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What drives nickel prices: A structural VAR approach

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What Drives Nickel Prices - A structural VAR Approach

Lars G. Ehrlich

30th August 2018

Hamburg Institute of International Economics (HWWI)

Abstract

Metal markets play a major role in the challenging area of natural resource economics and have a forceful impact on global and local development. Understanding the behaviour and nature of metal price fluctuation is an essential element for taking countermeasures. Nickel is an indispensable element for modern steel industries and therefore crucial to industrial countries. This paper presents a structural model to explain price fluctuations in the international nickel market. On the basis of a unique long-term data set from 1867 to 2015, demand and supply shocks affecting the real prices of nickel are identified by using a Structural Vector Autoregression (SVAR) model and are traced back to historical developments in the nickel market. The results demonstrate that in the late 19th century real nickel prices were most affected by "nickel-specific" demand shocks as well as "nickel supply" shocks. While over the course of the 20th century the weight of positive "world domestic product driven" demand shocks grew, from 1980 on nickel-specific demand shocks had the most influence on nickel price development. These findings underline the need to analyse the driving forces of metal prices individually and thereby take its particular features into account rather than generalising over a broad spectrum of mineral commodities.

1 Introduction

Nickel is an indispensable element for modern manufacturing industries and crucial to industrial countries and modern societies. Because of its valuable characteristics such as strength, durability and heat resistance as well as magnetic and anticorrosion-giving properties, nickel is a desirable input for a large variety of capital-intensive goods as well as high-performance products and has become pervasive in modern technological societies. Alongside certain specialised applications, about two thirds of globally consumed nickel is utilised in (stainless) steel production. Without the

corrosion-resistant properties of nickel countless essential stainless steel types, from ordinary V2A-steel[1] to high-performance superalloys, would be impossible to produce. The importance of nickel has grown extensively over the last century. However, real prices of nickel have been considerably volatile over the past 150 years. While prices skyrocketed in certain times, in other periods real prices sharply slumped or stagnated at certain levels for several years. The predominant proportion of today's world nickel consumption occurs in industrial countries without own mine production. Besides concerns for socially optimal exploitation of resources, there is a high sensitivity for sharp unexpected price movements in these countries. This is certainly not only true for nickel, but for the majority of metals. Most industrial countries and their economies are heavily dependent on metal imports, while developing and emerging countries are highly reliant on the revenues of metal (ore) exports and trade to finance their governmental spending. Accordingly, insights on metal price fluctuation are not only relevant for the metal industries (Labys *et al.*, 1998). Knowledge of the patterns and dynamics of these price fluctuations is important in regard to stabilisation strategies to alleviate macroeconomic effects of such price shocks (Cashin *et al.*, 2000). While many studies on metal prices have generated distinct knowledge on price movements, they offer few insights into the underlying driving forces of price behaviour. The explanations of the driving market forces remain ambiguous and there is still need for detailed clarification.

Hence, the purpose of this paper is taking a closer look at one individual metal and its specific market conditions and trying to identify and describe the underlying structural factors of nickel price developments. The paper is structured as follows: Section (2) provides a short review on the related literature on commodity prices, metal prices and a brief history of the nickel industry and nickel (price) research. Section 3 gives a brief background to the nickel market. In section 4 the dataset is described and a short review of the concept of SVAR models as well as the identification scheme is adressed. The results are presented and discussed in section 5. Section 6 concludes.

2 Literature review

Price fluctuations in the field of mineral commodities have a forceful impact on global and local economic developments (Deaton, 1999). Sharp price movements in important commodities are driven by unexpected distinct shocks. Such price fluctuations can cause enormous macroeconomic disruptions and even lead to political instability and unrest (Carter *et al.*, 2011). On the one hand severe shocks causing downswings can lead to unemployment and underutilized capital; this is especially true for developing and emerging countries where export earnings are often highly concentrated in specific commodities. As a result, this leads to high variation in their terms of trade since the financial systems in those countries are rather underdeveloped and therefore cannot cope with price volatility sufficiently (Worldbank, 2009). On the other hand sharp price booms can cause

[1] The most often used stainless stell is V2A with one third share of world production.

bottlenecks in industrialized countries during upswings, trigger fears of SVARcity and security of supply and raise inflation rates in these countries (Radetzki, 2008; Borensztein, 1994). Looking into history, booms and busts are no exceptional phenomena and there are multiple examples of metal price volatility with repeated periods of intense ascents and price slumps. Moreover, unexpected, rapid and "[...]large movements in commodity prices are an important feature of their behaviour" (Cashin & McDermott, 2001). Furthermore, as Deaton & Laroque (1992) put it "Commodity prices are extremely volatile". Recently, the enormous boom in commodity prices beginning about the year 2000 and lasting to the end of the decade with record highs in several metal prices renewed the necessity of modelling their price behaviour (Humphreys, 2010). Even more recently, the unforeseen sharp downfalls in metal prices during the last five years gained attention. However, thinking of commodity and especially metal markets there is no consensus in academic literature on how to model and describe the dynamics and driving forces behind these price fluctuations and long-term trends. Research tries to answer the question if real price fluctuations of metals are random or if they show some recurrent behaviour. In a nutshell, research simply tries to understand why metal prices move as they do.

Nevertheless, empirical studies have developed certain stylized facts regarding developments of real metal prices. One strand of research dealing with the cyclical nature of real metal prices tries to identify periodic patterns along with the magnitude and length of up- and downswings. As metal supply is relatively inelastic in the short term, whereas metal demand responds relatively quickly to economic activities, from a theoretical viewpoint real metal prices were thought to be demand driven and to behave cyclically. The dimension of cycles found by researchers however, cover ranges from business-cycles length to so-called "super-cycles".

Short-term cycles or business cycles in real metal prices have been examined by many scholars and have usually been found to have a duration of about 2 to 8 years (Roberts, 2009; Labys *et al.*, 2000, 1998). These cycles tend to behave asymmetrically with times of price depreciation lasting longer than times of increasing real prices (Roberts, 2009; Cashin *et al.*, 2000, 2002; Deaton & Laroque, 1992). In other words, these findings suggest price booms to be sharp and terse, while price slumps tend to be more long lasting. Furthermore, some researchers additionally find evidence for price falls being larger than price increases and therefore support the thesis of long-term falling real prices (Cashin *et al.*, 2002; Krautkraemer, 1998; Grilli & Yang, 1988; Cashin & McDermott, 2001), while other studies reject this hypothesis (Roberts, 2009; Ahrens & Sharma, 1997; Svedberg & Tilton, 2006). Moreover, the seminal Hotelling-rule (Hotelling, 1931) and its model extensions draw the conclusion of long-term price increases at the rate of interest as a result of persistant demand for a fixed stock of resources.

Literature on the long-run price cyclicity suggests commodity prices move in super-cycles. These cycles tend to be extraordinary in two characteristics. First, their duration goes well beyond usual business cycle length. Therefore, a complete cycle can last between 20 to 70 years (Cuddington

& Jerrett, 2008; Jerrett & Cuddington, 2008). Secondly, super-cycles have a great magnitude. Authors connect super-cycles mainly to extraordinary industrialisation and urbanisation phases of major economies or regions (Heap, 2005). In this regard super-cycles seem to be demand rather than supply side driven.

Although scholars have gathered substantial evidence, the findings on metal price behaviour are not conclusive. No study draws a conclusive picture of the underlying structural dynamics triggering the price movements. In other words, the driving forces behind price fluctuations are not identified or are merely identified to a limited degree. This leads to Krautkraemer's argument that the „[..] empirical investigation probably would demand greater information and likely would have to be tailored to the specific circumstances of individual non-renewable resources" (Krautkraemer, 1998, p. 2103). While other studies try to explain price fluctuation and market dynamics in aggregated groups of metals or commodities there is a need to tailor analyses to the specific commodity. Moreover, this is the way of Jerrett & Cuddington (2008, p. 195) who conclude that „[. . .] explaining the factors driving these large price cycles becomes a high priority task. Building a multi-sectoral model of the structural changes accompanying economic development, with explicit supply and demand roles for metals, would appear to be a productive approach to this modelling effort". Tilton, (1992) puts it in a more general context and states: "There is no general model or economic analysis applicable to all mineral commodities. Rather each mineral commodity must be considered individually, so that the analysis takes explicit account of its particular features." (p. 47). Consequently, this paper tries to fill a fraction of this gap in research by focussing its analysis on one exclusive metal, nickel, with its idiosyncratic market patterns and dynamics.

3 Background: a brief history of nickel and nickel related literature findings

The market for nickel and the nickel industry have exhibited many contrasting phases since the first discovery in the 18th century[2]. While nickel presumably has been used unknowingly for centuries, the first isolation of nickel as a pure element goes back to the year 1751, when it was firstly isolated by Axel Cronstedt, a Swedish scientist (Mizzi *et al.*, 1987; Habashi, 2009). The name "Nickel" can be traced back to mining sites in the region of the German towns Schneeberg and Annaberg, where it was brought to light in silver mines (Clow, 1992; Howard-White, 1963). Because of the presence of a - in these days - unknown substance, which made the processing and refining of the silver troublesome and harmful, it was believed to be cursed by mountain trolls (German: *Nickel*). Nickel was also recognized in copper mining so the name copper-nickel (*Kupfer-Nickel*) was also used. Even though the demand for nickel slowly developed in the 19th century in form of nickel-

[2]For a detailed historical background on nickel the interested reader is referred to (Howard-White, 1963) and (Habashi, 2009)

silver, an alloy of about 40 % copper 30 % nickel and 26 % zinc which was used as a substitute for silver, it took until the beginning of the 20th century to discover the full utility of the physical properties of this metal (Clow, 1992). The emergence of stainless steel as a material and significant scientific improvements in the field of metallurgy boosted the use of nickel tremendously. Today, nickel has become indispensable as an industrial input material and the nickel industry has grown to a multi-billion dollar business.

Nickel consumption

Nickel is primarily used as an alloy metal with its major use in the production of stainless steel. Nickel consumption for stainless and heat resistant steels accounts for about 65 % of the world usage. About 20 % is used for non-ferrous alloys like cupro-nickel, nickel-chromium or nickel-titanium alloys; electroplating accounts for about 9 % and 6 % of global nickel consumption is used for other applications like batteries or catalysts (BGS, 2008). However, the most desired attribute of nickel lies within its anticorrosion-giving properties, which makes it indispensable for a huge variety of steel alloys, most notably stainless steels of austenitic grades[3]. Because of its desirable properties concerning processability, strength even at elevated temperatures and - most of all - corrosion resistance, nickel-bearing products have many applications in industrial societies like building and construction, food processing, transport equipment, medical applications, electronic engineering and numerous more. Moreover, about 300 000 end-use utilisations of nickel are known which are spread through numerous application areas (e.g. pipelines, vessels, valves, turbine blades, aero engines etc.) However, options to substitute nickel tend to be very limited. In most cases, substitution of nickel would lead to a trade-off in performance and entail sacrifices of physical or chemical attributes in most application purposes (USGS, 2007; Hilmy, 1979). Furthermore, in the majority of cases substitution of nickel would come at a higher cost, which is why nickel has not undergone major substitution pressure in its history even in periods of high prices.

