Determinants of the Price of High-Tech Metals: An Event Study

Markus Wanner,[1,2] Tobias Gaugler,[1] Benedikt Gleich,[1] and Andreas Rathgeber[1]

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The growing demand for high-tech products has resulted in strong growth in demand for certain minor metals. In combination with production concentrated in China, this caused strong and unpredicted price movements in recent years. As a result, manufacturing companies have to cope with additional risks. However, the detailed reasons for the price development are only partially understood. Therefore, we analyzed empirically which determinants can be assigned to price movements and performed an event study on the high-tech metals neodymium, indium, and gallium. Based on our dataset of news items, we were able to find coinciding events to almost 90% of all price jumps (recall). We showed that if any information about these events occurred with a probability of over 50% there would also be a price jump within 10 days (precision). However, the classical set of price determinants has to be extended for these specific markets, as we found unorthodox factors like holidays or weather that may be indicators for price movements. Therefore, we hope that our study supports industry for instance in performing more informed short-term planning of metals purchasing based on information about specific events.

KEY WORDS: Determinants, Event study, High-tech metals, News, Prices.

INTRODUCTION

Production, sales, and revenues of modern high-tech goods have increased strongly in recent years, as, for instance, cell phones, notebooks, and photovoltaics have become essential for growing parts of the world's population. This development is not going to end soon, considering recent social and technological developments, like the enormous growth of the Chinese economy and the worldwide debate on the development of renewable energy (Moss et al. 2011). All these technologies have one common feature: they depend on a number of very scarce non-renewable resources, especially minor high-tech metals like neodymium (Nd), gallium (Ga), or indium (In) (Angerer et al. 2009; Reller et al. 2009). With growing demand for these technologies, the demand for these metals in the long run will likely increase further and influence the prices. The impact of this already growing demand can be seen by analyzing historical price trends of minor metals, in which for instance we often see high volatility (Chen 2010). For producing companies and whole economies, this development leads to high uncertainty for the future financial and strategic planning, as drops in profit or even production are possible consequences (EC 2010; Moss et al. 2011). Thus, in this paper, we aim to analyze whether there is an indication for fundamental determinants driving the prices of minor metals. As, in general, the topic of determinants of prices of non-renewable and scarce resources is not new, and substantial research exists in this area (e.g., Hotelling 1931; Radetzki 2008; Krautkraemer 1998).

[1]Institute for Materials Resource Management, University of Augsburg, Augsburg, Germany.
[2]To whom correspondence should be addressed; e-mail: markus.wanner@mrm.uni-augsburg.de

To date and to our best knowledge, there is no empirical analysis of actual determinants for the price of minor metals like Nd, In, or Ga, which might be of special interest due to their specific market conditions. For instance, their trading volumes are quite small, they are traded over the counter and not within a metal exchange, and there are no future markets, and thus less financial speculation or hedging activities. Moreover, these high-tech metals are concentrated regionally and temporally as, for instance, 97% of Nd was mined in China in 2011. Thus, to identify especially short-term determinants of the resource price, we assume this market to be suitable as one from which to extract more information than from other markets.

All in all, price development of minor metals is of strategic relevance for economies and manufacturing industry, but its actual determinants have not yet been empirically examined. In this paper, we want to find out which measurable determinants can have an impact on the price of Nd, In, and Ga. The results might also be of special interest for short-term planning and purchasing of manufacturing industry and other minor-metal-dependent market participants. As we want to analyze determinants in the form of events, we used the methodological framework of an event study. In the "Theoretical Analysis", we begin with an analysis of possible determinants of the resource price. In the "Hypotheses", we define our research hypotheses for the empirical analysis. The methodology we used is explained in detail in the "Methodology". Based upon that, we describe the findings in the "Findings" and discuss the results considering our research hypotheses in the "Discussion". Finally, we give conclusions and outlook for further research in the "Conclusion and Outlook".

THEORETICAL ANALYSIS

To find out what determinants can influence the price of minor metals, we analyze general and resource-specific literature along the price-discovery process of non-renewable resources, focusing on metal markets. According to the fundamental economic literature, every price of a commodity paid and received in a perfect market is determined by the intersection between the supply curve and the demand curve and every possible change of this equilibrium price is determined by information, leading to a shift of location or shape either in the demand curve, in the supply curve, or in both curves (e.g., Stiglitz 1993; Fama 1970).

The first subject of our literature analysis is the *supply curve*, and, therefore, we use the fundamental economic work of Stiglitz (1993) and Pindyck and Rubinfeld (1989), supplemented with different non-renewable-resource-specific papers to find out what factors can determine this curve. Hence, we first analyze the "manufacturing process" of a non-renewable resource.

Focusing on mining activities, we first have to consider the area of *exploration*. A higher level of exploration activity leads to new mines and more supply 5–10 years later on, but causes higher exploration costs in the present (Hartman and Mutmansky 2002). Optimal levels of exploration activity have been analyzed as well as technological progress and the quality of information (e.g., Pindyck 1978; Radetzki 2008; Cairns 1990).

If exploration activity is successful, mines are built up and resources are extracted. Thus, the next area influencing the supply curve is the area of *extraction* (or "exploitation"). The initial stock of a resource and the extraction quantity are important determinants for supply, which have been analyzed and regarded in fundamental research (e.g., Hotelling 1931; Krautkraemer 1998). According to Hotelling (1931), Solow and Wan (1976), and others, the optimal extraction quantity depends on extraction costs and extraction technology, which shifts over time. Finally, the existence of by- and co-products within the extraction of a resource may also influence its supplied quantity and hence prices (e.g., Slade 1982). This is of special interest for our research, as all three metals occur with co-products. Furthermore, we have to consider ore quality and the so-called cut-off grade, below which it is not economical to mine (e.g., Hartman and Mutmansky 2002; Krautkraemer 1989). The last factor in the area of extraction we can find in the common literature is environmental effects that influence the extracted and hence supplied output of a resource (Stiglitz 1993). Finally, one other means of resource production is *recycling*, as the recycled material can increase the supplied quantity (e.g., Cuddington 2008). This point is also of special interest, as in the moment, there are different recycling programs growing up for electronic waste, which contains those high-tech metals (e.g., Jing 2004).

