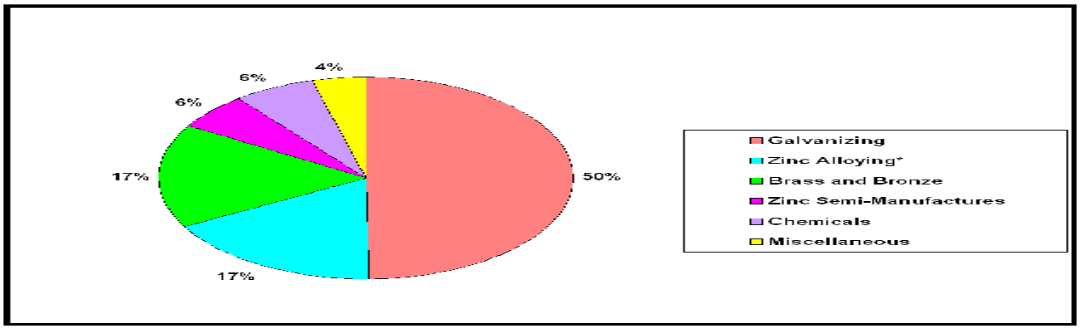

Figure 2. 12. Average End Use of Zinc Over Last Five Years

In terms of global mine and smelter production, similar to tin and lead, China has become the largest producer after the early 2000s (Figures 2.13 and 2.14) based on USGS data.

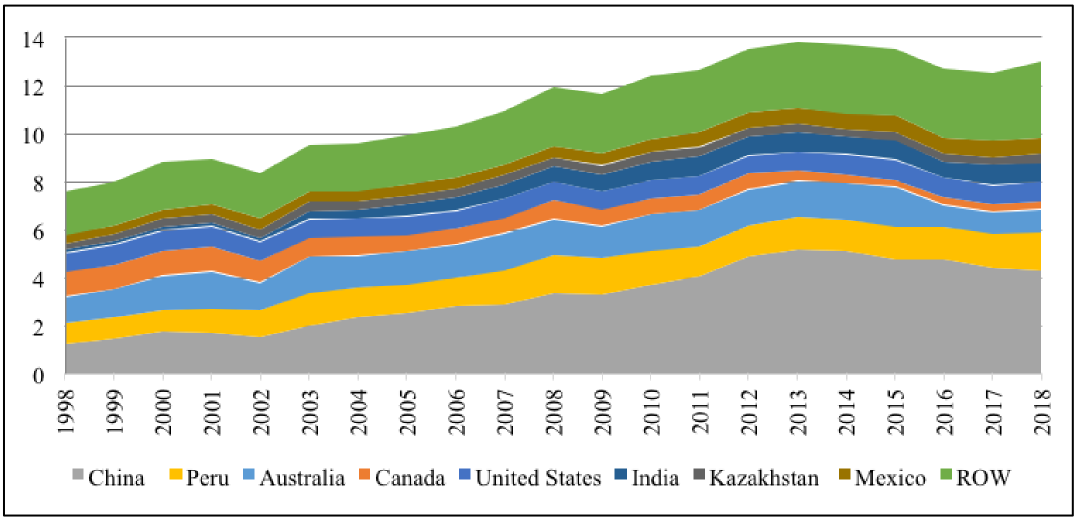

Figure 2. 13. Global Zinc Mine Production by Country (Million Metric Tonne)

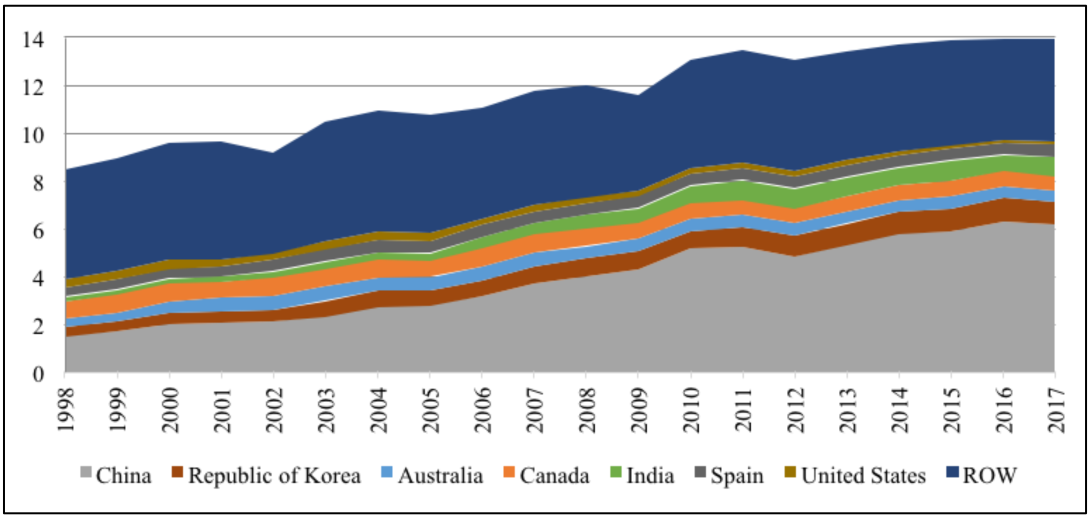

Figure 2. 14. Global Zinc Smelter Production by Country (Million Metric Tonne)

2.1.1.5. Tin

Similar to zinc, tin also has a low melting point. However, it is relatively less abundant compared to zinc. In addition, an invisible protective coating is formed as pure tin is exposed to oxygen in the atmosphere. This characteristic, combined with low melting point and firm adhesion to iron, steel, copper, and copper alloys, provides oxidation resistance. Moreover, it is non-toxic, malleable, ductile, and suitable for all kinds of cold working (Encyclopaedia Britannica, 2019e). Based on the International Tin Association, solder is the primary commercial use of tin (Figure 2.15). Chemicals and tinplates follow as other uses.

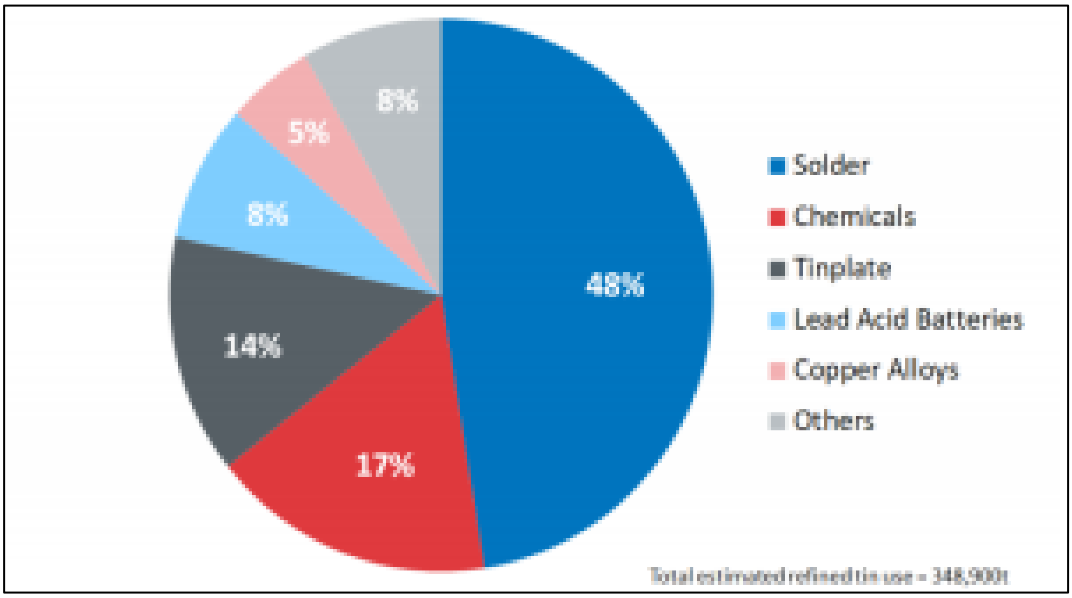

Figure 2. 15. Global Refined Tin Use by Application as of 2016

One observation would be the relatively low-scale production compared to other non-ferrous metals discussed so far. Another one would be the closeness of mine and smelter production displayed in Figures 2.16 and 2.17 based on USGS data. China and Indonesia compose about half of both mine and smelter production. However, countries following these two leading countries vary, as displayed in Figures 2.16 and 2.17. Global tin smelter production displays a relatively stable pattern regarding country contribution.

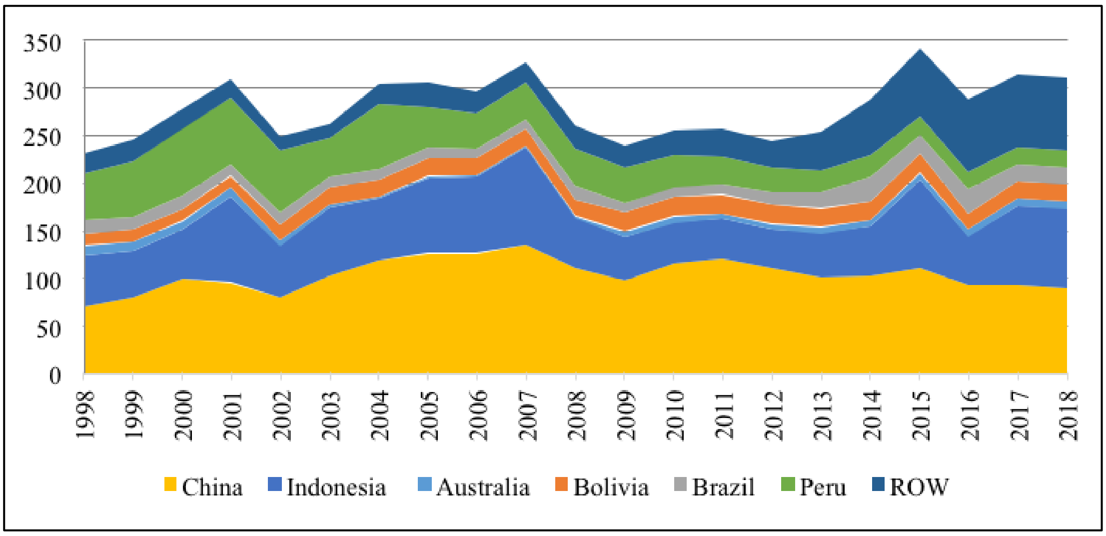

Figure 2. 16. Global Tin Mine Production by Country (Thousand Tonne)

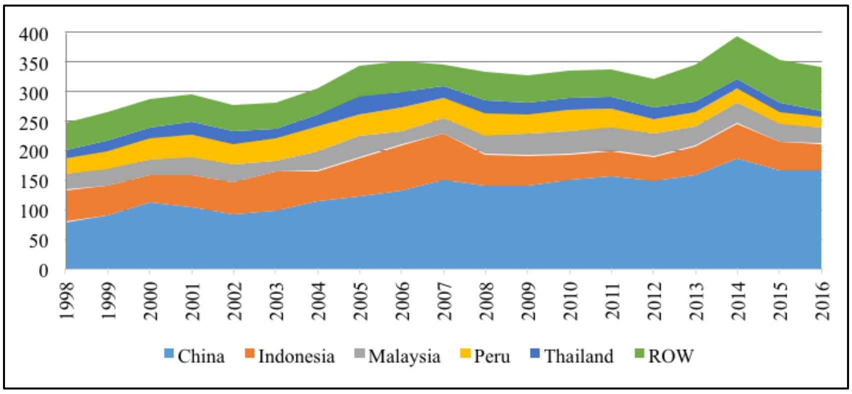

Figure 2. 17. Global Tin Smelter Production by Country (Thousand Tonne)

2.1.1.6. Nickel

Nickel has high electrical and thermal conductivity, similar to copper and aluminum. However, the most pronounced feature of nickel is its high resistance to oxidation and corrosion. Therefore, nickel is mostly used in alloys with iron (stainless steel). Moreover, it is also alloyed with copper (such as monel) for corrosion resistance and with chromium for heat resistance (Encyclopaedia Britannica, 2019f). Due to its favorable properties, nickel is commercially used in jet aircraft engines, guided missiles, space vehicles, high-performance batteries, sub-marines, and petroleum storage facilities (USGS, 2012:105).

While China is the leading country in terms of nickel plant production, its role in mine production is minor (Figure 2.18) based on USGS data. Unlike plant production, mine production generally depicts a relatively balanced view. Although China shifted global nickel production to a higher level after the early 2000s, this increase began to fade away as China lowered plant production (Figure 2.19).

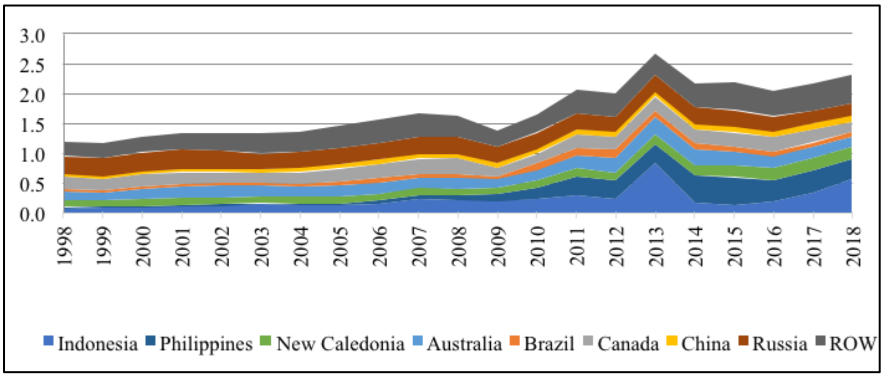

Figure 2. 18. Global Nickel Mine Production by Country (Million Metric Tonne)

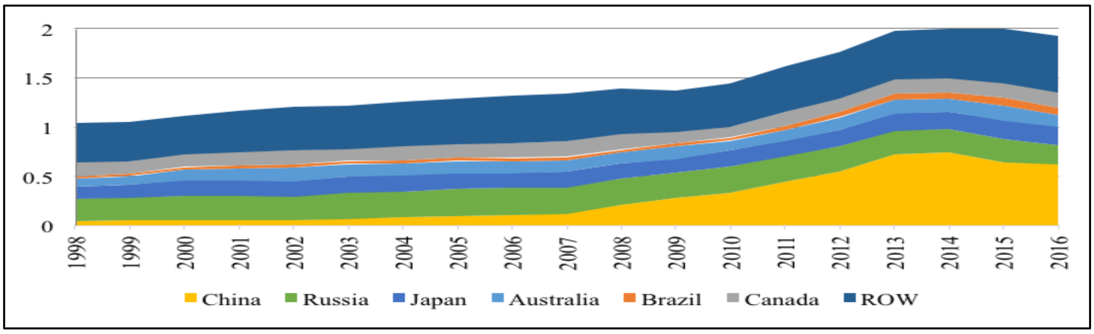

Figure 2. 19. Global Plant Nickel Production by Country (Million Metric Tonne)

2.1.2. Precious Metals

Like base metals, precious metals, which are also non-ferrous metals, have some industrial usage, e.g., platinum for autocatalysts. They are shiny, good electrical conductors, and relatively less reactive. They do not corrode or oxidize easily. Therefore, they are popularly used for jewelry. However, this industrial usage is limited due to the relatively scarce nature of the precious metals. The scarce nature triggers additional functions such as investment demand, safe haven or hedge role, store of value, and specie function. The merit of using precious metals as currency lies in the rarity, divisibility, and lack of corrosion underlined by Vigne et al. (2017). Due to the scarcity of precious metals, demand seemed to change more relative to supply. On the other hand, the same scarcity potentially eases the dramatic price effect, especially in the short run, of a sudden supply shock such as labor disputes or transportation problems. In terms of volatility, there is evidence that gold leads the precious metal markets. For instance, Sensoy (2013) reports uni-directional contagion volatility influence on silver, platinum, and palladium. The same study also presents results supporting similar effects from silver to platinum and palladium.

Based on a three-year average covering years between 2016 and 2018, China (11%), Mexico (21%), and South Africa (70%) lead the production of gold, silver, and platinum, respectively (International Monetary Fund, 2019:52). As possibly inferred, gold production is comparatively more dispersed, contrary to platinum. Moreover, we can not conclude the dominance of China in terms of precious metals production, with a marked contrast to base metals. In terms of the share of total demand among precious metals studied, while platinum has the highest industrial usage share (63.6

%), gold has the lowest share (7.6 %) based on 2015-17 three-year averages. However, gold has the highest investment demand share (29.7%) and jewelry demand share (52.3%). Similarly, gold is the only precious metal demanded by the official sector (forming 10.% of total demand) during the period 2015-17 on average (International Monetary Fund, 2019:52).

2.1.2.1. Gold

Gold, the most malleable and ductile element, is a good conductor of heat and electricity. It is also one of the densest of all metals. In addition to its favorable properties, it is a global medium of exchange. Due to its softness in its pure form, it is challenging to handle gold for jewelry production. Therefore, gold is alloyed with silver, copper, and a little zinc to produce various shades of yellow gold or with nickel, copper, and zinc to produce white gold (Encyclopaedia Britannica, 2019g).

As displayed in Figure 2.20, based on Gold Fields Mineral Services data, most of the gold supply has originated from mine production. In terms of mine production, Asia, specifically China, seems to be the main actor responsible for increasing global gold mine production (Figure 2.21). O'Connor et al. (2015:191) emphasize the high ratio of gold stock to annual flow. They highlight that only 1 percent of gold stock comes from the new gold supply on yearly basis.

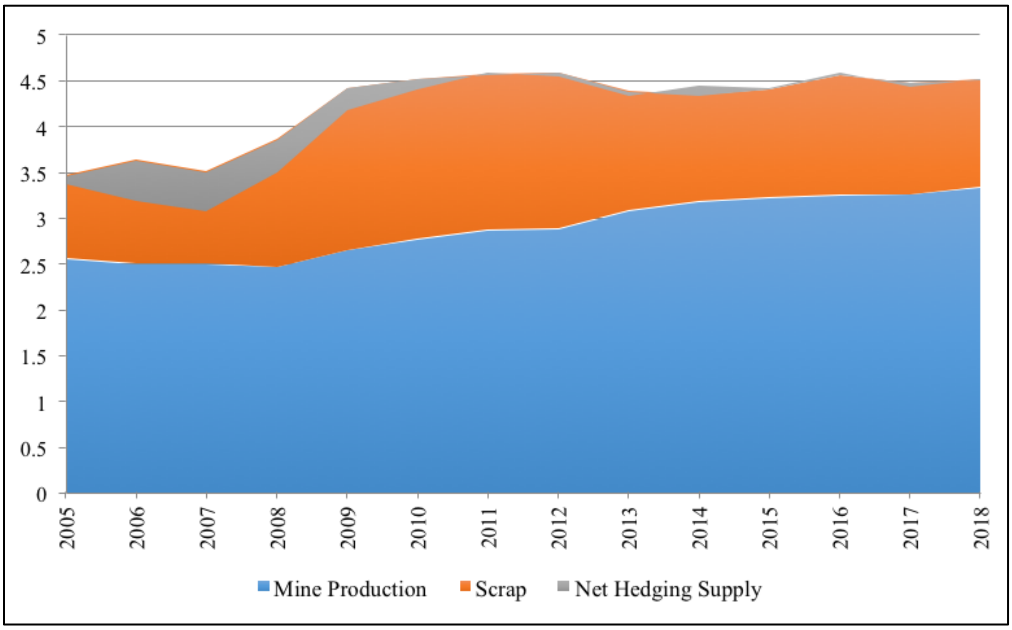

Figure 2. 20. Global Gold Supply (Thousand Tonne)

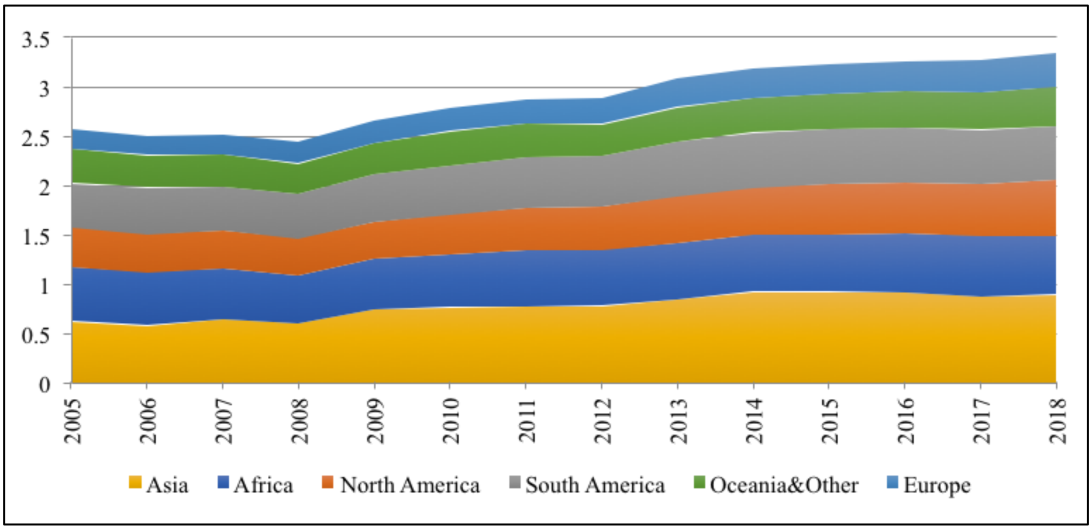

Figure 2. 21. Global Mine Production by Region (Thousand Tonne)

In terms of global demand, the majority of gold demand originates from jewelry and retail investment, approximately 78 % of global demand as of 2018 (Figure 2.22).

The retail investment share has become more pronounced after the Global Financial Crisis (GFC) and European Debt Crisis since gold is prevalently demanded as a hedge or safe haven instrument. In terms of gold fabrication, similar to mine production, Asia has the lion’s share (Figure 2.23). This investment demand also supports the mine production by strengthening the gold price.

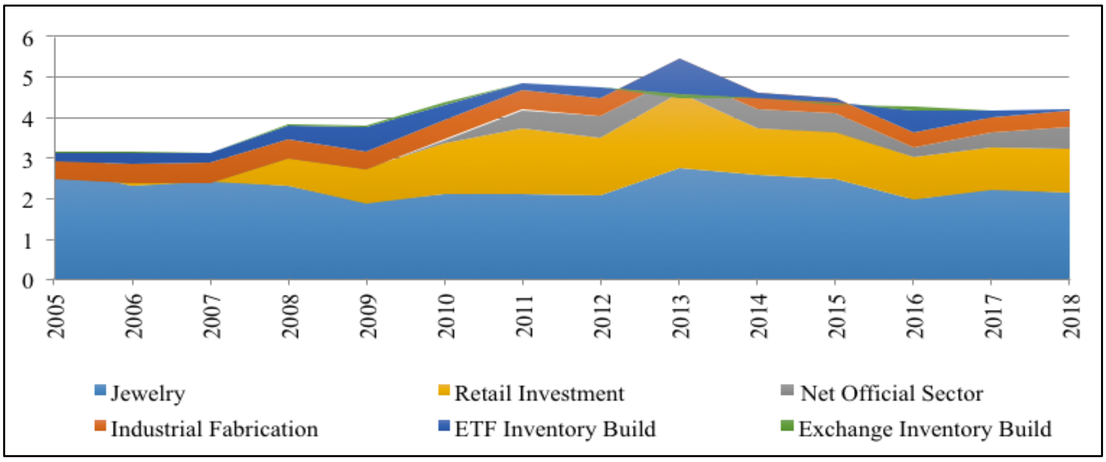

Figure 2. 22. Global Gold Demand by Application (Thousand Tonne)

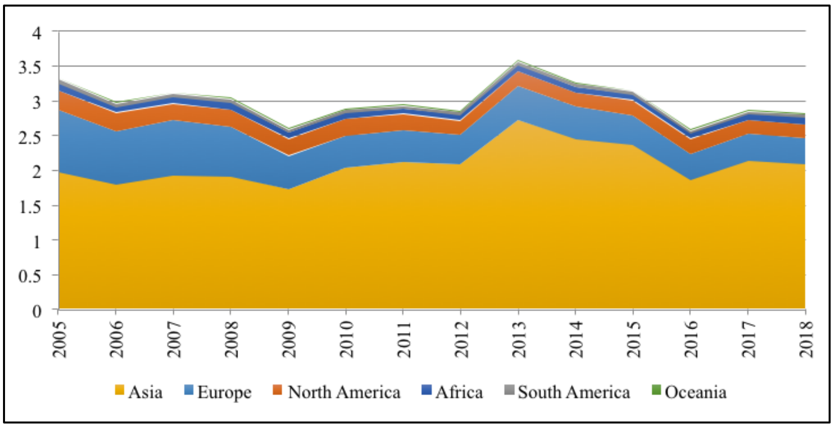

Figure 2. 23. Global Gold Fabrication Demand by Region (Thousand Tonne)

2.1.2.2. Silver

Silver, the greatest conductor of electricity and heat of all metals, is also malleable and ductile. It also has a resistance to atmospheric oxidation. Silver ores are recovered as a by-product of copper and lead production (Encyclopaedia Britannica, 2019h). In the study, we obtain the demand and supply data of silver from World Silver Surveys.

Similar to gold, silver mine production constitutes the majority of the silver supply (Figure 2.24). However, since silver has more industrial usage (especially for the electric industry due to the high electric conductivity of the metal), secondary production originating from old silver scrap also contributes to the silver supply. The distribution of mine production across regions has not changed, at least for the last decade (Figure 2.25). Most of the mine production has been originated from Central (e.g., Mexico) and South America (e.g., Peru).

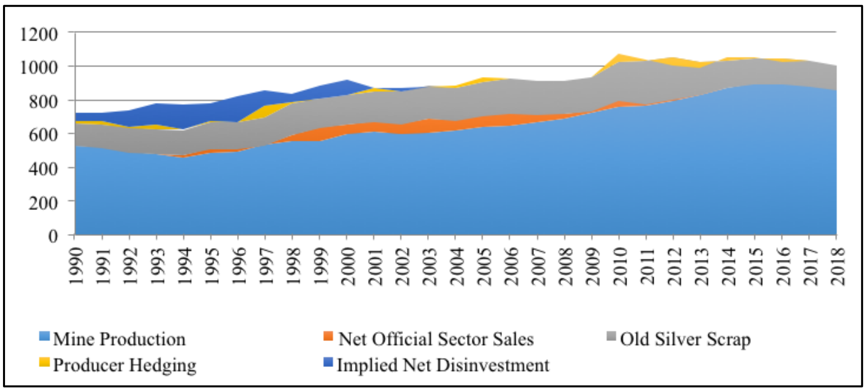

Figure 2. 24. Global Silver Supply (Million Oz)

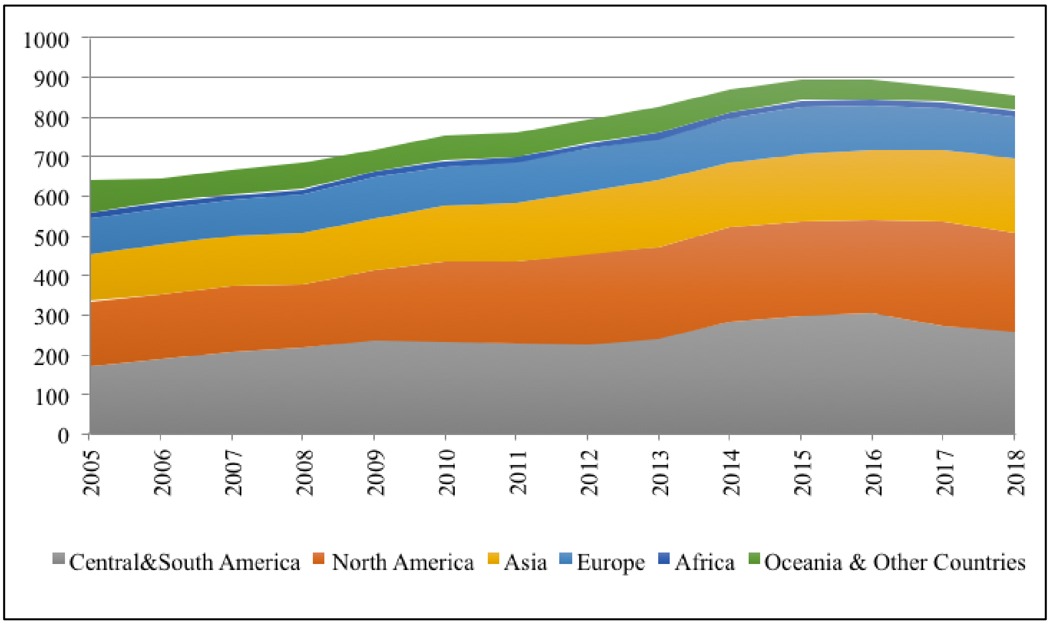

Figure 2. 25. Global Silver Mine Production (Million Oz)

On the demand side, industrial applications and jewelry compose most of the global demand (Figure 2.26). There are instances like the GFC where investment demand has seemed to have compensated for the drop in industrial applications. This compensation is observed in Figure 2.26. Furthermore, Asia has seemed to dominate the silver fabrication demand (Figure 2.27).

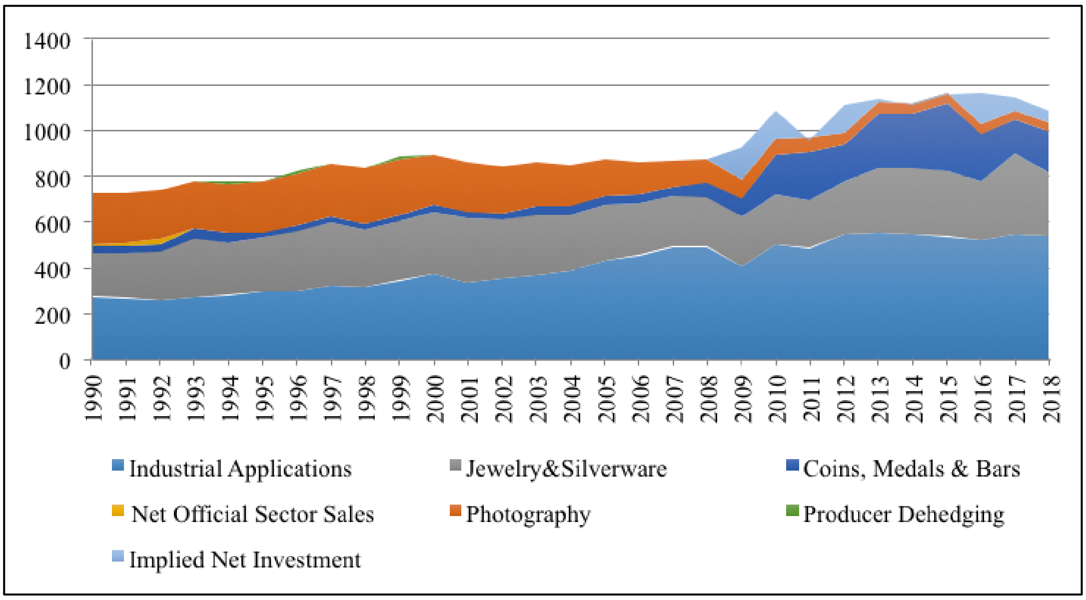

Figure 2. 26. Global Silver Demand (Million Oz)

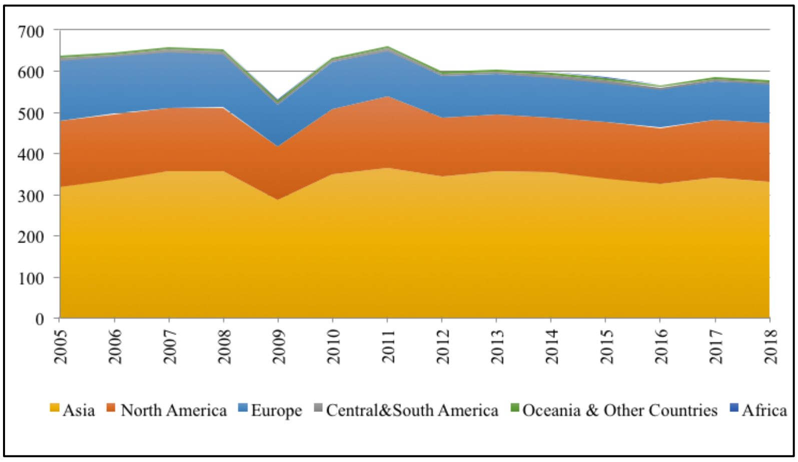

Figure 2. 27. Global Silver Fabrication (Million Oz)

2.1.2.3. Platinum

Platinum, the most prominent metal of platinum-group metals, has a high melting point and good resistance to corrosion and chemical attack (Encyclopaedia Britannica, 2019i). Before it was discovered as a precious metal, it was considered as an obstacle or nuisance for gold mining activities (Vigne et al., 2017). South Africa leads the mine production of platinum (Figure 2.28) based on World Platinum Investment Council data. Moreover, mine production has been mostly concentrated in four countries, namely South Africa, Russia, Zimbabwe, and Canada. Even though mine production has displayed a relatively stable pattern, there also exists sharp supply disruptions like the one in 2014, due to the longest workers strikes in South Africa's platinum mining industry (USGS, 2014:5).