The historical consumption path for nickel shows an obvious upward trend (see Figure 1). Noticeable nickel consumption began in the late 19th century when metallurgical developments and improvements were established on the back of accelerating industrialisation processes in the western world and the usefulness of nickel slowly became apparent. For example, nickel bearing steels (about 40 % Ni) were found to have a very low coefficient of expansion and therefore were useful for metal-in-glass seals or clock pendulums Habashi (2009). Furthermore, due to its strength and utilisation for military purposes like armour plating, nickel consumption picked up speed from that time on. Nonetheless, the accelerated expansion of nickel emerged in the beginning of the 20th century. Metallurgical researchers in the USA, Germany and France constantly developed new steel alloys with new characteristics including an austenitic alloy with 7 % nickel and 20 % chromium

[3]These steel grades make up over two thirds of stainless steel types and need nickel (typically 6 - 22 % nickel) to form an austenitic crystal micro structure

which had exceptional corrosion resistance and later became known as V2A[4] steel (Cobb, 2010). The invention of stainless steel quickly reached other countries all over the world and stimulated the development of further special steels and substantiated the status of nickel as an industrial metal within that process (Clow, 1992). Since the use of stainless steel grew extensively and had become ubiquitous in modern industrialized nations, it is not surprising that the importance of nickel has steadily grown alongside stainless steel usage. Hence, the rapid expansion of stainless steel had an undeniable effect on the nickel market. Even though one has to take World War I and II into account when nickel production rose significantly because of its military use in plating, the sharp increase in nickel production from the 20th century onwards was strongly connected to the upcoming use of stainless steel. From virtually nothing in the years before World War II the world production of stainless steel increased to one million metric tonnes in 1950 and grew to more than 41.7 million tonnes of stainless steel in 2014 of which more than half were chromium-nickel grades Clow (1992); ISSF (2015).

In the post WWII period there was a strong trend towards using nickel as the main component in stainless steel. This triggered an even faster growth in Nickel consumption and the percentage of total nickel consumption taken by stainless steel production increased (Maxwell, 2006; INSG, 2012). For example, while the share of stainless steel production in nickel consumption was about 40 % in the late 70s, today's percentage of use accounts for about two thirds Hilmy (1979); INSG (2012).

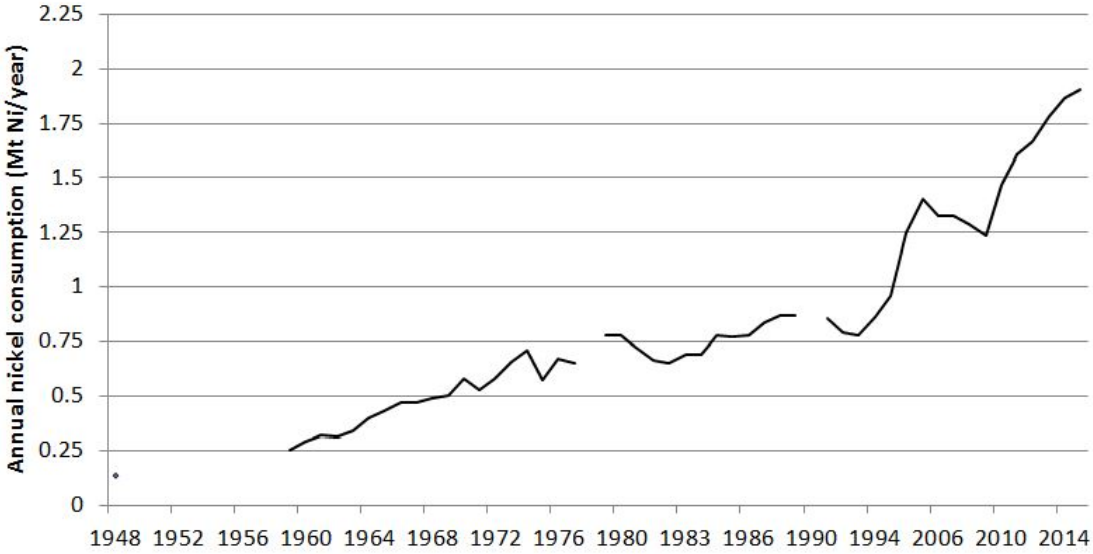
Consumption in the proper meaning of the word should express the nickel contained in end-use products purchased on the world market. Unfortunately, such data is not available since nickel is almost completely used as an input rather than a final good. Mostly the concept of "apparent consumption" is used denoting production plus imports minus exports and electively the changes in inventories. However, in regard to several practical reasons[5] like different definitions and varying concepts of respective sources, discontinued surveys or simply a lack of data, the publicly available figures on world aggregate nickel consumption figures are fragmentary and partially inconsistent (see Figure 1). Therefore, there are no continuous and consistent time series for the world nickel consumption over the past century which would allow robust statistical testing. Nonetheless, combining the different sources allows perceiving at least a rough impression of the overall consumption developments.

After World War II, nickel consumption increased rapidly by 5.6 % annually in the 1950s (Hilmy, 1979). Rafati (1982) estimates a growth rate of approximately 9 % per annum in the period between 1948 and 1959. From 1960 to 1974 the world wide nickel consumption rose each year by an average of 6.8 % (Hilmy, 1979). However, in the following period from 1974 to 1980 the cumulative world consumption rose by only 10 % (Rafati, 1982). According to the figures presented in Clow (1992))

[4] Acronym of „Versuch 2 Austenit"

[5] For example, since a significant share of nickel consumption is fulfilled via scrap metal, it is hard to exactly quantify the overall consumption.

Figure 1: World nickel consumption in selected years*



Source: Rafati (1982), Hilmy (1979), Clow (1992), Kitney (1996), INSG. *fragmentary due to inhomogeneous sources

the average annual growth rate from 1980 to 1990 was 2.4 %. As reported in Kitney & Maxwell (1996) world nickel consumption shrunk in the beginning of the 1990s and recovered in the middle of the decade. They calculate an average growth of more than 4 % per annum from 1950 to 1995. Finally, based on the latest consumption figures by the International Nickel Study Group, nickel consumption rose with an average annual growth rate of 4.2 % from 2004 to 2015. Nonetheless, besides some possible inaccuracy and incongruences due to the named reasons above, it is obvious that the consumption of nickel has grown immensely and steadily over the last century.

What drives nickel demand and how could the consumption path be explained? Several researchers address the strong correlation between income growth and nickel consumption because of its versatile usage in capital goods as well as consumer goods and therefore conclude that income is one of the most influential determinant in demand for nickel (Hilmy, 1979; Maxwell, 2006; Rafati, 1982; Maxwell, 1999). Furthermore, Clow (1992, p. 28) sees the demand for nickel even "conditioned by the state of the world economy". He connects the boom of nickel consumption in the post WWII era as well as the slump in consumption in the late 70s and early 80s to the industrial output and income growth and income stagnation respectively of the western world during that time periods. Nevertheless, he emphasizes that nickel consumption tends to overdraw business or industrial cycles. Kitney & Maxwell (1996) also discuss this factor and underline the strong influence of business cycles to nickel demand. Hence, one has to distinguish between two types

of changes in income that have an effect on nickel consumption: short-term income changes due to business-cycle fluctuation and long-term changes as a result of development caused by secular growth. Another view on the relationship between nickel consumption and GDP expansion is the intensity of nickel use. In early stages of the industrialisation process there is a strong increase in nickel consumption relative to GDP growth. According to Kitney & Maxwell (1996) and Maxwell (2006) the intensity-of-use of nickel for the world economy (from 1960-1995) appeared to be consistent with the classic intensity-of-use hypothesis[6] pattern of consumption in economies experiencing industrialization which was also recognised by Hilmy (1979). These findings underline the strong relation of nickel consumption and real economic growth.

Nickel resources and production

Like most other metals, nickel is found in ores and is an exhaustible resource. Today, the known land-based nickel reserves account for 78 Million tons of nickel content USGS (2017). It is worth mentioning, that 'reserves' is not a static, but rather a dynamic parameter. It displays the amount of metal which could be recovered economically at the present state of technology and current price level. The reserves-to-production ratio yields to a static range of coverage for nickel of about 31 years and determines the ceteris paribus future availability of nickel. In addition, the identified world land-based resources, defined as potentially or currently feasible amount of recoverable nickel containing not less than 1% nickel, are estimated to be at least 130 Million metric tons of nickel USGS (2017). Furthermore, there are huge nickel resources contained in manganese nodules on the seabed. Nevertheless, extraction of these resources is not economically feasible at present and subject to many uncertainties. In summary, exhaustion of world nickel deposits is not yet an immediate thread.

In nickel production there are basically two ore types which can be exploited economically: sulphide and laterite ores. Both deposit types occur in fundamentally dissimilar environments and differ in their geological properties. In addition, each ore type requires different producing, processing and refining methods. The majority of world nickel resources is contained in laterite ores, but historically the production has been dominated by sulphide ores. Even though sulphide ores usually require underground and 'hard rock' mining, they are typically of higher nickel grade and the processing is less complex than of laterite ores; the amount of nickel in sulphide ores ranges from 0.15 % to around 8 % (BGS, 2008). However the usually mined and processed sulphide ores contain typically 1.5 % - 3 % nickel (Crundwell, 2011). The nickel production from sulphide ores generally requires the following steps: after recovering the material from the mining site, the ore is concentrated by froth flotation to a concentrate of about 15 % nickel followed by a smelting process to obtain nickel matte with 40 % - 70 % nickel content which then could be refined to produce

[6]For a recent literature overview on this topic the interested reader is referred to Wårell (2014)

pure nickel (Crundwell, 2011). Sulphide ores make up about 40 % of the known world land-based resources of nickel USGS (2017). Typical nickel producing countries with sulphide ore deposits are Russia, South Africa and Canada.

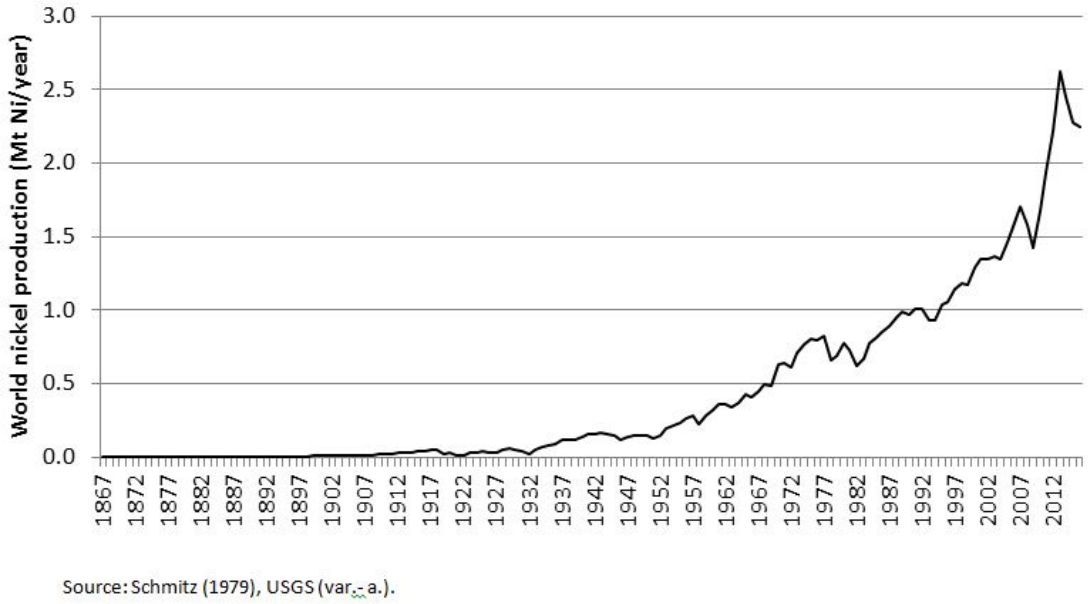
Nickel-bearing laterite deposits are typically found in hot, humid, tropical and sub-tropical areas. New Caledonia, Indonesia, Philippines and Cuba are typical examples for nickel producing countries from laterite deposits. Laterites have an average nickel content of 1.3 % - 2.5 % and account for around 60 % of the world land-based resources (Crundwell, 2011; USGS, 2017). These deposits usually occur near the surface and could typically be mined by open-pit methods. For their part, laterites have to be further distinguished in limonite (oxide) and silicate (saprolite) ore types and each of them requires suited treatments and fitted methods to extract nickel. Therefore, particular processes are customised to the different ore types and either high-pressure acid leach (HPAL), heap (atmospheric) leach or rotary kiln electric furnaces (RKEF) processes are carried out (Crundwell, 2011; Mudd, 2010). These techniques are complex and usually expensive treatments and therefore have historically been less attractive than sulphide ore processes (Mudd, 2010).