As for the analysis of the supply curve, we can also analyze the demand curve and its determinants. Stiglitz (1993) identified different areas that determine the demand curve. Demand depends on the *population* asking for goods that contain non-renewable resources. Thus, other determinants are population growth and population composition and taste (demographic effect), both now and in future (e.g., Meadows et al. 1972). Regarding especially the case of minor metals, we can also classify global technological progress (e.g., Kaplinskiy 2006).

Next, the demand for a good is determined by the *income* of a household, which depends on the actual economic situation, in case of a manufacturing industry. Two more determinants named by different authors are the *prices of substitutes* and *complements* of the resource (Hartwick 1978; Hoel 1983). Here, we have to mention that these are presumably less important for metals, as in most cases substitutes are uneconomic for the manufacturing industry (European Commission 2010).

However, not every determinant influences either the demand or supply curve. Several determinants can influence both curves, separately and mutually, or influence the price directly. First, we examine the *financial area*, where interest and exchange rates can influence the price-discovery process (e.g., Stiglitz 1993; Bhagwati and Johnson 1961). As not all extracted resources are pushed onto the market or are sold by the manufacturing industry immediately, another area to consider is *storage* (e.g., Fama and French 1987). The supply and demand sides may store resources if they expect higher prices in the future. Moreover, we have to consider costs of capital, as stored commodities can be seen as fixed capital (e.g., Telser 1958). Regarding exchange traded metals, *speculative activity* by financial investors in the derivatives markets may also influence resource prices (e.g., Gilbert 2010). For minor metals this point can be neglected, as there are no derivatives markets at the moment.

Another area that can influence supply and demand is *economic structure*. Demand and supply curves have different locations and shapes in monopoly, oligopoly, or perfect competition (e.g., Stiglitz 1976; Stiglitz and Dasgupta 1981). Particularly for minor metals like the rare earth elements, as about 97% of which have been mined in China in 2011, we can assume at least an oligopolistic market situation, concentrated in China (Reller et al. 2009; European Commission 2010). This situation relaxed, however, during the last years, e.g., due to the reopening of mines in the US.

One important area partly resulting from economic structure is *governmental intervention* (e.g., Bhagwati and Feenstra 1982). As we can see, for instance, in China, the governmental control over extraction and production and export quotas and drastically increasing taxes are useful tools that sharpen supply and thus increase prices (Bloomberg News 2010). The taxation of non-renewable resources has been analyzed by a number of authors. For instance, Krautkraemer (1990), Slade (1986), Karp and Newbery (1991) have shown that taxation in general shifts depletion and thus supply to the future. Finally, we have to regard basic economic influencing factors like *elasticity of demand and supply*, which determines the magnitude by which the curve may shift (e.g., Stiglitz 1993).

Table 1, presents an overview of the identified areas, determinants, and respective prior research.

HYPOTHESES

With the theoretical derivation of possible determinants in the "Theoretical Analysis", we can now frame the research hypotheses for the empirical analysis. As we described, in the rather small and straight markets of minor metals, we assume fundamental determinants to drive the prices. Hence, we expect that a relevant event that influences one or more of these determinants coincides with a resource price movement. We define an event as relevant if the related news item lists this event as a rationale for a price chance. This is fulfilled if the news item contains an economically founded notification that, for instance, delivers information about changes in supply, demand, or the price itself. Thus, we can define our hypotheses.

Firstly, we want to test, if the determinants from the literature can be assigned to price movements within markets for minor metals. Hence, with the first hypothesis, we want to find out whether there is an indication that certain events may influence the prices of Nd, In, and Ga. This assumption is based on the specific market situation described in the "Introduction". As explained above, we define an "event" as "information about an event within the news items."

Table 1. Overview of the Identified Determinants Within the Theoretical Analysis and Respective Prior Research

Supply/Demand	Area	Determinants	Prior Research
Supply	Exploration	Exploration activity Information Costs Technology Exploration success Information Technology	Hartman and Mutmansky (2002), Pindyck (1978), Deshmukh and Pliska (1980), Devarajan and Fisher (1982), Swierzbinski and Mendelsohn (1989), Neal (2007), Radetzki (2008), Cairns (1990)
	Extraction	Extraction quantity Initial stock New stocks by exploration Technology Costs Mine life cycle/cut-off grade Environmental effects Co-products Ore quality Mining area Mine life cycle	Hotelling (1931), Gray (1914), Dasgupta and Heal (1974), Solow and Wan (1976), Schulze (1974), Hanson (1980), Hartman and Mutmansky (2002), Krautkraemer (1988, 1989, 1998), Stiglitz (1993), Slade 1982, Heal (1976)
	Recycling	Recycling quantity Technology Costs	Cuddington (2008) Tilton (1999), Ayres (1997), Jing (2004), The European Parliament and the Council of the European Union (2003)
Demand	People and population	Population Composition Taste	Stiglitz (1993), Meadows et al. (1972)
	Wealth	Technological progress Income Economic situation/climate	Stiglitz (1993), Kaplinskiy (2006)
	Substitute	Price of substitutes Price of complements	Hartwick (1978), Hoel (1983), Stiglitz (1993)
Supply and demand	Finance	Exchange rate Interest rate	Stiglitz (1993), Hotelling (1931), Bodie et al. (2002), Bhagwati and Johnson (1961), Brecher and Bhagwati (1981)
	Storage	Storage quantity Storage costs	Fama and French (1987), Telser (1958)
	Speculation	Financial investments	Gilbert (2010), Brunetti and Gilbert (1995)
	Economy	Market structure Governmental intervention Export quotas Extraction quotas Taxes Elasticity of demand/supply	Stiglitz (1976), Stiglitz and Dasgupta (1981), Gaudet and Lasserre (1988), Fischer and Laxminarayan (2004), Bhagwati and Feenstra (1982), Makhija (1993), Slade (1986), Krautkraemer (1990), Karp and Newbery (1991), Lewis et al. (1979), Makhija (1993)