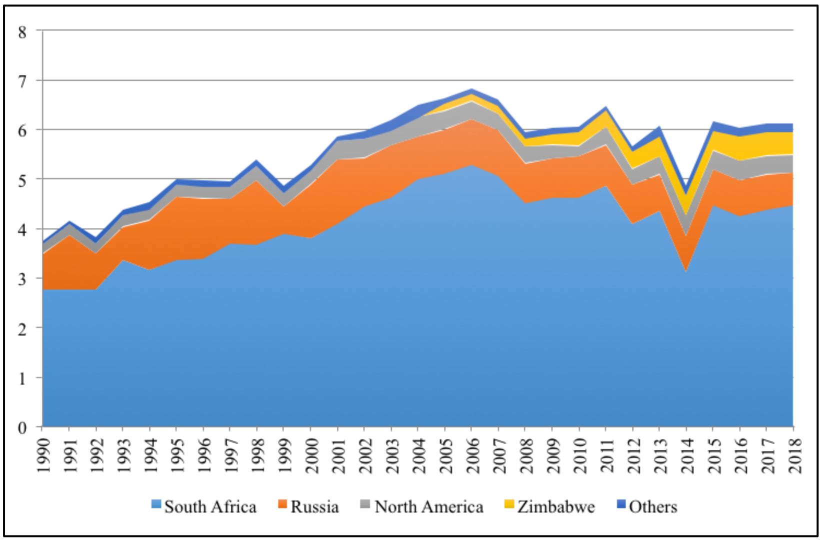

Figure 2. 28. Global Platinum Mine Production (Million Oz)

The regional dispersion of the global platinum demand is relatively balanced, as displayed in Figure 2.29. More than half of the platinum demand has been originated from China and Europe. In terms of global demand, demand for jewelry (12% as of 2018) and autocatalysts (60% as of 2018) constitute the majority (Figure 2.30). Its catalyst property determined the usage of platinum for the production of autocatalysts, which are required for emission control systems, especially for diesel automobiles. Autocatalysts are used to transform environmentally harmful emissions (carbon monoxide, oxides of nitrogen, and hydrocarbons) from automobile exhaust systems into unharmful gases.

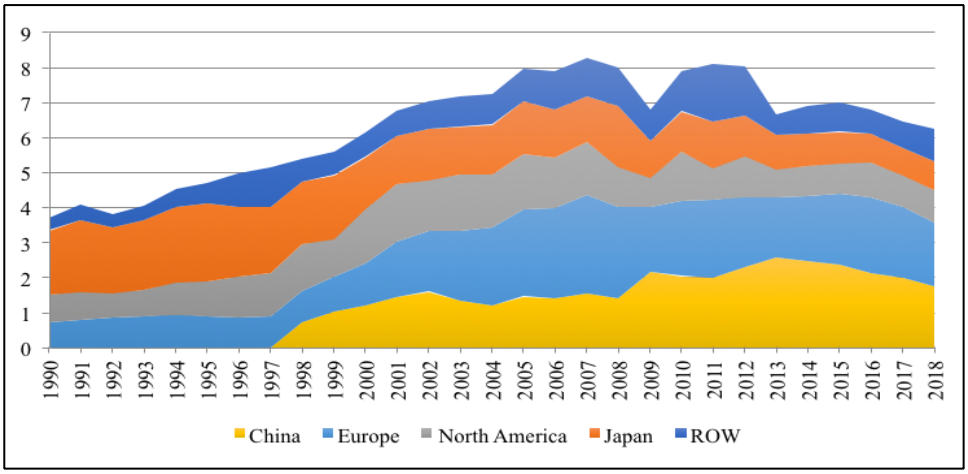

Figure 2. 29. Global Platinum Demand by Country (Million Oz)

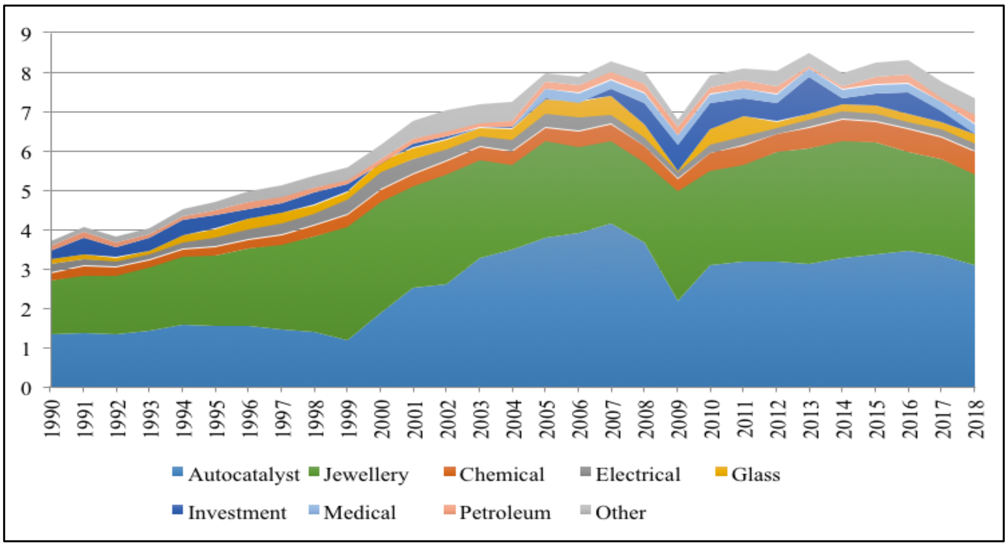

Figure 2. 30. Global Platinum Demand by Sector (Million Oz)

2.2. Price Dynamics of Metals

Based on World Bank data, global ores and metals exports constituted 4.36 percent of merchandise exports and approximately one percent of global GDP as of 2018. One may assert that it represents a small share relative to fuel exports, which formed 13.07 percent of merchandise exports and approximately three percent of global GDP as of 2018. Even though this argument can be claimed to be correct globally in relative terms, the argument can vary significantly on country detail. Some interesting country examples would be Zambia, Chile, Australia, and Peru, whose ores and metals exports cover 77.4, 53.5, 28.3, and 53.5 percent of their merchandise exports, respectively. Depending on the resource abundance of a particular country, large price movements may affect national economies and the global economy by influencing the price of that metal. These price movements may also potentially influence advanced economies through imported input prices of manufactured goods, such as automobiles, batteries, etc.

Starting with the seminal paper of Hotelling (1931), there has been a great interest in academia to explain the dynamics of resources and their effects on countries' economic growth. Some of the prominent seminal papers can be listed as Hotelling (1931), Prebisch (1950) and Singer (1950), Corden and Neary (1982), and Sachs and Warner (2001). Among these studies, we elaborate on the first two studies due to their relevance to resource prices[1]. Hotelling's Rule (Hotelling, 1931) asserts that the net price of a natural resource, defined as the market price net of the marginal cost of extracting it, should grow at the interest rate. On the other hand, the Prebisch and Singer Hypothesis, proposed by Prebisch (1950) and Singer (1950), asserts that relative commodity prices, in other words, prices deflated by some type of producer price index, follow a downward trend. This downward trend is commonly attributed to greater income elasticity demand for manufactured goods than natural resources. The examination of price dynamics is important for natural resources, especially metals, as well as all goods and services. In addition to many determinants, demand and supply developments are the most critical determinants in market economies.

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[1] The other two studies, namely Corden and Neary (1982) and Sachs and Warner (2001), focus on the growth discussions, namely Dutch disease and resource curse, respectively.

Metal prices play an important role for both resource-rich exporting, mostly emerging countries, and metal-importing industrially advanced countries or large emerging countries, like China and India. The immediate approach to analyzing prices would be to focus on demand and supply. Demand and supply conditions for metals are quite different than conventional consumption goods. The demand for a metal is derived, and stock demand. The derived demand refers to the dependence on the demand condition of the final good that the metal is used for. The stock demand can be defined as the inability to be consumed in a single use. As the derived demand property indicates, the metals are considered intermediate goods, which are produced for final goods (USGS, 2006). Mainly, the quantity of produced final goods and the amount of metal used in that final good production determine the demand for the metal (Roberts, 1996). USGS (2006) identifies seven factors driving U.S. mineral demand. These factors are population, consumption, construction, transportation, legislation, consumer choices, and recycling. Expectedly, Humphreys (1991) reports that U.S. metal consumption is mostly related to the durables and engineering sectors. Global cycles, substitutability of a metal with the other(s), technological advances resulting in a new usage area of the metal (e.g., space technologies enwidened the usage area of aluminum), and a sharp price rise can be considered potential factors affecting the demand for the metal. Recently, as metals become more financialized, investment demand has drawn the attention of analysts. This investment motive is highly pronounced for precious metals.

On the other hand, the supply of a metal depends primarily on factors affecting the (both primary and secondary) production or production cost of a metal. Hewet (1929) identifies geology, technology, economics, and politics as the most important factors affecting the production of a metal. Although these factors interact throughout history, production costs seem to be more influential on production. The production cost of a metal mainly includes the extraction and processing costs. The extraction costs are related to the mining of a metal, which is capital-intensive and technically demanding (World Bank, 2006a:16). These costs may fall due to technological advancements. However, on the other hand, as more of the metal is extracted, the marginal cost of extraction may rise due to grade depletion of the resource stock (Gaudet, 2007:1043). This is termed as the degradation cost (Solow and Wan, 1976).

The recycling of metals limits the degradation cost to some extent. Technological improvements (e.g., leaching and hydrometallurgical technologies), labor disputes (e.g., labor strikes in mining countries), industry structure (e.g., the degree of concentration and integration), government regulations (e.g., environmental regulations regarding carbon emissions), taxes (e.g., import or export taxes), political events (e.g., the dissolution of the Soviet Union), and energy or electricity prices (e.g., high electricity usage for processing metal or concentrate such as aluminum) can be listed as some factors affecting these costs. For instance, the price dynamics of copper are generally shaped by production costs and the balance or imbalance between demand and supply, although business cycles, government policy, and technological changes have a significant effect. In addition to the previously mentioned factors, high capital requirements and long lead periods for starting mine production result in a cyclical copper industry (USGS, 2012:46).

In Figure 2.31, we present the natural logarithm of nominal and deflated metal price series. We use two indices alternatively, namely the seasonally adjusted US consumer price index (CPI) for all urban consumers and the seasonally adjusted producer price index (PPI). In the literature, the terminology of deflated prices varies based on the index used for deflation. If nominal prices are deflated by PPI, it is popularly called relative prices. On the other hand, if they are deflated by CPI, they are called real prices. Base metals are presented in terms of USD per metric tonne, while precious metal prices are in terms of USD per troy oz. One metric tonne is approximately 32,150.75 troy oz.

As observed from Figure 2.31, both the natural logarithm of quarterly (end of the quarter) base metals' (largest exporters) and selected precious metals' (London afternoon fixing) prices seem to co-move in their own category. There are also some common movements across categories. Possible explanations of comovements can be listed as common demand and supply shocks and/or contagion of demand and supply shocks specific to a metal among metal markets (Labys et al., 1999). As an example of common demand shock, the GFC weakened the metal prices pronouncedly, except for gold. This weakening was mainly due to sluggish industrial demand.

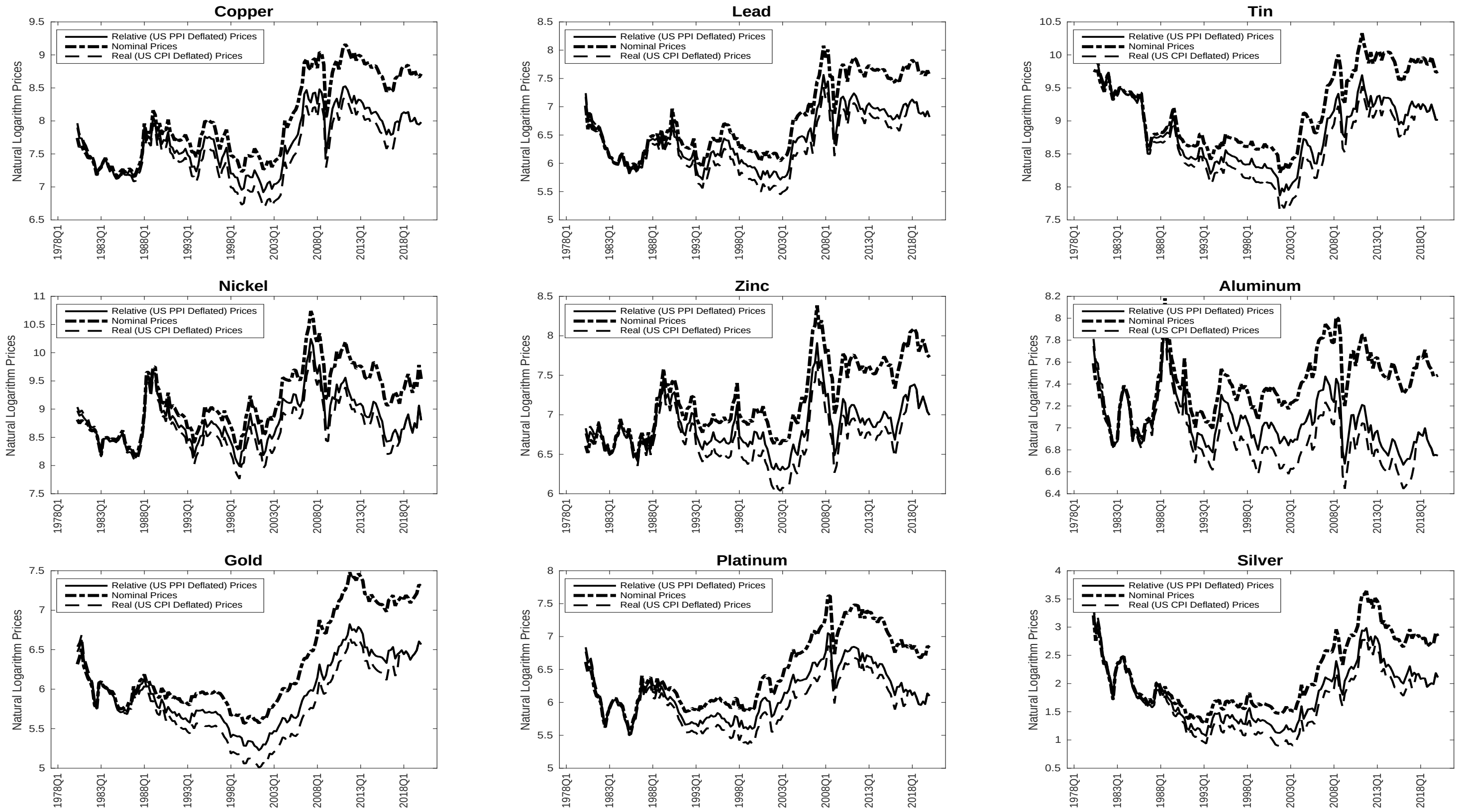

Figure 2. 31. Natural Logarithm of Base and Precious Metal Prices

Although relative and real metal prices behaved in a similar fashion to a great extent, as displayed in Figure 2.31, they are different conceptually. As articulated by Cuddington and Jerrett (2008:561), if a financial investor is interested in the metal sector, (s)he would probably care about real or CPI-deflated prices. On the other hand, if a mining company is assessing the profitability of the metal production process, its focus would be on relative or PPI-deflated prices.

Like the price of any good, metal prices are affected by fundamental factors such as demand and supply shocks, either in the short-run or long-run. In addition, the level of inventories may influence the magnitude of the shock. High level of metal inventories moderates the effect of shocks on prices (Carter et al., 2011), while low inventories intensify the impact, especially for base metals. However, in the case of precious metals, the inventory levels are not that critical due to their scarcity, investment asset role, and low storage costs relative to their price. Moreover, particularly gold is held as a part of official reserves, mostly by central banks.

Macroeconomic factors, i.e., real interest rates, real exchange rates, and industrial activity, potentially affect metal prices. Lower short-term real interest rates would strengthen metal prices through three channels, as Frankel (2006) suggests. First, low real interest rates may postpone the extraction of metal ores today and reduce the supply. The reason for this result is due to the fall in interest income from the sale of metal ores. The second channel would be the speculators’ preference for spot metal contracts instead of treasury bills since the return from treasury bills is lower. Thus, the metal demand would increase. The third channel is related to the motivation to carry inventories. The incentive to carry inventories is higher since the interest rate or opportunity cost of carrying inventory is lower. This can be perceived as increasing inventory demand. Similarly, the lower real exchange rate or depreciation of denomination currency would positively affect the price of metals. One channel would be that the supplier would be more inclined to reduce supply since the domestic currency equivalence of income would be lower. Another channel would be that the purchasing power of foreign consumers would be higher, resulting in higher demand and prices. On the contrary, industrial activity has a positive effect on metal (especially base metals) prices since it spurs the demand for metals due to their consumption in industrial activities. Slade (1982) attributes the high-income elasticity of prices to the significant consumption of metals in industrial activities.

In addition to macroeconomic influences and demand/supply shocks, uncertainties regarding the demand and supply would also have an effect on metal prices. Slade (1988) exemplifies some uncertainty sources. The uncertainties from demand may originate from a technical change in metal-consuming sectors, cyclical changes in GDP, changes in the price of substitutes and complements, and tariffs implemented by metal-importing countries (advanced countries). On the other hand, supply-side uncertainties may arise from the discovery of new deposits, strikes in the mines, political disruptions, or cartel actions of producing countries.

Unstrikingly, short-run and long-run metal price dynamics are different to some extent. One cause would be the low price elasticity of demand and supply in the short run. Slade (1982) attributes the low price elasticity of supply to the hardship of extending production capacity quickly and at a low cost. Fernandez (2019) reports that there is a two to three-year lagged response of mine production to a real price boom based on monthly real bauxite, copper, lead, nickel, zinc, and tin LME prices between 1995 and 2017. On the other hand, the low price elasticity of demand is related to the fact that metals are intermediate goods, and they cost less in comparison with the price of final output. Given the price unresponsiveness of demand and supply and low inventory levels in the short run, a demand or supply shock may exaggerate prices (Carter et al., 2011). For instance, an unexpected negative supply shock, i.e., a labor strike in a mine, would increase the prices. Since the demand would not adjust in the short run, prices may rise more than expected or may maintain their high levels. On the contrary to the low price elasticity of demand and supply, income elasticity, especially for base metals, is pretty high due to metal consumption directed to industrial activities. These features enable prices to be more exposed to business cycles. Cuddington and Jerrett (2008) argue that business cycles last from six to thirty-two quarters. Although the price elasticity of demand and supply is low in the short run, they are not low in the long run. The main reason would be the sufficiency of time to adjust. Furthermore, there are studies focusing on long-run super cycles lasting between twenty and seventy years in the literature. As

Buyuksahin et al. (2016) state, many economists claim that super-cycles (long-run cycles) occur as a result of a lagged response of supply to the unexpected demand shock. In line with Buyuksahin et al. (2016), Slade (1982) argues that long investment periods possibly lead to super cycles.

Long-run price dynamics are essential, especially for metal miners or producers. The main reasons for the argument are related to the fact that mining activities are capital-intensive, require long lead times, and respond slowly to unexpected demand shocks. These lead times can be up to seven-ten years for recently discovered oil wells and mines (Arango et al., 2012). Once producers increase their output as a response to an unexpected demand shock, it is important for them to rationally manage their quantity supplied during a downswing of a super-cycle to avoid some loss. Therefore, long-run price dynamics draw the attention of academicians relatively more. On the other hand, short-run price dynamics mostly affect speculators' behaviors. Since they just seek to earn profit from their market transactions, speculators give high importance to short-run dynamics. Speculators' activities can be perceived as a part of non-industrial or investment demand. Therefore, precious metals are more exposed to speculators' interest than industrial metals.

Geman (2005: 178) lists some possible factors affecting the movements in the long-run prices of metals. These are denomination currency, variation in demand and supply for risk capital, gradual changes in long-term economics, shocks, and gradual changes in consumption trends resulting from price elasticity of demand. Denomination currency such as the US dollar, Euro, or Pound is claimed to play a significant role in the long-term volatility of prices, apart from economic fundamentals. The second factor acts as a bridge between short-run price and long-run price. The risk capital, i.e., a debt or equity instrument, cost is highly affected by the liquidity position of the borrower. If the spot price of a specific metal is high, the cost of risk capital may fall due to cash income resulting from high spot prices. In turn, this leads to higher investment and then to higher supply in the long run and lower long-run prices. Gradual changes in long-term economics compensate for the smooth movements in production costs, the discovery of new mines, and the usage of existing mines in a planned manner as a result of ongoing effort of research, technological innovations, or investment activities. As a penultimate factor, shocks can be defined as unexpected events arising in production techniques, geopolitics resulting in supply changes, cartel instability, environmental regulations, etc. Given the close substitutability among some metals (e.g., platinum and palladium), an increase in the price of a metal may result in a shift of demand towards the close substitute in the long run.

Arguably, there is some chance that some or all of these factors may also affect short-run dynamics. For instance, with the help of structural vector autoregression (VAR) methodology, Wang and Wang (2019) report the variance of base metals' prices to be significantly explained by exchange rates based on monthly data between January 1999 and June 2016. Another example is the study by Jacks and Stuermer (2016). Using the same methodology as Wang and Wang (2019), Jacks and Stuermer (2016) analyze annual real commodity prices, including copper, lead, tin, and zinc, for the period between 1870 and 2013. They identify three shock types, namely global demand shocks, commodity supply shocks, and remaining inventory, or other demand shocks. They report the positive effect of global demand, inventory, and other demand shocks and the negative effect of a commodity supply shock. Moreover, the authors find evidence supporting the dominance of demand shocks on supply shocks. However, they document the significant effect of commodity supply shocks lasting up to five years in sugar and tin markets. Furthermore, this result is attributed to oligopolistic market structure and cartel agreements in these markets. In general, they conclude that commodity supply shocks just lead to short-run fluctuations.

Studies focusing on indices should be interpreted with caution since they may be exposed to different criteria for aggregation or weighting. However, they can still provide useful insights. For instance, Grilli and Yang (1981) implement quarterly and annual analyses based on monthly average indices of agricultural food products, agricultural non-food products, and base metals between 1948 and 1980, individually. The authors model relative price indices by employing a single equation. The annual relative indices are specified to be determined by industrial production, time trend (as a proxy for technology or other change), and world liquidity indicators (e.g., the share of liquidity held in private hands). The positive effects of both the industrial production and the world liquidity indicator and the negative effect of the time trend effect are reported. They argue that non-industrial or speculative demand and developments related to physical availability (e.g., labor disputes and security problems related to transportation) also gain economic significance in the short run. Therefore, they incorporate the interest rate (i.e., the Eurodollar rate in London) and the coefficient variation of the US dollar and the Deutsche Mark exchange rate as a proxy for exchange rate instability in the short-run regression. They present evidence supporting the negative effect of interest rates and the positive effects of business cycle indicators and exchange rate instability on the relative metal price index.

Similar to Grilli and Yang (1981), Carmen and Borensztein (1994) utilize a single equation model. They extend the “traditional structural approach” to the determination of real commodity prices, which is based on demand factors, by incorporating the supply factor. In addition to demand factors such as industrial production and real exchange rates, they include the non-oil import volume of industrialized countries as a proxy for non-oil commodity supply in regression. The authors study quarterly nominal IMF non-oil commodity price index deflated by US GNP deflator between 1970Q1 and 1992Q3. They find the negative effects of positive supply shocks and out-of-sample forecast improvements when the supply is taken into consideration.

Erten and Ocampo (2012) consider annual index data between 1865 and 2010. They report that the metal price index does not experience as strong and steep downward long-term trends as agricultural indices. Akram (2009) examines, among other indices, the Economist’s quarterly metal index between 1990:Q1 and 2007:Q4. In the paper, relationships among commodity prices, the interest rate, world economic activity, and the US dollar exchange rate are investigated with the help of structural VAR methodology. The author finds empirical evidence supporting the expectation that the negative real exchange rate (depreciation of the US dollar), the negative interest rate shock, and positive world economic activity result in higher real commodity prices. Furthermore, the gradual response of metal prices to interest rate shocks and shocks to world economic activity explains most of the fluctuations in metal prices.

Studies such as Radetzki (2006), Jacks and Stuermer (2016), Buyuksahin et al. (2016), and Stuermer (2017) point out the long-lasting effects of demand shocks on metal prices in the long run. Moreover, Stuermer (2017) investigates the elasticity of selected minerals, including base metal demand per capita manufacturing output, using panel data methodologies such as mean group estimator, pooled mean group estimator, and dynamic fixed effects estimator. The author reports only the elasticity of aluminum price to be greater than one, others to be either equal to one (copper) or less than one (lead, tin, and zinc). Issler et al. (2014) investigate various frequencies of real base metal prices. The authors examine monthly and quarterly data between 1957 and 2012 and annual data between 1900 and 2010. They conclude the significant effect of industrial production on real base metal prices, especially in the short run, by applying cointegration and other forecasting methodologies. Similar results are found by Labys et al. (1999), even though they implemented the dynamic factor analysis for monthly nominal base metals' (except nickel) price data between 1974 and 1995. Alquist et al. (2020) conduct a factor analysis on monthly real prices of various commodities, including six base metals, roughly between January 1968 and January 2013. Furthermore, they conclude that an indirect or non-commodity factor, such as global economic activity, explains the majority of the variance in commodity prices. So, there is empirical evidence supporting industrial production as a factor affecting the base metal prices both in the short run and long run.

Until this point, we discuss the price dynamics of base metals with some exceptions, such as Carmen and Borensztein (1994). The price dynamics of precious metals are different than base metals. Churchill et al. (2019) analyze annual real gold, silver, and platinum prices through a two-regime threshold time-varying error correction method. The authors find a positive effect of oil prices and a non-linear (first decreasing and then increasing) effect of the British pound/US dollar exchange rate for the period between 1880 and 2016. On the other hand, Bildirici and Turkmen (2015) present slightly different results for the relationship between monthly prices of gold, silver, and oil prices. The data spans the period between January 1973 and November 2012. By applying the non-linear ARDL and two popular causality tests, they reach the conclusion that there seems to be a nonlinear relationship only between gold and oil prices.

The studies regarding precious metal prices are not restricted to their relationship to oil prices, as expected. Batten et al. (2010) analyze monthly gold, silver, platinum, and palladium return volatility between 1986 and 2006 by applying a VAR methodology. The authors find evidence that monetary variables affect gold but not silver return volatility. Sari et al. (2010) examine the nexus among daily precious metal prices, oil prices, and the US dollar/euro exchange rate between January 4, 1999 and October 19, 2007. The authors conduct a VAR analysis. The generalized impulse response results underline the temporary but positive effects of oil prices and the US dollar value of the euro on precious metal prices. Batten et al. (2015) use weekly return and return volatility of the same precious metals between 1982 and 2013. They report significant spillovers between gold and silver. However, there is supporting evidence of disconnected platinum and palladium markets. Batten et al. (2014) study the gold price and inflation relationship between January 1985 and June 2012 on a monthly basis. They point out the time-varying nature of the relationship between the gold price and inflation. They also report that the sensitivity of the gold price to inflation is negatively affected by the value of the US dollar. Qadan (2019) employs Glosten-Jagannathan-Runkle generalized autoregressive conditional heteroscedasticity (GARCH) and causality models to investigate the nexus between precious metal prices and risk appetite (i.e., CBOE volatility index). Their data consists of five-minute returns of precious metal prices starting from January 1990 and ending in July 2018. Both precious metal prices and their return volatilities are reported to be linked to economic uncertainty and risk appetite shocks.

2.3. Efficiency Discussion

Analyzing price behavior conveys significant information about the efficiency of the relevant resource markets. There are three types of market efficiency, namely weak-form, semi-strong, and strong-form market efficiency. While the price of a strong form efficient market reflects all, either public or non-public, information, the price of a semi-strong form efficient market reflects all available public information. The price in a weak-form efficient market reflects only past prices. Econometrically, if the price series is integrated of order one, the relevant market can be claimed to be weak-form efficient. On the other hand, if it is reported to be stationary, the market can not be stated to be a weak-form efficient market.

Shocks to prices are not short-lived in a weak-form efficient market. Therefore, returns can not be predicted. As Hasanov and Omay (2007) argue, random walk prices fulfill the condition for return unpredictability, which in turn implies the efficiency of a market. So, serially dependent price series such as stationary prices violate the efficiency of the relevant metal market. The return unpredictability implies that an investor can not earn abnormal profit by just analyzing the historical prices or implementing technical analysis. Moreover, there is a lack of market forces that equilibrate the market in the long run. So, an active public policy may be designed for this purpose. However, if a market can not be claimed to be weak-form efficient, the prices do not fully reflect past price information in the market. Therefore, incorporating any important non-public information may result in excessive profit. Furthermore, shocks to prices are short-lived, which implies that there are market forces that bring the market into equilibrium, and returns are predictable.

Integration order of prices has implications regarding the efficiency of the related market in addition to many econometric consequences. Basically, stationary prices imply serial dependence or non-randomness. Moreover, stationary prices revert to their equilibrium value. Explicitly, the price moves towards the equilibrium value when it is above or below the equilibrium value (Kritzman, 1994:19). On the contrary, non-stationary prices comply with an efficient market and random behavior.

The argument that prices are non-stationary in an efficient market can also be theoretically justified with the statement that given the information set until today, the expectation of tomorrow’s price is today’s price. Intuitively, no trading strategy can beat the buy-and-hold strategy in an efficient market (Fama, 1970). Fama (1970) theoretically presents three types of models for efficient markets, namely the expected return model, the random walk model, and the (sub)martingale model. The stationarity argument is related to the martingale model since it is defined by the argument that given information set at time t, the expectation of the price at t+1 is the price of time t, or equivalently, the expectation of return at time t+1 is zero.

Lee and Lee (2009) further elaborate on the concept of efficiency. They identify the information in efficient markets as a factor possibly influencing prices. Moreover, the reason for the future price movements in an efficient market would be the information that is unknown today but will emerge randomly tomorrow.

Some studies, such as Solt and Swanson (1981), Smith (2002), and Charles et al. (2015), focus on other relatively simple methodologies to infer the efficiency or inefficiency of metal markets. These methodologies include autocorrelation coefficient, runs, and variance ratio tests, which Kritzman (1994) discusses in detail. Using weekly London afternoon fixing price changes of gold and silver between January 1971 and December 1979, Solt and Swanson (1981) apply the runs test and calculate autocorrelation coefficients. They report positive serial dependence, implying inefficiency. The authors also show that investors are not likely to be able to take advantage of this inefficiency to enjoy abnormal profits. On the other hand, Smith (2002) applies a multiple variance ratio test to three daily London gold return series, namely the morning fixing, afternoon fixing, and closing prices. The data covers the period January 3, 1990-September 27, 2001. The author concludes that due to return autocorrelation, two fixing prices are formed in an inefficient market, in accordance with Solt and Swanson (1981). However, closing prices are compatible with efficient market dynamics. On a broader perspective, Charles et al. (2015) work on daily closing prices of gold, silver, and platinum spanning the period January 3, 1977-October 23, 2013. They employ automatic portmanteau and variance ratio tests on log returns. They report time-varying return predictability, decreasing predictability (therefore increasing efficiency) for gold and silver over time. Just like stationarity analysis, the runs and the variance ratio tests also suggest serial dependence or predictability of a return series. However, these tests have certain limitations. For instance, the runs test does not consider the magnitude of deviation from the mean. Unlike stationary or unit root tests, other tests mainly do not evolve in such a way, which includes the possibility of structural changes (e.g., smooth or sharp breaks) to the best of our knowledge.