In nickel production it is not unusual that mining, smelting and refining takes place in different locations and countries. For example, in 2014 Japan produced 8.9 % of world refined nickel output with virtually no own mine production. By contrast in 2014 the Philippines accounted for 19.4 % of world mine production while producing only a world share of less than 1 % of refined nickel (BGR, 2015). Such patterns can either emerge from different regional factors like a lack of processing facilities, technology and infrastructure or can result from economic factors (e.g. energy prices, trade policies, etc.).

There have been considerable changes in the pattern of nickel mine production over time which were addressed by several scholars. Even though nickel was first mined in the 18th century, until the end of 19th century nickel was only mined at a very limited scale. However, from then on global nickel production has increased rapidly. From 300 tons in the year 1867, world mine production of nickel has grown to around 2.25 million tons in 2016 (Schmitz, 1979; USGS, 2017) (see Figure 2).

In the period of 1870 - 1880 the usefulness of nickel in alloy steels began to be recognized and was followed by a rising interest in this metal which was even more encouraged when superiority of nickel bearing steels in armor-plating was demonstrated in 1885 (Habashi, 2009). In this context, in the 1870s, 80s and 90s world nickel production increased enormously, even though the absolute tonnage was comparatively low and the year-on-year output considerably volatile. In these early years of the nickel industry, deposits mainly located in Austria, Czechoslovakia, France, Germany, Norway, Poland, Sweden and the US were exploited (Maurice & Mizzi, 1984). However, none of these deposits proved to be of sufficient size for larger scale production which entailed that the structure of the supply side was controlled by just a few countries with large nickel deposits. In particular nickel deposits in New Caledonia and the deposits in the Sudbury area of south west Canada gained great importance in the late 19th century. These centralizing developments had

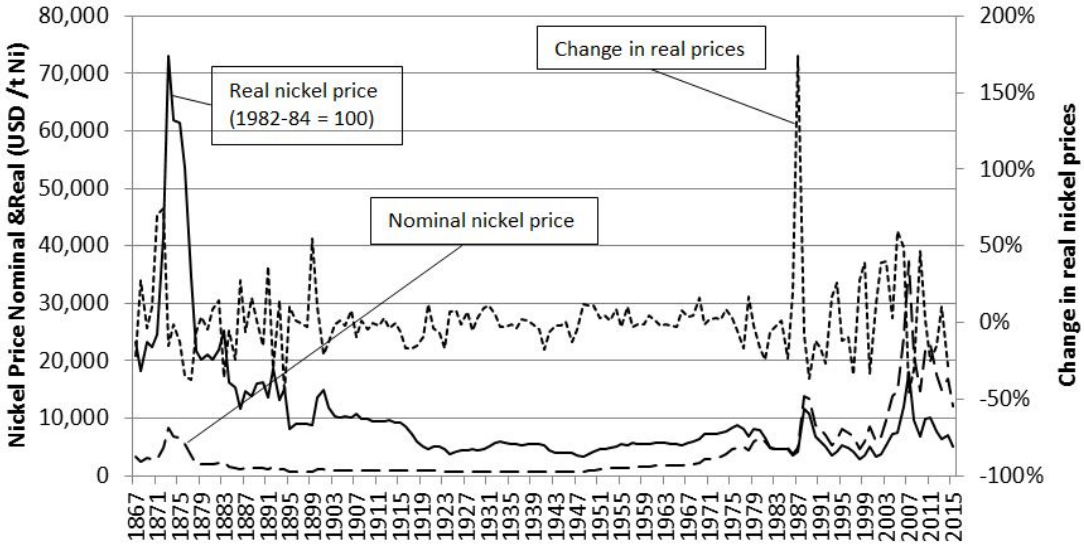
Figure 2: World nickel production



significant long-term impact on the nickel industry. Because of the missing infrastructure and a lack of skilled labor in New Caledonia, it had been predominantly Canada who benefited the most from the nickel industry growth. With its rich nickel sulphide ore deposits and improvements in the metallurgical process of sulphide ores, Canada had become the world's largest supplier of nickel within a short period of time. As a consequence, with 87 % market share in 1930, the nickel industry was heavily centred in Sudbury and effectively in the hands of the International Nickel Company of Canada (Inco) (Mizzi *et al.*, 1987).

Even though, Inco's percentage share of produced nickel significantly decreased during the following decades, the company could enjoy a market dominating position until the 1960s. However, during the middle of 20th century the geographical patterns of nickel production began to change significantly reflecting technological and economic considerations (Hilmy, 1979). Increasing exhaustion of the big sulphide nickel deposits accompanied by rising nickel demand as well as progression in metallurgy had made the exploitation of laterite deposits profitable and enabled market entries of new competitors. As a result, the extraction from laterite deposits has grown considerably from the middle of last century. Particularly, the processing of laterite ores to ferronickel, a product containing 20 % - 40 % nickel and 80 % - 60 % iron which could be used directly in steelmaking, and nickel pig-iron, a low grade ferronickel, had spurred nickel production from laterite deposits in the last decades. This shift in production continuously decreased Canada's share of world nickel

Figure 3: Historical nickel prices



Source: USGS var.-a, LME 2016, Officer and Williamson 2016, own calculation.

production and its market power. With the introduction of nickel trading at the London Metal Exchange (LME) in 1979 Inco's ability to influence supply had come to an end. Today, the nickel market is characterized by an oligopolistic structure with de facto competitive nature.

Nickel prices

Even though production as well as consumption showed a distinct upward trend through the past 150 years, real nickel prices experienced considerable fluctuations and ambiguous movements and did not show any particular trend on first sight (see Figure 3). Graphical inspection shows a strong increase following a sharp decline in real prices in the 1870s. From then on real nickel prices showed a slight downward trend while fluctuating considerably. Nonetheless, the price level throughout the turn of the century was comparatively high. The downward trend continued to the late 1920s and remained thereafter at a comparatively low level. After World War II real prices showed a slight upward trend until the end of 1970s. In the 1980s prices weakened considerably before spiking at the end of the decade. Throughout the 90s real prices of nickel exhibited a sharp decline once more and hit an all-time low in 1998. With the turn of the new millennium however, nickel prices experienced a tremendous boom and where skyrocketing in 2008 before they collapsed and remained at low levels until today.

Explaining the price behaviour and nature of (real) nickel prices has been the goal of several

researchers. In their study examining annual data of a broad basket of metals with time series analysis, Cuddington & Jerrett (2008) concluded that nickel prices follow super-cycle trends and had already completed four super-cycles since 1850. They presumed these trends to be demand driven. Cashin *et al.* (2002) suggested that the price of nickel had completed five short-run cycles from 1957 - 1999. They applied a Bry-Boschan cycle algorithm to monthly price data and find nickel price cycles to be asymmetric in behaviour and magnitude, with the duration and degree of price slumps exceeding the duration and dimension of boom phases. Hence, they found evidence to support the thesis of long term falling real prices. Despite noticing considerable volatility, Kitney & Maxwell (1996) supported this thesis. In their study based on industry knowledge they found a general downward trend in real nickel prices in the post war period and connected this to the usual inverse relationship between consumption and prices of a general downward trend in the post war period. Maxwell (1999) supported this view in a subsequent inquiry. Furthermore, Cashin *et al.* (2000) estimated that shocks to nickel prices are long-lasting (9 -18 years). Moreover, they observed strongly falling real prices of nickel during the 1920s before recovering.

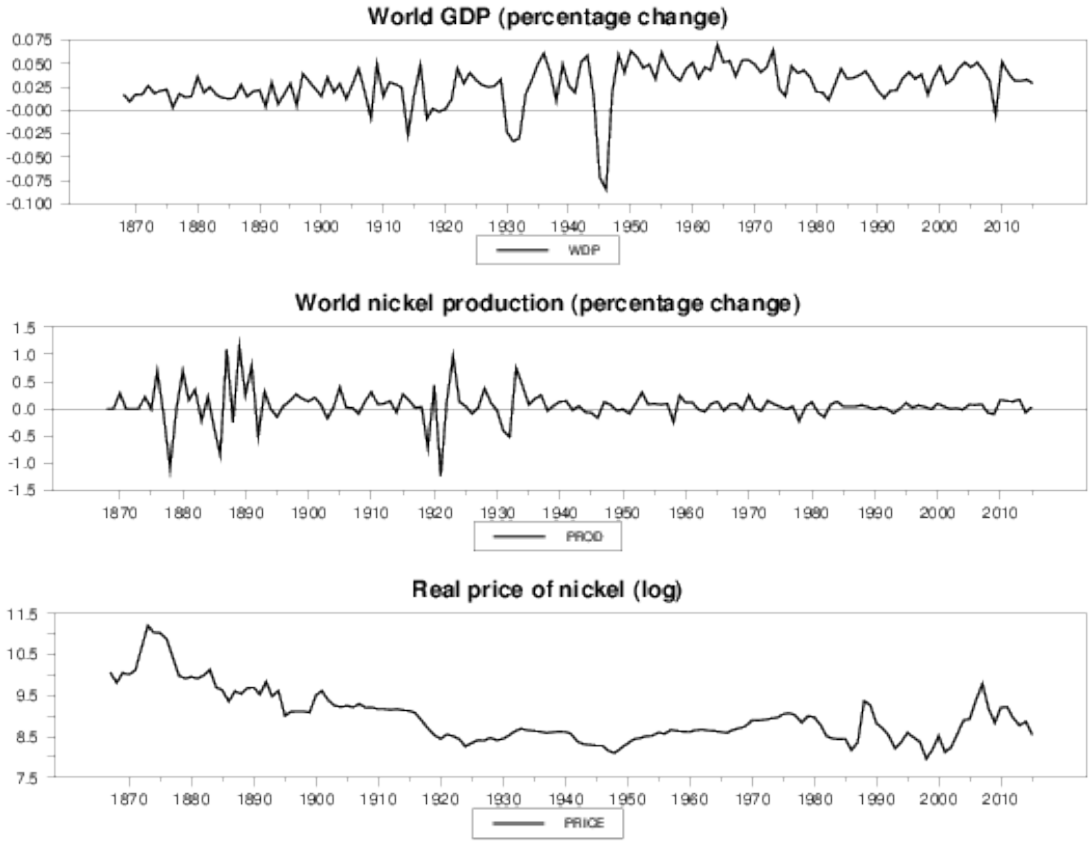
Table 1: Previous studies concerning nickel prices