H1 If an event from Table 1 occurs, we can observe a price movement.

Secondly, as we want to analyze whether the determinants identified in the literature are the only ones, we define a hypothesis in the opposite direction.

H2 If we observe a price movement, there is a coinciding event from Table 1.

Moreover, for the case of price movements where we cannot identify a coinciding event from Table 1, we extend our hypotheses and define hypotheses H3 and H4:

H3 If we observe a price movement, a coinciding event exists, although it cannot be found in Table 1.

H4 If an event occurs, although it cannot be found in Table 1, we can observe a price movement.

Furthermore, we will analyze whether the direction of the identified price jumps and coinciding events follows the theoretical assumptions and classification from the "Theoretical Analysis".

H5a If an event results in an increasing (decreasing) demand, the price movement is positive (negative).

H5b If an event results in an increasing (decreasing) supply, the price movement is negative (positive).

METHODOLOGY

As stated in "Introduction", we want to analyze empirically the price development of Nd, In, and Ga. Thus, we identify events from news items that would presumably lead to price jumps for these metals. To analyze the impact of events on the market price of a company, a commonly used method is an "event study." Within an event study, fundamentally described in Bodie et al. (2002) and Campbell et al. (1996), the abnormal return induced by an event can be analyzed. This approach can also be used to analyze the price development of resources. For instance, Demirer and Kutan (2010) tried to find out at what rate OPEC announcements influence oil spot and future prices.

This typical event study does not exactly fit with our research questions and approach for a number of reasons. Firstly, in contrast to other event studies, we perform an exploratory approach, as we initially do not know all the kinds of events we are looking for. Thus, we first have to find the events that are responsible for the price movements. Secondly, we want to analyze more than one kind of event, as we expect to find many events coinciding with price jumps. This assumption is based on the variety of possible determinants identified in the "Theoretical Analysis". If we analyze common event studies, we see that single events analyzed in the stock market context often occur more than 100 or even 1,000 times in a few years. With our focus on minor metals with relatively small markets and, thus, low quantity of sales, we expect this number to be lower. Therefore, we have to implement adaptations within the statistical evaluation based on what will probably be a smaller sample size.

The first step of our empirical analysis and, thus, our "adjusted event study" is the identification of the resources we want to analyze. As we explained in the "Introduction", the market for minor metals seems to be interesting for our analysis of determinants of the resource price. For instance, the regional and small market situations with less random noise within the price paths and the missing speculation by exchange brokers make these metals particularly suitable for our analysis. Furthermore, supported by the paper of Angerer et al. (2009) and the Critical Raw Material Report (European Commission 2010), we can identify three important and strategic minor metals for the future.

1. *Neodymium*. It is a rare earth metal, and in 2011, 97% of its production comes from China. Neodymium is important for the future of global technological progress, as it is an essential component of permanent magnets (e.g., for wind power plants) and laser technology.
2. *Indium*. In 2011, more than 81% of European In imports originate in China, and recycling possibilities are quite limited. Indium is used for liquid crystal displays (LCD) and thin-layer photovoltaic cells. The latter is obviously strategic for actual energy turnaround focusing on clean energy.
3. *Gallium*. Gallium is also produced mainly in China, in 2011 with about 75% of its production there. It is currently not being recycled. Like In, Ga is used for current and future thin-layer photovoltaic cells. Furthermore, it is an essential component of high-tech goods like integrated circuits (IC) and white light emitting diodes (WLED).

For a useful and significant analysis, we used spot prices of the three metals from January 1, 2007 to June 30, 2011 from the *Thompson Reuters Datastream*. The development of these prices is shown in Figure 1. Although these prices are published on a daily basis, price changes occur at most only twice a week. To the best of our knowledge, *Thompson Reuters Datastream* reflects these prices from *MetalPages.com,* which obtains the prices by detailed surveys of recent transactions every Tuesdays and

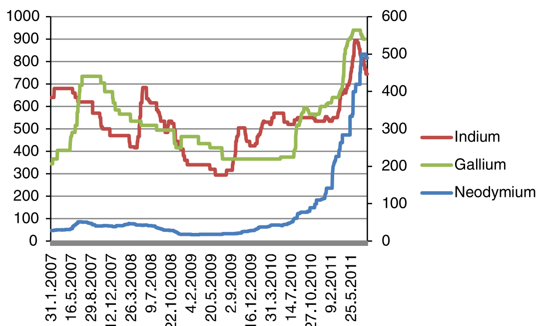

Figure 1. Price development of Nd, In, and Ga between January 1, 2007 and June 30, 2011.