2.4. Conclusion

Metals display some disparities from other commodities. They are recyclable and not consumed with single-use, unlike fuel commodities (e.g., oil, natural gas), and not subject to seasonal production, which is typical for agricultural commodities (e.g., corn, wheat). However, they also have some similarities, such as being storable like fuel or agricultural commodities. There is also a pronounced discrepancy between labor and capital manufactured by labor and non-renewable resources such as metals. This discrepancy originates from the limited supply of all metals existing in the Earth’s crust. While metals can be classified as a special category under commodities, there are also subcategories such as base or precious metals of the non-ferrous metals category, which is defined as metals that lack iron. Furthermore, there are also marked distinctions between base metals (copper, lead, nickel, aluminum, tin, and zinc) and precious metals (gold, silver, and platinum).

Base metals are subject to significant industrial demand due to their favorable technical properties, such as the electrical conductivity property of copper, the low weight of aluminum, or the high density of lead. Moreover, compared to precious metals, they are more abundant, which eases their intermediate good role in industrial production. On the other hand, due to their hedge, safe haven, financial investment role, scarcity, and pronouncedly high precious metals, especially gold, prices have a comparatively minor role in industrial production. Exceptionally, a significant amount of platinum and palladium is used for industrial purposes, such as autocatalyst production.

On the supply side, there are also two different narratives for these two subcategories. The precious metal-supplying countries and their share have not changed significantly. On the other hand, base metals have experienced major changes in terms of supply shares after the 2000s due to China’s fast-growth economic model. Particularly, China has constantly increased both its mine and smelter/ refinery production share for lead, zinc, and tin, especially after the 2000s, and become the major producer. On the other hand, for nickel, aluminum, and copper, the same development has occurred only for smelter/refinery production.

The metal, either base or precious type, prices play a critical role for both metal exporting, mostly emerging, countries, and metals importing relatively more industrialized countries. For major metal exporting countries, metal export volumes are significant due to their effects on export revenues and macroeconomic fundamentals. For metal-importing countries, imported metals, especially base metals, are among the cost items of industrial output. Therefore, metal price dynamics merit further attention.

It has been well documented that real metal prices, particularly base metal prices, are mainly affected by macroeconomic fundamentals such as industrial production, real interest rates, and real exchange rates. In the case of precious metals, due to their minor industrial use, especially for gold, industrial production does not seem to be an influential direct factor as much as base metals. On the other hand, even though industrial demand constitutes the majority of silver and platinum demand, investment and jewelry demand seem to moderate the cyclical price effects of industrial production. Interest rates and exchange rates should still be emphasized due to the precious metals’ distinctive financial investment role.

Analyzing price behavior conveys significant information about the efficiency of the relevant resource markets. There are three types of market efficiency, namely weak-form, semi-strong, and strong-form market efficiency. While the price of a strong form efficient market reflects all, either public or non-public, information, the price of a semi-strong form efficient market reflects all available public information. The price in a weak-form efficient market reflects only past prices.

Due to the crucial implications of efficiency analysis, the following chapter focuses on the weak-form efficiency of spot markets for six base metals (copper, lead, aluminum, nickel, zinc, and tin) and three precious metals (gold, silver, and platinum). Furthermore, we examine the weak-form efficiency of three-month futures markets for the same six base metals in the fourth chapter.

CHAPTER 3

MARKET EFFICIENCY IN NON-RENEWABLE RESOURCE MARKETS: EVIDENCE FROM STATIONARITY TESTS WITH STRUCTURAL CHANGES

The price behavior of exhaustible or nonrenewable resources has been a great concern for a long time, mainly due to their scarce nature. Analyzing price behavior conveys significant information about the efficiency of the relevant resource market, specifically selected metal markets. A market is said to be efficient if all relevant and available information is instantly reflected in prices so that no participant can earn excess returns consistently by utilizing past, current, or new information. Depending upon the level of available information, three types of market efficiency are defined. While the weak-form efficiency is based on an information set that involves only historical prices, the semi-strong and strong forms, respectively, account for publicly available information and any publicly or privately provided information.

In the field of energy, the most commonly examined form of efficiency is the weak form of market efficiency, which requires that energy prices can not be predicted by using historical price information. In turn, this implies that prices are expected to follow a random walk process with random successive price changes. Knowledge of the stochastic properties of energy prices is not only critical for the evaluation of the efficient market hypothesis but is also important for forecasting and forming firms' short and long-term investment decisions and diversification strategies. Moreover, for energy-dependent economies, the path of the prices is critical for revenue forecasting and management purposes. There are many studies available on the empirical validity of the efficient market hypothesis in the field of energy. While a major strand of this literature has focused on the efficiency of oil markets, such as Maslyuk and Smyth (2008), Charles and Darne (2009), Ozdemir et al. (2013), and Stevens and de Lamirande (2014), the literature on the market efficiency of non-renewable resources is relatively thin. When examining the literature for the market efficiency of non-renewable resources, it appears that earlier studies, including Macdonald and Taylor (1988), Chowdhury (1991), Moore and Cullen (1995), and Berck and Roberts (1996) have employed conventional ADF and PP tests. Despite some differences, almost all of these studies have concluded that most of the metal prices are non-stationary. Therefore, they can be characterized by the efficient market hypothesis.

Subsequently, Ahrens and Sharma (1997), Lee et al. (2006), Narayan and Liu (2011), and Presno et al. (2014) have attributed the nonstationarity finding of the earlier studies to the low power of traditional unit root tests in the presence of structural breaks. Since the seminal paper of Perron (1989), it is well acknowledged that the conventional unit root tests are biased towards falsely accepting the null hypothesis of a unit root when the time series is stationary around a break. Given that natural resource markets are sensitive to macroeconomic conditions and events of world geopolitical tensions, as underlined by Lee and Lee (2009) and Gil-Alana et al. (2015), the use of conventional unit root tests that ignore potential structural breaks might produce some serious limitations. In that sense, by imposing exogenously determined structural breaks associated with the Great Depression in 1929, the outbreak of World War II in 1939, or the end of World War II in 1945, Ahrens and Sharma (1997) investigate stochastic properties of 11 non-renewable natural resources' real prices. 6 of 11 prices appear to be characterized by a trend stationary process with a structural break. Although the assumed break date(s) of Ahrens and Sharma (1997) are quite reasonable from an economic viewpoint, it is evident that such a procedure may suffer from a pre-test bias.

Lee et al. (2006) employ the endogenously determined two-break unit root test of Lee and Strazicich (2003) to re-analyze the data of Ahrens and Sharma (1997). Contrary to previous studies, they find that all real price series follow a stationary process around deterministic trends with sharp structural breaks. Another study that utilizes the dataset of Ahrens and Sharma (1997) is by Presno et al. (2014). Presno et al. (2014) follow a two-step testing procedure with the focus being on the circularity problem between tests for structural breaks and stationarity or unit root behavior of the process. In the first step, they specify the presence of the structural change(s) by utilizing a procedure that is robust to the integration of order. Once the dates of the structural changes are estimated, they proceed with testing the null hypothesis of trend stationary against the alternative of a unit root. In that respect, they apply two tests, one allowing for sharp structural breaks and the other one allowing for gradual breaks through the use of a nonlinear logistic function where the transition variable is time. They find that all real prices except silver and natural gas follow a stationary path with sharp or smooth changes in trend depending on the price examined.

Unlike Ahrens and Sharma (1997), Lee et al. (2006), and Presno et al. (2014), Narayan and Liu (2011) examine the efficient market hypothesis over a more recent dataset. In that respect, Narayan and Liu (2011) analyze the stochastic properties of daily prices of 10 non-renewable natural resources for the period ending in March 2010. Although the beginning date varies based on the natural resource, the most minor beginning date is January 1976 for a natural resource, namely gold. The authors employ two unit root tests, one allowing for two sharp structural breaks in intercept and trend and the other one accounting for both structural breaks and the potential autoregressive conditional heteroscedasticity structure, which is necessary due to the use of daily data. Their findings reveal that the unit root null hypothesis can be rejected for five of 10 prices, while the remaining five series, namely gold, silver, platinum, aluminum, and copper, are found to have a random walk structure.

Price shocks are not short-lived in a weak-form efficient market. Therefore, returns can not be predicted. This condition implies that an investor can not earn abnormal profit by just analyzing the historical prices or implementing technical analysis. Moreover, there is a lack of market forces that equilibrate the market in the long run. However, if a market can not be claimed to be weak-form efficient, prices do not fully reflect past price information in the market. Therefore, incorporating any important nonpublic information may result in excessive profit. Furthermore, shocks to prices are short-lived, which implies that there are market forces that bring the market into equilibrium, and returns are predictable.

In this study, we aim to investigate whether quarterly real prices of copper, lead, tin, nickel, zinc, aluminum, gold, platinum, and silver can be characterized by the efficient market hypothesis or not over the period of 1980Q1 and 2017Q1. Methodologically, unlike the majority of the existing studies, we utilize two different stationarity tests, which are modified versions of the conventional KPSS test. Given that tests with the null of a unit root have low power with stationary but persistent data. Therefore, one cannot reject the null hypothesis of nonstationarity unless there is very strong evidence against it. To address this problem, one can naturally test the market efficiency under the null of stationarity, as in Presno et al. (2014). Moreover, following the proposal of Lee et al. (2006) that structural breaks and trends are important considerations for the analysis of stochastic properties of non-renewable natural resource prices, we adopt two different tests; one is to incorporate gradual breaks, and the other is developed to identify sharp breaks in the price series. Given that misspecification of the functional form of the breaks could be as problematic as ignoring the breaks, we consider both smooth and instant breaks. Instant or sharp breaks may occur as a result of all agents behaving simultaneously in a particular manner, such as demanding the asset as a reaction to an economic stimulus. Due to the heterogeneity among economic agents in terms of response to an economic stimulus (Leybourne et al., 1998), presuming a sharp break may be unrealistic (Harvey and Mills, 2004). Therefore, we also incorporate smooth breaks into our analysis. We contribute to the literature by incorporating the SPC method to smooth break the KPSS-type test of Becker et al. (2006). In addition to this contribution, two stationarity tests have not been utilized to examine the efficiency of global spot markets. The merit of the SPC method is to make KPSS-type tests consistent.

Specifically, we first use the endogenously determined two break stationarity tests of Carrion-i-Silvestre and Sanso (2007) to identify potential sharp breaks in the price series. Then, accounting for the possibility that structural changes might take a period of time for the effects to be observed in an economy and might not be captured well by dummy variables, we employ the stationarity test of Becker et al. (2006), designed to detect multiple smooth breaks of unknown form through the use of a Fourier function. The advantage of using the Fourier function over the nonlinear logistic function used by Presno et al. (2014) is that the Fourier approximation can also detect U-shaped breaks and smooth breaks located near the end of the series. Both approaches of Carrion-i-Silvestre and Sanso (2007) and Becker et al. (2006) are modified versions of the standard KPSS test. Given the sensitivity of the KPSS test to the estimation of the long-run variance, we are aware of this drawback throughout our analysis.

The rest of the chapter is organized as follows. Section 1 presents the literature review. The next section describes the econometric methodologies we adopt. While Section 3 discusses the data and the empirical results, Section 4 concludes the study.

3.1. Literature Review

Some studies about nonferrous metals, namely copper, lead, tin, zinc, aluminum, and nickel, can be listed as Macdonald and Taylor (1988), Chowdhury (1991), Moore and Cullen (1995), and Heaney (1998). While Macdonald and Taylor (1988), Chowdhury (1991), and Moore and Cullen (1995) investigate end-of-month, monthly average, and monthly and weekly (one o'clock) prices, respectively, Heaney (1998) examines the natural logarithm of weekly and quarterly data. Macdonald and Taylor (1988) analyze lead, tin, and zinc prices for the period between January 1976 and October 1985. Chowdhury (1991) focuses on copper, lead, tin, and zinc between July 1971 and June 1988. On the other hand, Moore and Cullen (1995) utilized weekly aluminum, tin, and zinc prices and monthly copper, lead, and nickel prices between 1988 and 1992. Heaney (1998) investigates weekly and quarterly lead prices between 1976 and 1995. While Moore and Cullen (1995) and Heaney (1998) apply the PP test, Macdonald and Taylor (1988) and Chowdhury (1991) utilize the Dickey and Fuller (1979) (DF) test, and the DF and augmented DF (ADF) test, respectively. Among these papers, only Moore and Cullen (1995) and Heaney (1998) report the stationarity of some metals. Moore and Cullen (1995) report monthly lead and weekly tin prices of LME to be stationary, while Heaney (1998) finds weekly and quarterly natural logarithms of lead prices of LME to be stationary. To sum up, the time span of the data of these papers does not differ significantly, and with some exceptions, most of the metal prices are reported to be nonstationary. So, it would not be surprising to infer these markets to be efficient for this short period of time. Furthermore, none of these papers consider breaks since the study periods are short. The probability of having a break can be argued to be relatively low.

Ahrens and Sharma (1997), Lee et al. (2006), and Presno et al. (2014) investigated annual US real prices of aluminum, copper, iron, lead, nickel, silver, tin, and zinc between 1870 and 1990. Ahrens and Sharma (1997) apply autocorrelation function, ADF, Perron (1989), Leybourne and McCabe (1994), and Ouliaris et al. (1988) tests, all of which do not consider endogenously determined structural breaks in stationarity analysis. The authors report lead, tin, nickel, and zinc as nonstationary, while aluminum, copper, and silver are reported to be stationary according to Perron's (1989) test. They apply the Perron (1989) test by assuming only one exogenous structural break in the trend during the Great Depression (1929), the outbreak of World War II (1939), and the end of World War II (1945).

Lee et al. (2006) and Presno et al. (2014) allow two breaks in the trend function in their analysis. Both studies take endogenously determined structural breaks into account. Lee et al. (2006) report only aluminum and silver to be nonstationary according to the lagrange multiplier (LM) unit root test with one endogenously determined break in the trend function. Moreover, all metals are reported to be stationary based on the unit root test with two endogenously determined breaks in the trend function. However, when the quadratic trend is added to the model of two endogenously determined breaks, prices of aluminum and silver are now reported as integrated of order one, which is the same as no break with the quadratic trend case. The result is the same as one endogenously determined break. Presno et al. (2014) employ the stationary test of Landajo and Presno (2010) to analyze the annual data of Lee et al. (2006). They focus on testing the null of stationarity with linear or quadratic trends with two sharp breaks at most and smooth transitions. Among eight metals, only silver is reported to be non-stationary. Unlike these two papers, Ahrens and Sharma (1997) do not consider any break, even though the same data is analyzed. However, since the period covers annual data between 1870 and 1990 in these three papers, the probability of a break increases. Both papers consider two endogenously determined breaks in the trend function. Interestingly, even though they follow different procedures, they present evidence of stationarity for almost all metals studied. These results generally contradict the evidence of a unit root reported by Ahrens and Sharma (1997). However, this supports the fundamental arguments regarding considering breaks in unit root or stationarity testing. Simply ignoring an existing break results in accepting a false unit root null hypothesis for a unit root test (Perron, 1989) and rejecting a true null of stationarity for a stationarity test (Lee et al., 1997). In technical terms, not allowing a break ends up in power loss in unit root testing procedures and size distortion in stationarity testing procedures.

At this point, the studies of Lee et al. (2006) and Presno et al. (2014), which emphasize stationarity tests contingent upon the existence of endogenous breaks, deserve further attention, even though they have different methodologies to identify breaks. Lee et al. (2006) apply the LM unit root test that includes a quadratic trend. Moreover, they use the same specification to detect the two breaks assumed both in level and the linear trend. On the other hand, Presno et al. (2014) implement the Kejriwal and Perron (2010) sequential test, including quadratic trend to test for multiple breaks in linear trend, and Harvey et al. (2009) test for multiple breaks in level. Then, they apply Landajo and Presno’s (2010) test, assuming the null of stationary series with both abrupt changes or smooth transitions. Since the overlapping period between this study and those two papers is the period between 1980 and 1990, we only present the breaks reported in those papers regarding the period between 1980 and 1990. Presno et al. (2014) present the year 1982 as a break for copper and lead and the year 1980 as a break for silver. Aluminum, iron, and zinc do not have breaks in the period between 1980 and 1990, according to Presno et al. (2014). Lee et al. (2006:361) do not report any break in the period between 1980 and 1990. Thus, the breakpoints, as pointed out by Lee et al. (2006) and Presno et al. (2014), differ based on methodologies even though the data span the same period. This observation pinpoints and motivates using different methodologies on metals data. There exists some advanced econometric research on the most metals considered here. However, gold and platinum are exceptions. Even though typical unit root tests, such as the ADF test, for various samples are considered enough for gold in studies like Ciner (2001) and Lucey and Tully (2006) or platinum price analysis (e.g., Huang and Kilic (2019)), no effort has been devoted to stationarity testing procedures like this study.

3.2. Methodology

This section is composed of three subsections. We commence with the long-run variance (LRV) discussion for KPSS-type stationarity tests and SPC methodology.

The second subsection presents the sharp break stationarity test of Carrion-i-Silvestre and Sanso (2007). The last subsection elaborates on the stationarity test of Becker et al. (2006) that permits smooth breaks of unknown form.

3.2.1. KPSS Test and Its Sensitivity to LRV Estimation

KPSS test is developed as a confirmatory test to standard unit root tests. This development is due to the argument that standard unit root tests are not very powerful against some alternatives, such as highly autoregressive stationary time series (Dejong et al., 1992) or fractionally integrated series (Diebold and Rudebusch, 1990) in the case of DF tests. In order to construct a test with the null of stationarity, KPSS (1992) adopt the approach of Nabeya and Tanaka's (1988) local best invariant test, which is designed to check the parameter constancy of regression coefficients under independent and identically distributed (iid) normal errors assumption. However, KPSS (1992) extend the work of Nabeya and Tanaka (1988) by rescaling the locally best invariant statistic by an estimator of LRV in order to consider non-iid errors, as displayed in equation 3.1.

$$\boldsymbol{\tau_{\mathrm{KPSS}} = \frac{1}{\mathrm{T}^2}\frac{\sum_{\mathrm{t}=1}^{\mathrm{T}} \hat{\mathrm{S}}_{\mathrm{t}}^2}{\widehat{\mathrm{LRV}}}} \tag{3.1}$$

where $\hat{\mathrm{S}}_{\mathrm{t}} = \sum_{\mathrm{j}=1}^{\mathrm{t}} \hat{\mathrm{e}}_{\mathrm{j}}$ and $\hat{\mathrm{e}}_{\mathrm{t}}$ are the ordinary least squares (OLS) residuals obtained from regressing dependent variable on Xt, independent variables, while T is the sample size. The estimator of LRV intuitively serves two purposes. One purpose is to balance the change in the test statistic due to a strong stationary autocorrelation. This would help to control the size of the test. The other is to allow the test statistic to correctly reject the null hypothesis or prevent power loss in the case of strong sample autocorrelation stemming from an integrated process (Müller, 2005). The estimation of LRV deserves special emphasis since it is considered as the main drawback of stationarity tests (e.g., Carrion-i-Silvestre and Sanso, 2006). There are two broad categories of LRV estimation, namely parametric, such as Lee and Phillips (1994) and Den Haan and Levin (1996), and non-parametric kernel-based estimators, such as Andrews and Monahan (1992), Newey and West (1994), Andrews (1996), and SPC. Our focus is on non-parametric kernel-based LRV estimation. The estimate of the LRV if strong mixing regularity conditions are satisfied (Phillips and Perron, 1988:336), can be obtained as presented in equation 3.2 using a nonparametric correction for non-i.i.d. errors.

$$\sigma^2 = \lim_{T\to\infty} T^{-1} E(S_T^2) \text{ where } S_T = \sum_{t=1}^{T} \varepsilon_t \qquad (3.2)$$

Non-parametric kernel-based LRV is commonly estimated with the following formula in equation 3.3 where $k(x)$ is kernel-based non-parametric weighting or kernel function satisfying $|k(x)| \leq 1$, continuity at x=0, and $\int_{-\infty}^{\infty} k^2(x) < \infty$, $\widehat{m}$ is estimated bandwidth or lag truncation parameter and e_t is defined as same as in equation 3.1.

$$\widehat{LRV} = \widehat{\Omega}_0 + 2\sum_{j=1}^{T-1} k\left({}^{j}/_{\widehat{m}}\right) \widehat{\Omega}_j \qquad (3.3)$$
$$\text{where } \widehat{\Omega}_0 = \frac{1}{T}\sum_{t=1}^{T} \hat{e}_t^2 \; and \; \widehat{\Omega}_j = \frac{1}{T}\sum_{t=j+1}^{T} \hat{e}_t \hat{e}_{t-j} \; where \; j \geq 1.$$

As displayed in equation 3.3, non-parametric LRV estimation entails some kind of weighting where these weights are based on the kernel $k(.)$ and the bandwidth parameter $\widehat{m}$ chosen. Furthermore, a preliminary choice of prewhitening or not prewhitening should also be made. A justification about prewhitening procedure should be made at this point. The most cited prewhitening procedure of Andrews and Monahan (1992) contains smoothing out $\hat{e}_t$ with the help of the AR(1) model, estimating a consistent estimate ,and recoloring it.

Some common kernel formulas such as Bartlett, Parzen, quadratic spectral (QS), truncated kernels, and LRV estimator formulas can be found in Andrews (1991:821) and Newey and West (1994:640), respectively. Kernel-based estimators mentioned above, except for the truncated kernel, assign weights less than one in order to provide a positive semi-definite estimator (Den Haan and Levin, 1997). It is crucial for the estimator to be positive semi-definite. Otherwise, estimated variances and test statistics will be negative for some linear combinations of estimated regression parameters (Newey and West, 1987). However, ensuring positive semi-definiteness comes with the price of asymptotic bias, as underlined by Den Haan and Levin (1997). Two kernels, namely Bartlett and QS kernels, are widely utilized in the literature. QS kernel-based estimators became more popular as Andrews (1991) reports the lowest mean squared error (MSE) among the kernels studied in the paper. Moreover, Newey and West (1994) also confirm this result in their work. Furthermore, the estimation performance of the variance of the first non-constant regressor based on QS kernel with Andrews (1991) methodology is compared with the heteroscedasticity consistent estimator of Eicker (1967) and White (1980) and a parametric estimator assuming homoskedastic errors. The punchlines of this Monte Carlo simulation analysis are that in terms of bias and MSE, while the QS heteroscedasticity and autocorrelation consistent (HAC) estimator is often the best when T=128, the parametric estimator is mostly the best when T=256 among four estimator.

KPSS (1992) test utilizes deterministic or fixed bandwidth parameters based on the sample size. However, as pointed out by Hobijn et al. (2004), in finite samples, while too large bandwidth implies overestimated LRV and significant power loss, too small bandwidth combined with highly autoregressive process leads to underestimated LRV and oversized test statistic. Therefore, too small or large bandwidth may severely distort the inference regarding computed test statistics based on the LRV estimator. This argument explains the motivation behind the research of the most popular optimal automatic bandwidth selection procedures of Andrews (1991) and Newey and West (1994), both of which are dependent on the sample rather than the sample size. The estimation of asymptotically optimal bandwidth parameters is first formulated by Andrews (1991) based on some kernels through the minimization of asymptotic truncated MSE. Newey and West (1994) further refine Andrews (1991) by considering not only first-order autocorrelation, but also other autocovariance and cross-covariances. However, both of these methods do not point out the exact optimal parameter value. They formulate bandwidth parameters dependent upon the rate at which the bandwidth parameter should increase as a function of the sample size (e.g., Den Haan and Levin, 1997). The advantages and disadvantages of employing the optimal bandwidth procedures of Andrews (1991) and Newey and West (1994) compared to deterministic bandwidths are reported in the literature for the KPSS test in studies by Lee (1996) and Hobijn et al. (2004).

Lee (1996) investigates the size and power properties of some selected fixed bandwidths, Andrews (1991) and Andrews and Monahan (1992) procedures for the KPSS test. The author shows that both Andrews (1991) and Andrews and Monahan (1992) procedures display better size properties than fixed bandwidth parameters. Strikingly, Andrews and Monahan’s (1992) prewhitening procedure depicts very good size properties, almost exactly 5 percent nominal size, especially for a sufficiently large sample regardless of autocorrelation structure. Unfortunately, significant power loss is reported for both procedures when compared with fixed bandwidths. Furthermore, employing a prewhitening procedure leads to inconsistency in the test. Lee (1996) attributes the power loss of Andrews’s (1991) procedure to overfitting caused by the conservative selection of lags. However, the inconsistency of the KPSS test in the case of Andrews and Monahan (1992) prewhitening procedure is argued to be caused by technical consequences of the procedure when the alternative hypothesis of a unit root is true.

On the other hand, Hobijn et al. (2004) illustrate that the KPSS test combined with Newey and West’s (1994) automatic bandwidth procedure ends up with consistent and better small sample results than the original KPSS test. However, even though the size distortion is generally reduced, for most of the identifications, the oversize of the test still remains.

As discussed above, while Andrews (1991) and Andrews and Monahan (1992) display rejection rates closer to nominal size and worse power properties relative to fixed bandwidths in the case of the KPSS test, Newey and West (1994) end up with relatively better size and consistent test statistic. Optimal bandwidth and prewhitening procedures also draw the attention of researchers who develop stationary tests involving LRV estimation. Tests proposed by Choi (1994), Choi and Ahn (1995, 1999), and Kurozumi (2002) can be listed as some examples.

Choi (1994) shows the stationarity tests developed in the study become inconsistent when Andrews (1991) or Andrews and Monahan (1992) procedures are employed. Therefore, the author uses fixed bandwidth parameters. Similarly, Choi and Ahn (1995, 1999) argue about the inconsistency of their tests when Andrews (1991) or Andrews and Monahan (1992) procedures are applied. Therefore, they limit the bandwidth by two if the estimated bandwidth according to Andrews's (1991) methodology is greater or equal to T^{δ}, where δ=0.7 for raw series and δ=0.65 for detrended series. Kurozumi (2002) also states that the Andrews (1991) methodology can not be applied to his test due to inconsistency. Therefore, the author sets an upper bound $1.1447\left(\frac{4\mathrm{f}^2\mathrm{T}}{(1+\mathrm{f})^2(1-\mathrm{f})^2}\right)^{1/3}$ where f=0.7 or 0.8. However, since both refinements are directed to Andrews's (1991) methodology, a refinement to Andrews and Monahan's (1992), which displays very good size properties for the KPSS test (Lee, 1996), would contribute more to the tests we apply in the chapter. The most important issue to be addressed about the Andrews and Monahan (1992) prewhitening procedure is its inconsistency.

SPC address the inconsistency problem of the KPSS test by restricting LRV through a new sample size-based rule $1-\frac{1}{\sqrt{T}}$ instead of an arbitrary rule of 0.97 in prewhitening procedure of Andrews and Monahan (1992). Before applying the new rule of SPC, the estimated residuals $\hat{\mathrm{e}}_{\mathrm{t}}$ are fitted to the AR(p) model in which appropriate lag order is possibly specified, for example, using the Bayesian information criterion (BIC), and the new rule is executed as presented by equations 3.4 and 3.5, respectively:

$$\hat{\mathrm{e}}_{\mathrm{t}} = \rho_1\hat{\mathrm{e}}_{\mathrm{t-1}} + \cdots + \rho_p\hat{\mathrm{e}}_{\mathrm{t-p}} + \hat{\varepsilon}_{\mathrm{t}} \tag{3.4}$$

$$\widetilde{\omega} = \frac{\widetilde{\omega}_{\varepsilon}}{(1-\tilde{\rho})^2} \text{ where } \tilde{\rho} = min\left(\rho_1 + \cdots + \rho_p, 1-\frac{1}{\sqrt{T}}\right) \tag{3.5}$$

and $\widetilde{\omega}_{\varepsilon}$ is the LRV estimator of $\hat{\varepsilon}_{\mathrm{t}}$. By this new methodology, SPC compare Newey and West (1987) fixed bandwidth procedure with prewhitening procedure using QS kernel with 0.97 and the new rule. They report evidence supporting significant power improvements even in relatively small samples and better size properties compared with undersized QS kernel with 0.97 rule for relatively low AR(1) parameters (smaller than 0.95). Unlike Lee (1996), SPC also consider the AR(1) parameter extending from 0.80 to 0.95 where generally better size properties are reported.

Carrion-i-Silvestre and Sanso (2006) compare the KPSS test results of Kurozumi (2002), Choi and Ahn (1995, 1999), and SPC methodology in terms of finite sample properties. SPC methodology provides better size and relatively less power loss (although consistent) results for both constant and trend case when compared with Kurozumi (2002), Choi and Ahn (1995, 1999). However, the KPSS test with SPC methodology results in oversized test statistics, especially for very highly autocorrelated processes, namely AR(1) parameter greater than 0.90. Another important observation of Carrion-i-Silvestre and Sanso (2006) is that the size improves even for strongly autocorrelated data-generating processes. For instance, when T=600 and the AR(1) parameter is 0.96, the size of the KPSS-SPC methodology is the proper size for the specification, allowing a time trend. Moreover, they report pronounced size distortion when the AR(1) prewhitening procedure is applied in the case of the AR(2) process. Kurozumi and Tanaka (2010) utilize SPC methodology using AR(p) filtering in their comparison analysis. They report relatively better size properties for some specifications compared to AR(1) prewhitening, including T=100 and a boundary rule of 0.90, which is very close to our sample size of T=149 and a boundary rule of 0.92. So, due to its merits in LRV estimation, we employ the SPC methodology in Becker et al. (2006) and Carrion-i Silvestre and Sanso (2007) KPSS-type tests, which consider breaks unlike the KPSS test. The elaboration regarding these tests is presented in the following subsections.

3.2.2. Sharp Break Stationarity Test of Carrion-i-Silvestre and Sanso (2007)

In order to test the null hypothesis of stationarity in the presence of instantaneous structural breaks, Carrion-i-Silvestre and Sanso (2007) consider the following data-generating process for the time series $\mathrm{y_t}$ defined as in equation 3.6:

$$y_t = f(t, T_{b1}, T_{b2}) + r_t + \varepsilon_t$$

$$f(t, T_{b1}, T_{b2}) = \theta_0 + \gamma_0 t + \sum_{i=1}^{2} \theta_i DU_{i,t} + \sum_{i=1}^{2} \gamma_i DT_{i,t} \quad (3.6)$$

$$r_t = r_{t-1} + u_t$$

where $\varepsilon_t$is the stationary error term, u_t is iid (0, σ_u^2), $DU_{1,t}$, and $DU_{2,t}$ are the dummy variables for mean shifts and $DT_{1,t}$, and $DT_{2,t}$ are the dummy variables for trend shifts, which occur at $T_{b1} = \lambda_1 T$ and $T_{b2} = \lambda_2 T$, where $\{\lambda_1, \lambda_2\} \in (0,1)$ and $T_{b2} \neq T_{b1} \mp 1$. $DU_{i,t}$ and $DT_{i,t}$ are defined as:

$$DU_{i,t} = \begin{cases} 1 & if\ t > T_{bi} \\ 0 & otherwise \end{cases} \ and\ DT_{i,t} = \begin{cases} t - T_{bi} & if\ t > T_{bi} \\ 0 & otherwise \end{cases}$$

If θ_i and γ_i are assumed to be zero, equation 3.6 characterizes the setting for the KPSS test statistic. The KPSS test statistic for the null hypothesis of trend stationary, i.e., $\sigma_u^2 = 0$, has the form displayed in equation 3.7:

$$\hat{\eta} = \hat{\sigma}^2 T^{-2} \sum_{t=1}^{T} \hat{S}_t^2 \quad (3.7)$$

where $S_t = \sum_{i=1}^{t} \hat{e}_i^2$ with $\hat{e}_i$ being the OLS residual obtained from the regression of y_t on the intercept and trend term and $\hat{\sigma}^2$ presenting the estimated long-run error variance. However, in the Carrion-i-Silvestre and Sanso (2007) setting, one needs to clarify two unknown points, break dates and the estimation of the long-run variance $\hat{\sigma}^2$, which is expected to capture the unknown autocorrelated structure. Carrion-i-Silvestre and Sanso (2007) advise identifying the break dates through the minimization of the sequence of the sum of squared residuals (SSR). That is, regression 3.6 is estimated by OLS for each possible break T_{b1} and T_{b2}, and then the dates which produce the minimum SSR are selected. More specifically, the break dates are estimated as:

$$(\hat{T}_{b1}, \hat{T}_{b2}) = \underset{\lambda_1 \lambda_2 \in \Lambda}{\operatorname{argmin}} SSR(T_{b1}, T_{b2})$$

where the interval Λ is set as $\Lambda = \left[\frac{2}{T}, \frac{T-1}{T}\right]$.