Literature	Interval	Time period	Method	Main nickel related results
(Cuddington, Jerrett 2008)	Yearly	1850 - 2004	Christiano - Fitzgerald Band Pass Filtering	(1) Nickel prices follow super cycle trends. (2) Four completed super-cycles since 1850 (fifth on its way) with super cycles phases from 10 to 35 years. (3) High correlation of super cycles between six LME metals. (4) Nickel prices falling strongly through the mid-1920s before ameliorating upward in the following (5) Rather demand driven
(Heap 2005)	Yearly	1850 - 2004	Common sense argumentation	(1) There have been two (third on its way) super cycles in the past 150 years (2) Super cycles are demand driven (3) Appropriate long-term (equilibrium) price for Nickel is 3.5 US$/t
(Ahrens, Sharma 1997)	Yearly	1913 - 1990	Various statistical testing for time series properties	(1) Nickel price series appear to be generated by a trend stationary process (when allowing for a possible break in trend) without a unit root.
(Cashin et al. 2002)	Monthly	1957:01 - 1999:8	Bry-Boschan commodity price cycle-dating algorithm	1) Nickel prices completed five cycles (peak to peak) in the analysed time frame. (2) Prices follow short-run price cycles which tend to show asymmetrical behaviour in duration and magnitude. The duration of slump phases [43 month] exceeds the duration of boom phases [31.3 month]. On Average the magnitude of slump phases [-42.7%] exceeds the magnitude of boom phases [+39.3%]. (3) Supports thesis of long term falling real prices. (4) Little evidence for a relationship between the severity of price slump and booms and their duration (5) Positively skewed and significant leptokurtosis
(Maxwell 2006)	Yearly	1960 - 2005	Common sense argumentation, industry knowledge	(1) The intensity of use of nickel for the world economy between 1960 and 1995 seems consistent with theory prediction (2) Strong movement towards stainless steel as main application in the post-WWII period (3) Long-run price elasticity of nickel demand greater than one between 1960 and 1995
(Rafati 1982)	Yearly	1960 -1979	Econometric fundamental market model	(1) Price stability and market disequilibrium have been the salient features of the nickel industry. (2) The desired level of stocks are more important than the actual stocks (3) Inelastic price elasticity of demand in the short-run and unit elasticity in the long-run (4) Price elasticity of supply of nickel is close to one in the short-run and greater than one in the long run. (5)
(Cashin et al. 2000)	Monthly	1975 - 1998	Median-unbiased AR / Unit Root Estimation	(1) Shocks to nickel prices are long-lasting [9-18 years, half-life of a unit shock]
(Humphreys 2010)	Monthly	2003 - 2008	Common sense argumentation, industry knowledge	(1) Structural changes are found to be on the supply side rather than demand side like shift of nickel production from sulphide ores to oxide ores [exploitation of higher cost resource]
(Hilmy 1979)	Yearly	1950 - 1977	Industry knowledge, common sense argumentation basic statistics	(1) Close relation of nickel consumption, GDP growth and capital outlays (2) Changed geographical production patterns (3) Shift in geographical structure because of technology progress
(Kitney, Maxwell 1996)	n.a.	n.a.	Common sense argumentation, industry knowledge	(1) Despite considerable volatility, the price of nickel has experienced a general downward trend in post-war period (2) Nickel consumption for individual countries follows the predictions according to intensity-of-use hypothesis (3) Strong influence of business cycles (4) Nickel has not faced competition from substitutes
(Maxwell 1999)	n.a.	n.a.	Common sense argumentation, industry knowledge	(1) Downward trend in nickel prices in the last 50 years which has been positively correlated to its increased consumption (2) Direct relation between income growth and use of nickel (3) Government policies have often influenced nickel consumption

Interpretation of shocks to nickel prices

The lasting sources of price fluctuation are referred to as shocks. These (economic) shocks are unanticipated innovations with a significant impact, either positive or negative, on the supply or demand side of the market. In this regard, they refer to an unanticipated change in exogenous factors hitting the economic system. Through economic relationships these innovations can have an impact on endogenous variables, which thereby affect the system on their own. These unforeseen events/structural shocks are seen as the major drivers of unexpected price movements by impacting the demand or supply curve.

Figure 4: Historical evolution of world GDP, world nickel production and the real price of nickel from 1867 to 2015.



This leads to the following questions of concern to this study: What kind of structural shocks drive nickel price fluctuations and what is their frequency? What are the relative contributions of demand and supply disturbances? Which shocks have been the main drivers? Did this pattern

change over the last century? The knowledge of frequency and persistence of demand and supply shocks and a deep understanding of the structural impact on prices is an important precondition for developing stabilisation schemes to mitigate the effects of such shocks. Only after decomposing residual errors into mutually uncorrelated shocks with an economic interpretation, is it possible to identify the causal effects of these shocks on the system variables. For this purpose, this paper proposes a structural VAR model of the global nickel market to identify innovations to the nickel price with an economic interpretation. Following Kilian (2009), who analysed the oil market with a SVAR model, and Stürmer (2013), whose work analysed the copper, tin, zinc and lead market with SVAR methodology, three different shocks are distinguished via long-run restrictions, namely "world domestic product-driven demand shocks", "supply shocks" and "nickel-specific demand shocks".

4 Data and Method

Data

The data-set used in this study is freely available from public sources USGS (var.-a.); Schmitz (1979); OECD (2016); Maddison (2010); U.S. Bureau of Labor Statistics (2016). It contains time series on an annual basis for the real price of nickel, nickel world production, and data on World-GDP (WDP from now on). Since the aim of this study is to provide insights on the driving forces of the historical price movements, a data series covering a long time is mandatory. To my knowledge the longest time span without gaps covering all three variables is 1867 to 2015. While price data has been available since 1840 this is not the case with the other two variables. Unfortunately, data in a higher frequency than annual is, if at all, merely fragmentarily available. While monthly data on prices is accessible from 1929 on, to my best knowledge neither data on world nickel production nor WDP on quarterly or monthly basis do exist for a long time span. Hence, annual data is used in this study. This does not weaken the analysis, since the identification scheme is based on long run-effects. All exact sources are shown in detail in the Appendix.

For the price of nickel two different sources were employed. First, time series of the nominal price for nickel from 1840 to 2010 from the U.S. Geological Survey (USGS) were used. The values for the years 2011 to 2015 were taken from the London Metal Exchange (LME). The data series from the latter source was available for the years 1960 - 2015. The prices of the overlapping time span were nearly the same (max. dev. = 1.4 %; av. dev. = 0.24 %). Following Cuddington & Jerrett (2008) this study uses the U.S. CPI to deflate the nominal nickel price. Data on world production were taken from Schmitz (1979) and the USGS data service. The first series covers data from 1867 - 1976, the latter data ranges from 1900 - 2015 and denotes the yearly world primary production of nickel. Finally, to measure world economic activity, data from Maddison's data base was used (1867 - 2008). Since aggregated world data is only available from 1950 onwards, for the

years 1867 - 1950 the country based data is summed up. In cases where country based data is missing for some years the missing values were imputed with a linear trend. For the years 2008 to 2015 data on world GDP development is taken from the OECD data base.

This approach resembles the one of Stürmer (2013) and stands in contrast to the SVAR analysis of Kilian (2009) and Kilian & Murphy (2014) who applied a constructed index based on freight rates to create a measure for monthly global real economic activity from 1968. Since two thirds of produced nickel is used in the steel industry, a measure of world industrial production would suit best. Unfortunately indices for industrial production are only available for a few countries.

Structural VAR Models

The current investigation is based on a dynamic simultaneous model in the form of a structural VAR. Therefore, a trivariate SVAR Model is conducted to analyse the historical fluctuation of real nickel prices. Unpredictable changes in the nickel price may be deconstructed into three different orthogonal shocks with an economic interpretation. As a result, three mutually uncorrelated shocks were identified, notably "world output-driven demand shocks", "nickel supply shocks" and "nickel-specific demand shocks".

Structural VAR (SVAR) models have become an essential instrument in the toolbox of modern macroeconomic studies and "[...]continue to be the workhorse of empirical macroeconometrics and finance" Kilian (2012, p. 1). Although varying identifying assumptions lead to different classes of SVAR models, all structural vector autoregressive models aim on how to identify structural relationships in data. Moreover, they usually focus on the attempt to analyse the dynamic behaviour of economic time series by focussing on independent shocks. Shocks can be seen as the final source of stochastic deviation of the variables and are obtained by imposing identifying restrictions (Amisano & Giannini, 1997). With SVAR analysis it is possible to examine the dynamic interactions and instantaneous correlation between relevant variables of the economic system to investigate.

Structural VAR theory

Consider the 3-dimensional time series $X_t, t = 1, 2, ..., T$. It is assumed that X_t can be approximated with a VAR of order p, which leads to the following representation (1)

$$A_0 X_t = \alpha + \sum_{i=1}^{p} A_i X_{u-i} + \varepsilon_t \tag{1}$$

The matrix representation (2) for a three variable case is the following:

$$\begin{bmatrix} a_{110} & a_{120} & a_{130} \\ a_{210} & a_{220} & a_{230} \\ a_{310} & a_{320} & a_{330} \end{bmatrix} \begin{pmatrix} x_{1t} \\ x_{2t} \\ x_{3t} \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{pmatrix} + \begin{bmatrix} a_{111} & a_{121} & a_{131} \\ a_{211} & a_{221} & a_{231} \\ a_{311} & a_{321} & a_{331} \end{bmatrix} \begin{pmatrix} x_{1t-1} \\ x_{2t-1} \\ x_{3t-1} \end{pmatrix} + ...$$
$$+ \begin{bmatrix} a_{11p} & a_{12p} & a_{13p} \\ a_{21p} & a_{22p} & a_{23p} \\ a_{31p} & a_{32p} & a_{33p} \end{bmatrix} \begin{pmatrix} x_{1t-p} \\ x_{2t-p} \\ x_{3t-p} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \end{pmatrix} \tag{2}$$

The objective is to learn about the parameters and their structure analysed with respect to their relative importance of the SVAR model and in particular about the structural shocks ε. These shocks do have an explicit economic meaning. The so called "structural" part arises from the A_0 matrix, where the mutually contemporaneous effects of the variables are embedded in the parameters. Without this coefficient-matrix the model would be an "ordinary" VAR in a so called "reduced form". In the reduced form all endogenous variables are described as a function of already realised (lagged) parameters, which therefore could be considered as exogenous variables. Such reduced forms VARs have some useful characteristics in terms of estimation and econometric handling. This is why they became very popular in the middle of the last century with a broad span of literature. Nevertheless, with the work of Sims (1980) - who characterised the identification used in these kinds of VAR as "incredible" - the traditional large scale simultaneous equation models came under strong criticism. The basic idea of the critique was that these models per definition leave out potential information about structural relations between the variables. Relating to (1) this would imply A_0 to be an identity matrix. Such ad hoc assumptions for identification often made no economic sense Kilian (2012). Furthermore, simultaneous equation models were seen as problematic because they are usually employing more restriction as needed so that these models are often over-identified (Lütkepohl & Krätzig, 2004). Critics forced the evolution of structural VAR modelling where most models are just-identified, meaning that no more than necessary restrictions are imposed. Hence, since the 1980s the literature on SVAR analysis evolved extensivly and is still growing. Different identification schemes had been proposed and applied empirically in a broad spectre of economic studies. With respect to the analysed economic model there have been short-run and long-run identification schemes, identification by sign restriction or identification via changes in volatility. New insights and ideas for identification are still being generated by new research.