Thursdays.[3] We are aware, that for this reason, our price data do not represent all market transactions. This of course is due to a missing regulated market. Yet, regarding the wide usage of these published prices, we consider them appropriate indications for actual transaction prices in these special markets. Moreover, traders in general orientate by these published prices and negotiate prices that are compatible to those. This signaling function may be (in small markets) comparable to a prime rate announcement by the Federal Reserve Bank. Finally, as both, events and prices are collected from market participants ("insiders"), we assume to have a suitable database for our event study.

In the second step, we have to identify the price jumps in question. The notion of a "price jump" is not defined clearly in the literature, and we found different papers with different definitions (e.g., Press 1967; Merton 1976; Ait-Sahalia 2004; Joulin et al. 2008). Regarding one of the most common definitions, we have to compare the values of the examined days with the moving average (Joulin et al. 2008). This identifies a price jump as having occurred if the value r of a specific interval t is higher than the moving average m: $|r(t)|>m(t)$.[4] This approach is common and useful for underlying values with frequent daily price changes.

Regarding our dataset (of 1,173 days), we identified 180 price changes for Nd, 89 price changes for In, and 88 price changes for Ga. Therefore, the prices of these minor metals change quite rarely. This is likely due to the surveys, which are performed only twice a week but regarding the small number of price changes, there are several weeks without any price changes.

Thus, for our analysis we want to define every price change as a "price jump." Therefore, we define a price jump as having occurred if the following relation is fulfilled: $\frac{p(t+1)+p(t)}{p(t)} \neq 0$, where p is the price of the metal and t the respective day (regarding all 1,173 days).

This relation leads to a number of jumps i_k with $k \in \{1, \ldots, n\}$.

If we screen the price values in detail, we recognize that several price changes are followed by price changes in the same direction within a few days. Here, we consider long price movements and assume the following definition: If the points of time t_1 and t_2 of two identified jumps i and $i + 1$ do not exceed *five* days and both are positive or, respectively, negative, then jump $i + 1$ is assigned to jump i. The length of the movement is $t_{(i+1)} - t_i$. The height of the movement is $\frac{p(t_{i+1})+p(t_i)}{p(t_i)}$.

The 5-day interval to assign two single jumps is the result of screening of all price values where we can spot these long movements. Furthermore, we will see later that the relevant news items are not exactly assignable to 1 day, but mostly assignable to 1 week. This assumption will make our analysis more realistic and accurate. Using this definition of a price jump, we finally got 56 jumps for Nd, 51 jumps for In, and 32 jumps for Ga. In the "Findings", we present the specific analysis of these findings.

In the next step of our analysis, we want to find out which events can be assigned to the different jumps, if there are any relevant events at all. For this purpose, we use the news archive from Metal-Pages (2011). This dataset is suitable for our needs, as it includes news items sorted by metals and date. Furthermore, the news items are specific for the different metals as they contain, for instance, interviews with mine operators to get their estimation of a specific situation. The dataset contains news items for all kinds of metals, including Nd, In, and Ga. Most of the news items are reports, mostly based on actual interviews with market insiders (mine operators, traders, suppliers, etc.). As these participants, in general, offer better insights into the metal markets than any outside observing journalist, we expect the news items to be appropriate indications for important market activities. Furthermore, reports are published frequently (at least twice a week) so that we may assume to minimize the risk of time lags. As most of these minor metals are traded in the People's Republic of China (PRC), of course we may be faced with missing information and events that are not reported by surveys as well as biased news. However, by screening all news items we found also various domestic political events, like for instance the announcement of new or higher taxes as well as governmental stockpiling. In general, one may assume that such events would not be reported in countries with strong governmental control. As we found such events, this is at least an indication for a less biased and thus acceptable news quality. Furthermore, the source of each news item is described relatively transparent. For instance, a news

[3] Details of the Metal-Pages pricing methodology can be found at: http://www.metal-pages.com/metalprices/our-pricing-methodology.

[4] Joulin et al. (2008) added an additional modulating factor s, multiplied with the moving average m. Thus, it is possible, by modulating s, to define smaller and higher jumps. For details and usage, we refer the reader to Joulin et al. (2008).

item could look like the following paragraph, which is part of our dataset:

> Nd prices expected to move higher in October BEIJING […]. Prices for […] neodymium in China are expected to move further up in the coming weeks, on the back of an anticipated increase in consumer purchases and the expected state stockpiling of rare earths. Transactions for 99% […] neodymium have been reported at $13,165-13,334/ton, and many suppliers have been reluctant to sell the rare earth […] in wait for a further increase foreseen next month. A Jiangxi-based producer reported having received more enquiries for the rare earth […] in the past few days. "And there have been more contracts concluded recently. The market seems to have been a little more active," said an executive of the southern producer. According to the source, contracted prices have been in the range of $13,165–13,334/ton, although some suppliers would not like to sell at less than $13,502/ton. (Metal-Pages 2011).

All in all, taking into account the mentioned advantages and disadvantages of the chosen dataset, we assume to get appropriate and at least only less biased insight into minor metal markets and their determinants. With these conditions, the specific dataset from Metal-Pages is well fitted to our requirements for the empirical analysis.

Within our dataset, we have 1,910 news items for Nd, 2,051 for In, and 1,340 for Ga. The news items deliver information about developments for a group of different metals or for specific metals. We can find information not only about global developments like a crisis or increasing demand in Western markets, but also about specific, domestic activities, like, for instance, the implementation of a new tax system in China or an increasing demand for indium caused by an innovative product. We identified two kinds of relevant news items that contain information about events responsible for the price jumps. The first appears a few days before the price jump and, thus, delivers information about a current or shortly appearing event. The second is often published a few days after a price jump and analyzes the jump with interviews and opinions from mine operators, suppliers, or buyers. Although these news items appear temporally after the price jumps, they are quite useful for our analysis as they deliver information about relevant events. If we analyze the first announcement of an event within a news item in comparison to the first day of the price jump, we see in Figure 2 that about 80% of the news items appear temporally before the price jumps and about 20% afterward. Furthermore, we identified several news items within a few days that obviously contain information about only one single event. We also have to consider this aspect in our analysis.