The estimation of the long-run variance, which is the main drawback of stationarity tests, is the next problem to be addressed to compute the KPSS-type test statistic. In their original paper, KPSS (1992) have proposed a nonparametric estimator $\widehat{\sigma}^2$ in the form of

$$\hat{\sigma}^2 = T^{-1}\sum_{t=1}^{T}\hat{e}_t^2 + 2T^{-1}\sum_{j=1}^{l} w(j,l)\sum_{t=j+1}^{T}\hat{e}_t\hat{e}_{t-j}$$

where $\hat{e}_t$ is the residual obtained from the OLS estimation of the regression of y_t on the deterministic terms and w(j,l) is the Bartlett kernel set with a truncation lag $l = \text{integer}[q(T/100)^{0.25}]$ $q = 0, 4$ or 12. Although Bartlett kernel is used by KPSS to weigh the estimated autocovariance, different kernels, like Parzen and QS kernel, can also be applied. Among all available kernels, the QS kernel appears to be the most preferred one in the literature due to Andrews (1991) and Newey and West (1994), who have shown that the QS kernel has the optimal asymptotic mean squared error properties and yields more accurate long-run variance estimates than other kernels in finite samples. The other determinant of the estimation of the long-run variance is the truncation lag l. Its calculation has received more attention in the literature. Regarding optimal lag truncation lag, there are different suggestions. In that respect, while Lee (1996) suggests using Andrews' (1991) method, Hobijn et al. (1994) prefer to employ the method proposed by Newey and West (1994). However, Choi (1994), Choi and Ahn (1995, 1999), Kurozumi (2002), and SPC have criticized the data-based selection methods of Andrews (1991) and Newey and West (1994) for leading to the inconsistency of the test under the random walk alternatives and suggest to eliminate the inconsistency by imposing some bounds to control the estimated truncated lag. Recently, Carrion-i-Silvestre and Sanso (2006) provide a comparative analysis to investigate the finite sample properties of the KPSS test under different estimation methods for the long-run variance. According to their Monte Carlo analysis, the procedure suggested by SPC appears to be the one with less size distortion and reasonable power. Therefore, Carrion-i-Silvestre and Sanso (2007) have advised using the prewhitened HAC estimator of SPC for the long-run variance in their two-break KPSS test.

The procedure suggested by Sul et al. (2005) is as follows. First, an autoregressive model is estimated for the residuals, $\hat{e}_t$ as in equation 3.8:

$$\hat{e}_t = \rho_1 \hat{e}_{t-1} + \cdots + \rho_p \hat{e}_{t-p} + \psi_t \tag{3.8}$$

where the optimal lag order can be determined using information criteria such as Bayesian information criteria. After the estimation of the AR model in equation 3.8, the long-run variance of the estimated residuals $\tilde{\sigma}_{\psi}^2$ is obtained through the use of a HAC estimator with the QS kernel to take the presence of heteroscedasticity into account. In the subsequent step, the estimated long-run variance $\tilde{\sigma}_{\psi}^2$ is recolored as:

$$\hat{\sigma}^2 = \frac{\tilde{\sigma}_{\psi}^2}{\tilde{\rho}(1)^2}$$

where $\tilde{\rho}(1)$ denotes the autoregressive polynomial $\tilde{\rho}(L) = 1 - \tilde{\rho}L - \cdots - \tilde{\rho}L^p$ evaluated at L=1. At last, in order to address the inconsistency problem of the KPSS test statistic that originates from the use of prewhitened long-run variance estimate, SPC impose the boundary condition as in equation 3.9.

$$\hat{\sigma}^2 = \min\left\{T\tilde{\sigma}_{\psi}^2, \frac{\tilde{\sigma}_{\psi}^2}{\tilde{\rho}(1)^2}\right\} \tag{3.9}$$

After the estimation of break dates and long-run variance, Carrion-i-Silvestre and Sanso (2007) derive the nonstandard asymptotic distribution of the KPSS type statistic $\hat{\eta}$ in the formula 3.7, which depends on the relative positions of the breaks in the sample. Hence, the authors provide finite sample critical values using response surface regressions, where the finite sample critical values converge to their asymptotic values as the sample size increases.

3.2.3. Smooth Break Stationarity Test of Becker et al. (2006)

Due to the possible heterogeneity among economic agents in terms of reaction to an economic stimulus (Leybourne et al., 1998), directly presuming a sharp break may be erroneous (Harvey and Mills, 2004). Different from the sharp break stationarity test of Carrion-i-Silvestre and Sanso (2007), which implicitly assumes that breaks occur at a particular point in time and their effects are observed instantaneously, the test of Becker et al. (2006) considers the possibility that structural changes can occur gradually. It is designed to capture multiple smooth breaks in the series through the use of a Fourier function, which can approximate any integrable functions to any desired degree of accuracy. In this framework, the time series process $\mathrm{y_t}$ is defined as in equation 3.10:

$$\begin{gathered} y_t = \alpha + \beta t + \alpha(k,t) + r_t + \varepsilon_t \\ \alpha(k,t) = \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) \\ r_t = r_{t-1} + u_t \end{gathered} \tag{3.10}$$

where $\mathrm{\alpha(k,t)}$ denotes the time-varying deterministic component that requires no prior information regarding the number and forms of breaks, k is the single frequency selected for the approximation, γ_1 and γ_2 measure the amplitude and displacement of the frequency component, t is a trend term, T is the sample size, $\pi = 3.1416$, ε_t is a stationary disturbance term and $\mathrm{u_t}$ is the iid disturbance term with the variance σ_u^2. In this setting, it is obvious that under the null hypothesis $\sigma_\mathrm{u}^2 = 0$, $\mathrm{y_t}$ is a trend stationary and the KPSS statistic has the form of equation 3.11.

$$\tau_t(k) = \hat{\sigma}^2 T^{-2} \sum_{t=1}^{T} \tilde{S}_t(k)^2 \tag{3.11}$$

where $\hat{\sigma}^2$ being the estimated long-run error variance and $\mathrm{\tilde{S}_t(k)} = \sum_{\mathrm{i=1}}^{\mathrm{t}} \mathrm{\tilde{e}_i^2}$ with $\mathrm{\tilde{e}_i}$ the OLS residual from the regression in equation 3.12.

$$y_t = \alpha + \beta t + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + e_t \tag{3.12}$$

Calculating KPSS statistics requires estimated long-run variance and an appropriate single frequency k. Although Becker et al. (2006) follow the approach of KPSS to estimate the long-run variance, we prefer to use the approach of SPC due to its previously discussed merits in long-run variance estimation. Given that the actual value of k is unknown, the next issue to be addressed is specifying the appropriate frequency, k. To accomplish that, Becker et al. (2006) suggest employing a grid search procedure. That is, equation 3.10 is estimated through OLS for each integer value $k \in [1, 5]$, and the optimum frequency that produces the smallest residual sum of squares is chosen. Becker et al. (2006) show that the asymptotic distribution of the proposed KPSS statistic $\tau_t(\tilde{k})$, where $\tilde{k}$ is the optimum single frequency obtained from the grid search procedure, is non-standard and depends on the frequency of the Fourier series. Hence, the authors tabulate the critical values through Monte Carlo simulations for different integer values of k.

If the application of the test provides empirical evidence supporting the stationarity of y_t, then Becker et al. (2006) advise proceeding further with testing for the presence of the smooth breaks since the null hypothesis of $\sigma_u^2 = 0$ lacks any specific assumption regarding the presence of the breaks. In that sense, the null hypothesis $H_0: \gamma_1 = \gamma_2 = 0$ is tested in specification 3.10 by using an F-statistic, $F(\tilde{k})$. The distribution of the F-test is non-standard due to the presence of the nuisance parameter under the null. Therefore, the critical values are generated through Monte Carlo simulations and tabulated in Becker et al. (2006).

3.3. Data and Empirical Results

In the study, we analyze quarterly real prices of six base metals (aluminum, copper, lead, tin, nickel, zinc) and three precious metals (gold, silver, and platinum). The rationale for studying real metal prices is to save the analysis from the cyclicality of the exchange rate. While base metals oxidize or corrode quickly, precious metals resist to corrosion or oxidation. Furthermore, base metals can be divided into two categories, namely ferrous metals and nonferrous metals. Ferrous metals (e.g., iron) are such metals that are redundant and heavy. On the other hand, non-ferrous metals (e.g., copper, nickel, zinc, aluminum, tin, lead) typically do not contain iron in significant amounts.

Nominal metal (except for gold, silver, and platinum) prices and US Producer Price Index (1982=100) by Commodity for Final Demand: Finished Goods are collected from the database of the Federal Reserve Bank of St. Louis. The remaining metal prices are obtained from the World Bank (Pink Sheet). Using end-period nominal metal prices and seasonally adjusted US Producer Price Index (1982=100), the natural logarithm of quarterly real prices is calculated. Using the US Producer Price Index to deflate nominal metal prices is common in the literature (e.g., Slade (1982), Ahrens and Sharma (1997), Lee et al. (2006), and Presno et al. (2014)).

We commence with employing standard ADF and KPSS tests. In the standard KPSS test, we utilize SPC methodology for long-run variance estimation. The KPSS test with SPC methodology is used to address the inconsistency problem originating from the computation of data-based truncation lag selection procedures of Andrews (1991) and Newey and West (1994). The test results are illustrated in Table 3.1. The results present strong evidence for nonstationary, except for zinc and aluminum. Zinc and aluminum prices, almost uniformly, are reported to be stationary based on ADF and KPSS tests. However, as indicated before, both tests may be misleading, such that both tests have a bias supporting the existence of a unit root if a structural break exists. Hence, to furnish more trustworthy results, we proceed with the stationarity tests of Becker et al. (2006) and Carrion-i-Silvestre and Sanso (2007), which allow structural breaks in the price series.

Table 3. 1. ADF and KPSS Tests for Quarterly Real Metal Prices

	ADF Test Statistic Without Trend	ADF Test Statistic With Trend	KPSS Test Statistic Without Trend	KPSS Test Statistic With Trend
Copper	-1.796	-2.640	2.632	0.404
Lead	-1.453	-2.569	2.998	0.727
Tin	-2.391	-2.342	2.789	2.784
Nickel	-2.858	-3.035	0.985	0.179
Zinc	-3.391**	-3.631**	0.294**	0.123**
Aluminum	-3.760**	-3.931**	0.538	0.063**
Gold	-1.134	-2.042	7.785	4.381
Platinum	-2.131	-3.165	2.992	0.595
Silver	-2.901**	-3.410	2.956	2.392

Notes: The maximum autoregressive order is 8 for both of the tests. The lag order for the ADF test is based on the minimization of the Akaike Information Criteria (AIC). For the KPSS procedure, the SPC method is utilized with the QS kernel. BIC is utilized for choosing the optimal lag order in prewhitening procedure of Andres and Monahan (1992). ** denotes the stationarity of the series at the 5% significance level.

We employ the smooth break stationarity test of Becker et al. (2006) and commence with incorporating smooth breaks in real metal prices. The regression stated in equation 3.12, which assumes a trending series, for each integer single frequency is estimated to compute the test statistic $\tau_t(\tilde{k})$ and the optimal single frequency $\tilde{k}$ is selected through the minimization of the sum of squared residuals based on the specification. The same procedure is also utilized for computing $\tau_\mu(\tilde{k})$ with an additional assumption of nontrending series, i.e., $\beta = 0$ in equation 3.12. Although Becker et al. (2006) have proposed that one or two frequencies should be sufficient to capture the important breaks in the series and higher frequency implies stochastic parameter variability rather than structural breaks, we prudently employ the grid search for each integer value of $k \in [1,5]$.

The test results based on a single frequency are presented in Table 3.2. We tabulate test statistics, including either a linear trend or not. Results do not vary nearly for all metals. Except for zinc and aluminum prices, all optimum frequencies are either one or two, which is consistent with the expectation of Becker et al. (2006) about the argument that optimal frequency should be one or two in order to indicate important structural breaks. Since there is already strong evidence supporting the stationarity zinc and aluminum prices based on ADF and KPSS test results presented in Table 3.1, we focus on other metals. Based on test results, we can not reject the null hypothesis of level stationary or trend stationary for most of the metals, except for gold and copper. Furthermore, $F_\mu(\tilde{k})$ and $F_t(\tilde{k})$ indicate the significance of the Fourier terms for metal prices, which are reported to be stationary.

Table 3. 2. Becker et al. (2006) Stationarity Test Results

	$\tilde{k}$	$\tau_\mu(\tilde{k})$	$F_\mu(\tilde{k})$		$\tilde{k}$	$\tau_t(\tilde{k})$	$F_t(\tilde{k})$
Copper	2	0.244**	54.19**		2	0.142	NA
Lead	1	0.091**	84.31**		1	0.043**	56.35**
Tin	1	0.126**	286.02**		1	0.046**	340.02**
Nickel	2	0.303**	35.90**		2	0.080**	38.54**
Zinc	2	0.117**	24.75**		4	0.081**	21.98**
Aluminum	2	0.391**	14.50**		4	0.063**	17.19**
Gold	1	0.830	NA		1	0.060	NA
Platinum	1	0.104**	143.752**		1	0.051**	81.39**
Silver	1	0.106**	239.916**		1	0.049**	241.91**

Notes: $\tau_\mu(\tilde{k})$ $(\tau_t(\tilde{k}))$ and $F_\mu(\tilde{k})$ $(F_t(\tilde{k}))$ indicate the KPSS-type test statistic of Becker et al. (2006) and F-statistic to test the presence of smooth breaks assuming the absence (presence) of a linear trend. Critical values are taken from Table 1 of Becker et al. (2006). The SPC method is utilized with the QS kernel and a maximum autoregressive order of 8. NA stands for 'Not Applicable' since F-statistic is not reliable when stationarity is rejected. ** denotes the significance of KPSS-type statistics and F-statistics at the 5% significance level.

We further present the real metal prices and the estimated Fourier functions in Figure 3.1. It seems from the figure that Fourier approximations are plausible to reflect the overall pattern of the real prices. They do not seem to perform very well identifying the sharp breaks in terms of break magnitudes and timings. This observation is consistent with the proposal of Jones and Enders (2014) that Fourier approximations can perform plausibly well mimicking sharp breaks, though they might struggle with the identification of the time and magnitude of the break. This is an issue that might affect the performance of the stationarity test of Becker et al. (2006) since, as suggested by Harvey and Mills (2004), the size distortion of the smooth break stationarity tests in the presence of instant breaks might worsen with the magnitude of the break.

Taking this potential problem into account, we proceed with the sharp break stationarity test of Carrion-i-Silvestre and Sanso (2007). In their paper, Carrion-i-Silvestre and Sanso (2007) have proposed seven different specificants for the deterministic terms that are represented by $\mathrm{f(t, T_{b1}, T_{b2})}$. Among them, we use three popular models, namely Model AA, Model BB, and Model CC. Model CC is the most general form that allows for two structural changes in the intercept and trend terms.

The test results are illustrated in Table 3.3. The test statistic $\hat{\eta}$ from equation 3.7 and the corresponding estimated structural breaks are presented based on the specification. Three alternative models are considered. These models can be obtained from equation 3.6 with appropriate restrictions. Model CC does not require any restriction. In equation 3.6, $\theta_\mathrm{i} = 0$ for each i is required to obtain Model BB. Model AA requires that all γ_is equal zero.

Strikingly, when two structural breaks in level (Model AA) are considered, all metal prices are reported to be stationary. A similar picture is also displayed for two breaks in the linear trend, Model BB, and two breaks both in the level and linear trend, Model CC, with some exceptions. Interestingly, except for copper, silver, and tin, metal prices are reported to be stationary for Model BB. On the other hand, excluding aluminum, gold, and silver, metal prices are reported to be stationary for Model CC. Inference about aluminum price series may be due to power loss originating from additional unnecessary break-related variables since there is already strong evidence of stationarity based on standard ADF and KPSS tests. Another important observation here would be that only real platinum prices among precious metal prices are uniformly found to be stationary, meaning inefficiency of the market. It can be attributed to low investment demand for platinum when compared to other precious metals, especially gold (see Huang and Kilic, 2019, Figure 5). More than half of the global platinum demand comes from autocatalyst producers.

Table 3. 3. Carrion-i-Silvestre and Sanso (2007) Stationarity Test Results

	Model AA $\hat{\eta}_{AA}$ $(\hat{T}_{b1}, \hat{T}_{b2})$		Model BB $\hat{\eta}_{BB}$ $(\hat{T}_{b1}, \hat{T}_{b2})$		Model CC $\hat{\eta}_{CC}$ $(\hat{T}_{b1}, \hat{T}_{b2})$
Copper	0.037** (1987Q3, 2005Q2)		0.079 (2003Q3, 2006Q3)		0.022** (1987Q3, 2003Q4)
Lead	0.037** (2003Q4, 2006Q3)		0.040** (2003Q1, 2007Q3)		0.037** (1986Q3, 2003Q4)
Tin	0.056** (1985Q4, 2006Q3)		0.096 (2001Q4, 2010Q4)		0.025** (1985Q4, 2003Q4)
Nickel	0.027** (1987Q3, 2003Q3)		0.040** (2002Q2, 2007Q1)		0.024** (1987Q3, 2003Q3)
Zinc	0.020** (1987Q4, 2005Q3)		0.063** (2005Q2, 2006Q1)		0.018** (1988Q1, 2005Q3)
Aluminum	0.024** (1987Q1, 2003Q4)		0.025** (2003Q3, 2006Q3)		0.069 (1987Q2, 1993Q4)
Gold	0.039** (2005Q3, 2009Q2)		0.047** (2002Q1, 2011Q4)		0.061 (2000Q4, 2013Q1)
Platinum	0.043** (1980Q4, 2003Q2)		0.024** (1998Q2, 2010Q4)		0.016** (1999Q3, 2010Q4)
Silver	0.056** (1984Q2, 2005Q4)		0.121 (2001Q2, 2011Q4)		0.068 (1992Q4, 2010Q3)

Notes: The SPC method is utilized with a QS kernel and the maximum autoregressive order of 8. ** denotes the stationarity of the series at the 5% significance level. The dates in parentheses correspond to the estimated break dates. Critical values of Model AA, Model BB, and Model CC are taken from the response surfaces in Table 3, Table 4, and Table 5 of Carrion-i-Silvestre and Sanso (2007), respectively.

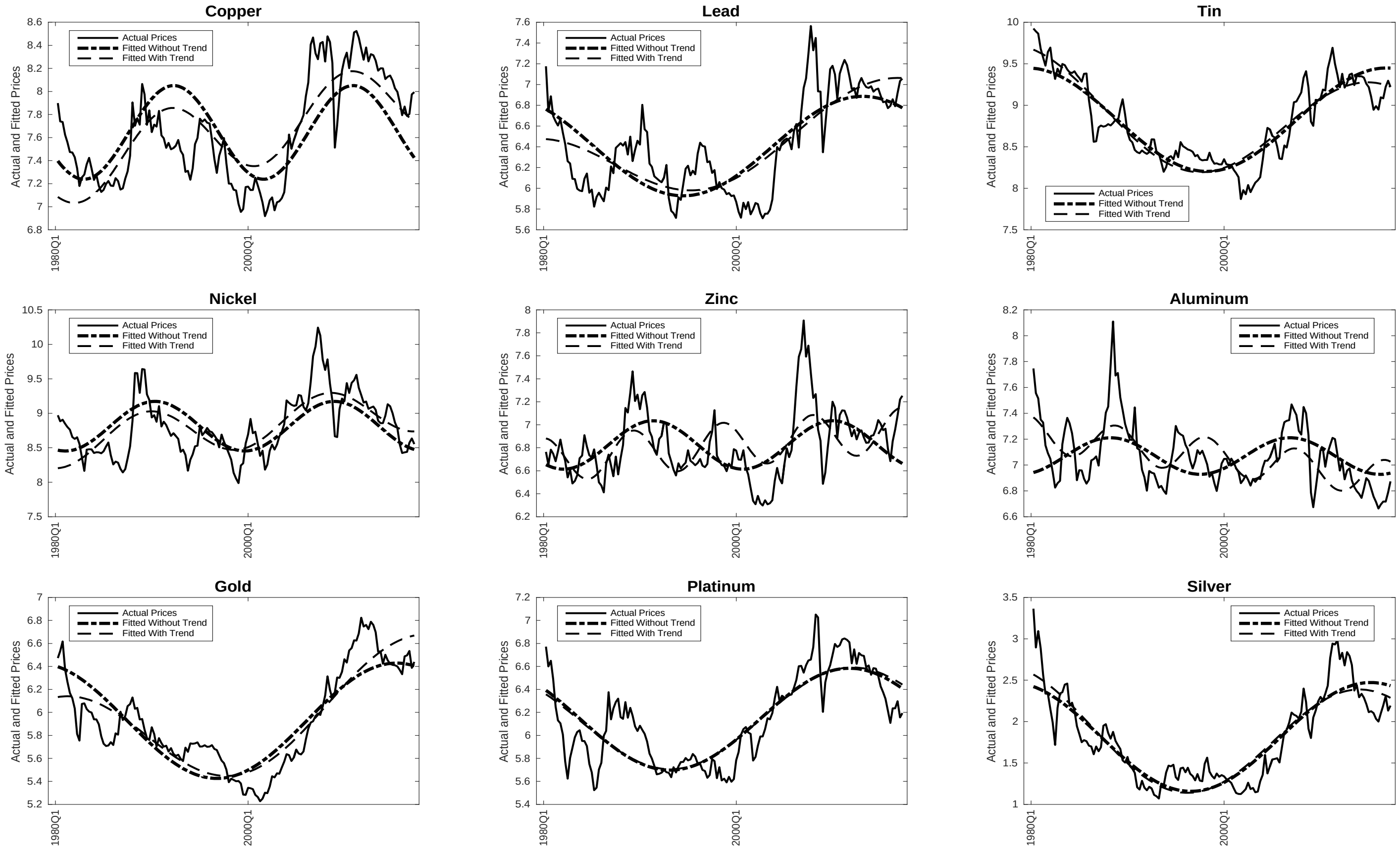

Figure 3. 1. Real Metal Prices with Fitted Fourier Functions

Unfortunately, there is no agreed statistical method for selecting a model among these three model specifications. All real metal prices are reported to be stationary for only model AA. Lead, nickel, zinc, and platinum prices are reported to be stationary for all three model specifications. At this point, copper, tin, and aluminum prices deserve further emphasis since all those prices are reported to be nonstationary for only one model. In the case of copper prices, although both AA and CC models present the third quarter of 1987 as a structural break, model BB can not capture that break. We argue that this is the main reason for model BB's inference about the stationarity of copper since, due to growing world consumption and historically low inventory, prices peaked at the end of 1988 (USGS, 2012:49). Similarly, unlike models AA and CC, model BB for tin prices can not capture the break of the fourth quarter of 1985 which is the collapse of International Tin Council (ITC). ITC was the organization that defended the tin price to keep high until October 24, 1985. The case is quite different for aluminum prices since stationarity is rejected only for model CC. This is possibly due to the failure to capture the break of the third or fourth quarter of 2003. The years between 2004 and 2008 coincide with the rise of the emerging economies of Brazil, China, India, and Russia, resulting in high aluminum demand (USGS, 2012:4). As pointed out before, there is strong evidence supporting the stationarity of aluminum prices based on standard ADF and KPSS tests. The rejection of null of stationarity may be affected by additional variables due to the break specifications. However, unfortunately, similar arguments can not be made for gold and silver, which are the main precious metals and are not subject to industrial end-use as much as industrial non-ferrous metals. Since model CC is the most general case and seems to better capture the trough in the early 2000s, we argue that gold and silver prices are nonstationary.

The observed structural breaks are plotted together with the original price series in Figure 3.2. Overall, it seems that the observed dates and magnitudes of the breaks are more coherent with the original price series compared to those derived from the approach of Becker et al. (2006), which is presented in Figure 3.1.

Some peaks and troughs of fitted Fourier functions and original metal prices coincide. Reasonably, some metals' prices share common overlapping peaks or troughs, while some metals' prices overlapping peaks or troughs are specific to that metal. Except for some instances, common peaks or troughs are related to global events. For instance, copper, lead, platinum, and silver have overlapping peaks of 2011Q2 or 2011Q3. Interestingly, the peak is mostly related to growing stress and global uncertainties regarding the European sovereign debt problem and concerns about slowing industrial demand in China (World Bank, 2011a). In addition, due to its precious metal property, the decline in silver prices is also partly attributed to investor liquidation at the time (World Bank, 2011a, 2011b). As a result of rising Chinese exports and inventories, the peak occurred at the end of 2006 or the beginning of 2007 is common in nickel, zinc, and aluminum price paths (World Bank, 2007a, 2007b, 2007c). Nickel and zinc prices share the peak of the 1989Q1. The price of nickel soared with the demand for cyclical stainless demand in 1987 (Bureau of Mines, 1989a:739). Similarly, from November 1987, the price of zinc rose due to strong demand and tight supply (Bureau of Mines, 1989b:1155). Copper, tin, gold, and silver prices share the trough of the third quarter of 2001, which is mainly related to the global economic slowdown. Specifically, tin and gold price falls is related to slowing demand in the electronic sector and jewelry fabrication, respectively (Bureau of Mines, 2001a, 2001b), while silver price fall can be attributed to weak fabrication demand (The Silver Institute, 2002).

Justifications related to the peak of aluminum price in the second quarter of 1988 and the trough of nickel price in the fourth quarter of 1998 are quite different in the sense that they are caused by financial and relatively local reasons, respectively. The aluminum price peak was due to the financial event, namely the Big Sequeze, in which short position holders could not cover their positions from long position holders during huge price increases in the LME (The Metal Bulletin, 2015). On the other hand, the nickel price trough is caused by reduced nickel consumption in Russia, a recession in Japan, and economic problems in other parts of East Asia (Bureau of Mines, 1998). Thus, the overlapping peaks and troughs were mostly related to global cyclical events. However, there is a chance that sharp structural breaks specific to a metal may also exist. In order to capture some of those, Carrion-i-Silvestre and Sanso's (2007) methodology is used as a complementary econometric tool.

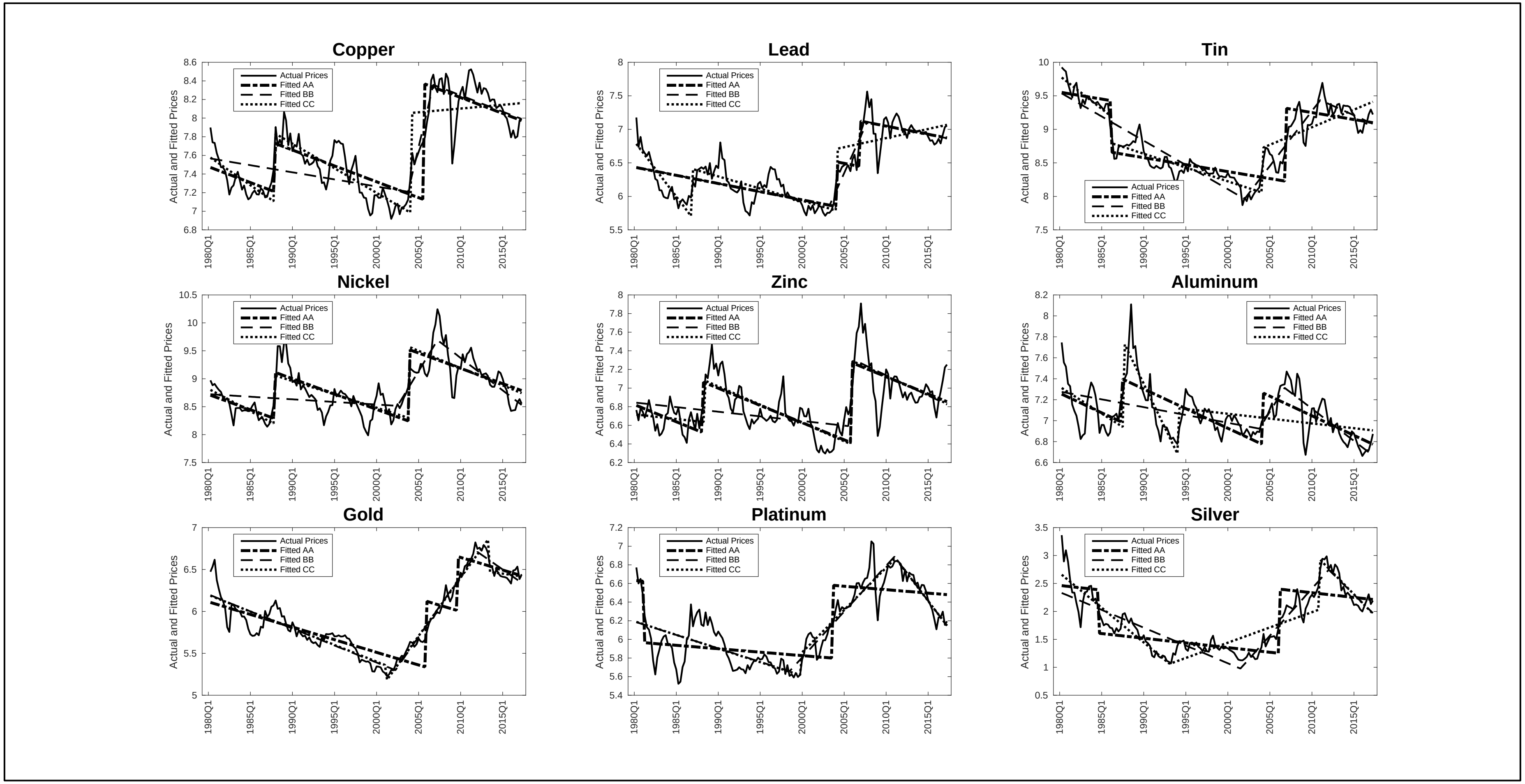

Figure 3. 2. Real Metal Prices with Fitted Sharp Breaks

Estimated structural breaks are also checked in terms of plausibility. A reasonable way to approach this analysis would be to start with the most comprehensive model among the three models, i.e., the model CC. However, the preliminary condition for interpreting the estimated break dates of model CC would be the stationarity of metal prices. As elaborated in studies by Bai (1994, 1997) and Nunes et al. (1995), the main reason would be the inconsistency of estimated break dates if the data series is nonstationary. If the data series is nonstationary, the estimated break dates do not converge in probability to the actual break dates as the sample size goes to infinity. Among the investigated metals, only aluminum, gold, and silver prices are reported to be nonstationary for model CC. However, we argue that nonstationary aluminum metal prices for model CC can be attributed to missing the break of the third or fourth quarter of 2003 that both models AA and BB capture. On the other hand, the nonstationarity of gold and silver prices can be claimed to be due to the relatively non-industrial use of those metals. Lastly, we consider model AA for gold and silver prices, which is reported to be stationary for both precious metals. For models AA and CC, copper, lead, tin, nickel, and zinc are reported to be stationary. Moreover, for copper, lead, tin, and nickel, estimated structural breaks are very close to each other for model CC. The third or fourth quarter of 2003 break is common to all four metals. This break can be attributed to the rise in demand for those metals due to the emergence of some economies, especially China (USGS, 2012).