With that said, the nucleus of the whole SVAR methodology is finding and applying an appropriate, convenient and intelligent identification pattern; which is what literature is orbiting around. The so called "identification problem" is the following: Consider the "true" structure of the economy to be represented by the model described in (1). It is not possible to directly estimate (1) and derive the coefficients in A_0 and A_i and therefore the shocks ε_t, because there is an infinite number of

possible values with the same probability distribution of the observed data "[...]which makes it impossible to infer from the data alone what the true values [...] are" and leave the system unidentified (Gottschalk, 2001). In other words, several structural forms can have the identical reduced form. Therefore, while a model in a reduced form does not fit most economic patterns (because it leaves out potential structural interdependencies) the structural model cannot be identified without "exogenous" information.

Identification problem

Dividing the left hand side of equation (1) with the inverse of matrix A_0 leads to the reduced form of the model, given by

$$X_t = \beta + \sum_{i=1}^{p} B_i X_{t-i} + e_t \tag{3}$$

with $\beta = A_0^{-1}\alpha$, $B = A_0^{-1}A_i$, $e_t = A_0^{-1}\varepsilon_t$ and the variance-covariance-matrix of the error term $\sum_e = A_0^{-1}\sum_\varepsilon A_0^{-1'}$. The matrix representation in the trivariate case would be

$$\begin{pmatrix} x_{1t} \\ x_{2t} \\ x_{3t} \end{pmatrix} = \begin{pmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \end{pmatrix} + \begin{bmatrix} b111 & b_{121} & b_{131} \\ b_{211} & b_{221} & b_{231} \\ b_{311} & b_{321} & b_{331} \end{bmatrix} \begin{pmatrix} x_{1t-1} \\ x_{2t-1} \\ x_{3t-1} \end{pmatrix} + \ldots + \begin{bmatrix} b_{11p} & b_{12p} & b_{13p} \\ b_{21p} & b_{22p} & b_{23p} \\ b_{31p} & b_{32p} & b_{33p} \end{bmatrix} \begin{pmatrix} x_{1t-p} \\ x_{2t-p} \\ x_{3t-p} \end{pmatrix} + \begin{pmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \end{pmatrix} \tag{4}$$

In this form, the endogenous variable is a function of lagged, hence deterministic, variables only. Equation (3) can be easily estimated with ordinary least squares and therefore the reduced form parameters B_i, the reduced form shocks e_t and the corresponding covariance matrix $E(e_t e_t') \equiv \sum_e$ can be obtained.

Even though the parameters can be estimated unbiased and consistently via OLS, the disturbance term $e_t = A_0^{-1}\varepsilon_t$ cannot be interpreted economically. The target parameters ε_t cannot be directly observed, since ε_{1t}, ε_{2t} and ε_{3t} are contemporaneously correlated. The contribution of every particular shock to the fluctuations of the aggregate cannot be assessed. Comparing (1) and (3) one can see why the identification problem arises. The number of parameters differs by n^2 (9 parameters in the trivariate case). Hence, it is obvious that identification requires assumptions (restrictions) to these nine parameters to infer from the reduced form given by (3) to the structural model, which is the one of interest, given by (1). In the end the identification procedure is about to fill this "parameter-gap" with assumptions. The first widely taken assumption is that the structural shocks are mutually independent, hence orthogonal. It follows the perceptions that one structural shock (e.g. demand shock) has no direct effect on another structural shock (e.g. supply shock) or in other words, that the shocks are instantaneously uncorrelated. It is therefore assumed that the variance-covariance matrix of the structural shocks $\sum_\varepsilon$ is diagonal, which implies that all covariances are set to zero. Secondly the variance of $\sum_\varepsilon$ is normalised to a unity matrix (set to 1). Therefore, $\sum_\varepsilon = I$ and thus $\sum_e = A_0^{-1}A_0^{-1'}$. This normalisation is only about scaling and

does not change any of the internal model structure. As the focus of interest lies on the response of the model to a shock, the normalisation corresponds to a standard deviation shock in the impulse response function. The assumptions to $\sum_{\varepsilon}$ give us a total of six $[n(n+1)/2]$ restrictions in the considered example. Beyond that there are still three $[n(n-1)/2]$ restrictions left for identification. The assumptions to these remaining parameters (3 in the trivariate case) are taken from economic theory. In the case of long-run restrictions the three remaining restrictions are put on the long-run impact matrix. This matrix can be obtained from the Moving Average (MA) representation of the VAR model. In lag-operator notation (3) equals $X_t = B(L)X_t + e_t$ which can be transferred to

$$X_t = (I - B(L))^{-1} e_t \tag{5}$$

In the MA notation one can see, that the realisation of today's X_t is expressed as the function of past and present shocks e. Since $e_t = A_0^{-1}\varepsilon_t$ it follows that $X_t = (I - B(L))^{-1} A_0^{-1}\varepsilon_t$.

$$X_t = C(L)\varepsilon_t = C_0\varepsilon_t + C_1\varepsilon_{t-1} + \cdots \tag{6}$$

with $(L) = (I - B(L))^{-1} A_0^{-1}$. Therefore, restricting the long-run impact matrix $C = C_0 + C_1 + \cdots$ implies setting $[n(n-1)/2]$ elements of the matrix fix. This could be zero restriction from economic theory ("no effect in the long run") or other numbers (e.g. known elasticities). With these restrictions to the long-run impact matrix the system is identified and can be derived.

Structural VAR model for the international nickel market

In the present approach a three variable VAR as described in (1) is used. Consider the 3-dimensional time series X_t, $t = 1, 2, 3...T$. It is assumed that X_t can be approximated with a VAR of order p, which leads to the following representation

$$A_0 X_t = \alpha + \sum_{i=1}^{p} A_i X_{t-i} + \varepsilon_t \tag{7}$$

X_t is the vector of endogenous variables $(\Delta wpd_t, \Delta prod_t, \Delta rprice_t)'$, where Δwdp_t denotes the percentage change of world output, $\Delta prod_t$ stands for the change in world nickel production and $\Delta rprice_t$ is the real price of nickel. ε_t defers to the serially and mutually uncorrelated error term with zero mean, also referred to as structural innovations or structural shock. Additionally, the error term is assumed to be unconditionally homoscedastic. Matrix A_0 determines the contemporaneous (structural) effects of the endogenous variables, whereas A_i denotes the 3x3 - coefficient matrices and α is an intercept vector with three rows. Via long-run restrictions three structural shocks are identified.

Identification and Interpretation of the shocks

This paper uses long-run restrictions for the identification of the structural shocks[7]. The identification is based on three assumptions. The basic idea is the following: Since the exact behaviour/dynamics and interdependencies of the variables are unknown, knowledge on specific long-run effects are used which most economists can agree on or which are widely accepted in economic theory. With the help of this "exogenous" information, identification can be achieved. This method was first developed by Blanchard & Quah (1989) who used a bivariate SVAR to identify supply and demand disturbances in the US economy. They used the simple theoretical scheme from a regular AS/AD-model, which assumes that aggregated demand shocks (e.g. monetary shock) have no impact on the level of output in the long run, while supply disturbances (e.g. technology shock) do. This scheme rests on the idea that "[...]if certain economically plausible long-run neutrality are imposed, then reliable inferences can be drawn about the short-run dynamics of behavioural disturbances in the economy" (Faust & Leeper, 1994, p. 2). Whereas Blanchard & Quah (1989) used long-run restrictions to identify supply and demand shocks in the US economy from 1950 to 1987, this paper employs long-run restrictions to detect structural shocks to a distinct commodity market.

Given a VAR with three variables, $K(K-1)/2 = 3$ restriction are needed to identify the system. In the case of long-run restrictions this means three elements of the long-run impact matrix have to be set to zero. Obviously, these zero restrictions have to be economically plausible. In this way, this paper follows the procedure of Stürmer (2013) and Kilian (2009) for identification of shocks to commodity prices. The existence of three different shocks to commodity prices is assumed, notably "world output-driven demand shocks" (referred to as wdp-demand shocks), "nickel supply shocks" and "nickel-specific demand shocks".

The identification is based on the following assumptions on the long-run impact matrix. It is assumed that the matrix is lower triangular, meaning that the zero restrictions are put in the upper right corner of the long-run impact matrix obtained from the MA-representation.

$$\begin{pmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \end{pmatrix} = \begin{bmatrix} * & 0 & 0 \\ * & * & 0 \\ * & * & * \end{bmatrix} \begin{pmatrix} \varepsilon^{wdp-demand-shock} \\ \varepsilon^{supply-shock} \\ \varepsilon^{specific-demand-shock} \end{pmatrix} \tag{8}$$

World GDP-demand shocks In this identification scheme wdp-demand shocks are seen as unexpected innovations to the real global economic activity which leads to global demand for all commodities. This rise in demand (a rightward shift of the demand curve) therefore requires additional supply capacity. As the supply is given in the short run (fixed mine operations, etc.),

[7]Section A1 in the appendix outlines the identification problem and gives a brief background to the SVAR methodology

extra capacity needs more effort by the producers, which is regularly accompanied by higher variable cost and therefore higher prices. With the short-run supply getting more inelastic as capacity limits are converged, a sharp demand shift can trigger an intense price rise. An example could be unanticipated secular economic growth from one year to another or strong industrialization phases as well as other unexpected strong growth episodes.

In the long-run identification scheme the two first-row zeros postulate that neither nickel supply shocks nor nickel-specific shocks have any permanent effect on global GDP. By contrast, wdp-demand shocks do affect the global GDP, the production of nickel as well as the real nickel price in the long run. These assumptions seem reasonable considering that nickel is of little importance in comparison to global trade. In his study, Kilian (2009) finds that oil supply shocks only affect the level of US GDP in the first two years. Since Nickel is of much less relevance than oil, the assumption of no permanent effect of a shock on the global GDP seems legitimate. Moreover specific demand shocks to the nickel industry do not cause permanent effects on the global GDP.

Nickel supply shocks Nickel supply shocks are innovations to the production of nickel due to unanticipated changes in the production. In a standard AS/AD-model a leftward shift of the supply curve, for example, would indicate that existing capacity is temporary unavailable and therefore resulting in an upward push of the price. Examples would be natural catastrophes (e.g. mine flooding), strikes or an accident impairing an important mine or a mineral processing plant (Radetzki, 2006). An example of positive supply shock could be an unexpected technology shock improving exploration techniques or process improvements.