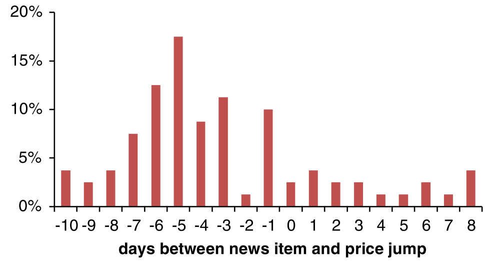

Figure 2. Price jumps versus news (Nd).

As the news items are not structured consistently to look like classical newspaper items, we had to analyze these items manually. We began with a first sample of five price jumps and screened all news items in an interval of 30 days around the price jumps. To identify objectively relevant and significant events from these news items, we set up two assumptions:

1. Based on the news items, an event can be matched clearly to the chosen metal. (Therefore, the metal has to be mentioned within the news item.)
2. The news items state that the event is responsible for a development in supply, demand, or even price at the relevant point of time for the examined price jump.

With this sample, we discovered that only news items from within a range of 10 days at the maximum around the jumps deliver relevant events. Thus, for our analysis, we decided to screen the 10-day-news interval around a jump for relevant events. The respective event study timeline can be found in Figure 3.

With this methodology, we were able to identify possible events for about 89% of the price jumps for Nd, 97% for In, and 91% for Ga. In several cases, we found more than one possible event for a price jump. As the news did not state how much each of the events was responsible for a price development, we assumed all identified events to share the responsibility for price jumps. This step results in a list of price jumps with coinciding events.

For a useful result and statistical analysis, in the next step, we clustered the events by their impact

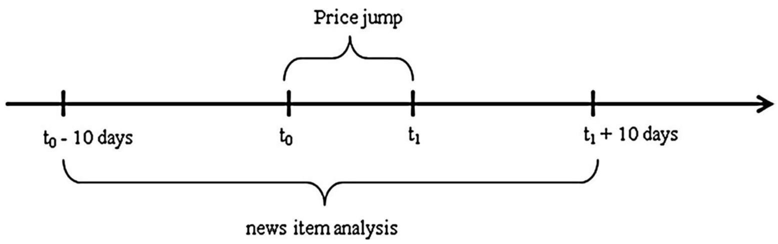

Figure 3. Timeline event study.

and direction on supply, demand, or price. Often the events were quite similar, but with small variations. Therefore, we aggregated events where an obviously similar reason could be found. For instance, we summed up different events involving the Chinese government regulating mines to reduce or stop production. Although they justified this action with several different arguments, for our analysis, we clustered all these events under "Governmental control over production."

Having obtained a list of jumps and coinciding events, it is possible to begin our statistical analysis of the results. In the first step, we counted the different and already clustered events to find out which events occurred how frequently. Thus, for each of the events, we were able to calculate the mean height and length of the respective jump. To get a full statistical overview, we added also the standard deviation.

For each event, the mean jump height $\bar{h}$ is $\frac{1}{m}\sum_j^m h_j$, where h is the jump height $\frac{p(t_{i+1})+p(t_i)}{p(t_i)}$ as described above and $[j, \ldots, m]$ are the respective jumps for the event. Accordingly, the standard deviation of the jump height σ is $\sqrt{\sum_j^m (h_j - \bar{h})^2}$. The lengths of the jumps can be calculated in the same way. As the jumps have different lengths, we also calculated the mean jump height and standard deviation per day for each event.

As mentioned above, we identified different price jumps with one or more relevant coinciding events. In standard event studies, these confounding events are often ignored. As we got confounding events for most jumps, we assumed that every event is responsible for the full price jump. We discuss this assumption in the "Conclusion and Outlook".

As the joining of news items, events, and price jumps appeared quite challenging, we want to know whether the results of our analysis have adequate quality. Thus, we define a precision and recall test. With the recall test, we define at which ratio the jumps lead to a coinciding event. In the first step, we calculated the complete recall as:

$$\frac{\text{Number of jumps with one or more coinciding events}}{\text{Number of all jumps}}.$$

In a second step, we calculated which ratio of all jumps an event is responsible for a price jump:

$$\frac{\text{Number of jumps for event } i}{\text{Number of all jumps}}.$$

The precision test uses the opposite approach:

$$\frac{\text{Number of events } i \text{ for a jump}}{\text{Number of all events } i}$$

Here, we want to identify at which ratio our identified events lead to price jumps. For the precision test, we need a more extensive approach. Hence, we have to analyze all news items, irrespective of price jumps. Thus, we want to identify events of the same kind, although there was potentially no resulting price jump discovered within the empirical analysis. For this, we have to define keywords for each event. We detected and extracted these keywords from news items we found in the analysis of the price jumps described above. We implemented this searching algorithm as a Boolean text search within our news items dataset. The results had to be adjusted manually based on objective sensible criteria, as there were different news items in the results that are not relevant. For instance, we condensed different news items clearly concerning the same event. These news items mostly appeared within a few days by different sources. In other cases, news items can be found within the results that obviously address no relevant event, but cover other news fitting the keywords. For instance, we eliminated news items, that discussed out of context the possible consequences of a higher tax or duty, whereas no such action has been announced or implemented by the government at this point of time.

As a last step, we want to analyze whether the identified price jumps for each event are significantly different from the mean price development. Therefore, we use three different non-parametric tests, as these are suitable for small samples.