Similarly, the estimated break of the third quarter of 1987 is reported for copper and nickel. The nickel price rise was due to the record worldwide stainless steel production, which was not expected (Bureau of Mines, 1987b: 648), while the copper price hike can be attributable to the tight scrap copper supplies, which are accompanied by relatively high consumption demand (Bureau of Mines, 1987a: 307). The first quarter of 1988 is estimated to be a break for zinc prices for model CC. This period coincided with the increased Chinese buying and tightening of zinc supplies in Europe and the United States (Bureau of Mines, 1987c:938). As mentioned before, the break of 1985’s fourth quarter for tin prices is due to the collapse of ITC. Until the October 24, 1985, ITC defended the price to be kept high. However, ITC declared the exhaustion of the funds required to support the price on

October 24, 1985. This event led to severe disruption in the World tin market (Bureau of Mines, 1985: 969).

The case for aluminum is quite different than other industrial metals under investigation. Aluminum prices are reported to be nonstationary for model CC, even though it is reported to be stationary for both models AA and BB. We argue that it is due to the failure of model CC to capture the break of the third or fourth quarter of 2003, which is explained by the rise of Chinese demand. Model CC identifies one break as the second quarter of 1987, which is very close to the first quarter of 1987, a break of model AA. The peak of 1987Q1 was mostly related to excess demand. For instance, some countries such as Brazil, Cameroon, Indonesia, and Suriname had to reduce their production due to drought conditions badly affecting the hydroelectric power (Bureau of Mines, 1987: 97). Under these conditions, we could not separate aluminum from other base metals investigated in this study.

Among precious metals, only platinum prices are reported to be stationary for model CC. The break of the third quarter of 1999 was mainly related to increased consumption by the automobile industry combined with limited physical availability (USGS, 2012:121). On the other hand, the break of the fourth quarter of 2010 is due to the significant substitution of platinum with palladium. The increasing use of palladium in the catalytic converter industry can be stated as the main driver of the fall of platinum prices (Bureau of Mines, 2010).

Model AA, which is reported to be stationary for both precious metals, is considered for checking the reasonability of estimated breaks. The peak of 2009Q2 is due to strong investment demand for gold in the form of exchange-traded funds, bars, and coins (World Bank, 2009: 13). The estimated peak of 2005Q3 coincides with the concerns of inflation (World Bank, 2005). The trough of 1984Q2 is related to increased world mine silver production of developing countries to obtain foreign exchange for debt repayment (Bureau of Mines, 1984:814). The peak of 2005Q4 is claimed to be the result of fresh investment due to global liquidity (World Bank, 2006b). The price increase is also positively affected by silver’s being an alternative to gold. Our conclusion about the nonstationarity of gold and silver prices is in line with the inferences proposed by the most recent studies of Narayan and Liu (2011) and Presno et al. (2014), despite the differences in methodologies and the time span of data.

Overall, our results indicate that while industrial metals are affected mainly by market-specific conditions, precious metals are driven specifically by global macroeconomic conditions. This finding is quite revealing given that precious metals’ role as a store value, especially in times of financial turmoil since their inclusion yields risk reduction in portfolios through hedging strategies.

3.4. Conclusion

In this study, we examine the efficient market hypothesis for several non-renewable resources, including copper, lead, tin, nickel, zinc, aluminum, gold, silver, and platinum, from 1980Q1 to 2017Q1. The standard ADF and KPSS-SPC test results support the existence of a unit root, except for zinc and aluminum. This result implies that almost all metal markets are weak-form efficient. These results mainly corroborate the picture drawn by Moore and Cullen (1995), Macdonald and Taylor (1988), and Chowdhury (1991), even though those three papers relatively cover a short period with different frequency structures. Following the inference of the existing literature that structural breaks and trends are important considerations for the analysis of stochastic properties of non-renewable natural resource prices, we employ two stationarity tests. One is designed to identify smooth breaks. The other is designed to detect abrupt changes in trend. The motivation behind the consideration of smooth and sharp breaks is to avoid any misspecification of the functional form of the breaks, which could be as problematic as ignoring the breaks.

The methodologies of Becker et al. (2006) and Carrion-i-Silvestre and Sanso (2007) augmented with optimizing quadratic spectral kernel (Andrews, 1991) are applied. Furthermore, the SPC prewhitening approach to make those KPSS-type tests consistent is also used for both methodologies. When Becker et al. (2006) methodology is utilized, all metals, except for copper and gold, are reported to be stationary whether they include a linear trend or not. The main merits of Becker et al.

(2006) approach can be claimed to be regular periodicity consideration and lack of priori assumption regarding breaks. However, Becker et al. (2006) admit that their methodology is better for gradual breaks. Moreover, some metal price data visually support the existence of a structural break. The fitted values of Becker et al. (2006) coincide with the global economic events. To capture more of the metal-specific events, the employment of a KPSS test allowing structural breaks enriches the analysis. Therefore, Carrion-i-Silvestre and Sanso's (2007) methodology, which allows two endogenously determined breaks, is employed.

Our results reveal that the empirical evidence of stationarity of metal prices increases when structural breaks are appropriately considered. In that sense, the sharp break stationarity test of Carrion-i-Silvestre and Sanso (2007) appears to be decisive in uncovering evidence for the stationarity of metal prices, while the smooth break stationarity test of Becker et al. (2006) seems to perform relatively poor in identifying the sharp breaks in terms of break magnitudes and timings. In particular, we find that almost all metal prices follow a stationary trend with the observed structural changes, which are related to market-specific and economic events. The global financial conditions have appeared to be effective, especially on precious metals. Although it is not a direct focus of this study, our results can be helpful for forecasting purposes. Heterogeneity among economic agents is the primary determinant of sharp or smooth breaks. As elaborated in the second chapter, precious metals are subject to non-industrial and industrial demand. Non-industrial demand moderates the shocks originating from industrial activity. On the other hand, demand for base metals is solely composed of industrial demand. Thus, the demand structure of precious metals is heterogeneous. For forecasting purposes, we argue that sharp breaks and smooth breaks are suitable for base and precious metal prices, respectively.

Reported evidence of inefficiency means that prices do not fully reflect all available information in the market. The implication of weak-form inefficiency finding in all these markets enables one to perform technical analysis to predict prices and make excess profits. Moreover, stabilization policies effectively deal with exogenous shocks, which will be temporary and short-lived. Gold and silver, exceptionally, appear to be characterized by the efficient market hypothesis, with stationarity rejected for almost all of the specifications considered in this study. This result advises that the effects of exogenous shocks on these metal prices would be permanent and strong policy measures should be implemented to bring metal prices to their original trend.

CHAPTER 4

FUTURES MARKET EFFICIENCY OF BASE METALS: EVIDENCE FROM LONDON METAL EXCHANGE

As metal markets have become more financialized, they have become increasingly important (Cheng and Xiong, 2014). Furthermore, related to climate change concerns, countries have started to prefer increasingly metal-intensive technologies rather than fossil fuel mechanisms, especially after the 2015 Paris Agreement (World Bank, 2017:19). In a recent report by the IMF (2023), copper, nickel, cobalt, and lithium have been listed as crucial mineral inputs for the green transition. On the other hand, since metal production consumes a significant amount of energy and emits a significant amount of greenhouse gases, environmental regulations would probably cause a transformation of production methods and amounts. These developments draw more attention to the price dynamics of metals. Futures as well as spot prices should be emphasized in this regard. There are even studies, such as Figueralla-Ferreti and Gonzalo (2010) and Zhang and Wang (2013), arguing that the futures price is superior to the spot price in terms of being an indicator of the spot price. Figueralla-Ferreti and Gonzalo (2010) present evidence supporting that the 15-month futures price of metals, except for lead, is the dominant factor in the price discovery function. Zhang and Wang (2013) report that one period-lagged oil futures price, relative to one period-lagged spot price, carries out 95.71 percent of the price discovery function.

The empirical investigation of futures metal market efficiency requires a different approach from the spot metal market efficiency. The efficiency of a spot metal market is popularly analyzed through a unit root or a stationary test to infer predictability from spot metal prices. If the price series of a metal is non-stationary or displays a random walk structure, then it can be characterized by the efficient market hypothesis. On the other hand, metal futures market efficiency is inspected by implementing methodologies using both spot and futures metal prices to argue about whether futures price is an unbiased predictor of future spot price. However, unbiasedness of futures price also presumes risk neutrality of the traders. Therefore, unbiasedness is a stronger concept than efficiency. In other words, “efficiency” is a necessary condition for unbiasedness but not vice versa.

Analyzing futures market efficiency has been an important research subject since efficient markets do not allow profitable trading strategies between futures and spot markets. There are essential repercussions of futures market efficiency on hedgers, speculators, arbitrageurs, and regulators. In an inefficient futures market, hedgers can not hinge upon the risk transfer role of futures contracts. Therefore, they will be unwilling to buy/sell a futures contract. Thus, they forego lower transactions, faster execution of transactions, and short-selling opportunities in the futures market. Since the speculator is the economic agent who takes the risk of the hedger in exchange for a premium in a futures market, and the hedger is less likely to participate in an inefficient futures market, speculation activity also will fall. However, arbitrageurs will transact to earn riskless profits in an inefficient futures market. The return motive for a speculator and an arbitrageur is different. The speculator seeks a return in exchange for the hedger’s risk. The arbitrageur takes simultaneous positions in markets to earn profits without taking any risk. Even though regulators do not take any positions in futures or spot markets, they should intervene in the markets with regulations.

Due to the LME’s reference role for global metal pricing, the investigation of the LME futures market efficiency has been a subject in the metal literature for a long time. Goss (1981, 1983), Hsieh and Kulatilaka (1982), Canarella and Pollard (1986), Macdonald and Taylor (1988), Sephton and Cochrane (1990, 1991), Arouri et al. (2011), Otto (2011), Chinn and Coibion (2014), and Park and Lim (2018) are some of these studies. Following the literature, our focus will be on LME futures markets.
Although there are some exceptions, e.g., Park and Lim (2018) and Chinn and Coibion (2014), the majority of papers in the literature investigate the stationarity or the existence of a unit root in spot and futures metal price data before efficiency

analysis of a futures metal market. For varying metals, studies report both spot and futures metal prices to have a unit root in most of the cases based on tests such as exponential smooth transition unit root test (Cagli et al., 2019), ADF test (Reichsfeld and Rauche, 2011; Otto, 2011; Arouri et al., 2011, 2013; Kuruppuarachchi et al., 2019), Zivot and Andrews test (Arouri et al., 2011, 2013), PP test (Arouri et al., 2011, 2013)) and KPSS test (Otto, 2011). Furthermore, based on preliminary stationary analysis results, some papers, such as Reichsfeld and Rauche (2011), Cagli et al. (2019), and Kuruppuarachchi et al. (2019), point out the efficiency of futures metal markets in contrast with other studies like Chinn and Coibbion (2014) and Park and Lim (2018). The unit root test results support the existence of a unit root. However, some papers, such as Adewuyi et al. (2020), present evidence supporting the stationarity based on non-linear unit root tests. They conclude that all metal prices are stationary by at least three of five unit root tests with a structural break.

In our study, we focus on non-overlapping price data of six base metals, namely copper, lead, nickel, zinc, tin, and aluminum, to make inferences about the weak-form efficiency of related LME futures markets between the period January 1990 and April 2020. We follow the common approach in the literature and apply ADF and PP tests. Moreover, the standard KPSS test with the SPC prewhitening procedure to make the test consistent, elaborated in the previous chapter, is also applied. Then, we employ the ARDL bounds test of Pesaran et al. (2001), designed to investigate the presence of a cointegrating relationship between spot and futures prices. This testing procedure is robust to the integration of order and has some superior features in comparison with Engle and Granger (1987), Johansen (1988), and Johansen and Juselius (1990). Other than its robustness to the integration of order, this procedure does not mandate a large sample for validity, unlike the Johansen cointegration techniques. Furthermore, varying optimal autoregressive orders are allowed for each series in this method. In the literature, we do not encounter any study applying this method prior to efficiency analysis. This is the main contribution of this chapter to the literature. Finally, based on test results, we continue with the examination of futures market efficiency.

In the study, the first section presents a discussion about overlapping and non-overlapping data due to its relevance to futures market efficiency. Then, the elaboration is presented regarding the futures market efficiency. The third section reviews the literature. The fourth section elaborates on the methodologies utilized in the study. The fifth section presents and discusses the data and empirical results. The last section concludes the study.

4.1. Discussion about Overlapping and Non-overlapping data

The distinction between overlapping and non-overlapping data can be clarified simply by using the return calculation concept. To discuss the concept, consider an asset, such as a stock, with a daily market price. We can compute the overlapping monthly return of an asset daily by subtracting the logarithm of the closing price of the previous business day. Thus, a return is calculated for each business day of the month. However, if the monthly non-overlapping return is to be calculated, it is found by subtracting the logarithm of the first business day's price from the last business day's price of the month. In fact, there will be just one non-overlapping return for the month. On the other hand, there are overlapping returns calculated for each business day of the month. Thus, the periods regarding the overlapping return calculation coincide to some extent, which is not the case for non-overlapping returns. This leads to statistical dependence for overlapping returns. An example can reveal the difference. Consider a metal futures contract with a 3-month maturity. Since futures contracts are daily marked-to-market, daily prices can be obtained. The efficiency of a futures market is investigated through its relationship to future spot, equivalently prompt price. Therefore, both futures and future spot metal prices are used. Overlapping price data refers to a price pair consisting of futures and future spot prices, which have overlapping periods. As an overlapping data example, daily futures prices can be related to future spot prices, which occur after three months of futures prices. Thus, overlapping data for each business day can be constituted for the whole contract period, i.e., three months. Thus, there will be an observation for each business day until the maturity of the contract. However, these observations will have coinciding contract periods leading to statistical dependence. On the other hand, in the case of non-overlapping data, there would be just one observation for the whole contract period.

With the non-overlapping data, serial autocorrelation that may arise due to using informationally overlapping data may be prevented (e.g., Hansen and Hodrick, 1980; Kellard et al., 1999). Even if a market is efficient, autocorrelation due to overlapping data leads to incorrect inference of inefficiency (Kellard et al., 1999: 416)). Kellard et al. (1999:415) ascribe autocorrelation to the argument that subsequent futures prices reflect the expectations about future spot prices. By working with non-overlapping data, we aim to eliminate overlapping futures contracts' effects that would result in autocorrelation in errors.

In the metal literature, both overlapping data (Hsieh and Kulatilaka, 1982; Canarella and Pollard, 1986; Sephton and Cochrane, 1990; Otto, 2011) and non-overlapping data (Canarella and Pollard, 1986; Beck, 1994; Park and Lim, 2018) are utilized in futures metal market efficiency analysis. Due to its econometric merit, we use non-overlapping data.

4.2. Background Information about Futures Market Efficiency

A futures contract is a standardized contract to buy or sell a particular asset of a predetermined quantity to be delivered at a specified future date. Futures contract transactions take place in Exchanges. These contracts are marked-to-market, which means the daily realization of the profit or loss originating from market price movements.

Regardless of the underlying asset of the futures contract, e.g., a commodity or a foreign currency, futures contracts furnish market participants with some understanding of future spot prices, i.e., price discovery function, and enable short/long hedgers to pass on their risk to speculators, i.e., risk transfer function. These two functions are closely related to each other and the pricing mechanism. In turn, futures prices comprise the primary means for efficiency investigation.

Consider a risk-averse metal producer who plans to sell some amount of metals in the future and prefers to manage the risk of downward price movement. Therefore, the producer sells a futures contract to a speculator as insurance regarding the fall of the price. In this scenario, the producer is the short hedger. The speculator assumes the risk in return for a reward. On the other hand, the short hedger would accept a lower price than the expectation of the future spot price to insure against the risk of price fall. Thus, the short hedger accepts a futures price below the expected future spot price at the maturity of the contract, even if the expected future price is higher than the futures price. This relationship between the futures price and the expected future spot price is termed normal backwardation. Conversely, consider a risk-averse metal consumer, such as a stainless steel producer, who plans to purchase some amount of metal, in this case, the metal is nickel, in the future and prefers to limit the extra cost due to a possible price rise. Therefore, the consumer buys a futures contract from a speculator to restrict the risk originating from a possible price increase. In this context, the metal consumer is the long hedger. The long hedger accepts a higher price than the expectation of the future spot price to limit the cost. The futures price will be above the expected future spot price at the maturity of the contract. This condition is termed as contango.

There exist two models for the pricing of a futures contract, namely the risk premium theory and the theory of storage. The risk premium theory originates back to Keynes (1930) and Cootner (1960). The theory of storage dates back to Kaldor (1939), Working (1949), Telser (1958), and Brennan (1958). The risk premium theory focuses on the relationship between the futures price and the expected spot price at the maturity of a futures contract. On the other hand, the theory of storage explains the nexus between futures price and contemporaneous spot price.

The theory of storage contends that the futures price of a storable commodity is determined by the spot price and the cost of carry. The cost of carry refers to all costs until the future delivery date. It includes storage/insurance costs, financial costs, and possibly the risk premium. Financial costs can be the opportunity cost of holding a commodity or the cost of funding. The relationship between futures and spot price can be summarized in equation 4.1.

$$F_{t-1,t} = S_{t-1} + c_{t-1,t} \tag{4.1}$$

$\mathrm{S}_{\mathrm{t-1}}$ represents the natural logarithm of the spot price of the metal at time, t-1, $\mathrm{F}_{\mathrm{t-1,t}}$ is the natural logarithm of the price of a metal futures contract at time t-1 of issuance with the future delivery date, t. $\mathrm{c}_{\mathrm{t-1,t}}$ denotes the natural logarithm of the cost of carry, the sum of storage cost, interest costs, and the risk premium minus convenience yield. The convenience yield refers to the benefit obtained from the possession of a particular asset rather than the futures contract of that asset.

The risk premium theory asserts that the expected future spot price equals the sum of the futures price and risk premium. It can be stated as in the equation 4.2.

$$E_{t-1}S_t = F_{t-1,t} + RP_{t-1} \tag{4.2}$$

where $\mathrm{E}_{\mathrm{t-1}}\mathrm{S}_{\mathrm{t}}$ denotes the expectation of spot price for time t at time t-1 and $\mathrm{RP}_{\mathrm{t-1}}$,i.e., the risk premium, is the difference between $\mathrm{E}_{\mathrm{t-1}}\mathrm{S}_{\mathrm{t}}$ and $\mathrm{F}_{\mathrm{t-1,t}}$. Risk premium can be either positive or negative. In the case where a metal producer hedges against the possible price fall by selling a futures contract, we expect the risk premium to be positive. Thus, the speculator has the incentive to insure against downward price movement. On the other hand, when a metal consumer hedges against the price rise through buying a futures contract. In such a case, we expect the risk premium to be negative so that the speculator is compensated for taking the risk of the price rise. The sign of the risk premium relies on which type of hedger dominates the trading volume. For instance, if the risk premium is reported to be negative (positive), we can infer that metal consumers (producers) carry out most of the transactions.

As Fama (1970) states, in an efficient market, the price already reflects all available information. The efficient market hypothesis implies that the futures price is the optimal forecast of the future spot price. Empirical work is structured around this concept. Futures market efficiency implies the absence of constant arbitrage opportunities between futures and spot markets. Constant arbitrage opportunities are present if there exists a consistent and simultaneous price differential between futures and spot markets, which may lead to riskless profits in excess of transaction costs. Basically, in an efficient market, there should not be any perpetual prospects to earn profits without assuming any risk. Although investigation methodologies for futures market efficiency vary in the literature, the risk premium theory is commonly embraced for testing market efficiency. The primary justification for such a choice is the challenge of finding a good proxy for convenience yield (Davies and Krinsky, 1992:97).

No arbitrage condition and risk-neutral speculators, i.e., $\mathrm{RP}_{t-1} = 0$, force that there is no discrepancy between the current futures price and expected spot price at the futures contract maturity, displayed in equation 4.3.

$$E_{t-1}S_t = F_{t-1,t} \tag{4.3}$$

The efficiency hypothesis further assumes that expectations are rational. The rational expectation concept basically refers to the equivalence of today's price and yesterday's price expectation about today's price, given yesterday's information set and the unsystematic error. The equation 4.4 formulates this relationship.

$$S_t = E_{t-1}(S_t|\Omega_{t-1}) + u_t \tag{4.4}$$

$\mathrm{E}_{t-1}(\mathrm{S}_t|\Omega_{t-1})$ refers to the t-1 expectation of spot price at the time t, i.e., S_t, given the information set at time t-1 including lagged forecast errors, i.e., Ω_{t-1}, and u_t represents the unsystematic error term orthogonal to Ω_{t-1}. The assumption of risk neutrality can be relaxed in the case of efficiency analysis since it is related to the unbiasedness of futures prices. The efficiency and unbiasedness analysis can be done with the specification expressed in equation 4.5 for stationary time series.

$$S_t = a + bF_{t-1,t} + u_t \tag{4.5}$$

The joint hypothesis of market efficiency and unbiasedness can be tested by the null hypothesis that $\mathrm{a} = 0$ and $\mathrm{b} = 1$. However, the unbiasedness can be considered as a special case of efficiency property. Unbiased futures prices can only exist in an efficient market. The null hypothesis shrinks to $b = 1$ when one is to test only the efficiency hypothesis. It should be noted that this test provides inference about the weak-form efficiency of the futures market by the specification stated in equation 4.5, since only current and lagged prices of spot and futures markets related to the same asset or commodity are exploited. The fundamental intuition is that one investigates the weak-form efficiency of a futures market by examining its forecast performance of the future spot price. When some macroeconomic variables such as industrial production, interest rate, or futures/spot price of other relevant assets or commodities are incorporated as public information into the analysis, the inference about semi-strong efficiency can be made. Furthermore, if private information is added to the analysis, it will be possible to comment on strong efficiency. We focus on the weak-form efficiency of futures markets in our study.

Elam and Dixon (1988) highlight the importance of the stationarity assumption to investigate the weak-form efficiency by applying econometric techniques to test the null hypothesis $b = 1$ in the equation 4.5. If the nonstationary prices are not first differenced, a spurious relationship can be inferred. As a remedy, some authors, like Hansen and Hodrick (1980), Hakkio (1981), and Bailie et al. (1983), embrace subtracting the lagged values of each price series. This approach is stated in equation 4.6.

$$S_t - S_{t-1} = a + b(F_{t-1,t} - F_{t-2,t-1}) + u_t \tag{4.6}$$

where $\mathrm{F}_{\mathrm{t-2,t-1}}$ is the natural logarithm of the price of a metal futures contract at time t-2 of issuance with the future delivery date, t-1. In equation 4.6, $a = 0$ and $b = 1$ is tested for efficiency and unbiasedness.

Alternatively, some authors, e.g., Fama and French (1987), Zulauf et al. (1999), and Chinn and Coibion (2014), examine efficiency by incorporating the lagged basis instead of the first difference of the natural logarithm of the futures price. This specification is presented in equation 4.7.

$$S_t - S_{t-1} = a + b(F_{t-1,t} - S_{t-1}) + u_t \qquad (4.7)$$

where $(F_{t-1,t} - S_{t-1})$ represents the lagged basis and u_t is the iid disturbance term. The same null hypothesis, i.e., $a = 0$ and $b = 1$, is utilized for efficiency and unbiasedness.

Even though Hansen and Hodrick (1980) and Bilson (1981) mention the term unbiasedness as simple efficiency and speculative efficiency, respectively, Lai and Lai (1991) argue that those authors test the unbiasedness hypothesis rather than the market efficiency hypothesis. As previously discussed, the unbiasedness hypothesis consists of risk neutrality and efficiency at the same time. They focus on the forecast error, i.e., $(S_t - F_{t-k,t})_t$ as the dependent variable. In the literature, this approach is also followed through studies by authors like Canarella and Pollard (1986) and Otto (2011). Basically, the approach entails forecast errors not to be affected significantly by previous forecast errors in regression 4.8. The null hypothesis of efficiency is $c_i = 0$ for all i.

$$(S_t - F_{t-k,t})_t = c_0 + \sum_{i=1}^{p} c_i \, (S_t - F_{t-k,t})_{t-i} + v_t \qquad (4.8)$$

where $(S_t - F_{t-k,t})_t$ is the forecast error, $(S_t - F_{t-k,t})_{t-i}$ is the ith lagged error, and v_t is an iid disturbance term.

However, all of these approaches may be inadequate if spot and futures prices are cointegrated. In the case of cointegration, the long-run relationship should also be considered. Furthermore, long run efficiency and short run efficiency can be investigated by using cointegration methodologies. The error correction model of Johansen (1988) rather than Engle and Granger (1987) is embraced. The main reason for such a choice is that tests based on Engle and Granger (1987) do not have a well-defined limiting distribution, unlike Johansen's (1988) test. Without a well-defined limiting distribution, one cannot asymptotically test futures market efficiency. Consider a simple error correction model specified in equation 4.9.

$$\Delta S_t = -\rho u_{t-1} + \beta \Delta F_{t-1,t} + \sum_{i=2}^{m} \beta_i \Delta F_{t-i,t-i+1} + \sum_{j=1}^{k} \psi_j \Delta S_{t-j} + v_t \quad (4.9)$$

where u_{t-1} is the lagged error correction term, i.e., $u_t = S_{t-1} - a - bF_{t-2,t-1}$, ΔS_t is the first difference of spot price at time t, $\Delta F_{t-1,t}$ is the first difference of futures price at time t-1, and $\Delta F_{t-i,t-i+1}$ and ΔS_{t-j} are the ith and jth lagged differences of futures and spot prices, respectively. The cointegration implies the parameter ρ to be greater than zero since spot prices respond to previous long-run disequilibrium. The existence of cointegration is a necessary but not sufficient condition for efficiency. For the long-run efficiency and unbiasedness to exist, the null hypothesis that $a = 0$ and $b = 1$ should also hold. The short-run efficiency restrictions can be obtained by replacing u_{t-1} with $S_{t-1} - a - bF_{t-2,t-1}$ as McKenzie and Holt (2002:1521) suggest. The open version of the equation 4.9 is presented in the equation 4.10.

$$S_t = (1-\rho)S_{t-1} + \beta F_{t-1,t} + (\rho b - \beta)F_{t-2,t-1} + \rho a + \sum_{i=2}^{m} \beta_i \Delta F_{t-i,t-i+1} + \sum_{j=1}^{k} \psi_j \Delta S_{t-j} + v_t \quad (4.10)$$

The efficient market hypothesis dictates that all the past information should be inherent in the t-1 futures prices. Thus, futures prices prior to t-1 should not have any effect on the spot price, i.e., $\beta_i = \psi_j = 0$. In addition, the variables except $F_{t-1,t}$ must not have any effect on the spot price. Thus, the restrictions to be tested are $\beta_i = \psi_j = 0, \rho = 1,$ and $\rho b = \beta \neq 0$ for short-run market efficiency. The reason for allowing a and b to be different than 0 and 1, respectively, is to permit risk premium (Beck, 1994: 250).

4.3. Literature Review

In this section, we first explore metal prices literature focusing on the investigation of integration order, which is prior to efficiency analysis. Second, approaches to futures market efficiency analysis are investigated. These approaches obviously vary based on stationary results. Moreover, the most recent studies regarding both subsections are simultaneously presented in Table 4.1.

4.3.1. Preliminary Analysis of Stationarity

In the metal futures efficiency literature, the stationary of spot and 3M metal futures prices has been investigated through unit root tests such as the ADF test (e.g., Chowdhury 1991; Beck, 1994; Watkins and McAleer, 2006; Arouri et al., 2011, 2013; Otto, 2011; Reichsfeld and Rauche, 2011; Kuruppuarachchi et al., 2019), PP test (e.g., Chowdhury, 1991; Moore and Cullen, 1995; Arouri et al., 2011), exponential smooth transition unit root test (Cagli et al., 2019), and Zivot and Andrews (1992) test (e.g., Arouri et al., 2011, 2013). Zivot and Andrews's (1992) test is the only unit root test considering an endogenously estimated break between these papers, which study the futures market efficiency. The exponential smooth transition unit root test is the only nonlinear unit root test. Cagli et al. (2019) attribute their nonlinear approach to several important financial crises and global sociopolitical events during the period they investigated. Arouri et al. (2011) refer to Ahti (2009) for their approach. Ahti (2009) presents evidence that nonlinear forecast models for base metals contribute to market visibility in less-developed countries.

Although sampling frequency, metals, or period vary among studies mentioned above, they report non-stationary price series. Chowdhury (1991) applies both ADF and PP tests to copper, lead, tin, and zinc prices. The author presents evidence supporting the non-stationary copper, lead, tin, and zinc prices based on both tests. Moore and Cullen (1995) analyze the stationary of copper, zinc, lead, tin, nickel, and aluminum with the help of the PP test and find evidence supporting the non-stationarity of all metals except for tin. In addition to ADF and PP tests, Arouri et al. (2011) employ Zivot and Andrews (1992) test for aluminum prices. Zivot and Andrews (1992) allow one endogenously determined break in their proposed test procedure. They present evidence supporting the non-stationary of aluminum prices.
Kuruppuarachchi et al. (2019) and Cagli et al. (2019) present evidence supporting the existence of a unit root. While Cagli et al. (2019) focus on the same six base metals as our study, Kuruppuarachchi et al. (2019) investigate copper, nickel, zinc, and aluminum as base metals. Cagli et al. (2019) present evidence supporting the existence of a unit root based on the nonlinear unit root test proposed by Maki

(2015). Kuruppuarachchi et al. (2019) apply the ADF test procedure and conclude the existence of a unit root.

In a nutshell, it can be argued that the metal price integration order is commonly based on ADF and PP tests. We follow the dominant approach in the literature and apply ADF and PP tests. In addition, we also apply the KPSS test with the SPC prewhitening approach to eliminate possible inconsistency due to data-dependent bandwidth selection methods. We allow both a constant and a linear trend in the test regressions.

4.3.2. Futures Market Efficiency

After stationarity investigation of metal prices, methodologies to test the efficiency of futures metal markets vary based on the data. The recent literature is presented in Table 4.1. The estimation of regression in equation 4.5 and cointegration methodologies in equation 4.10 are the most common methodologies. Cointegration methodologies (e.g., Chowdhury, 1991; Moore and Cullen, 1995; Reichsfeld and Rauche, 2011; Arouri et al., 2011, 2013; Cagli et al., 2019; Kuruppuarachchi et al., 2019) are utilized due to the existence of a cointegrating vector when metal prices are reported to have a unit root. Moore and Cullen (1995), Reichsfeld and Rauche (2011), Cagli et al. (2019), and Kuruppuarachchi et al. (2019) report the efficiency of base metal futures markets in their research. On the other hand, the efficiency analysis is alternatively carried out by estimating regressions in which metal's futures and prompt prices are used directly (e.g., Park and Lim, 2018) or indirectly (e.g., Canarella and Pollard 1986; Otto, 2011; Chinn and Coibion, 2014) in a single equation, e.g., equations 4.5-4.8. Otto (2011), Chinn and Coibion (2014), and Park and Lim (2018) point out the inefficiency of LME futures markets, while Canarella and Pollard (1986) report the efficiency of LME for copper, lead, tin, and zinc futures markets.

As displayed in Table 4.1, the efficiency of various futures markets is analyzed. Some of these markets are LME, Chicago Mercantile Exchange (CME), Shanghai Futures Exchange (SHFE), the New York Merchantile Exchange (NYMEX), Tokyo, and India markets. Among these markets, the futures market efficiency of LME is mainly investigated regarding base metals in the literature. On the other hand, the analysis of the futures market efficiency of CME and NYMEX is prevalent in the literature regarding precious metals.

The futures contract period also varies in the literature. Relatively short periods of up to three months are relatively common. However, there are also studies (e.g., Otto, 2011; Reichsfeld and Rauche, 2011; Chinn and Coibion, 2014) that investigate the efficiency of futures markets with longer maturity. The most recent studies (e.g., Park and Lim, 2018; Kuruppuarachchi et al., 2019; Cagli et al., 2019) focus on short-term,i.e., less than three months, futures contracts.