The long-run identification scheme therefore proposes that both wdp-demand shocks and nickel supply shocks do influence the long run production of nickel while specific demand shocks only have a transitory effect on production. The intuition behind the last zero restriction on the specific demand shock is the following. It is assumed that a surge in demand triggered by nickel-specific demand shocks (speculation, producer market power, stocking program) does not induce investments in production. In the short-run these shocks can raise prices and stretch capacities but will not trigger a long term production adjustment.

Nickel-specific demand shock Specific nickel demand shocks are those identified shocks, which are neither wdp-demand shocks nor nickel supply shocks. This shock category hence covers all residual shocks that are uncorrelated with the two first shocks above. Examples could be unexpected changes in inventories due to stocking programs, producer market power (cartels), shift in expectations of downstream processing industry of the future supply and demand schedule or simply rational or irrational expectations of increasing prices, which result in demand for speculative purposes (Radetzki, 2006; Stürmer, 2013; Kilian, 2009; Kilian & Murphy, 2014).

5 Results

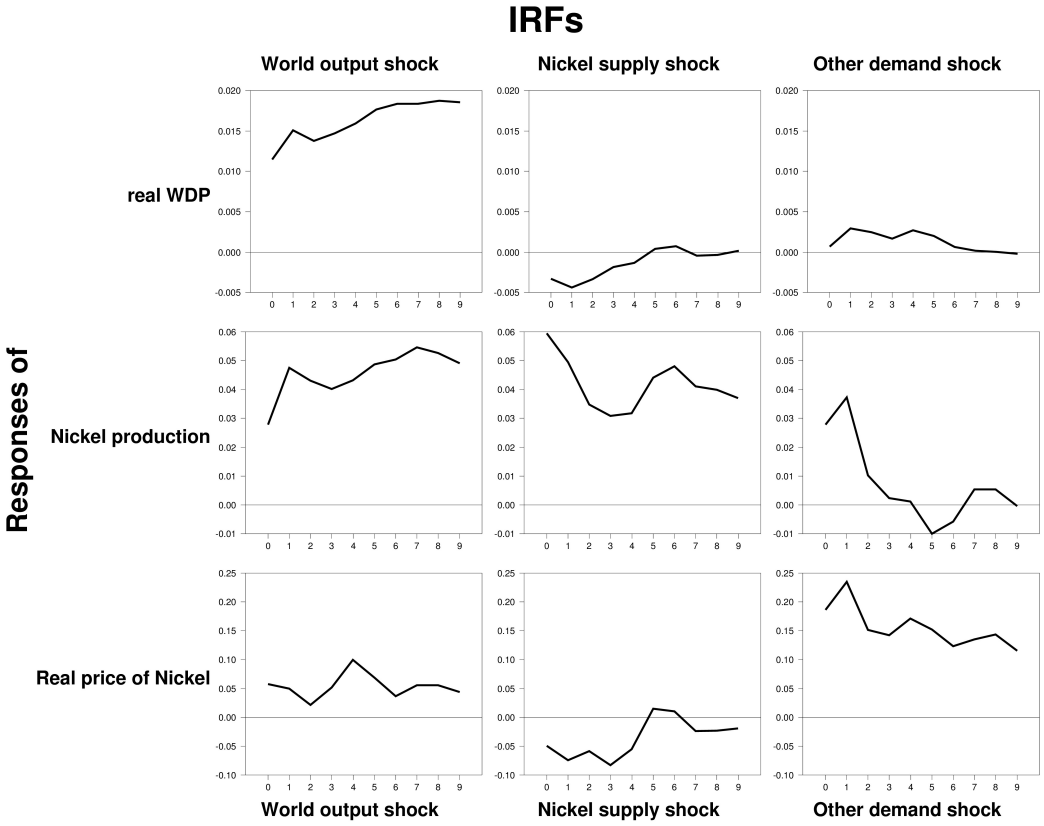
It is argued in the Introduction that the driving structural forces behind metal price fluctuations are nor or only partially identified. The main purpose of this work is to take a closer look at the nickel market, its specific conditions and to identify and describe underlying structural shocks as factors of nickel price development. In general results show that the main driving factors of nickel price fluctuation have changed over time. While in the beginning of the industry supply shocks had the most influence in nickel price development, in the mid-20th century and the emerging oligopolistic structure of the nickel industry, wdp-demand shocks had an increasing influence on nickel prices. In the late 20th century the nickel-specific demand shocks were the most influential. In the following the identified shocks are connected to evidence from history and analysed with respect to their relative importance. This is done by analysing the evolution of the shocks as given in Figure 5. The identified shocks are compared to historical events to give the shocks a concrete meaning and helps to evaluate and interpret the shocks. Furthermore, the impulse response functions (Fig. 6) are analysed to track the duration of the shocks to a respective variable. Finally the historical decomposition as given in Figure 7 are evaluated to study the cumulative effects of the identified structural shocks on the price of nickel.

Empirical results

The reduced form of the VAR in (1) was consistently estimated with ordinary least squares. On the basis of the respective estimates for the contemporaneous impact matrix and the long-term impact matrix, the Structural VAR representation of the model was obtained. Following Kilian (2009) and Stürmer (2013) a recursive-design wild bootstrap with 2000 replications was used for inference. Figure 5 illustrates the accumulated response to a one standard deviation shock at a horizon of 20 years. As can be seen, positive wdp-demand shocks have a significant and persistent effect on the real World Domestic Product. In addition, they have a strong positive and long lasting effect on the world production of nickel. Moreover, they cause increasing nickel prices with a maximum duration of 4 years after the shock. While shocks to the supply of nickel have no long-term impact on the real WDP (according to the identification assumptions), a positive shock induces a strong increase in nickel production which decreases after three years before stabilising. In addition a supply shock causes a distinct reduction of the real price of nickel for the first 4 years after the shock, before returning back to normal level. By assumption, a positive nickel-specific demand shock has no long-term effect on the WDP as well as production. Nevertheless, it induces a significant increase in nickel production for the first three years after the shock. By contrast, the real price of nickel exhibits a significant increase when a positive nickel-specific demand shock occurs.

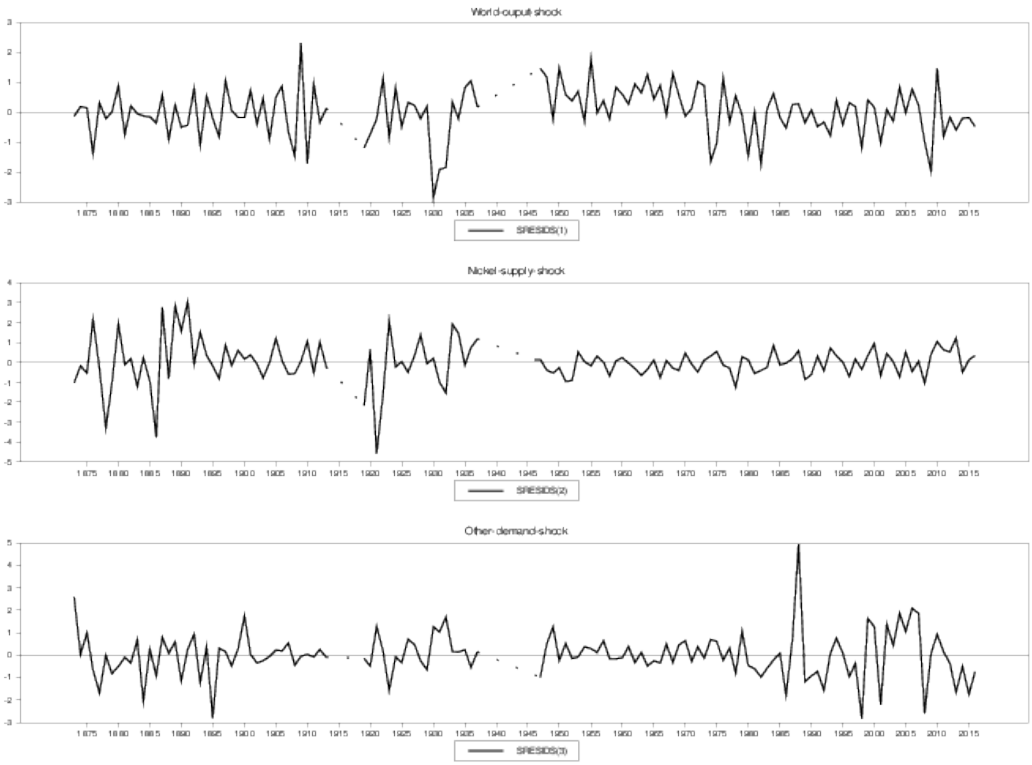
The time paths of structural shocks to the nickel price implied by the model are presented in Figure 6. Generally speaking, the identified structural shocks are mainly in line with the historical

Figure 5: Impulse responses to structural shocks for the nickel market



findings from literature. Furthermore, it is apparent that the real price of nickel reacts to a multitude of different and partly superimposed shocks. However, as also can be seen from Figure 6, some changes in the relative contribution of the shocks are likely. Therefore, it is useful to focus on specific time periods successively.

Figure 6: Historical evolution of structural shocks for nickel



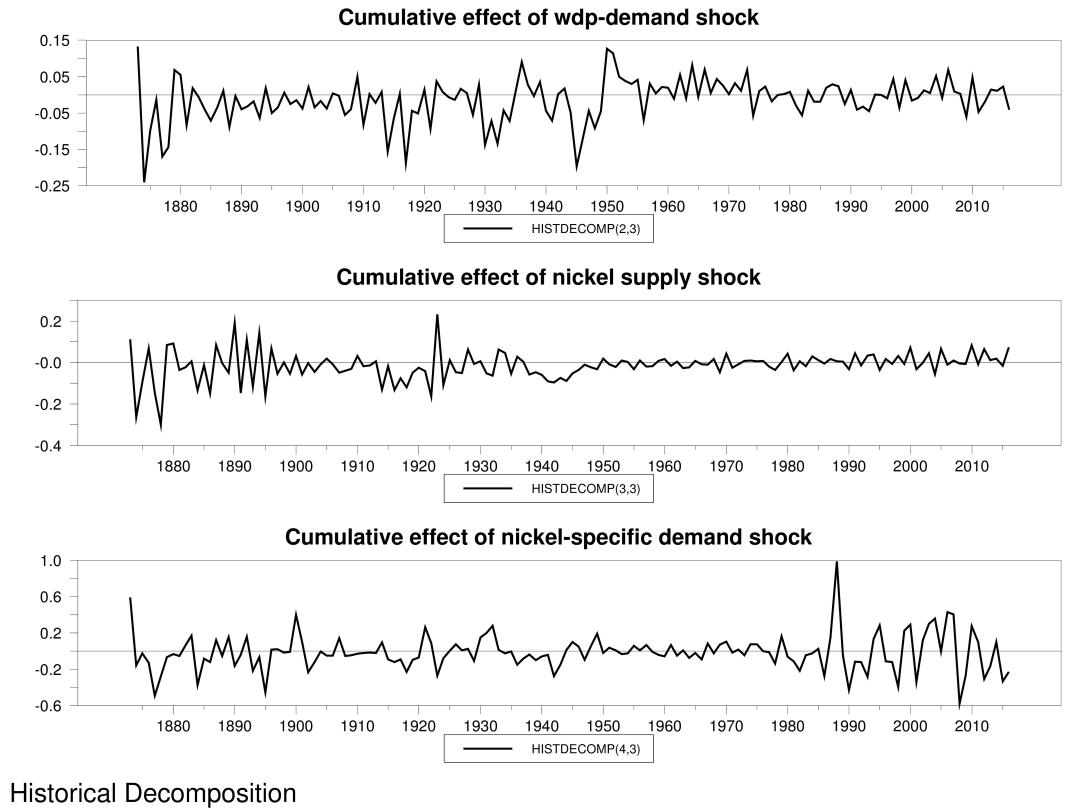
Structural shocks for the nickel market

In the early years of the nickel industry real nickel prices showed massive volatility. While the real price skyrocketed in the years 1873-74 with year on year growth rates of more than 70%, prices in the subsequent years dropped back sharply and stopped falling in 1880. These price movements were mainly driven by a positive nickel-specific demand shock at first and a huge positive nickel supply shock accompanied by a negative wdp-demand shock in the second half of the decade. In the period of 1870 - 1880 the usefulness of nickel in alloy steels began to be recognized and was followed by a rising interest in this metal; world production by that time stayed at the same level. Even though no distinct event is found in the literature, this precautionary demand could explain the strong positive nickel-specific demand shock at the start of the 1870s. However, this shock was