With the first test, we compare the mean jump height per day (price change per day) of each event with the distribution of all other price changes per day. With the frequency distribution of all price changes per day, we can find out to what impacts each event leads. We are interested in the values for each event as well as in the values for each metal's overall events.

With the second test, we want also to compare the distribution of the jumps to the residual values. Therefore, we use the common Mann–Whitney–Wilcoxon test (Wilcoxon 1945). We implement this test again for each event. Therefore, we compare two samples. The first sample consists of all price jumps resulting from the event itself, and the second sample contains the remaining values of the price changes from January 2007 to June 2011. As we have both jumps with more than 1 day of length and more than one jump per type of event, we have to build new samples for each tested event. For instance, we have to compare a 20-day jump with 20-day values. For an event consisting of one 20-day jump and one 10-day jump, we have to build a sample with 50% values of 20 days and 50% values of 10 days.

Finally, we want to prove our results with a third test. Therefore, we use the van der Waerden test (van der Waerden 1952, 1953). This test also converts ranks, like the Mann–Whitney–Wilcoxon test. For the tested samples, we built the same assumptions as for the Mann–Whitney–Wilcoxon test. We implemented both tests also for the precision values, where we added 0% jumps with a median length.

Using this research methodology, we present our findings in the next section.

FINDINGS

Based on the empirical analysis described in the "Hypotheses", we have identified price jumps according to our definition for neodymium, indium, and gallium. For almost all of these price jumps, we were able to find one or more coinciding events. Here, we explain our findings according to the described research methodology for this empirical analysis.

The first results of our analysis are price jumps, identified by the respective approach as described in the "Methodology". These jumps occurred in the period from January 1, 2007 to June 30, 2011. We see in Table 2 that most price jumps, for all metals, do not exceed a length of 5 days, and price jumps with a length of more than 20 days are quite rare.

In the next step, we matched the price jumps with the events we identified in the news items. As some price jumps were attributed to more than one coinciding event, the number of events is higher than the number of jumps. In Tables 3, 4, 5, we show the resulting events sorted by frequency with the mean value and standard deviation of the jumps' height, length, and height per day.

The event "Restraining supply" has the highest frequency for Nd and Ga and the second highest value for In. The event "Restraining demand" occurs relatively often for all three metals, but less frequent than "Restraining supply." Events with a similar frequencies are, for instance, the shutdown of mines by the government, export duties, or export policies, whereas events like fire in a smelter or innovation occur less often.

As shown in Tables 3, 4, 5, we identified coinciding events for almost 90% of the price jumps with our empirical research approach. Therefore, we now explain the substance and the impact of the different events we found within our empirical analysis. The explanations are based on the contents of the relevant news items that we identified within our news database. The statistical values of each event can be found in Tables 3, 4, 5.

For better understanding and classification of the events, we have to consider that to the time period of our study, the PRC mines and produces 97% of the world's Nd, 58% of In, and about 75% of Ga. Hence, most of the news and resulting events have their focus on the specific economic aspects in China. As we described in the "Introduction", this situation is especially interesting and critical for future development of the prices of minor metals.

We classified these events by their influence on price. Altogether, we identified five categories similar to the areas described within the theoretical analysis. Events can result in *increasing supply*, *decreasing supply*, *increasing demand*, or *decreasing demand*. The fifth category of events *directly* influences the resource price.

The first category of events we have identified influences the supply of the metals, and hence the price. These events belong to the category

Table 2. Price Jumps for Nd, In, and Ga

Neodymium		Indium		Gallium	
Length	Number	Length	Number	Length	Number
1 day	20	1 day	26	1 day	18
2–5 days	15	2–5 days	11	2–5 days	4
6–10 days	9	6–10 days	6	6–10 days	6
11–15 days	4	11–15 days	5	11–15 days	2
16–20 days	0	16–20 days	1	16–20 days	1
21–25 days	5	21–25 days	2	21–25 days	0
26–30 days	2	26–30 days	0	26–30 days	0
>30 days	1	>30 days	0	>30 days	1
Σ	56	Σ	51	Σ	32

Table 3. Events Associated with Price Jumps for Nd

Event	Number of Price Jumps	Mean Jump Length in Days	Standard Deviation Jump Length in Days	Mean Jump Height in %	Standard Deviation Jump Height in %	Mean Jump Height Per Day in %	Standard Deviation Jump Height Per Day In %
Decreasing supply—restraining supply	17	8.18	8.35	15.73	15.51	1.69	3.29
Decreasing supply—lower export quotas	8	9.13	8.58	21.20	18.18	2.63	5.26
Rainy season	7	11.43	8.63	16.85	18.94	1.27	2.62
Decreasing demand—general	5	3.40	2.24	−3.52	1.91	−1.04	1.42
Decreasing demand—restraining demand	5	15.60	14.07	−14.88	14.59	−1.11	1.86
Increasing demand—positive outlook	5	18.40	7.31	24.57	9.83	1.20	1.84
Decreasing supply—closure of mines by government	5	12.00	8.37	26.43	20.35	1.88	4.10
Holiday	4	16.50	13.16	−12.19	9.90	−0.81	1.41
Higher export duties	4	6.75	8.32	15.84	21.91	1.60	1.74
Increasing supply—suppliers sell stocks	4	11.00	14.47	−8.51	10.77	−0.87	1.36
Holiday before/after	3	17.00	4.32	33.97	20.58	1.73	4.05
Decreasing demand—global crisis	3	23.33	12.68	−23.19	13.08	−1.17	1.88
Decreasing supply—governmental control over production	3	2.00	1.41	15.01	5.32	7.45	7.65
Increasing supply—new/more production	2	19.50	16.50	−17.03	10.13	−0.98	1.55
Decreasing supply—lower production	2	4.00	2.00	5.64	1.58	1.11	1.49
Decreasing supply—state stockpiling	2	13.50	7.50	17.03	9.80	1.08	1.94
Fire	1	21.00	0.00	53.73	0.00	2.15	4.10
No event found	10						
Sum/average over all jumps	90	12.51	8.11	9.81	11.91	1.05	2.80
Total over all values (“random noise”)						0.24	1.86

“*Decreasing supply.*” They result in significantly increasing prices as shown in Tables 3, 4, 5.