Considering intra-market or interexchange, multi-contract effects of other metals or bivariate regressions are rarely encountered in efficiency analysis. If encountered, these analyses are fulfilled by only using overlapping data. Hsieh and Kulatilaka (1982) perform tests using forecast errors in the exchange. They test whether forecast errors have a zero mean, no correlation with their own lagged and other metal markets' lagged forecast errors, and zero mean and no correlation with their own lagged and other metal markets' lagged growth rates. They cannot present evidence supporting the efficiency of copper, tin, zinc, and lead. Canarella and Pollard (1986) criticize Hsieh and Kulatilaka (1982) for not considering the moving average structure, which is inherent in the overlapping data. Furthermore, they utilize the autoregressive moving average (ARMA) model, which strengthens their results. Otto (2011) discusses multi-contract efficiency by means of an autoregressive moving average with distributed lag (ARMAX) methodology applied to forecast errors. The author studies monthly averages of 3M and 15M futures contracts of LME base metals. Although efficiency results vary according to specifications, the author finds a strong impact of 3M futures on 15M futures, but not vice versa. Canarella and Pollard (1986) use the full information maximum likelihood technique to estimate bivariate regression. Their results also point out the efficiency of metal markets.

In our study, we focus on the three-month futures market efficiency of six base metals in the LME.

Table 4. 1. Summary of Related Recent Literature About Futures Market Efficiency

Author(s)	Data Time Coverage	Data Frequency	Analyzed Metals/Source	Futures Contract Period	Unit Root/Efficiency Testing Methodology	Main Findings/Results
Cagli et al. (2019)	January 1985-February 2019	Daily / Overlapping	6 Base Metals (BMs) (Copper, aluminum, lead, tin, zinc, nickel) (LME) and 4 Precious Metals (PMs) (Gold, silver, platinum, and palladium) (CME) / Bloomberg	1M (Month)	**Unit root test:** Exponential smooth transition unit root test **Efficiency test:** Exponential smooth transition cointegration test	**Unit root test:** All spot and futures prices have a unit root **Efficiency test:** All metals are reported to be efficient in the long run based on the nonlinear cointegration test
Kuruppuarachchi et al. (2019)	February 2000 – December 2014	Varying frequency by Exchange (mostly monthly) / Overlapping	Copper (CME, LME), Aluminum (LME, SHFE)), Zinc (LME), Nickel (India), Gold (CME, Tokyo, India), Silver (Tokyo, India), Platinum (Tokyo), Palladium (Tokyo) / Bloomberg	Nearest Futures Maturity	**Unit root test:** ADF Test **Efficiency test:** $S_t = \beta_0 + \beta_1 F_{t-k,t} + \varepsilon_t$ $\beta_1 = 1$ is tested via a likelihood ratio test, given a stationary error term. The authors also propose a test for efficiency integrating heteroscedastic error and time-varying risk premium	**Unit root test:** All spot and futures prices have a unit root. **Efficiency test:** The efficiency of futures metals, except for silver and aluminum (SHFE) for heteroscedastic errors, is supported. The proposed test reverses the efficiency inference of silver and gold (CME).
Park and Lim (2018)	January 2000-June 2016	Daily / Overlapping	6 BMs (Copper, Lead, Aluminum, Nickel, Zinc and Tin) (LME) / Reuters	3M	**Unit root test:** None **Efficiency test:** $S_t = \beta_0 + \beta_1 F_{t-k,t} + \varepsilon_t$ $\beta_0 = 0 \; and \; \beta_1 = 1$ tested via Wald test. They also employ robustness checks with monthly (end of the month) data with the OLS and GARCH (1,1) model.	**Unit root test:** None **Efficiency test:** The joint null hypothesis of efficiency is rejected for all conventional significance levels. The robustness results support the results of the daily base regression except for zinc. Zinc is reported to be efficient.

Table 4.1 (continued) Summary of Related Recent Literature About Futures Market Efficiency

Author(s)	**Data Time Coverage**	**Data Frequency**	**Analyzed Metals/Source**	**Futures Contract Period**	**Unit Root/Efficiency Testing Methodology**	**Main Findings/Results**
Chinn and Coibion (2014)	January 1990 – July 2012- (PMs) July 1997- July 2012- (BMs)	End of month values / Overlappinng	2 PMs (Gold and Silver) (NYMEX), 5 BMs (Copper, Aluminum, Lead, Tin, Nickel) (LME) / Bloomberg	3M, 6M, 12M	**Unit root test:** None **Efficiency test:** $\beta_0 = 0\ and\ \beta_1 = 1$, tested via Wald test based on the basis $(F_{t-k,t} - F_{t-k,t-k+1})$. This study investigates the unbiasedness $(\beta_1 = 1)$ and efficiency $(\beta_0 = 0\ and\ \beta_1 = 1)$.	**Unit root test:** None **Efficiency test:** Based on simple basis regressions, PMs analyzed are uniformly reported to be inefficient. On the other hand, BMs display a different pattern. For instance, for all futures horizons, aluminum and nickel are reported to be efficient. For other base metals, results vary.
Arouri et al. (2013)	January 1999- March 2011	Daily / Overlapping	4 PMs (Gold, Silver, Platinum and Palladium) (NYMEX) / Bloomberg	3M	**Unit root test:** the ADF test, PP test, and Zivot and Andrews (1992) test **Efficiency test:** $S_t = \beta_0 + \beta_1 F_{t-k,t} + \varepsilon_t$ For the long run market efficiency, after confirming the cointegration relationship $\beta_0 = 0$ (risk neutrality), $\beta_1 = 1$ (market efficiency), $\beta_0 = 0\ and\ \beta_1 = 1$ (unbiasedness) For the short-run efficiency, linear error correction model (ECM), ECM-GARCH-M, and nonlinear exponential switching transition ECM are employed.	**Unit root test:** All futures and spot prices are reported to be non-stationary according to the ADF and PP tests. Only platinum spot and futures prices are reported to be stationary according to Zivot and Andrews (1992) test. **Efficiency test:** Both Johansen trace and Engle-Granger testing procedures point out the cointegration of metals. However, market efficiency is not supported both in the short run and long run.

Table 4.1 (continued) Summary of Related Recent Literature About Futures Market Efficiency

Author(s)	Data Time Coverage	Data Frequency	Analyzed Metals/Source	Futures Contract Period	Unit Root/Efficiency Testing Methodology	Main Findings/Results
Reichsfeld and Rauche (2011)	January 1990 – June 2011	Weekly / Overlapping	2 BMs (Copper and Aluminum) (LME) and 1 PM (Gold) (CME) / Bloomberg	Aluminum (3M, 6M, 12M), Copper and Gold (3M, 6M, 12M, 24M)	**Unit root test:** ADF test with optimal lags according to BIC. **Efficiency test:** Based on the result of the degree of integration, efficiency methodology varies. 1-If required conditions hold, cointegration methodology is employed. 2- If they are both stationary, the regression based on level data is estimated.	**Unit root test:** All metals (except for 24-month futures copper) are reported to have a unit root. **Efficiency test:** All metals (except for 3M futures markets) are reported to be inefficient.
Otto (2011)	July 1991-March 2008	Monthly Averages / Overlapping	6 BMs (Copper, Aluminum, Lead, Tin, Zinc, and Nickel) (LME) / LME	3M, 15M	**Unit root test:** ADF and KPSS tests were employed to forecast errors $(S_t - F_{t-k,t})$ **Efficiency test:** Single Contract ARMA methodology Multi-Contract ARMAX (ARMA with a distributed lag) methodology	**Unit root test:** All forecast errors are reported to be stationary. **Efficiency test:** The efficiency of futures metal markets is rejected for all metals except for aluminum and 3M lead futures contracts.

4.4. Methodology

There exist three subsections under this section. We elaborate on the methodology of the unit root tests of ADF and Phillips and Perron (1988) in the first subsection. However, we do not present the procedure of the KPSS-SPC test method since we have already explained the procedure in subsection 3.2.2 of the previous chapter. To investigate the existence of a cointegration relationship, we employ the integration order robust ARDL bounds test of Pesaran et al. (2001). We present details of this methodology in the second subsection. In the last subsection, the details of subsequent testing procedures of futures market efficiency are presented.

4.4.1. Unit Root Testing Methodologies

In this subsection, we present the procedures of two popular unit root tests, which are ADF and Phillips and Perron (1988) tests. The main distinction between these two tests is the way that they handle the possible serial correlation. ADF test handles the possible serial correlation parametrically. On the other hand, Phillips and Perron (1988) address the possible serial correlation and heteroscedasticity in errors nonparametrically.

4.4.1.1. ADF Test Procedure

To conduct valid inference regarding the existence of a unit root, the ADF test procedure includes the lagged first differences to address the problem of possible serial correlation in the errors. ADF test statistic is calculated based on the following equation 4.11.

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \sum_{i=1}^{p} \theta_i \, \Delta y_{t-i} + \varepsilon_t \tag{4.11}$$

where α and β are the constant and the linear trend parameter, respectively, and p is the lag order of the autoregressive process. Δ is the difference operator and ε_t is the white noise disturbance term. The optimal lag order may be found through the minimization of information criteria such as AIC, BIC, or the highest lag order, which has a significant t statistic. Once the optimal lag order is found, the null hypothesis $H_0: \gamma = 0$ against the alternative hypothesis $H_1: \gamma < 0$ can be tested. The test statistic is computed as follows

$$\mathrm{t}_{\gamma=0} = \hat{\gamma}/(\hat{\mathrm{s}}^2 \mathrm{b})^{1/2}$$

where $\hat{\mathrm{s}}^2$ is the standard error of the regression, b is the third diagonal term of the matrix $(\mathrm{X}'\mathrm{X})^{-1}$ with X being the matrix of regressors.

4.4.1.2. Phillips and Perron (1988) Test Procedure

The fundamental distinction between the PP test and the ADF test is the approach related to possible serial correlation and heteroscedasticity in the errors. The ADF test approximates the ARMA structure by including the lags of the dependent variable, which is the first difference of the time series that is subject to the testing procedure. On the other hand, PP propose a non-parametric modification to address potential serial correlated and heteroscedastic errors.

Although the PP test considers only constant and constant and trend cases, we elaborate on the most general case, which is the constant and trend cases. Let y_t be a time series generated by the following process

$$y_t = \mu + y_{t-1} + \varepsilon_t$$

This process assumes the null of a unit root. The subsequent regression is estimated for the case of a constant and linear trend case in equation 4.12.

$$y_t = \tilde{\mu} + \tilde{\beta}\left(t - \frac{1}{2}T\right) + \tilde{\alpha} y_{t-1} + \tilde{\varepsilon}_t \qquad (4.12)$$

($\tilde{\mu}$, $\tilde{\beta}$, $\tilde{\alpha}$) are the conventional parameters obtained by the OLS estimation method. The t statistic of parameter $\tilde{\alpha}$, $t_{\tilde{\alpha}}$, is computed as follows

$$t_{\tilde{\alpha}} = (\tilde{\alpha} - 1)/(\tilde{s}^2 c)^{1/2}$$

where $\tilde{s}^2$ is the standard error of the regression, c is the third diagonal term of the matrix $(X'X)^{-1}$ with X being the matrix of regressors. The $Z(t_{\tilde{\alpha}})$ statistic of PP is computed

$$Z(t_{\tilde{\alpha}}) = \left(\frac{\tilde{s}}{\tilde{\sigma}}\right) t_{\tilde{\alpha}} - \tilde{\lambda}'\tilde{\sigma}/M^{1/2}$$

$$M = (1 - T^{-2})m_{yy} - 12m_{ty}^2 + 12(1 + T^{-1})m_{ty}m_y - (4 + 6T^{-1} + 2T^{-2})m_y^2$$

$$\tilde{\lambda}' = \frac{(\tilde{\sigma}^2 - \tilde{s}^2)}{2\tilde{\sigma}^2},\ m_{yy} = T^{-2}\sum_{t=1}^{T} y_t^2,\ m_{ty} = T^{-5/2}\sum_{t=1}^{T} t y_t,\ m_y = T^{-3/2}\sum_{t=1}^{T} y_t$$

where $\tilde{\sigma}^2$ is the estimated long-run variance, which is time-invariant. The common formula for $\tilde{\sigma}^2$ is

$$\tilde{\sigma}^2 = T^{-1}\sum_{t=1}^{T} \tilde{\varepsilon}_t^2 + 2T^{-1}\sum_{s=1}^{l} w(s,l) \sum_{t=s+1}^{T} \tilde{\varepsilon}_t\, \tilde{\varepsilon}_{t-s}$$

where $w(s, l)$ is the weighting function depending on the specified kernel and bandwidth parameter.

4.4.2. ARDL Bounds Testing Methodology of Pesaran et al. (2001)

Pesaran et al. (2001) suggest a method enabling the researcher to comment on cointegration without any prior examination of the integration order. The procedure also has some other merits as well. One merit would be the allowance of different autoregressive orders. Another merit is that it does not require the sample to be large for validity. Initially, we estimate the following ARDL (p,q) regression as in equation 4.13 to find the optimal p and q through the minimization of information criterion, i.e., AIC.

$$y_t = \alpha + \beta t + \sum_{j=1}^{p} \varphi_j \, y_{t-j} + \sum_{i=0}^{q} \rho_i x_{t-i} + \varepsilon_t \tag{4.13}$$

where ε_t is the iid disturbance term. Then regression in equation 4.14 is estimated to test the existence of cointegration, given the estimated p and q. The testing approach has the null of no cointegration $H_0: \gamma_i = 0$ against the alternative hypothesis, $H_1: \gamma_i \neq 0, i = 1, 2$. The joint F-statistic or Wald statistic is computed to test the null hypothesis

$$\Delta y_t = a + ct + \sum_{j=1}^{p-1} b_j \, \Delta y_{t-j} + \sum_{i=0}^{q-1} c_i \Delta x_{t-i} + \gamma_1 \, y_{t-1} + \gamma_2 x_{t-1} + \ \omega_t \tag{4.14}$$

where ω_t is an iid disturbance term. The authors provide two sets of critical values for F-statistics. These values comprise the lower bound and upper bound of critical values. Pesaran et al. (2001: 304) suggest a guide to make an inference about the presence of cointegration. If the computed test statistic is between the lower and upper bound, i.e., inconclusive region, then a test regarding the integration of order will be applied. If the computed test statistic is smaller than the lower bound of the critical value, the null hypothesis of no cointegration can be accepted. However, if the computed test statistic is higher than the upper bound of the critical value, further t-test regarding the null hypothesis $H_0: \gamma_1 = 0$ should be performed. The authors also present the upper and lower-bound critical values for the t-test. If the computed test statistic is lower than the lower bound critical value, the null of no cointegration can be accepted. If it is higher than the upper bound critical value, the result indicates the existence of a cointegration. However, this cointegration relationship may be degenerate if γ_2 is statistically insignificant.

4.4.3. Futures Market Efficiency Methodologies

Given the nonstationarity of metal prices and no cointegration, two alternative specifications in equations 4.15 and 4.16 are utilized in the study. However, prior to the estimations, the stationarity is ensured through a standard unit root test such as the ADF test. Equation 4.15 is utilized to assess whether the basis is the optimal predictor of the spot price change or not. In particular, the weak-form efficiency of a futures market $\mathrm{H_0}: \theta_2 = 1$ is tested against the alternative hypothesis $\mathrm{H_1}: \theta_2 \neq 1$.

$$(s_t - s_{t-k}) = \theta_1 + \theta_2\left(f_{t-k,t} - s_{t-k}\right) + \vartheta_t \tag{4.15}$$

where ϑ_t is an iid disturbance term. On the other hand, equation 4.16 represents the forecast error based approach to evaluate the weak-form efficiency of a futures market. A futures market is to be efficient if forecast error $(s_t - f_{t-k,t})_t$is not significantly affected by its previous values $(s_t - f_{t-k,t})_{t-i}$. To be more precise, the weak-form efficiency of a futures market $\mathrm{H_0}: c_i = 0, i = \{0, 1, \ldots, p\}$ is tested against the alternative hypothesis $\mathrm{H_1}: c_i \neq 0$ for some i.

$$(s_t - f_{t-k,t})_t = c_0 + \sum_{i=1}^{p} c_i\,(s_t - f_{t-k,t})_{t-i} + v_t \tag{4.16}$$

where v_t is an iid disturbance term.

4.5. Data and Empirical Results

Both LME prompt and 3M futures closing prices of selected metals, namely, copper, lead, aluminum, nickel, zinc, and tin, on the first trading day of the month are obtained from Bloomberg. Due to discussions about the caveat of using overlapping observations, as elaborated in the first section, we prefer to utilize non-overlapping observations from the first trading day closing prices of January, April, July, and October of 3M futures and their corresponding future spot prices, namely spot prices of the first trading day of April, July, October, and January similar to Sephton and Cochrane (1990, 1991). Furthermore, following the common approach in the literature, the natural logarithm of the prices is used. The data spans the period between January 1990 and April 2020 for 3M futures prices and April 1990 and July 2020 for future spot prices.

In the following subsection, we present and discuss the empirical results of unit root and stationary tests. Then, the existence of a cointegration is examined through the ARDL bounds testing procedure of Pesaran et al. (2001). Based on our inference about these tests, we further investigate the efficiency of metal markets.

4.5.1. Unit Root and Stationarity Test Results

We summarize the results of ADF, PP, and KPSS-SPC tests in Table 4.2. ADF and PP tests assume the existence of a unit root under the null hypothesis, while the KPSS-SPC test presumes the null of stationary. Since the methodology of the KPSS-SPC test is elaborated in the previous chapter, the reader is referred to methodology subsection 3.2.2 in the third chapter. We allow a constant and a linear trend in all test specifications. The optimal lag order choice for the ADF test is based on the minimization of AIC with a maximum lag order of 12. QS kernel and Andrews’s (1991) automatic bandwidth selection method are used for long-run variance in the PP test. For the KPSS procedure, the SPC method is utilized with the Quadratic Spectral kernel. AIC is utilized for choosing the optimal lag order in the pre-whitening procedure of Andrews and Monahan (1992), with a maximum autoregressive order of 12. The critical value of ADF and PP tests for 5% is -3.447. The critical value of KPSS tests for 5% significance is 0.146. All test results imply the non-stationarity of each price series based on 5% significance level.

Table 4. 2. Results of ADF, PP, and KPSS-SPC Tests

Metal	Prices		ADF Test		PP Test		KPSS-SPC Test
Copper	**Futures**		-2.23		-2.03		0.53
	Prompt		-2.37		-2.29		0.50
Lead	**Futures**		-3.04		-2.40		0.44
	Prompt		-2.92		-2.61		0.47
Aluminum	**Futures**		-3.34		-2.98		0.20
	Prompt		-3.45		-3.18		0.21
Nickel	**Futures**		-2.66		-2.28		0.48
	Prompt		-2.80		-2.37		0.49
Zinc	**Futures**		-3.19		-2.84		0.23
	Prompt		-3.40		-3.09		0.22
Tin	**Futures**		-2.40		-2.38		0.51
	Prompt		-2.44		-2.47		0.47

4.5.2. Results of Pesaran et al. (2001) ARDL Bounds Test

Based on the nonstationary inference results derived from the application of unit root and stationarity tests, we proceed with the investigation for the presence of a cointegrating relationship. We prefer the integration order robust ARDL bounds testing procedure proposed by Pesaran et al. (2001). The most unrestricted case (Case V) of the ARDL bounds test is employed. The empirical results of ARDL bounds tests are presented in Table 4.3. In the first row of Table 4.3, the fitted ARDL models for price series are presented. The fitted ARDL model is found by minimization of AIC with a maximum lag order of 12. We also test the presence of serial correlation with the Breusch-Godfrey test for all specifications. The results support the absence of serial correlation for all errors both in ARDL and ARDL bounds test regression. ARDL bounds F test statistic is above the upper bound only for aluminum prices, which points out a cointegration relationship. Then, we apply t bounds test to investigate the cointegration relationship. The statistic for t bounds test is below the lower bound. Therefore, we infer the absence of co-integration of aluminum prices as well. Thus, we can rule out the cointegration relationship for all metals. Thus, we do not need to take long-run dynamics into account for efficiency analysis.

Table 4. 3. Empirical Results of ARDL Bounds Test (Case V)

	Copper	**Lead**	**Aluminum**	**Nickel**	**Zinc**	**Tin**
Fitted ARDL(p,q) model	(0,1)	(3,0)	(0,1)	(0,2)	(0,1)	(0,1)
Breusch-Godfrey Test Statistic (Lag 12)	5.29 [0.95]	11.84 [0.46]	13.64 [0.32]	9.76 [0.64]	8.47 [0.75]	11.03 [0.53]
$\Delta y_t = a + ct + \sum_{j=1}^{p-1} b_j \, \Delta y_{t-j} + \sum_{i=0}^{q-1} c_i \Delta x_{t-i} + \gamma_1 \, y_{t-1} + \gamma_2 x_{t-1} + \omega_t$						
Constant	**0.57**[b] (0.26)	**0.66**[a] (0.23)	**1.14**[a] (0.35)	**0.90**[a] (0.33)	**0.67**[b] (0.32)	**0.74**[a] (0.29)
Trend	**0.00**[c] (0.00)	**0.00**[a] (0.00)	**0.00**[c] (0.00)	0.00 (0.00)	**0.00**[b] (0.00)	**0.00**[b] (0.00)
y_{t-1}	-0.23 (0.74)	0.09 (0.90)	**-1.46**[c] (0.85)	0.19 (1.09)	-0.96 (0.90)	-0.06 (1.32)
x_{t-1}	0.15 (0.75)	-0.20 (0.90)	1.30 (0.85)	-0.29 (1.10)	0.85 (0.93)	-0.03 (1.32)
Δy_{t-1}	-	0.21 (0.86)				

Table 4.3. (continued)

Δy_{t-2}	-	**0.16**^{c} (0.09)				
Δx_t	0.32 (0.76)	-0.31 (0.90)	**1.59**^{c} (0.88)	-0.17 (1.11)	1.12 (0.94)	0.11 (1.34)
Δx_{t-1}	-	-	-	**0.18**^{c} (0.10)	-	-
Breusch-Godfrey Test Statistic (Lag 12)	4.31 [0.98]	14.66 [0.26]	15.11 [0.23]	9.12 [0.69]	9.16 [0.69]	10.59 [0.56]
ARDL Bounds F test with $\gamma_1 = \gamma_2 = 0$	2.97^{aa}	4.14^{aa}	7.62^{cc}	3.78^{aa}	5.97^{aa}	3.23^{aa}
Bounds t test with $\gamma_1 = 0$	N/A	N/A	-1.71^{aa}	N/A	N/A	N/A
Cointegration	NO	NO	NO	NO	NO	NO

Notes: Estimated values for parameters of ARDL bounds F test regression are presented with their standard errors in parenthesis. Values presented in brackets are p-values of related test statistics based on χ^2 distribution. ARDL Bounds F test critical values are presented in Table CI(v) of Pesaran et al. (2001:301). Bounds t-test critical values are presented in the Table CII(v) of Pesaran et al. (2001:304). Critical value for Breusch-Godfrey Serial Correlation Test Statistic in the above table is $\chi^2_{12,0.05} = 21.026$. ^{aa}, ^{bb}, and ^{cc} denote the statistic lying below the lower bound critical value, within the bound, and above the upper bound critical value for 5% significance level, respectively. N/A stands for 'Not Applicable' since we are already unable to reject null of no cointegration. ^{a}, ^{b} and ^{c} denotes 1%, 5%, and 10% significance levels, respectively.

4.2.3. Results of Efficiency Analysis

Due to the nonstationary of each price series and no cointegrating relationship between futures and prompt prices, it is suitable to investigate the efficiency of metal markets with the aid of alternative specifications based on first differences, basis, and forecast errors as stated in equations 4.7 (4.15) and 4.8 (4.16) elaborated in section 4.2 (subsection 4.4.3 of the methodology section).

Since we can conclude the nonstationary of metal prices based on unit root and stationarity tests and infer the non-existence of a cointegration relationship by ARDL bounds testing procedure originating from the most unrestricted case, we apply a method based on the basis as stated by Chinn and Coibion (2014) to test the weak-form efficiency. In particular, to examine the efficiency of a futures market, we analyze whether the basis is the optimal predictor of the spot price change. The merit of this approach is that basis and spot price change are stationary. ADF test results are presented in the upper panel in Table 4.4. The empirical results regarding efficiency test regression are tabulated in the lower panel of Table 4.4.

Table 4. 4. Empirical Results of Basis-Based Efficiency Test

ADF Test Results						
(With Only Constant)	**Copper**	**Lead**	**Aluminum**	**Nickel**	**Zinc**	**Tin**
$(s_t - s_{t-k})$	-8.16 [0.00]	-6.41 [0.00]	-8.25 [0.00]	-9.92 [0.00]	-9.01 [0.00]	-9.79 [0.00]
$(f_{t-k,t} - s_{t-k})$	-3.91 [0.00]	-5.01 [0.00]	-4.82 [0.00]	-6.07 [0.00]	-3.51 [0.01]	-6.21 [0.00]
(With Constant and Trend)	**Copper**	**Lead**	**Aluminum**	**Nickel**	**Zinc**	**Tin**
$(s_t - s_{t-k})$	-8.16 [0.00]	-6.37 [0.00]	-8.21 [0.00]	-9.88 [0.00]	-8.99 [0.00]	-9.75 [0.00]
$(f_{t-k,t} - s_{t-k})$	-3.92 [0.01]	-5.32 [0.00]	-4.92 [0.00]	-6.05 [0.00]	-5.75 [0.00]	-6.99 [0.00]
Efficiency Test Regression $(s_t - s_{t-k}) = \theta_1 + \theta_2(f_{t-k,t} - s_{t-k}) + \vartheta_t$						
	Copper	**Lead**	**Aluminum**	**Nickel**	**Zinc**	**Tin**
Constant	0.01 (0.01)	0.01 (0.01)	-0.02 (0.01)	0.00 (0.02)	-0.01 (0.01)	0.01 (0.01)
$f_{t-k,t} - s_{t-k}$	0.66 (0.64)	-0.20 (0.38)	1.21 (0.84)	0.14 (1.16)	**1.63**[a] (0.79)	-0.28 (1.00)
Wald Statistic (θ_1=0)	0.46 [0.50]	0.26 [0.61]	1.16 [0.28]	0.02 [0.88]	0.54 [0.46]	0.43 [0.51]
Wald Statistic ($\theta_2 = 1$)	0.28 [0.60]	9.93 [0.00]	0.06 [0.80]	0.55 [0.46]	1.05 [0.31]	1.64 [0.20]
Wald Statistic (θ_1=0, $\theta_2 = 1$)	0.64 [0.72]	10.14 [0.01]	1.85 [0.40]	0.55 [0.76]	1.12 [0.57]	1.69 [0.43]

Notes: Critical values for ADF test statistic are -4.04, -3.45, and 3.15 for 1%, 5%, and 10%, respectively. [a], [b] and [c] denotes 1%, 5%, and 10% significance, respectively. Standard errors and p-values are presented in parentheses and brackets, respectively. Newey and West (1987) heteroscedasticity autocorrelation consistent standard errors are used.

Essentially, we test the constant term to be zero and the basis term parameter to be one with the aid of the Wald test. To avoid unfavorable outcomes due to serial autocorrelation or heteroscedastic errors, we use Newey and West's (1987) heteroscedasticity and autocorrelation robust standard error following Chinn and Coibion (2014). Except for lead markets, we can not reject the null hypothesis of efficiency at a 95 or 90 percent confidence level. Thus, we infer the efficiency of all other base metal markets according to the basis-based efficiency test.

We also employ a forecast error-based procedure, which is also applied in the literature (e.g., Canarella and Pollard, 1986; Otto, 2011) to infer the efficiency of metal markets. In the forecast error based approach, the market is weak-form efficient if the current forecast error is not significantly affected by its previous values. To prevent wrong inferences related to serially correlated and heteroscedastic errors, we use Newey and West’s (1987) heteroscedasticity autocorrelation consistent standard errors. Initially, we apply the ADF test for forecast errors. The results are shown in the upper panel of Table 4.5. We conclude that forecast errors are stationary for all metals investigated.

The empirical results are presented in the lower panel of Table 4.5. Based on efficiency test results, all markets are reported to be weak-form efficient at a 95 percent confidence level. However, if the confidence level is lowered to 90 percent, we will be able to reject the efficiency of lead and zinc markets. Except for zinc markets, the results of forecast error-based results corroborate our basis-regression based efficiency analysis at a 90 percent confidence level. The zinc market is reported as an efficient market based on basis-regression results displayed in Table 4.4.

Overall, based on basis and forecast error regression results, we find evidence against efficiency for lead and zinc markets at a 90 percent confidence level. Although the data and methodology vary, our results are in line with the literature to some extent. Cagli et al. (2019) report all metal markets to be efficient, while Park and Lim (2018) present strong evidence against the efficiency of all six base metal markets, except for zinc markets. On the other hand, Otto (2011) infers the efficiency of aluminum and lead. Chinn and Coibion (2014) conclude the efficiency of aluminum and nickel markets in 3M, 6M, and 12M futures contracts. Reichsfeld and Rauche (2011) report that 3M aluminum and copper markets are efficient.

Table 4. 5. Empirical Results of Forecast Error-Based Efficiency Test

ADF Test Results (With Only Constant)						
	Copper	**Lead**	**Aluminum**	**Nickel**	**Zinc**	**Tin**
$(s_t - f_{t-k,t})$	-9.51 [0.00]	-6.21 [0.00]	-8.00 [0.00]	-9.78 [0.00]	-9.07 [0.00]	-9.67 [0.00]
ADF Test Results (With Constant and Trend)						
$(s_t - f_{t-k,t})$	-9.46 [0.00]	-6.18 [0.00]	-7.97 [0.00]	-9.74 [0.00]	-9.06 [0.00]	-9.65 [0.00]
Efficiency Test Regression $(s_t - f_{t-k,t})_t = c_0 + \sum_{i=1}^{p} c_i \, (s_t - f_{t-k,t})_{t-i} + v_t$						
	Copper	**Lead**	**Aluminum**	**Nickel**	**Zinc**	**Tin**
Constant	0.01 (0.01)	0.00 (0.01)	-0.01 (0.01)	0.00 (0.02)	-0.01 (0.01)	0.01 (0.01)

Table 4.5. (continued)

$(s_t - f_{t-k,t})_{t-1}$	0.13 (0.09)	0.07 (0.08)	0.20 (0.14)	0.11 (0.10)	**0.19**^{c} (0.11)	0.11 (0.09)
$(s_t - f_{t-k,t})_{t-2}$	-	0.17 (0.13)	-0.14 (0.12)	-	-	-
$(s_t - f_{t-k,t})_{t-3}$	-	-0.09 (0.12)	-	-	-	-
$(s_t - f_{t-k,t})_{t-4}$	-	**-0.16**^{c} (0.09)	-	-	-	-
Wald Statistic ($All\ c_i = 0$)	2.57 [0.28]	9.53 [0.09]	3.53 [0.31]	1.08 [0.58]	4.83 [0.09]	1.83 [0.40]

Notes: Critical values for ADF test statistics are -4.04, -3.45, and 3.15 for 1%, 5%, and 10%, respectively. Optimal lag order is found by minimization of AIC with a maximum lag order of 12 for both ADF and efficiency test regression. Standard errors and p-values are presented in parentheses and brackets, respectively. Newey and West (1987) heteroscedasticity autocorrelation consistent standard errors are used. ^{a}, ^{b}, and ^{c} denotes 1%, 5%, 10% significance levels, respectively.

4.6. Conclusion

There have been some significant developments in base metal markets during the last two decades. The three most important developments are Chinese growth, the financialization of commodities, and climate change concerns. These developments draw more attention to the price dynamics of metals. Futures, as well as spot prices, should be emphasized in this regard. Due to its essential policy implications, futures market efficiency has been subject to academia. In this regard, we aim to analyze the weak-form efficiency of base metal futures markets of LME.

Since our inference about the presence of a unit root is supported, we further investigate the existence of cointegration with the ARDL bounds testing procedure of Pesaran et al. (2001). ARDL bound testing procedure has important merits such as the integration order robustness, flexibility related to lag order, and less dependence on large samples about validity. Our results are based on the most unrestricted case of the ARDL bounds test procedure. They support the lack of a cointegration relationship. Then, we employ regressions based on the basis, spot price change, and forecast errors, which turn out to be stationary. To infer the efficiency of metals investigated in our study, we apply both basis and forecast error-based approaches. Based on our efficiency analyses, all base metal futures markets, except for lead and zinc, are reported to be efficient.