then overcompensated by a large positive nickel supply shock and negative wdp-demand shocks. Mining in New Caledonia began in 1875. From that time until 1905 New Caledonia was the top producer of nickel Habashi (2001). Eight years after massive nickel deposits in New Caledonia were discovered, the production began in 1875 and nickel output reached the markets Clow (1992). Because of the relative small size of the market in these days, even limited absolute changes in the world out put could have significant effects on prices. Because of New Caledonia, from 1975 to 1976 the world nickel output doubled and caused a positive nickel supply shock. This shock hit the nickel price parallel to negative wdp-demand shocks during the *Long Depression* which started in 1873 and had impacts on the world economy until 1896 due to financial crisis in England and the USA Kindleberger & Aliber (2009). The accumutated effects of wdp-demand shocks reflect this impact. The interplay of both shocks led to a sharp price drop for three consecutive years with negative double digit growth rates. The sudden stop of this fall in prices can be explained by a negative nickel supply shock that hit the market in 1878 because of a complete shut down of production plants in New Caledonia due to a rebellion of the indigenous people of the island Clow (1992). However, in the following years some minor shocks counterbalanced each other whereupon the real nickel price stayed relatively leveled for half a decade.

After real nickel prices experienced a small peak in 1983 owing to a negative nickel supply shock, prices experienced a long down turn until 1900. Surprisingly, an output stop in New Caledonia in 1886 had no huge impact on the real nickel price. As Clow (1992) notes the output stop was due to a lack of orders it can be assumed that a negative nickel-specific demand shock and the negative supply shock balanced each other out to some extent. However, thereafter prices began to fall steadily until the turn of the century. Mainly a number of positive nickel supply shocks effected the real price of nickel during this time span. These shocks can be explained by several factors that effected nickel supply in this period. First, in the late 1880s the production in the Sudbury region of Canada gained momentum. While nickel mining in Canada began in the Silver Islet mine near Lake Superior in the early 1870's, the rich nickel deposits in the Sudbury region - which is the main Canadian production site until today - were discovered and developed throughout the 1880's and came into production later that decade Clow (1992); Mizzi *et al.* (1987). Additionally, this ramp-up phase in Canadian nickel production was accompanied by technological progress in nickel processing. A prime example of this being the *Orford Process* which made nickel from copper-nickel mines exploitable and boosted recovery rates in the processing as well as the development of the *Mond Process* which made the refining process significantly more productive Clow (1992); Habashi (2009). Consequently, in the last decade of the 19th century the world nickel output nearly quadrupled while real prices halved in that period. This price development was further supported by a pronounced negative nickel-specific demand shock in 1895 and a couple of negative wdp-demand shocks in the 1890s. These shocks can be explained with the aftermath of the *Long Depression* in

Figure 7: Historical decomposition of the real nickel price



the United States as well as the impact of the *Panic of 1893*.[8] Notwithstanding this, it has to be noted that in the 19th century wdp-demand shocks appear to have had a milder influence on nickel prices than in the 20th century. Part of the explanation is that stainless steel had not yet become the major factor in nickel consumption. Hence, the relative lower importance of wdp-demand shocks is not particularly surprising. However, with the beginning of broad usage in steel production in the early 20th century, the sensitivity of nickel to the world economy increased significantly.

With the beginning of the new century prices began to rise with a prominent peak in 1901. This was caused by a pronounced positive nickel-specific demand shock around the turn of the century, while there was neither remarkable nickel supply nor wdp-demand shocks. The shock took place in the immediate run-up to a big merger of the Canadian Copper Company and Orford Copper

[8]The Panic of 1893 can be linked to the *Baring Crisis* in Argentina in 1890. In 1893 the ability of the United Stated to hold the gold standard came into question and resulted in a massive confidence and banking crisis. Kindleberger & Aliber (2009)

Company to International Nickel Company. It can be assumed that the impeding signs of that merger with its likely growth in market power triggered demand for speculative purposes. However, this shock had no long lasting impact on the price which went back to the level before the shock within one year. From the middle of the first decade in the 20th century until the begin of World War I the real nickel price experienced further significant reduction. In particular, positive nickel supply shocks and negative wdp-demand shocks put downward pressure on real nickel prices. In the year 1905 and 1906 as well as around the year 1911 the nickel market experienced pronounced nickel supply shock. These shocks are both associated with the ramping-up production in Canada which was from 1905 on the world's largest producer of nickel and in the years before the outbreak of WWI the Canadian nickel industry experiences a veritable output boom Clow (1992). From 1908 to 1912 the world nickel output nearly doubled and sustained the downward trend in prices. Secondly, in the first fifteen years of the 20th century the world economy experienced some major fluctuation. Mainly due to financial recession in the United States negative wdp-demand shocks evolved. Furthermore, it was the time when stainless steel variants were developed and the necessary input of nickel for these kinds of steel became clear. In 1905 Léon Guillet discovered the first austenitic Chromium-Nickel and in the year 1910 the later famous steel type V2A amongst other nickel bearing stainless steels were discovered in the Krupp laboratories Cobb (2010). Already in the Russo-Japanese war from 1904-05 the importance of nickel in armour plating was demonstrated and played a significant role in the navy fleet build up prior to WWI. In war times there have been governmental stockpiling programs or even limited governmental takeovers of nickel suppliers. Nevertheless, particularly during world wars, the market mechanism in the nickel industry was suspended. Consequently, the economical interpretation of price and market movements during these times serves little purpose.

However, in the interwar period real nickel prices stayed relatively stable. During this time prices experienced a small low in 1924 and to small peaks in 1921 and 1932. Nevertheless, these high and low points seem to have had a subordinated rather than outstanding character and reflect the interplay of a variance of different shocks. The first peak can mainly be attributed to a negative nickel supply shock due to a six month closure of the Inco mines and smelters in the Sudbury region. This caused the world mine output to sink by 70 % from 1920 to 1921 and to stay at that level in 1922. However, even though this negative supply shock to world production was accompanied by a positive wdp-demand shock and nickel-specific demand shock, it only had moderate price influence. This seems odd, since the combination of all three shocks should have led to a pronounced spike in prices. However, after world disarmament agreements in 1921 and therefore expectations of a plummeting military market, Inco - the world largest producer at that time - was caught with huge nickel stocks and fearful of loosing one of its main markets. To cope with the arising situation of oversupply, Inco decided to shut down production and sell from its stockpile for a distinct period. This behavior can explain the mild response of the real nickel price to the supply shock, since supply shocks represent shocks to world production and not to change in stockpiles. Nevertheless,

until 1924 prices fell owing to a negative nickel-specific demand shock and a positive nickel supply shock. However, afterwards prices grew until 1933. Surprisingly, the great recession after the *Wall Street Crash of 1929* had only a mild influence on the real nickel price development. The pronounced negative wdp-demand shock that followed the Black Thursday occurred simultaneously to a positive nickel-specific demand shock, which apparently offset the impact of the wdp-demand shock. This positive nickel-specific demand shock reflects the producers' market power which was notably strong in that time period. By signing a long-term contract with Germany's I.G. Farben, Inco had formed a temporarily cartel and had supplied Germany with nickel for their war plans. This massive intervention in the market dynamics and use of market power can on the one hand explain the moderate impact of wdp-demand shocks as well as the steady rising price up to beginning of World War II.

In the post-WWII era until the end of the 1970s, nickel prices experienced a constant upswing. With the occurrence of some small peaks in 1955, 1957, 1962, 1970 and a large peak in 1976 the real price of nickel grew steadily over this long period. In the 1950s the real nickel price grew by a rate of 36 % overall.This growth in real prices can mainly be connected to multiple positive wdp-demand shocks. Especially the German and the Japanese economic miracles in the post-war period resulted in severe positive wdp-demand shocks which mainly drove the price development of nickel upwards. The strength of this development was additionally supported by the growing inherent nickel intensity. A rise in the proportion of nickel to a unit of GDP which is common for industrialisation phases and in the post-war reconstruction of both countries boosted the demand for nickel further. Additional positive influence on prices can be connected with U.S. government action in this time period. For a distinct period of time in the early 1950s the U.S. regime took control over national nickel allocation and implemented a stock piling program Kuck (1998). As consequence, a significant shortage of nickel for non-military purposes occurred and induced a strong positive nickel-specific demand shock. On the supply side, the 1950s were described as a "decade of expansion" Clow (1992, p. 11) and nickel mine production grew with a annual rate of 5.4 percent in that decade Hilmy (1979) which are reflected in some minor supply shocks in the 1950s. Moreover, the drastic growth of supply appears to have been anticipated by market participants and accordingly were no "shocks", since these movements only occurred with little amplitude.

In the 1960s however, nickel prices experienced a milder, but still significant, price growth of 15 % overall with one small peak in 1962. This development is mainly connected to a multitude of positive wdp-demand in this decade. The expansion of the world economy in this *golden age of capitalism* was sustained and rapid. The real output in the Western Europe and Japan increased by more than 5 % and investment rates in the OECD countries were about 18 % in the early 1960s resulting in pronounced positive wdp-demand shocks. Notwithstanding the magnitude of these shocks, nickel prices only grew moderately. On account of technical advances, the supply side could cope with the rising demand to a certain extend and rising nickel prices fostered some major

developments on the supply side of the nickel market Clow (1992) which had profound impact on the future shape of the industry. The development of the *AOD process*[9] allowed the use of lower quality nickel forms - ferro-nickel, which is mainly produced from nickel laterites - to be used in stainless steel production and thereby lowered the importance of sulphides, which were still the dominant nickel source at this time accounting for about two thirds of mine output. This development abated the position of the world's main supplier at that point, the Canadian mining company Inco, and began to weaken the oligopolistic structure of the nickel industry. Nevertheless, short strikes at Inco and Canadian labour strikes in the 1960s occurred and are mainly reflected in the supply shocks over this period. Nickel-specific demand shocks had only little impact on nickel price determination in this decade.