1. *Restraining supply*: In many cases, we observed that the supply was restrained by the suppliers themselves. In the relevant news items, we found evidence that suppliers were staying on the sidelines and did not sell their material on the market, as they expected growing demand in the near future, thus increasing prices and profits.

2. *Lower export quotas*: This incident is characteristic of metals mined mainly in China. The Chinese government has set up export quotas for minor metals and adapted them regularly since 2005 (Bradsher 2010). These export quotas were reportedly established to ensure that the domestic companies would not be short in these metals. We identified different news items, where the announcement of lower export quotas leads to price jumps as demanders panicked and bought the material at a high rate.

Table 4. Events Associated with Price Jumps for In

Event	Number of Price Jumps	Mean Jump Length in Days	Standard Deviation Jump Length in Days	Mean Jump Height in %	Standard Deviation Jump Height in %	Mean Jump Height Per Day in %	Standard Deviation Jump Height Per Day in %
Decreasing demand—general	11	5.09	4.56	−7.08	4.33	−1.43	1.98
Decreasing supply—restraining supply	9	11.00	7.41	22.10	18.44	1.90	2.88
Decreasing demand—global crisis	6	1.83		−7.26	3.32	−4.00	3.56
Increasing demand—general	6	5.83	5.84	12.37	12.95	2.29	3.14
Increasing supply—suppliers sell stocks	5	8.80		−7.50	4.85	−0.89	1.30
Decreasing supply—governmental control	5	11.80	7.19	17.26	14.08	1.03	1.24
Decreasing demand—restraining demand	5			−4.12	3.23	−1.05	1.11
Decreasing supply—less production	4	9.75	8.53	27.28	26.20	2.35	3.55
Decreasing demand—announcement export policy	3	1.00	0.00	−3.03	0.08	−3.03	0.08
Increasing demand—positive outlook	3	7.67	3.86	10.71	1.43	1.35	1.95
Holiday	2	1.00	0.00	−4.95	3.11	−4.95	3.11
Increasing demand—fill stocks after disaster	2	14.50	8.50	17.04	11.74	1.06	1.33
Higher taxes	1	1.00	0.00	6.25	0.00	6.25	0.00
Increasing supply—recycling	1	1.00	0.00	−6.00	0.00	−6.00	0.00
Increasing demand—innovation	1	21.00	0.00	65.06	0.00	2.48	3.77
Lower taxes	1	6.00	0.00	−12.20	0.00	−2.10	3.02
Unchanged taxes	1	1.00	0.00	−5.56	0.00	−5.56	0.00
Decreasing supply—general	1	6.00	0.00	9.20	0.00	1.51	2.53
Holiday before/after	1	13.00	0.00	19.09	0.00	1.20	1.64
Increasing demand—more LCD before FIFA	1	1.00	0.00	3.64	0.00	3.64	0.00
Decreasing demand—disaster	1	4.00	0.00	−2.22	0.00	−0.56	0.62
No event found	2						
Sum/average over all jumps	72	6.49	2.81	7.15	4.94	−0.21	1.75
Total over all values ("random noise")						0.03	1.35

3. *Rainy season*: Within different news items, we found information about a decreasing supply during the rainy season in China. China is troubled with a rainy and stormy season between spring and summer. This often leads to high masses of water, which can flood the mines and stop production abruptly. Hence, a decrease of supply is inducted immediately.
4. *Government closing mines*: As the news items state, the Chinese government has closed several mines in recent years. The news items show two main reasons for this action: First, the government closed many illegal mines that tried to evade governmental control. Second, they closed several small mines to increase the power of big, state-controlled mines. We found both types of events, but irrespective of the justification for this action, the news items indicate a decreasing supply and, thus, we can observe an increasing price.
5. *Governmental control over production*: We found several situations in which the Chinese government strictly reduced the activity of the mines, and thus their output. They justified this action as environmental protection, as mining of metals causes high air and water pollution values. However, there are opinions that this justification is a pretext for an intended and resulting price increase.
6. *Lower production and stocks*: Several of our identified news items state that suppliers