We argue that the main reason for the weak-form inefficiency of lead and zinc markets is transaction costs. In LME markets, the transaction fee is fixed. In particular, it does not vary with the contract amount or the market price. It depends on the contract type, category, and the type of the transaction. These costs matter more if the price of the metal is low. Lead and zinc prices are relatively lower than other base metals.

Besides lead and zinc futures markets, investigated LME metal futures markets favor both commercial traders and market regulators. In efficient markets, commercial traders protect their income levels against significant price changes while market regulators recognize market anomalies without much effort. On the other hand, arbitrageurs can benefit from the lead and zinc futures market if they can obtain critical information before it is reflected in the price.

CHAPTER 5

CONCLUSION

Metals display both similarities and disparities from other commodities. For instance, they are storable like fuel or agricultural commodities. On the other hand, they are recyclable and do not perish with single-use, unlike fuel commodities such as oil and natural gas. There are some similar and opposite technical features between metals. On the other hand, metals are not homogeneous in terms of their usage. For instance, copper and gold are good conductors of electricity and heat. Lead and gold are dense metals. However, lead is a poor conductor of electricity. These features play an essential role in related metal demand. This role is more pronounced in base metals since base metals are relatively abundant and used for industrial purposes. On the other hand, precious metals such as gold and silver are scarce and subject to significant demand from non-industrial purposes such as safe haven, hedge, store of value, or specie. Specifically, this non-industrial demand compensates for the industrial demand shocks in the case of precious metals. On the supply side, base metals have experienced a significant change in terms of the amount supplied after the 2000s due to China’s fast-growth economic model. In particular, China constantly has increased its mine and smelter/ refinery production share for lead, zinc, and tin especially and has become the primary producer. On the other hand, for nickel, aluminum, and copper, the same development occurred only for smelter/refinery production. We should note that until China’s base metal supply reached the level to meet its demand for industrial production, its demand significantly increased prices before the mid-2000s. On the contrary, since the Chinese growth model was industrial production-oriented, it did not affect the supply of precious metals in such a manner. Countries and their global supply shares did not change markedly for precious metals. Due to their scarcity, mainly adverse supply shocks such as labor strikes have put upward pressure on the prices of precious metals.

The metal, either base or precious type, prices play a critical role for both metal exporting, mostly emerging, countries, and metals importing relatively more industrialized countries. For major metal exporting countries, metal export volumes are significant due to their effects on export revenues and macroeconomic fundamentals. For metal-importing countries, imported metals, especially base metals, are among the cost items of industrial output. Therefore, metal price dynamics merit further attention.

It has been well documented that real metal prices, particularly base metal prices, are mainly affected by macroeconomic fundamentals such as industrial production, real interest rates, and real exchange rates. In the case of precious metals, due to their minor industrial use, especially for gold, industrial production does not seem to be an influential direct factor as much as base metals. On the other hand, even though industrial demand constitutes the majority of silver and platinum demand, investment and jewelry demand seem to moderate the cyclical price effects of industrial production. The price behavior is also critical for efficiency analysis.

In the dissertation, we apply tests to investigate the weak-form efficiency of global spot and three-month futures metal markets. The weak-form efficiency of global spot markets is investigated through stationarity tests. The existence of a unit root relates to the weak-form efficiency of the market. Shocks to prices are not short-lived in a weak-form efficient market. Therefore, returns can not be predicted. The return unpredictability implies that an investor can not earn abnormal profit by just analyzing the historical prices or implementing technical analysis. Moreover, there is a lack of market forces that equilibrate the market in the long run. So, an active public policy may be designed for this purpose. The narrative of futures market efficiency is different than the spot market efficiency. The fundamental intuition is that one investigates the weak-form efficiency of a futures market by examining its forecast performance of the future spot price. In an efficient futures market, commercial traders protect their income levels against significant price changes while market regulators recognize market anomalies without much effort. On the other hand, arbitrageurs can benefit from an inefficient futures market if they can obtain critical information before it is reflected in the price.

The efficiency of global spot metal markets are examined by the analysis of real metal prices. Nominal metal (except for gold, silver, and platinum) prices and US Producer Price Index (1982=100) by Commodity for Final Demand: Finished Goods are collected from the database of the Federal Reserve Bank of St. Louis. The remaining metal prices are obtained from the World Bank (Pink Sheet). Using end-period nominal metal prices and seasonally adjusted US Producer Price Index (1982=100), the natural logarithm of quarterly real prices is calculated. To examine the efficiency of global spot metal markets, we focus on stationarity tests, which allow smooth or two-sharp breaks. Instant or sharp breaks may occur as a result of all agents behaving simultaneously in a particular manner, such as demanding the asset as a reaction to an economic stimulus. Due to the heterogeneity among economic agents in terms of response to an economic stimulus (Leybourne et al., 1998), presuming a sharp break may be unrealistic (Harvey and Mills, 2004). Therefore, we also incorporate smooth breaks into our analysis. We contribute to the literature by incorporating the SPC method into the KPSS-type test of Becker et al. (2006). In addition to this contribution, these two stationarity tests have not been utilized to examine the efficiency of global spot markets in the literature. The merit of the SPC method is to make KPSS-type tests consistent.

To a great extent, the empirical evidence reveals the stationary of investigated global metal prices. However, the sharp break stationarity test of Carrion-i-Silvestre and Silvestre (2007) captures the breaks better than the smooth break stationarity test of Becker et al. (2006). The observed structural changes are related to market-specific and economic events, though the global economic conditions have appeared to be effective, especially for precious metals. Except for gold and silver, our empirical results present evidence against the efficiency market hypothesis. Market inefficiency refers that prices do not fully reflect all available information in the market. The implication of weak-form inefficiency findings in all these markets enables one to perform technical analysis to predict prices and make abnormal profits. Moreover, stabilization policies will be effective in dealing with exogenous shocks, which will be temporary and short-lived. The result of efficient gold and silver markets advises that the effects of exogenous shocks on these metal prices would be permanent. Strong policy measures should be implemented to return metal prices back to their original trend. Metal prices return to their original trend with the help of strong policy measures.

Although it is not a direct focus of this study, our results can be helpful for forecasting purposes. Heterogeneity among economic agents is the primary determinant of sharp or smooth breaks. As elaborated in the second chapter, precious metals are subject to non-industrial and industrial demand. Non-industrial demand moderates the shocks originating from industrial activity. On the other hand, demand for base metals is solely composed of industrial demand. Thus, the demand structure of precious metals is heterogeneous. For forecasting purposes, we argue that sharp breaks and smooth breaks are suitable for base and precious metal prices, respectively.

We analyze the weak-form efficiency of three-month futures base metal markets in the LME as well. The weak-form efficiency of LME 3M futures markets is examined by using futures and future spot prices. Both LME prompt and 3M futures closing prices of selected metals, namely, copper, lead, aluminum, nickel, zinc, and tin, on the first trading day of the month are obtained from Bloomberg. Due to discussions about the caveat of using overlapping observations, we prefer to utilize non-overlapping observations from the first trading day closing prices of January, April, July, and October of 3M futures and their corresponding future spot prices, namely spot prices of the first trading day of April, July, October, and January. With the non-overlapping data, serial autocorrelation that may arise due to using informationally overlapping data may be prevented (e.g., Hansen and Hodrick, 1980; Kellard et al., 1999). Furthermore, following the common approach in the literature, the natural logarithm of the prices is used. The data spans the period between January 1990 and April 2020 for 3M futures prices and April 1990 and July 2020 for future spot prices. Prior to efficiency analysis, we apply ADF, PP, and KPSS tests to investigate the order of integration for base metals since the efficiency analysis is dependent upon the stationarity of futures and prompt prices. Metal prices are reported to have a unit root based on these three tests. Furthermore, the integration order robust ARDL bounds test of Pesaran et al. (2001) is employed to examine the cointegration relationship. The test result points out that there exists no cointegration relationship.

In the literature, we do not encounter any study applying this method prior to efficiency analysis. This is the main contribution of the fourth chapter to the literature. Based on the test results of integration of order and cointegration, we employ basis and forecast error-based regression to examine the efficiency of 3M futures markets. Except for lead and zinc futures markets, we find strong evidence of market efficiency. We attribute the weak-form inefficiency of lead and zinc futures markets to transaction costs. In LME markets, the transaction fee is fixed. In particular, it does not vary with the contract amount or the market price. It depends on the contract type, category, and the type of the transaction. These costs matter more if the price of the metal is low. Lead and zinc prices are lower than other base metals. Besides lead and zinc futures markets, investigated LME metal futures markets favor commercial traders and market regulators. In an efficient futures market, commercial traders protect their income levels against significant price changes while market regulators recognize market anomalies without much effort. On the other hand, arbitrageurs can benefit from the lead and zinc futures market if they can obtain critical information before it is reflected in the price.

In sum, we report the inefficiency of global spot markets for all six base metals and only one precious metal, i.e., platinum, in the third chapter. On the other hand, the other spot market prices of two precious metals, i.e., gold and silver, display the characteristics of efficient markets. Thus, the spot prices of gold and silver reflect the historical information. This is not surprising since platinum is the closest precious metal to base metals due to its relatively limited financial investment role. Stabilization policies are ample for the six base metal markets and the platinum market in case of an exogenous shock. On the other hand, strong policy measures are required to moderate the effect of exogenous shocks directed to gold and silver. However, due to their limited availability and reserve role, especially gold, it is unlikely for responsible institutions to intervene in the market to absorb the exogenous shocks.

However, even though the inefficiency of global spot markets based on the largest exporter’s price for all six base metals is found, we infer the efficiency of 3M LME futures markets for four of the same six base metals in the fourth chapter. We report the inefficiency of lead and zinc futures markets. We can conclude that even though spot market prices of six base metals do not reflect all historical prices of the largest exporter, 3M LME futures prices of these base metals, except for lead and zinc, reflect the future spot prices. The efficiency of futures markets eliminates any perpetual prospects to earn profits without assuming any risk. Based on the argument, an investor can earn investing in lead and zinc 3M LME futures markets without assuming any amount of risk since constant arbitrage opportunities between futures and spot markets are present in inefficient futures markets. On the other hand, there are no constant arbitrage opportunities between efficient futures markets. In this regard, the 3M LME futures markets of copper, lead, aluminum, and tin do not attract arbitrageurs, unlike lead and zinc markets. Therefore, hedgers and speculators are the economic agents in these four markets. The long (short) hedgers can manage the risk of price fall (rise) in efficient markets by selling (buying) a 3M futures contract.

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APPENDICES

A. CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: Kara, Alper

Nationality: Turkish (TC)

EDUCATION

Degree	Institution	Year of Graduation
MA	Duke University-Economics	2009
BA	Hacettepe University-Business Administration	2003
High School	Trabzon-Yomra Science High School	1999

WORK EXPERIENCE

Year	Place	Enrollment
2021-Present	Central Bank of the Republic of Türkiye	Director
2017-2021 (May)	Central Bank of the Republic of Türkiye	Economist
2004-2017 (Sep)	Central Bank of the Republic of Türkiye	Specialist
2004-2004 (Jun)	Ziraat Banking School	Asst. Specialist

FOREIGN LANGUAGE

Advanced English, Beginner German

PUBLICATIONS

1. Kara, A., Kasap, D. Y. and Tunç, G. İ. “Market efficiency in non-renewable resource markets: Evidence from stationarity tests with structural changes”, Mineral Economics, 36(2), 279-290 (2023)

2. Kara, A., Unalmis, D. and Hacihasanoglu, Y. S. “Financial Contagion and the Role of Firm Characteristics”, Finance Research Letters, 38, 1-9 (2021)

3. Kara, A., Çolak, M. S., Hacihasanoglu, Y. S. and Unalmis, D. “Firmaların Seçilmiş Finansal Rasyoları ve Borsa Getirilerindeki Ayrışma”, TBB Bankacılar Dergisi, 113, 114-126 (2020)

HOBBIES

Tennis, Running, Reading, Fitness

B. TURKISH SUMMARY / TÜRKÇE ÖZET

Metaller, tükenebilen veya yenilenemeyen emtialardır. Emtialar içindeki sınıflandırılmasından da anlaşılacağı gibi, metaller yerkabuğunda sınırlı olarak bulunmaktadır. Ancak metaller depolanabilir ve tek bir kullanım ile tüketilemez. Metalleri iki ana kategoriye ayırmak mümkündür. Bu kategoriler demir içeren ve demir içermeyen metallerdir. Demirli metaller tipik olarak demir içerir. Öte yandan demirsiz metaller demir içermez. Tez kapsamında demir içermeyen metallere odaklanılmaktadır. Özellikle bakır, kurşun, alüminyum, nikel, çinko ve kalay olmak üzere altı ana metal ile altın, gümüş ve platin olmak üzere üç kıymetli metal üzerinde yoğunlaşıyoruz.

Metaller, özelliklerine göre endüstriyel ve endüstriyel olmayan amaçlar için kullanılmaktadır. Ana metaller, görece bollukları ve faydalı teknik özellikleri nedeniyle sanayi üretiminin girdisi olarak kullanılmaktadır. Örneğin, ana metaller arasında ısıyı ve elektriği en iyi ileten madde bakırdır. Bu özelliği ile, bakır elektrik ve genel mühendislik sektörlerinde tercih edilmektedir. Diğer bir örnek alüminyum olabilir. Alüminyum, hafifliği sayesinde ulaşım araçları üretiminde yaygın olarak kullanılmaktadır. Kıymetli metallerin bazı olumlu teknik özellikleri olmasına rağmen yatırım güdüsü genellikle kıymetli metallere olan talebin şekillenmesinde kritik bir öneme sahiptir. Yatırım güdüsünün yanı sıra, güvenli liman, riskten korunma rolü, değer saklama ve tür işlevi de kıymetli metal talebine katkıda bulunur. Kıymetli metallerin en iyi örneği altındır. Mücevher üretimi ve perakende yatırımları küresel altın piyasasındaki talebin çoğunluğunu oluşturmaktadır.

Metaller diğer mallarla hem benzerlikler hem de farklılıklar gösterir. Örneğin yakıt veya tarım ürünleri gibi depolanabilirler. Öte yandan, petrol ve doğal gaz gibi yakıt emtialarının aksine geri dönüştürülebilir ve tek kullanımlık olarak yok olmazlar. Metaller arasında benzer ve zıt bazı teknik özellikler bulunmaktadır. Örneğin bakır ve altın elektriği ve ısıyı iyi iletir. Kurşun ve altın yoğun metallerdir. Ancak kurşun elektriği iyi iletmez. Bu özellikler ilgili metal talebinde önemli bir rol oynamaktadır.

Bu rol ana metallerde daha belirgindir. Bunun nedeni, ana metallerin nispeten bol bulunması ve endüstriyel amaçlarla kullanılmasıdır. Öte yandan, altın ve gümüş gibi değerli metaller kıttır ve güvenli liman, korunma, değer saklama veya türev gibi endüstriyel olmayan amaçlı olarak talep edilmektedir. Spesifik olarak, endüstriyel olmayan bu talep, değerli metaller söz konusu olduğunda endüstriyel talep şoklarını telafi etmektedir. Arz tarafında ise Çin'in hızlı büyüyen ekonomik modeli nedeniyle 2000'li yıllardan sonra ana metallerde önemli bir değişim yaşanmıştır. Özellikle Çin, kurşun, çinko ve kalay metallerinin maden ve izabe tesisi/rafineri üretimindeki payını sürekli artırarak ana üretici konumuna gelmiştir. Nikel, alüminyum ve bakırda ise aynı gelişme sadece izabe/rafineri üretiminde yaşanmıştır. Çin'in ana metal arzının sanayi üretimi talebini karşılayacak seviyeye ulaşana kadar talebinin 2000'li yılların ortalarından önce fiyatların canlanmasına önemli ölçüde katkıda bulunduğunu belirtmeliyiz. Diğer taraftan, Çin'in büyüme modeli sanayi üretimi odaklı olduğundan ve halihazırda arzı oldukça kıt olduğundan kıymetli metal maden arzını bu şekilde etkilemedi. Değerli metallerde ülkeler ve küresel arz payları belirgin bir değişiklik göstermedi. Kıtlık nedeniyle özellikle işçi grevleri gibi olumsuz arz şokları değerli metal fiyatları üzerinde yukarı yönlü baskı oluşturdu.

Metallerin makroekonomik sistemedeki önemi nedeniyle fiyat dinamiklerinin incelenmesi özel bir vurguyu hak etmektedir. Metallerin fiyat dinamiklerini açıklamak için yazında çokça çalışma bulunmaktadır. Hotelling Kuralı (Hotelling, 1931), net piyasa fiyatının faiz oranında artması gerektiğini savunur. Prebisch ve Singer Hipotezi ise (Prebisch, 1950; Singer, 1950) göreli emtia fiyatlarının düştüğünü belirtmektedir. Ancak, bu akademik çalışmalar yakın zamanda yapılmış çalışmalar değildir. Ayrıca, söz konusu çalışmalar özellikle fiyat değişimine odaklanmaktadır. Son dönemde yapılan çalışmalar, kısa ve uzun vadede arz ve talep şokları, makroekonomik faktörler, arz ve talebe ilişkin belirsizlikler gibi temel faktörlerin metal fiyatlarını etkilediği iddiasını desteklemektedir. Metaller depolanabilir emtia olduğundan metal stoklarının düzeyi şokların etkilerini artırıcı veya hafifletici rol oynamaktadır. Metal stoklarının yüksek olması şokların fiyatlar üzerindeki etkisini hafifletirken (Carter ve diğerleri, 2011), düşük stoklar ise özellikle ana metaller için etkiyi yoğunlaştıracaktır. Kıymetli metallerin fiyatlarına göre düşük depolama maliyetleri sebebiyle metal stok düzeyinin fiyatlar üzerinde belirleyici etkisi bulunmamaktadır.

Fiyat davranışının analiz edilmesi, ilgili kaynak piyasalarının verimliliği hakkında önemli bilgiler aktarır. Esas itibariyla fiyatın piyasanın verimlilik yapısını yansıtması gerekmektedir. Zayıf formda, yarı güçlü ve güçlü formda piyasa verimliliği olmak üzere üç tür piyasa verimliliği bulunmaktadır. Güçlü-etkin formda bir piyasada oluşan piyasa fiyatı, kamuya açık veya kamuya açık olmayan tüm bilgileri yansıtmaktadır. Yarı güçlü formda verimli bir piyasada oluşan fiyat, mevcut tüm kamuya açık bilgileri yansıtır. Zayıf formda verimli bir piyasada fiyatlar yalnızca geçmiş fiyatları yansıtır. Daha spesifik olarak, eğer fiyat serisinde birinci dereceden entegre ise ilgili piyasanın zayıf formda verimli olduğu iddia edilebilir. Diğer taraftan, fiyatların durağan olduğu sonucuna ulaşılıyorsa piyasanın zayıf formda verimli bir piyasa olduğu söylenemez. Zayıf formda verimli bir piyasada fiyatlara gelen şoklar kısa ömürlü değildir. Bu nedenle piyasa getirileri tahmin edilemez. Bu durumda, bir yatırımcı, sadece metalin geçmiş fiyatını analiz ederek veya teknik analiz yardımıyla ekonomik kar elde edemeyecektir. Üstelik uzun vadede piyasayı dengeleyecek piyasa güçleri bulunmamaktadır. Ancak bir piyasanın zayıf formda verimli olduğu iddia edilemiyorsa fiyatlar, piyasadaki geçmiş fiyat bilgilerini tam olarak yansıtmamaktadır. Bu nedenle, kamuya açıklanmamış herhangi bir önemli bilginin dahil edilmesi aşırı kârla sonuçlanabilir. Ayrıca fiyatlara gelen şoklar kısa sürelidir; bu da piyasayı dengeye getiren piyasa güçlerinin var olduğu ve getirilerin öngörülebilir olduğu anlamına gelir. Bu argümanın spot piyasa verimliliğine yönelik olduğunu belirtmekte fayda bulunmaktadır.

Enerji fiyatlarının stokastik özelliklerinin bilinmesi, yalnızca verimli piyasa hipotezinin değerlendirilmesi açısından kritik öneme sahip değildir, aynı zamanda firmaların uzun ve kısa vadeli yatırım kararlarının ve çeşitlendirme stratejilerinin tahmin edilmesi ve oluşturulması açısından da önemlidir. Ayrıca enerjiye bağımlı ekonomiler için fiyatların izlediği patika, gelir tahmini ve yönetimi açısından kritik öneme sahiptir. Enerji alanında verimli piyasa hipotezinin ampirik geçerliliğine ilişkin pek çok çalışma mevcuttur. Petrol piyasalarının verimliliğine ilişkin yazın çok genişken, yenilenemeyen kaynakların piyasa verimliliğine ilişkin yazın nispeten zayıftır. Yenilenemeyen kaynakların piyasa verimliliğine ilişkin yazın incelendiğinde, önceki çalışmaların ampirik kanıtlarının durağan olmayan fiyatları ortaya çıkardığı ve dolayısıyla ADF ve PP testlerinin sonuçlarından hareketle etkin piyasa hipotezini desteklediği görülmektedir. Güncel çalışmalar (örneğin, Presno ve diğerleri, 2014), daha önceki çalışmaların durağan olmama bulgusunu, yapısal kırılmaların varlığında geleneksel birim kök testlerinin gücünün düşük olmasına bağlamıştır. Perron'un (1989) ufuk açıcı makalesinden itibaren, akademisyenler, geleneksel birim kök testlerinin, zaman serisi bir kırılma çevresinde durağan olduğunda birim kökün sıfır hipotezini hatalı bir şekilde kabul etme yönünde önyargılı olduğunu kabul etmiştir. Bununla birlikte, Perron (1989) tarafından önerildiği gibi dışsal bir kırılmayı içeren bir yöntem ön test yanlılığından zarar görebilir. Bu argüman, kırılmaların içsel olarak belirlendiği test yöntemlerinin uygulanmasını teşvik etmektedir. Yazındaki ampirik çalışma sonuçları, testin içsel olarak belirlenmiş kırılmalar içermesi nedeniyle daha fazla emtia fiyatlarının durağan olduğuna dair kanıtları desteklemektedir (örneğin, Lee ve diğerleri, 2006; Presno ve diğerleri, 2014).

Vadeli işlem sözleşmesi belirli bir gelecek tarihte teslim edilmek üzere önceden belirlenmiş miktardaki belirli bir varlığın satın alınmasına veya satılmasına ilişkin standart bir sözleşmedir. Vadeli işlem sözleşmesinin dayanak varlığına (örneğin bir emtia veya yabancı para birimi) bakılmaksızın, vadeli işlem sözleşmeleri piyasa katılımcılarına gelecekteki spot fiyatlara ilişkin bir miktar anlayış (fiyat keşif işlevi) sağlar ve kısa/uzun vadeli hedge yapanların risklerini spekülatörlere devretmelerine olanak tanır. Diğer bir ifade ile, vadeli işlem sözleşmesi risk transferi veya riskten korunma fonksiyonu sağlar. Bu özellikler, birçok araştırmacıyı vadeli işlem piyasalarının verimliliğini araştırmaya çekmektedir.

Verimli piyasalar, vadeli işlemler ve spot piyasalar arasında kârlı ticaret stratejilerine izin vermediğinden, vadeli işlem piyasasının verimliliğini analiz etmek önemli bir araştırma konusu olmuştur. Vadeli işlem piyasasının verimli olup olmaması, riskten korunmayı sağlayanları, spekülasyon yapanları, arbitrajcıları ve politika düzenleyicilerini belirgin şekilde etkilemektedir. Etkin olmayan bir vadeli işlem piyasasında, riskten korunmayı sağlayanlar vadeli işlem sözleşmelerinin risk transfer rolüne güvenemezler. Bu nedenle, vadeli işlem sözleşmesi almak/satmak konusunda isteksiz olacaklardır. Böylece vadeli işlemler piyasasında daha düşük işlem maliyetlerinden, işlemlerin daha hızlı gerçekleştirilmesinden ve açığa satış fırsatlarından vazgeçerler. Spekülatör, vadeli işlem piyasasında bir prim karşılığında riskten korunan kişinin riskini üstlenen ekonomik aktör olduğundan ve riskten korunan kişinin verimli olmayan bir vadeli işlem piyasasına katılma olasılığı daha düşük olduğundan, spekülasyon faaliyeti de düşecektir. Ancak, arbitrajcılar verimli olmayan bir vadeli işlem piyasasında risksiz kâr elde etmek için işlem yapacaklardır. Bir spekülatörün ve bir arbitrajcının işlem yapma motivasyonu farklıdır. Spekülatör, riskten korunanın riski karşılığında getiri aramaktadır. Arbitrajcı, herhangi bir risk almadan kâr elde etmek için piyasalarda eş zamanlı pozisyon alır. Politika düzenleyicilerinin vadeli veya spot piyasalarda herhangi bir pozisyon almamasına rağmen düzenlemelerle piyasalara müdahale etmesi gerekmektedir.

Vadeli metal piyasasının verimliliğinin ampirik olarak incelenmesi, spot metal piyasasının verimliliğinden farklıdır. Metal vadeli işlem piyasasının verimliliği, vadeli işlem fiyatının gelecekteki spot fiyatın tarafsız bir göstergesi olup olmadığını tartışmak için hem spot hem de vadeli işlem metal fiyatlarını kullanan yöntemler uygulanarak sınanmaktadır. Vadeli ve spot fiyatların ekonometrik değerlendirilmesi sonucu ulaşılan birim kökün veya eşbütünleşme bulgularına göre araştırma yöntemi değişiklik göstermektedir.

Bazı çalışmalarda (örneğin, Chowdhury, 1991; Moore ve Cullen, 1995; Reichsfeld ve Rauche, 2011; Arouri ve diğerleri, 2011, 2013; Cagli ve diğerleri, 2019; Kuruppuarachchi ve diğerleri, 2019) eşbütünleşme yöntemleri kullanılmaktadır. Moore ve Cullen (1995), Reichsfeld ve Rauche (2011), Cagli ve diğerleri (2019) ve Kuruppuarachchi ve diğerleri (2019) araştırmalarına konu olan ana metal vadeli işlem piyasalarının etkinliğini rapor etmektedir. Öte yandan Otto (2011), Chinn ve Coibion (2014) ve Park ve Lim (2018) tarafından yapılan çalışmalarda metalin vadeli işlemlerinin ve spot fiyatının doğrudan veya dolaylı olarak tek bir denklemde kullanıldığı regresyon tahminleri verimli olmayan piyasalara işaret etmektedir. Canarella ve Pollard (1986) LME'nin bakır, kurşun, kalay ve çinko vadeli işlem piyasalarındaki verimliliğini rapor etmektedir.

Tezde hem spot metal piyasalarının hem de üç ay vadeli vadeli metal piyasalarının zayıf formdaki verimliliğine odaklanılmıştır. Spot metal piyasalarının analizinde, 1980 yılının ilk çeyreği ile 2017 yılının ilk çeyreği arasındaki dönemi boyunca bakır, kurşun, kalay, nikel, çinko, alüminyum, altın, platin ve gümüşün üç aylık fiyat seviyesine göre düzeltilmiş fiyatlarının verimli piyasa hipotezi ile karakterize edilip edilemeyeceğini araştırmayı amaçlanmıştır. Mevcut yazın takip edilerek fiyat seviyesine göre düzeltilmiş metal fiyatları döviz kurunun potansiyel döngüselliğini ortadan kaldıracak şekilde seçilmiştir. Yöntem olarak, mevcut çalışmalardan farklı olarak, tezde geleneksel KPSS testinin değiştirilmiş versiyonları olan iki farklı durağanlık testi kullanılmıştır. Birim kök sıfır hipotezine sahip testlerin durağan ancak ısrarcı verilerle düşük güce sahip olduğu ve buna karşı çok güçlü bir kanıt olmadığı sürece durağan olmama sıfır hipotezini reddedemeyeceği göz önüne alındığında, durağanlığın sıfır hipotezi altında piyasa verimliliği daha doğal olarak test edilebilir. Ayrıca Lee ve diğerleri (2006) yenilenemeyen doğal kaynak fiyatlarının stokastik özelliklerinin analizinde yapısal kırılmaların ve eğilimlerin önemli hususlar olduğu bulgularından hareketle, kademeli ve keskin kırılmaları içeren iki farklı test benimsenmiştir. Kırılmaların yanlış karakterize edilmesinin, kırılmaları göz ardı etmek kadar sorunlu olabileceği göz önüne alındığında, hem kademeli hem de keskin kırılmalar dikkate alınmıştır.

Ana metallerle ilgili yapılan bazı çalışmalar Macdonald ve Taylor (1988), Chowdhury (1991), Moore ve Cullen (1995) ve Heaney (1998) olarak sıralanabilir. Macdonald ve Taylor (1988), Chowdhury (1991) ile Moore ve Cullen (1995) sırasıyla ay sonu, aylık ortalama ve saat birdeki aylık ile haftalık fiyatları incelerken, Heaney (1998) haftalık ve üç aylık fiyatların doğal logaritmasını incelemişlerdir. Macdonald ve Taylor (1988) 1976 yılının Ocak ayı ile 1985 yılının Ekim ayı arasındaki dönem için kurşun, kalay ve çinko fiyatlarını analiz etmiştir. Chowdhury (1991) 1971 yılının Temmuz ayı ile 1988 yılının Haziran ayı arasındaki bakır, kurşun, kalay ve çinko fiyatlarına odaklanmıştır. Diğer taraftan, Moore ve Cullen (1995) 1988 ile 1992 yılları arasındaki haftalık alüminyum, kalay ve çinko fiyatlarından ve aylık bakır, kurşun ve nikel fiyatlarından yararlanmaktadır. Heaney (1998) 1976 ile 1995 arasındaki haftalık ve üç aylık kurşun fiyatlarını analiz etmiştir. Moore ve Cullen (1995) ile Heaney (1998) PP testini, Macdonald ve Taylor (1988) ve Chowdhury (1991) sırasıyla DF testini ve DF ile ADF testlerini uygulamıştır. Bu çalışmalar arasında yalnızca Moore ve Cullen (1995) ve Heaney (1998) bazı metal fiyatlarının durağanlığını raporlamıştır. Moore ve Cullen (1995) Londra Metal Borsası'nın aylık kurşun ve haftalık kalay fiyatlarının durağan olduğunu bildirirken, Heaney (1998) aynı borsanın kurşun fiyatlarının durağan olduğu bulgusuna ulaşmıştır. Özetlemek gerekirse, bu çalışmalarının verilerinin zaman aralığı önemli ölçüde farklılık göstermektedir. Ayrıca söz konusu çalışmalarda bazı istisnalar dışında metal fiyatlarının çoğunun durağan olmadığı belirtilmektedir. Metal piyasalarının belirli bir dönem için verimli olması şaşırtıcı değildir. Ayrıca, bu çalışmaların hiçbiri yapısal kırılmaları dikkate almamaktadır.

Yazında yapısal kırılmaları dikkate alan test çalışmaları da mevcuttur. Ahrens ve Sharma (1997), Lee ve diğerleri (2006) ile Presno ve diğerleri (2014) 1870 ile 1990 yılları arasında alüminyum, bakır, demir, kurşun, nikel, gümüş, kalay ve çinkonun yıllık ABD fiyat seviyesine gore düzeltilmiş fiyatları incelemektedir. Ahrens ve Sharma (1995) otokorelasyon fonksiyonu, ADF, Perron (1989), Leybourne ve McCabe (1994) ile Ouliaris ve diğerleri (1988) testlerini uygulamıştır. Bu testler içinde içsel olarak yapısal kırılmaların belirlendiği bir test bulunmamaktadır. Yazarlar Perron (1989) testine gore tezde incelenen metallerden sadece aluminyum, bakır ve gümüş fiyatlarının bir yapısal kırılmalı durağan olduğu sonucuna ulaşmıştır. Aynı veri setine Lee ve diğerleri (2006) iki yapısal kırılmaya izin veren LM birim kök testi uygularken, Presno ve diğerleri (2014) ise yine iki yapısal kırılmaya izin veren Landajo ve Presno (2010) durağanlık testi uygulamıştır. Bahsi geçen her iki testte yapısal kırılmalar içsel olarak belirlenmiştir. Lee ve diğerleri (2006) tüm fiyatların durağan olduğu sonucuna ulaşırken, Presno ve diğerleri (2014) gümüş metali hariç aynı sonuca ulaşmıştır. Birebir aynı veri set kullanılarak ulaşılan sonuçlar yapısal kırılmaların birim kök veya durağanlık testlerinde dikkate alınmasının öneminin altını çizmektedir.