During the 1970s, the pattern of relatively stable price development - as observed in the two decades before - began to change. Even though prices increased by 10 % over the decade, the volatility increased. The price reached peaks in 1970, 1976 and 1979 as a result of an interplay of several shocks. With the oil price crisis and the 1973-75 recession, the world economy experienced some major shocks in this decade. However, even though the positive wdp-demand shocks in the decade before had serious impact, it appears that this is not the case for negative shocks during this decade. In contrast, during the years of recession the annual nickel price grew, however, the reason for this phenomenon is difficult to determine. It should be noted, that this was also the case in the work of Stürmer (2013), who conducted studies with the same methodology for other mineral commodities. Nevertheless, the main suppliers carried out warehousing measures and used their market power to cope with lesser demand and protected prices. These actions are reflected in the consistently positive nickel-specific demand shocks in this period and apparently weighed more than the drastic negative demand shocks. However, by the end of the decade real nickel price experienced two pronounced peaks. One can be connected to a severe negative nickel supply shock when a nine month strike in the Canadian Sudbury region took place with the result of 40 % reduction in Canadian nickel mine output. The second peak can be explained with a distinct positive nickel-specific demand shock in 1979. In that year nickel was first traded at the London Metal Exchange (LME). It can be assumed that this shock represents the expectation of rising prices for speculative purposes. The introduction of nickel trading at the LME had a great importance for the following decades. In the 1980 real nickel prices experienced positive and negative extremes. From the beginning of the decade to 1986 the real price fell about 55 %, whereas it skyrocketed unprecedentedly in the following three years by about 200 %. The main explanation for both movements was extreme wdp-demand shocks as well as nickel-specific demand shocks. The *early 1980s recession* was the main cause for the prolonged price slump and is reflected in significant negative wdp-demand shocks. All western economies and OECD countries experienced major economic problems with low income growth and high unemployment rates. These shocks

[9] Argon-Oxygen-Decarburization:

induced the dramatic downswing in nickel prices. By contrast to the 1970, this time the negative wdp-demand shocks had a severe impact. The established LME trading had made producer prices irrelevant and thereby broke the market power of the main nickel suppliers. Hence, their ability to take countermeasures by market manipulation no longer existed resulting in a logical market reaction of decreasing prices. Accompanied by strong negative nickel-specific demand shocks, which can be interpreted as speculative over estimation of the price trend, prices reached an all-time low in 1986. From this low point the nickel market suddenly changed direction. Within two years real nickel prices tripled. This was mainly caused by an outstanding positive nickel-specific demand shock. With a stabilising world economy and an unforeseen demand surge for stainless steel, in addition nickel suppliers had been reducing their production because of low prices in the early 1980s. This critical market situation was then over-enhanced by speculation. This shock was accompanied by a negative nickel supply shock in the year 1987. The Dominican Republic abruptly levied export duties on ferro-nickel Kuck (1998). In the following period, the expectation of a tight demand and supply schedule and corresponding expectations of increasing prices for speculative purposes triggered a stand-alone nickel-specific demand shock that drove the price for three years.

However, in the 1990s nickel prices quickly fell back to pre-boom levels and experienced further low points in the course of the decade. From 1989 to 1993 real nickel prices fell by 66 % on total. After a short recovery, the real nickel price fell to its all-time low in 1998. Both low points can primarily be connected to negative nickel-specific demand shocks with an interplay of negative wdp-demand shocks. The huge positive nickel-specific demand shock in 1987 was followed by prominent and long-lasting negative shocks. The irrational exaggerated rise in prices was then superseded by an excessive fall due to abrupt adjusted expectations of the future price direction. The dissolution of the Soviet Union had two significant consequences for the nickel market. Firstly, the world economy was shaken by uncertainty which is reflected by negative wdp-demand shocks in the beginning of the decade and drove down prices. Secondly, with the U.S.S.R. break-up a significant rise in Russian nickel exports followed Kuck (1998) and induced postive nickel supply shocks in the 1990. However, after a short price recovery mainly due to an interplay of positive wdp- and nickel-specific demand shocks, in 1998 the real nickel price hit a historical low. On the back of the Asian crisis in 1997/98 which created significant negative wdp-demand shocks, this tendency toward speculative overreactions once again lead to a sharp negative nickel-specific demand shock. Even though, wdp-demand shocks and shocks to the supply side had a significant impact, it appears as if nickel-specific demand shocks - once triggered by wdp-demand shocks - induced major overreactions and hence were the dominating factor in nickel price determination.

The period from the beginning of the 21st century up to today was one with the most significant market movements of all times. From 2001 to 2007 the real price of nickel more than quadrupled. This was the most unprecedented price boom in the history of nickel in terms of duration an magnitude. This boom can once more be connected to massive positive nickel-specific demand

shocks triggered by positive wdp-demand shocks. From 2003 to 2007 the world GDP grew with an annualized rate of 4.9 %, which was unexpectedly strong. Especially the economic rise and industrialisation in China accompanied with a rising nickel intensity had an immense impact. This unforeseen growth is captured by positive and large wdp-driven demand shocks which drove the real nickel price upwards. However, the following overreaction most likely of speculative nature therewith sent the price into overdrive. For example, from 2005 to 2006 the world GDP grew by 5.4 % whereas the real nickel price rose by 59 %. This exaggeration can be linked to positive nickel-specific demand shocks. These shocks hit the nickel market five years in a row and caused the annualized real nickel price to reach a historical peak in 2007. With the beginning of the financial crisis in 2007, nickel prices began to fall and plummeted in 2009. This event is evident in a pronounced negative wdp-demand shock that drove down prices. This shock was accompanied by a sharp negative nickel-specific demand shock. However, economic policy measures as a reaction to the global economic crisis created a sudden rebound of the global economy in 2010 and 2011 and helped to stop the downward trend in nickel prices. This measure is reflected in the positive wdp-demand shock at that time. Nevertheless, this movement did not prevail and prices fell afterward until reaching a near all-time low in 2016. This development can mainly be connected to two shocks. First, the largest post-war positive nickel supply shock and a subsequent negative nickel-specific demand shock. The previous years of surging prices generated huge investments in production facilities and new nickel projects. The effect of these measures was underestimated by the market and resulted in a positive nickel supply shock which drove down prices. With a small lag, the impact of this shock was enhanced by a negative nickel-specific demand shock.

6 Conclusion

Prior work has generated distinct knowledge on price fluctuations of mineral commodities and gathered substantial insights in metal price behaviour. However, these studies have either gained their findings by analysing an aggregated group of mineral commodities or did not specify the driving structural forces behind the price fluctuations. In this study the underlying structural dynamics triggering the price movements of the nickel market were analysed using a decomposition of shocks gained from a structural VAR model with long run restrictions for the time period of 1867 to 2015. Three different shocks and their realtive contribution to nickel price developement were identified, namely “world domestic product” - driven demand shocks, “nickel supply” - shocks and “nickel-specific” - demand shocks. These findings extend those of prior research by connecting the identified structural shocks to the nickel market with specific historical events. In addition, it was found that the relative influence of respective shocks has considerably changed over time. While in the late 19th century nickel-specific demand shocks as well as nickel supply shocks mostly effected prices, over the course of the 20th century the weight of positive wdp-demand shocks grew. From

1980, nickel-specific demand shocks had the most influence on nickel price development. These results offer a novel understanding of the driving forces to metal prices by focussing on one specific metal and its idiosynctratic dynamics. Moreover, the findings suggest that the pattern of over-exaggeration of impulses by specific-nickel demand shocks, as observed in the last decades, will likely maintain. Market participants and policy makers should therefore include this perception in their market anticipations.

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A Regression results

Table 2: Estimated coefficients

Dependent variable: WDP (percentage change)	Annual data: 1873 to 2016	Usable observations: 144	Degrees of freedom 125
Variable	Coefficient	T-statisic	Significance
WDP {1}	0.4744	5.261	0.000
WDP {2}	-0.1300	-1.299	0.196
WDP {3}	0.0150	0.148	0.882
WDP {4}	-0.0030	-0.030	0.975
WDP {5}	-0.0334	-0.371	0.710
PROD {1}	0.0003	0.058	0.953
PROD {2}	-0.0015	-0.250	0.802
PROD {3}	-0.0018	-0.307	0.759
PROD {4}	-0.0053	-0.877	0.381
PROD {5}	0.0036	0.584	0.560
PRICE {1}	0.0074	0.903	0.367
PRICE {2}	-0.0109	-1.306	0.193
PRICE {3}	0.0072	0.847	0.398
PRICE {4}	-0.0030	-0.367	0.713
PRICE {5}	0.0028	0.350	0.726
Constant	0.01277	2.906	0.004
Trend	0.0001	2.120	0.035
WWI	-0.0129	-1.427	0.155
WWII	-0.0171	-2.462	0.015

Table 3: Estimated Coefficients

Dependent variable:	Annual data:	Usable observations:	Degrees of freedom:
PRICE (percentage change)	1873 to 2016	144	125
Variable	Coefficient	T-statisic	Significance
WDP {1}	-0.275	-0.304	0.760
WDP {2}	1.529	1.524	0.129
WDP {3}	-0.423	-0.415	0.678
WDP {4}	0.648	0.642	0.521
WDP {5}	-0.543	-0.602	0.547
PROD {1}	0.017	0.285	0.776
PROD {2}	-0.069	-1.128	0.261
PROD {3}	0.097	1.592	0.113
PROD {4}	-0.114	-1.857	0.065
PROD {5}	0.117	1.882	0.062
PRICE {1}	0.174	2.095	0.038
PRICE {2}	-0.251	-2.995	0.003
PRICE {3}	-0.035	-0.418	0.676
PRICE {4}	0.077	0.940	0.348
PRICE {5}	-0.317	-3.827	0.000
Constant	-0.064	-1.465	0.145
Trend	0.000	0.592	0.554
WWI	-0.061	0.679	0.498
WWII	-0.049	-0.709	0.479

Table 4: Estimated Coefficients

Dependent variable:	Annual data:	Usable observations:	Degrees of freedom:
PROD (percentage change)	1873 to 2016	144	125
Variable	Coefficient	T-statisic	Significance
WDP {1}	1.432	1.096	0.274
WDP {2}	1.459	1.005	0.316
WDP {3}	-2.779	-1.888	0.061
WDP {4}	2.752	1.884	0.061
WDP {5}	-0.617	-0.474	0.636
PROD {1}	-0.235	-2.645	0.009
PROD {2}	-0.179	2.005	0.047
PROD {3}	-0.198	-2.244	0.026
PROD {4}	-0.188	-2.115	0.036
PROD {5}	-0.103	-1.141	0.255
PRICE {1}	0.146	1.214	0.226
PRICE {2}	0.181	1.498	0.136
PRICE {3}	-0.084	-0.685	0.494
PRICE {4}	0.194	1.636	0.104
PRICE {5}	-0.253	-2.115	0.036
Constant	0.162	2.549	0.012
Trend	-0.001	-1.996	0.048
WWI	0.078	0.595	0.552
WWII	-0.000	-0.009	0.992

Table 5: Estimated contemporaneous impact matrix

	WDP	PROD	PRICE
WDP	0.011	-0.003	0.001
PROD	0.027	0.059	0.027
PRICE	0.057	-0.049	0.186

Table 6: Estimated long-run impact matrix

	WDP	PROD	PRICE
WDP	0.0001		
PROD	0.0001	0.0051	
PRICE	0.0009	0.0038	0.0404

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