Spot piyasaların verimliliğini incelemek için altın, gümüş ve platin haricindeki metallerin fiyatları ve Emtia Nihai Talebine göre Mamuller için ABD Üretici Fiyat Endeksi (1982=100) Amerikan Merkez Bankası, St. Louis'den elde edilmiştir. Kalan metal fiyatları Dünya Bankası'ndan (Pembe Sayfa) alınmıştır. Nominal metal fiyatları ve mevsimsellikten arındırılmış ABD Üretici Fiyatları Endeksi (1982=100) kullanılarak fiyat seviyesine göre düzeltilmiş üç aylık dönem sonu fiyatların doğal logaritması kullanılmıştır. Nominal fiyatların fiyat seviyesine göre düzeltmek için üretici fiyat endeksinin kullanılması yaygındır (örneğin, Slade, 1982; Ahrens ve Sharma, 1997; Lee ve diğerleri, 2006; Presno ve diğerleri, 2014). Öncelikli olarak standart ADF ve KPSS testlerini uygulanmıştır. Standart KPSS testinde uzun vadeli varyans hesaplaması için SPC metodu kullanılmıştır. SPC metodu, Andrews (1991) ve Newey ve West (1994)' ün veriye dayalı kısaltma gecikme seçme yöntemi kaynaklı tutarsızlık problemini çözmektedir (Choi, 1994; Choi ve Ahn, 1995, 1999; Kurozumi, 2002; SPC). Söz konusu iki testin sonuçları çinko ve aluminyum dışındaki bütün metal fiyatların durağan olmadığına işaret etmektedir.

Bu noktada SPC metodunu açıklamakta fayda bulunmaktadır. Metot elde edilmiş hata terimlerinden uzun vadeli varyansı hesaplamak için öncelikle belirlenmiş bir bilgi kriterine hata terimlerine uygun otoregresif model seçilmektedir. Tezde Bayesgil bilgi kriteri, ikincil dereceden spectral kernel ve en fazla 8 gecikme benimsenmiştir. Seçilen model sonrası otoregresif modelin kalıntılarından uzun vadeli varyans hesaplanmaktadır. Ancak hesaplanan varyans doğrudan kullanılmamaktadır. Testte kullanılan varyans hesaplanmış iki değerden küçük olandır. İki değerden birisi uzun vadeli varyans olarak hesaplanmış varyansın örneklem büyüklüğü ile çarpımıdır. Diğeri ise hesaplanmış varyansın tahmin edilmiş otoregresif parametrelerin toplamının birden çıkarılarak bulunan değerin karesine bölünmüş değeridir.

ADF ve KPSS sonuçlarına göre çinko ve aluminyum metalleri dışındaki metal fiyatlarında birim kök sonucuna ulaşılması yanıltıcı olabilecektir. Bu durumun temel sebebi veride dikkate alınmamış yapısal kırılma olması durumunda her iki testte de birim kökü destekleyen hipoteze yönelik yanlılık bulunmaktadır. Bu sebeple tezde iki keskin yapısal kırılmaya izin veren Carrion-i-Silvestre ve Sanso (2007) ile Fourier fonksiyonlar yardımıyla kademeli kırılmalara izin veren Becker ve diğerleri (2006) durağanlık testleri uygulanmıştır. Her ikisi de KPSS tipi testtir. Tezde özgün olarak tutarsızlık problemini çözmek için her iki testte SPC metotu kullanılmıştır. Becker ve diğerleri (2006) testinde kırılmaların sayı ve yapısına ilişkin herhangi bir varsayıma gerek yoktur. Diğer taraftan, söz konusu testin keskin yapısal kırılmaların zamanı ve büyüklüğünü tahmin etmekte güçlü değildir (Jones ve Enders, 2014). Bu problem keskin yapısal kırılmaların büyüklüğü ile derinleşmektedir (Harvey ve Mills, 2004). Bu problem dikkate aldığımızdan ayrıca Carrion-i-Silvestre ve Sanso (2007) testi uygulanmıştır. Söz konusu durağanlık testinde aylak değişkenler yardımıyla keskin yapısal kırılmaları metota dahil edilmiştir.

Becker ve diğerleri (2006) metodunda kalıntı karelerinin toplamını minimize eden tekil frekans bulunmaktadır. Söz konusu frekansın 1 ya da 2'den büyük olmaması beklenmektedir. Frekansın 2'den büyük olması yapısal kırılmadan ziyade stokastik parametre değişkenliği anlamına gelebilmektedir. Buna rağmen ihtiyatlı bir yaklaşımla maksimum tekil frekansını 5 olarak uygulanmıştır. Optimum frekans ızgara araması yöntemiyle bulunmuştur. Yöntemin uygulanması sonucunda çinko ve aluminyum dışındaki metallerin optimum tekil frekansı 2'yi geçmemiştir. Söz konusu metal fiyatları halihazırda ADF ve KPSS testlerine göre durağan olarak raporlandığından diğer metallere odaklanılmıştır. Sadece altın fiyatlarının doğrusal trend olup olmamasından bağımsız olarak durağan olmadığı sonucuna ulaşılmıştır. Diğer taraftan, bakır haricinde diğer metallerin fiyatları doğrusal trend olup olmamasından bağımsız durağan olarak raporlanmıştır. Doğrusal trendin eklenmesi durumunda bakır fiyatlarının durağan olmadığı sonucuna ulaşılmıştır. Ayrıca, durağan olarak raporlanan metal fiyatları için yapılan Fourier fonksiyonlara ilişkin F testi sonuçları da Fourier fonksiyonlarının istatistiksel olarak anlamlılığına işaret etmektedir. Optimum tekil frekansa göre uyumlaştırılmış fiyatlar ile gerçek fiyatlar karşılaştırıldığında Fourier fonksiyonlar kaynaklı dalgalarının en yüksek ve alçak noktaları arasında bazı eşleşmeler gözlenmektedir. Bazı istisnalar dışında, söz konusu eşleşmelerin küresel olaylarla ilgili olduğu değerlendirilmektedir. Örneğin, bakır, kurşun, platinyum ve gümüş fiyatlarında 2011 yılının ikinci çeyreği veya üçüncü çeyreği örtüşen dalganın en yüksek noktası olarak gözlenmiştir. Söz konusu zirve Avrupa'nın borç problemine ilişkin artan stres ve küresel belirsizlik ile Çin'in yavaşlayan sanayi talebi ile ilintilidir (Dünya Bankası, 2011a). Buna ek olarak, kıymetli metal özelliğinden dolayı yatırımcıların varlıklarını likiditeye çevirmeleri gümüş fiyatlarındaki düşüşte kısmi katkı sağlamıştır (Dünya Bankası, 2011a, 2011b). Çin ihracatı ve stoklarındaki artışın sonucu olarak, 2006 yılının sonu veya 2007 yılı başında nikel, çinko ve aluminyum fiyatlarında zirve gözlenmiştir (Dünya Bankası, 2007a, 2007b, 2007c). Nikel ve çinko fiyatları 1989 yılının ilk çeyreğindeki zirveyi paylaşmaktadır. Nikel fiyatları 1987 yılında döngüsel olarak paslanmaz çelik talebi kaynaklı artmıştır (Madenler Bürosu, 1989a:739). Benzer şekilde, 1987 yılının Kasım ayından itibaren çinko fiyatları güçlü talep ve kıt arz sebebiyle artmıştır (Madenler Bürosu, 1989b:1155). Bakır, kalay, altın ve gümüş fiyatları 2001 yılının üçüncü çeyreğinde dip noktasını paylaşmaktadır. Söz konusu dip noktası temelde küresel iktisadi faaliyette yavaşlamayla ilişkilidir. Kalay ve altın fiyatları sırasıyla elektronik sektörü ve kuyum sektöründeki talepteki azalma kaynaklı azalmıştır (Madenler Bürosu, 2001a, 2001b). Diğer taraftan, gümüş fiyatlarındaki düşüş imalat talebindeki düşüş ile ilişkilendirilebilir (Gümüş Enstitüsü, 2002).

1988 yılının ikinci çeyreğindeki aluminyum fiyatlarındaki zirve ile nikel fiyatlarında 1998 yılının dördüncü çeyreğinde gözlenen dip noktasına ilişkin açıklama diğer metal fiyat açıklamalarına göre farklılık arz etmektedir. Aluminyum fiyatlarındaki zirve finansal gelişmelerden kaynaklanırken, nikel fiyatlarındaki dip noktası görece yerel gelişmelerden kaynaklanmaktadır. Aluminyum fiyatlarındaki zirve finansal bir olay olan Büyük Sıkma'dan kaynaklanmıştır. Söz konusu olayda kısa pozisyona sahip kişiler pozisyonlarını fiyatlardaki yüksek artış olan dönemde uzun pozisyon sahiplerinden pozisyonları kapatmak için aluminyum alamamışlardır (Metal Bülteni, 2015). Diğer taraftan, nikel fiyatlarındaki dip noktası Rusya'daki nikel tüketiminin azalması, Japonya'daki durgunluk ve Doğu Asya'daki diğer ülkelerdeki iktisadi problemler sebebiyle talebin azalması kaynaklıdır (Madenler Bürosu, 1998). Sonuç olarak, eşleşen dalga en alçak ve en yüksek noktaları çoğunlukla küresel döngüsel olaylarla ilişkilidir. Metallerin kendine özgü yapısal kırılmaları da yakalamak için Carrion-i-Silvestre ve Sanso (2007) metodu benimsenmiştir.

Carrion-i-Silvestre ve Sanso (2007) metodunda ise belirlenen spesifikasyona göre iki adet yapısal kırılmaya göre kalıntı karelerini minimize eden kırılma noktalarını bulunmaktadır. Becker et al. (2006)'daki optimum tekil frekansı bulurken kullanılan ızgara araması yöntemi kullanılmaktadır. Yazarlar makalelerinde yedi adet spesifikasyon kullanmış olsa da tezde en az kısıtlamalı model de dahil olmak üzere üç adet spesifikasyon kullanılmıştır. Söz konusu üç spesifikasyon sadece seviyede iki kırılma (model AA), sadece eğilimde iki kırılma (model BB) ve hem seviyede hem de eğilimde iki kırılma (model CC) içeren modellerdir. Metodun uygulamasında Becker ve diğerleri (2006)' daki gibi uzun dönemli varyans hesaplanmasında SPC metodu benimsenmiştir. Model AA için tüm metal fiyatları durağan olarak raporlanmıştır. Diğer taraftan model BB için sadece kalay, bakır ve gümüş fiyatlarında birim kök raporlanmıştır. Model CC spesifikasyonu kullanıldığında ise aluminyum, altın ve gümüş fiyatlarında birim kök bulgusuna ulaşılmıştır. Kurşun, nikel, çinko ve platinyum fiyatları her üç modele göre durağan olarak raporlanmıştır. Bu noktada bakır, kalay ve aluminyum fiyatlarına sadece bir modele göre durağan olmadığı için daha fazla odaklanmakta fayda bulunmaktadır. Hem model AA hem de model CC'ye göre bakır fiyatlarında 1987 yılının üçüncü çeyreği için keskin yapısal kırılma tahmin edilmiştir. Diğer taraftan, model BB söz konusu keskin yapısal kırılmayı tahmin edememiştir. Model BB'nin bakır fiyatlarının durağanlığını desteklememe sebebinin küresel tüketimdeki artışla birlikte tarihsel düşük bakır stokları sonucunda 1988 yıl sonunda fiyat zirvesini yakalayamaması olduğu değerlendirilmektedir (USGS, 2012:49). Benzer şekilde, model AA ve model CC'nin aksine, model BB kalay fiyatlarındaki 1985 yılının son çeyreğinde Uluslararası Kalay Konseyinin (ITC) yıkılması sonrasındaki sert düşüşü yakalayamamaktadır. ITC, 1985 yılının Ekim ayı sonuna kadar kalay fiyatlarındaki düşüşü engelleyecek politikaları uygulayan uluslararası bir kuruluş olarak faaliyet göstermiştir. Aluminyum fiyatlarındaki durum sınırlı olçüde farklıdır. Zira aluminyum fiyatlarının durağanlığı sadece model CC için reddedilebilmektedir. Bu durumun model CC'nin 2003 yılının üçüncü veya dördüncü çeyreğindeki kırılmayı yakalayamaması ile ilgili olduğu düşünülmektedir. 2004 ile 2008 yılları arasında gelişmekte olan ülkelerden olan Brezilya, Çin, Hindistan ve Rusya'nın yükselişi kaynaklı artan aluminyum talebi söz konusu kırılma ile eşleşmektedir (USGS, 2012:4). Daha öncede de belirtildiği gibi halihazırda standart ADF ve KPSS test sonuçları aluminyum fiyatlarının durağanlığına işaret etmektedir. Diğer taraftan, ana metaller için yapılan yorumlar altın ve gümüş fiyatları için yapılamamaktadır. Söz konusu iki metal kıymetli metal olup, endüstriyel demir içermeyen metallere göre sanayi kaynaklı talebe baskın olarak konu olmamaktadır. Model CC en genel spesifikasyon olduğu ve 2000lerin başındaki dip noktasını yakaladığı için altın ve gümüş fiyatları için söz konusu model temel alınmıştır. Model CC'ye göre altın ve gümüş fiyatlarının durağan olduğuna dair sıfır hipotezi reddedilebilmektedir.

Carrion-i-Silvestre ve Sanso (2007) testine göre tahmin edilen iki keskin yapısal kırılmanın gerçek fiyat kırılmaları ile eşleşme durumu da incelenmiştir. En kapsamlı model olan model CC sonuçlarına göre incelemek mantıklı bir yaklaşım olacaktır. Ancak, model CC sonuçlarına dayanarak eşleşme durumunu incelemek için ön koşul olarak fiyatların durağan olması gerekmektedir. Bunun temel nedeni birim köke sahip fiyatların tahmin edilmiş yapısal kırılmalarının tutarsız olmasıdır (Bai, 1994, 1997; Nunes et al., 1995). İncelenen metaller içinde sadece aluminyum, altın ve gümüş fiyatları model CC'ye göre durağan değildir. Ancak, aluminyum metal fiyatlarının model CC'ye göre durağan olmama sebebinin model AA ve model BB tarafından yakalanan 2003 yılının üçüncü veya dördüncü çeyreğin model CC tarafından yakalanamadığından kaynaklandığı değerlendirilmektedir. Diğer taraftan, altın ve gümüş fiyatlarının durağan olmamasının sebebinin söz konusu metallerin endüstriyel olmayan nihai tüketimi ile ilgili olabileceği değerlendirilmektedir. Son olarak, altın ve gümüş fiyatlarının model AA'ya göre durağanlık sonuçları incelenmiştir. Model AA ve model CC için bakır, kurşun, kalay, nikel ve çinko fiyatları durağan olarak raporlanmıştır. Ayrıca, söz konusu bakır, kurşun, kalay ve nikel fiyatlarınıdaki yapısal kırılmalar model CC için birbirine çok yakındır. 2003 yılının üçüncü ve dördüncü çeyreği söz konusu 4 metal fiyatları için ortaktır. Söz konusu kırılma dört metale ilişkin talebin Çin gibi bazı ekonomilerin yükselişi kaynaklı artışı ile ilintilendirilebilir (USGS, 2012).

Bakır ve nikel fiyatları için 1987 yılının üçüncü çeyreği tahmin edilmiş keskin yapısal kırılma raporlanmıştır. Nikel fiyatlarındaki yükseliş dünya çapında paslanmaz çelik üretimindeki beklenmedik artıştan kaynaklanmıştır (Madenler Bürosu, 1987b:648). Bakır fiyatlarındaki sıçrama ise kıt hurda bakır arzı ile yüksek tüketim talebi ile ilişkilidir (Madenler Bürosu, 1987a:307). 1988 yılının ilk çeyreği çinko fiyatları için model CC'ye tahmin edilmiş keskin bir yapısal kırılmadır. Bu dönem Çin alımlarının artması ve Avrupa ile Amerika Birleşik Devletlerinin kıtlaşan çinko arzına denk gelmektedir (Madenler Bürosu, 1987c:938). Daha önce de ifade edildiği gibi 1985 yılının dördüncü çeyreğindeki kalay fiyatlarındaki yapısal kırılma

ITC'nin çöküşünden kaynaklanmaktadır. 24 Ekim 1985 tarihine kadar ITC fiyatlarının düşmemesini sağlamıştır. Ancak, ITC fiyatları destekleyecek finansmanlarının kalmadığını duyurmuştur. Bu olay dünya kalay piyasasında şiddetli bozulmaya sebep olmuştur (Madenler Bürosu, 1985:969).

Aluminyum fiyatlarındaki durum tezde çalışılan diğer endüstriyel metallerden ayrışmaktadır. Aluminyum fiyatları model AA ve model BB'ye göre durağan olarak raporlanmış olsa da model CC'ye göre fiyatların durağan olmadığı sonucuna ulaşılmıştır. Bu durumun kaynağının Çin talebinden dolayı 2003 yılının üçüncü veya dördüncü çeyreğindeki kırılmayı model CC'nin yakalayamaması olduğu değerlendirilmektedir. Model CC 1987 yılının ikinci çeyreğini model AA tarafından tahmin edilen 1987 yılının ilk çeyrek kırılmasına yakın olarak belirlemiştir. 1987 yılının ilk çeyreğindeki keskin yapısal kırılma arzın talebe göre daha kıt olmasından kaynaklanmaktadır. Örneğin, Brezilya, Kamerun, Endonezya ve Surinam hidroelektrik üretimini olumsuz etkileyen kuraklık sebebiyle üretimlerini azaltmak zorunda kalmıştır (Madenler Bürosu, 1987:97). Bu anlamda aluminyumu tezde incelenen diğer endüstriyel metallerden ayrılmamaktadır.

Kıymetli metaller içinde sadece platinyum fiyatları model CC için durağan olarak raporlanmıştır. 1999 yılının üçüncü çeyreğindeki kırılma sınırlı fiziksel stoklar ile genel olarak otomotiv endüstrisi tarafında tüketimin artmasıyla ilgilidir (USGS, 2012:121). Diğer taraftan, 2010 yılının dördüncü çeyreğindeki kırılma platinyumun ciddi oranda paladyum ile ikame edilmesinden platinyum fiyatlarında gözlenen düşüşten kaynaklanmaktadır (Madenler Bürosu, 2010).

Altın ve gümüş fiyatları model AA'ya göre durağan olarak raporlanmıştır. Bu sebeple tahmin edilen kırılmaların makul olup olmadığı incelenmiştir. 2009 yılının ikinci çeyrek zirvesi borsada işlem gören fon, külçe ve sikke formunda güçlü altın yatırım talebinden kaynaklanmıştır (Dünya Bankası, 2009: 13). 2005 yılının üçüncü çeyreğindeki zirve enflasyon endişeleri ile aynı döneme denk gelmektedir (Dünya Bankası, 2005). 1984 yılının ikinci çeyreğindeki dip noktası gelişmekte olan ülkelerin borç geri ödemeleri için döviz elde etmek için küresel gümüş üretimini artırmasından kaynaklanmaktadır (Madenler Bürosu, 1984:814). 2005 yılının son çeyreğindeki zirvenin küresel likidite artış kaynaklı taze yatırımların belirleyici olduğu değerlendirilmelidir (Dünya Bankası, 2006b). Fiyat artışı gümüşün altının alternatifi olmasından da olumlu yönde etkilenmiştir. Her ne kadar model AA'ya göre tahmin edilen yapısal kırılmalar makul olsa da en az kısıt içeren model CC'nin altın ve gümüş fiyatlarının durağan olmadığı bulgusu daha ağır basmaktadır. Metotlardaki ve incelenen dönemler farklı olsa da altın ve gümüş fiyatlarının durağan olmadığı bulgusu Narayan ve Liu (2011) ile Presno ve diğerleri (2014) güncel çalışmalarıyla uyumludur.

Spot piyasaların verimliliğini inceledikten sonra altı ana metalin vadeli piyasalarının verimliliği analiz edilmiştir. Çalışmamızda, Ocak 1990 ile Nisan 2020 dönemi arasındaki LME vadeli işlem piyasalarının zayıf formdaki verimliliği hakkında çıkarımda bulunmak amacıyla bakır, kurşun, nikel, çinko, kalay ve alüminyum olmak üzere altı ana metalin örtüşmeyen fiyat verilerine odaklanılmıştır. Yazındaki ortak yaklaşımı takip ederek ADF ve PP testlerini uygulanmıştır. Ayrıca testi tutarlı kılmak için daha önce açıklanan SPC ön beyazlatma prosedürlü standart KPSS testi de uygulanmıştır. Durağanlık ve birim kök testlerinden sonra Pesaran ve diğerleri (2001) tarafından geliştirilen ARDL sınır testini kullanılmıştır. Söz konusu test vadeli işlemler ve spot fiyatlar arasında eşbütünleşme ilişkisinin varlığını araştırmak için tasarlanmıştır. Bu sınama yöntemi, verinin durağan olup olmamasına duyarlı değildir. Ayrıca, söz konusu yöntem Engle ve Granger (1987), Johansen (1988), ve Johansen ve Juselius (1990) ile karşılaştırıldığında bazı üstün özelliklere sahiptir. Durağanlığa duyarlı olmaması dışında, bu prosedür, Johansen eşbütünleşme tekniklerinin aksine, geçerlilik için büyük bir örneklemi zorunlu kılmaz. Ayrıca bu yöntemde her seri için değişen optimal otoregresif yapıya izin verilmektedir. Son olarak test sonuçlarına göre vadeli işlem piyasasının etkinliğinin incelenmesi ile devam ediyoruz.

Tezde bakır, kurşun, aluminyum, nikel, çinko ve kalay metallerinin Londra Metal Borsasındaki üç ay vadeli sözleşme ve vadedeki ayın ilk işlem günü kapanış fiyatları Bloomberg'den sağlanmıştır. Sephton ve Cochrane (1990, 1991) çalışmasını temel alarak ocak, nisan, temmuz ve ekim ayı başındaki üç aylık vadeli sözleşme fiyatları ile nisan, temmuz, ekim ve ocak ayı başındaki sözleşme vadesine tekabül eden gelecekteki spot fiyatları kullanılmıştır. Yazındaki ortak yaklaşımı benimseyerek fiyatların doğal logaritması tezde benimsenmiştir. Veri seti üç ay vadeli sözleşmeler için 1990 yılının Ocak ayı ve 2020 yılı Nisan ayı arasını kapsarken, gelecekteki spot fiyatları 1990 yılı Nisan ayı ve 2020 yılı Temmuz ayınının ilk işlem gününü kapsamaktadır. Yazında üç ay vadeli sözleşme piyasalarının etkinlik incelenmesinde hem örtüşen (Hsieh ve Kulatilaka, 1982; Sephton ve Cochran, 1990; Canarella ve Pollard, 1986; Otto, 2011) hem örtüşmeyen (Canarella ve Pollard, 1986; Beck, 1994; Park ve Lim, 2018) veriler kullanıldığına rastlanmıştır. Tezde örtüşmeyen veriler kullanılarak örtüşen veri kaynaklı serisel korelasyon ihtimalini ortadan kaldırmak amaçlanmıştır.

Fama (1970) verimli bir piyasada oluşan fiyat halihazırda mevcut tüm bilgi setini yansıttığını belirtmektedir. Verimli piyasa hipotezi vadeli sözleşme fiyatının gelecekteki spot fiyatının optimum kestirim olduğunu ima etmektedir. Ancak bu analiz için öncelikle her iki fiyatın durağanlık ve/veya eşbütünleşim durumları incelenmelidir.

Yazında spot ve üç ay vadeli sözleşme fiyatlarının durağanlığı ADF testi (örneğin, Chowdhury, 1991; Beck, 1994; Watkins ve McAleer, 2006; Arouri ve diğerleri, 2011, 2013; Otto, 2011; Reichsfeld ve Rauche, 2011; Kuruppuarachchi ve diğerleri, 2019), PP testi (örneğin, Chowdhury, 1991; Moore ve Cullen, 1995; Arouri ve diğerleri, 2011), üssel kademeli geçiş birim kök tesi (Cagli ve diğerleri, 2019) ve Zivot ve Andrews (1992) (örneğin, Arouri ve diğerleri, 2011, 2013) kullanılarak incelenmiştir. Çalışmaların çoğu fiyatların durağan olmadığı sonucuna ulaşmıştır. Tezde yazının çoğu takip edilerek ADF ve PP testleri kullanılmıştır. Ayrıca standart KPSS testi uzun dönem varyansı SPC metoduna göre hesaplanarak uygulanmıştır. Her üç test sonuçlarına göre tüm metal fiyatlarının durağan olmadığı sonucuna ulaşılmıştır. Sonrasında etkinlik analizi için üç ay vadeli sözleşme fiyatı ile vadedeki spot fiyat arasında eşgüdüm olup olmadığını da incelemek gerekmektedir. Zira eşgüdüm olması durumunda uygulanması gereken metot farklılık arz etmektedir.

Eşgüdüm analizi için Pesaran ve diğerleri (2001) ARDL sınır testi uygulanmıştır. Durağanlığa karşı duyarlı olmayan testte en az kısıtlanmış model kullanılmıştır.

Testte önce gelecekteki spot fiyatların Akaike bilgi kriterine göre en çok uyan ARDL modeli bulunmuştur. Sonrasında ise ilk farklar üzerinde bir gecikmeli gelecekteki spot ve vadeli sözleşme fiyatlarının katsayılarının ortak olarak istatistiksel olarak önemliliği F testi ile değerlendirilmiştir. F-testi sonuçlara göre aluminyum fiyatları haricinde bütün ana metalleri gelecekteki spot ve vadeli sözleşme fiyatları arasında eşgüdüme rastlanmamıştır. Diğer bir ifade ile, hesaplanan F testi ARDL testinin kritik alt sınır değerinin altındadır. Aluminyum fiyatları için ise hesaplanan istatistik ise kritik üst sınırının üstünde bulunmuştur. Bu sebeple, aluminyum fiyatları için Pesaran ve diğerleri (2001:304) önerisini benimseyerek bağımlı değişkenin bir gecikmeli değeri için sınır t testi ile analize devam edilmiştir. Söz konusu test sonucu kritik alt sınırın altında olduğu için eşgüdüm olmadığı sonucuna ulaşılmıştır. Sonuç olarak, ARDL sınır testi sonuçlarına göre eşgüdümün varlığına dair kanıt bulunmadığından hata terimleri modellerinin kullanılmasına gerek bulunmamaktadır. Metal fiyatlarının durağan olmaması ve eşgüdüm bulunmaması sebebiyle birincil fark, bir varlığın spottaki vadeli sözleşme fiyatı ile spot fiyatı arasındaki fark ve kestirim farklarını kullanarak iki alternatif piyasa etkinlik analizi yapılmıştır. İlk modelde spot fiyat değişikliklerinin spottaki vadeli sözleşme fiyatı ile spot fiyatı arasındaki fark tarafından birebir belirlenip belirlenmediğine ilişkindir. Eğer belirleniyorse, piyasanın verimliliğinden bahsedilebilir. İkinci modelde ise vadeli sözleşme fiyatı ile vadedeki spot fiyatı arasındaki farkın gecikmeli değerlerinden etkilenip etkilenmediği incelenmektedir. Eğer söz konusu etki yoksa piyasanın verimliliği olduğu sonucuna ulaşılabilecektir. Analize geçmeden önce ADF testi aracılığıyla durağanlık analizi yapılmıştır. Regresyonlarda kullanılan tüm değişkenlerin durağan olduğu sonucuna ulaşılmıştır. Üç ay vadeli çinko piyasaları dışında iki alternatif verimlilik analiz sonuçları uyumludur. Kurşun piyasası dışında diğer piyasaların verimli olduğu sonucuna ulaşılmıştır. Kestirim hatası spesifikasyonuna göre çinko piyasasının verimli olmadığı raporlanmıştır. İhtiyatlı bir yaklaşımla söz konusu iki piyasa dışındaki diğer üç ay vadeli sözleşme metal piyasalarının verimli olduğu değerlendirilmektedir.

Tezde küresel spot ve üç ay vadeli metal piyasalarının zayıf formda verimliliğini araştırmak amacıyla testler uygulanmıştır. Küresel spot metal piyasalarının verimliliğini incelemek için kademeli veya iki keskin kırılmalara izin veren durağanlık testlerine odaklanılmıştır. Tezdeki ampirik kanıtlar büyük ölçüde spot metal fiyatlarının durağan olduğunu ortaya koymuştur. Bununla birlikte, Carrion-i-Silvestre ve Silvestre'nin (2007) keskin kırılma durağanlık testi, kırılma olaylarını Becker ve diğerlerinin (2006) kademeli kırılma durağanlık testinden daha iyi yakalamıştır. Gözlenen yapısal değişiklikler piyasaya özgü ve ekonomik olaylarla ilgili olmakla birlikte, özellikle değerli madenler üzerinde küresel ekonomik koşulların etkili olduğu görülmektedir. Altın ve gümüş dışında ampirik sonuçlarımız etkinlik piyasası hipotezine karşı kanıt sunmuştur. Piyasanın verimli olmaması, fiyatların piyasada mevcut tüm bilgileri tam olarak yansıtmaması anlamına gelir. Tüm bu piyasalarda zayıf formda verimli olmama bulgularının varlığı, fiyatları tahmin etmek ve anormal karlar elde etmek için teknik analiz yapılmasına olanak sağlar. Ayrıca istikrar politikaları, geçici ve kısa süreli olacak dışsal şoklarla etkili bir şekilde mücadele edebilecektir. Altın ve gümüş piyasalarının verimli olması, dışsal şokların bu metal fiyatları üzerindeki etkilerinin kalıcı olacağına işaret etmektedir. Bu piyasalarda metal fiyatlarının orijinal eğilimine dönmesi için güçlü politika önlemlerinin uygulanması gerekmektedir. Güçlü politika önlemlerinin de etkisiyle metal fiyatları eski seyrine dönüyor.

Londra Metal Piyasalarında üç aylık vadeli sözleşme ana metal piyasalarının zayıf formdaki verimliliği de analiz edilmiştir. Birim kök ve eşbütünleşme test sonuçlarına dayanarak, etkinliği incelemek için bir varlığın vadeli sözleşme fiyatı ile cari fiyatı arasındaki fark ve tahmin hatasına dayalı regresyon kullanılmıştır. Kurşun ve çinko vadeli sözleşme piyasaları dışında piyasa verimliliğine dair güçlü kanıtlar bulunmuştur. Kurşun ve çinko piyasalarının zayıf formda verimli olmamasının işlem maliyetleri ile ilişkili olduğu değerlendirilmektedir. Londra Metal piyasalarında işlem ücreti sabittir. İşlem ücretleri, sözleşme tutarına veya piyasa fiyatına göre değişiklik göstermemektedir. Sözleşme türüne, kategorisine ve işlemin türüne bağlıdır. Metalin fiyatı düşükse bu maliyetler daha da önem kazanır. Kurşun ve çinko fiyatları diğer ana metallere göre daha düşüktür. Kurşun ve çinko vadeli işlem piyasalarının dışında, incelenen LME metal vadeli sözleşme piyasaları hem ticari yatırımcıların hem de piyasa düzenleyicilerinin lehinedir. Etkin vadeli sözleşme piyasalarında, ticari tüccarlar gelir düzeylerini önemli fiyat değişimlerine karşı korurken, piyasa düzenleyicileri piyasa anormalliklerini fazla çaba harcamadan fark edebilecektir. Diğer taraftan, arbitraj yapanlar, kritik bilgileri fiyata yansımadan önce elde edebilirlerse kurşun ve çinko vadeli işlem piyasasından faydalanabilecektir.

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