Table 5. Events Associated with Price Jumps for Ga

Event	Number of Price Jumps	Mean Jump Length in Days	Standard Deviation Jump Length in Days	Mean Jump Height in %	Standard Deviation Jump Height in %	Mean Jump Height Per Day in %	Standard Deviation Jump Height Per Day in %
Decreasing supply—restraining supply	8	9.50	12.03	11.16	10.87	1.17	2.02
Decreasing demand—restraining demand	8	3.38	3.60	−4.60	1.81	−1.36	1.76
Increasing demand—positive outlook	4	17.00	13.55	20.75	12.85	1.22	2.00
Increasing demand—LED technology	4	15.50	13.35	18.41	15.43	1.19	2.18
Decreasing supply—low stocks	3	16.33	15.76	16.64	12.98	10.96	0.00
Decreasing supply—governmental control over production (power)	3	4.33	1.25	3.91	1.80	0.90	0.71
Higher export duties	2	4.50	3.50	12.20	6.40	2.71	3.13
Decreasing demand—global crisis	2	4.50	3.50	−11.78	5.33	−2.62	2.97
Holiday before/after	2	21.00	17.00	19.30	15.29	0.92	1.31
Increasing demand—announcement export duties	1	11.00	0.00	31.06	0.00	2.82	3.60
Decreasing supply—general	1	1.00	0.00	5.76	0.00	5.76	0.00
Decreasing demand—general	1	1.00	0.00	−4.88	0.00	−4.88	0.00
Decreasing demand—big stocks	1	9.00	0.00	−5.14	0.00	−0.57	0.69
Decreasing supply—state stockpiling	1	6.00	0.00	6.07	0.00	1.01	0.93
Holiday	1	10.00	0.00	−4.32	0.00	−0.43	0.53
No event found	4						
Sum/average over all jumps	46	8.94	5.57	7.64	5.52	1.25	1.46
Total over all values (“random noise”)						0.09	1.16

reduce the output of their mines, and thus the supply. In some relevant news items, this is explained as an instrument to counteract falling prices induced by decreasing demand in domestic or global markets, and thus cause rising prices. We also identified news items that stated these low stocks are the result of previous high demand.

7. *State stockpiling*: In many news items, we identified a state stockpiling system as a relevant event. To protect its strategic resources, China introduced this system for different metals. The announcement of this system has in many cases caused increasing demand from scared industrial demanders, but the implementation has led to a decreasing supply because these demanders, belonging to the state, are preferred and less material will be available on the market.
8. *Disaster*: The news we analyzed often mentioned environmental and external events, which had an obvious influence on the output of the resource. Examples are a fire in a smelter, which reduced production, or an earthquake in a mining area, which destroyed several mines.

Other events we identified had an opposite influence and led to increasing supply of the metals and hence to decreasing prices. These events belong to the category “*Increasing supply.*” It is quite interesting that there are obviously fewer events in this category compared to other categories.

1. *Suppliers sell stocks*: Suppliers regularly clear their stocks and thus increase the supplied quantity of metals. We identified this event mostly at the turn of the year or at the end of a quarter, and found information that the suppliers want to generate cash flow to improve their financial statement to this point of time.
2. *New/more production*: We identified this event as the reason for a positive change in the quantity of the produced metal. According to the relevant news, it is the result of the start of new mines, the restart of formerly closed mines, or increased production activity.
3. *Recycling*: This identified event describes an increasing supply caused by recycled material available on the market.

Some other events we identified explain falling prices, caused by "*Decreasing demand*":

1. *Restraining demand*: With prices falling in a sluggish market, we found news which state that some buyers expect this trend to go on for some time. Hence, they do not buy the material they need for future production, as they expect falling prices and thus better margins. As the companies in this case have to fall back on their stocks to continue production, this strategy is only feasible if there are enough stocks on hand.
2. *Holidays*: We identified several news items that describe the negative impact of Chinese holidays on domestic demand for metals. China has two main holidays in which economic life regularly comes to a standstill, which is an explanation for decreasing demand. The first holiday is the Chinese Spring Festival, which slows down the Chinese economy for about 1 week. This festival is a so-called lunisolar festival, and thus its point in time changes every year, according to the moon and solar cycle. The Chinese National Holiday in the first days of October has the same effect. We also identified news items in summer that explain a decreasing demand because of general holiday-indicated slowdowns in summer all around the world. We identified a second event on this topic, which considers the time before and after holidays. According to its impact, this event can be found in the category "Increasing demand."
3. *Announcement of export policy*: We found several news items that lead to the assumption that export policies impact price changes even before they are adopted. Even at the moment of governmental announcements of upcoming new policies, we identified price jumps as demanders stop buying the material while they wait for the configuration of the new policy.
4. *Global economic development*: We discovered several news items that indicate a decreasing demand based on a sluggish global economy during the global financial crisis. During this global financial crisis since 2007, global economies around the world felt a sensible slowdown, and demand, especially in the manufacturing industry, was drastically reduced. For this event, in particular, we have to repeat that we generally only considered news items that could be matched clearly to a coinciding jump.
5. *Big stocks*: With this event, we identified a situation in which demanders own big stocks for production and thus temporally decrease their buying activities, for instance, waiting for a clearer market situation.
6. *General*: With this event, we found several news items that indicate generally decreasing demand in the market but do not specify reasons for this reaction of the market.

Furthermore, we identified several events of the category "*Increasing demand*" that resulted in increasing prices.

1. *Positive outlook*: In a number of news items, we discovered this event as a kind of speculation for future development. If markets expect good or even outstanding future conditions, their demand for the analyzed metals increases. This reaction is explained with boosted production in many countries, as producers want to be prepared for an expected rise in the demand for produced goods in the near future.
2. *Before/after holidays*: As we described above, during holidays the demand decreases, as there is economic standstill in the market. However, in the days before and after the holidays, the news items we analyzed regularly indicate an increased demand for the metals, which can be seen in increasing prices on these days. This can be explained by the fact that many manufacturing companies have to catch up with their production after the delay during the holidays.
3. *Fill stocks after disaster*: We identified this event especially for indium after the great earthquake in Japan in 2011. The Japanese demanders stopped their production and buying activities suddenly after the earthquake, but restarted these activities with growing demand a few weeks later.
4. *Increasing demand for special products*: We were able to identify a number of events where the demand for a specific product led to growing global demand. For instance, a few months before the soccer World Cup in 2010, buyers increased the production of

LCD screens and thus their demand for indium. Moreover, we found events where innovative goods, like solar and LED products, led to increasing demand for these materials.

5. *General*: With this event, we cover different news items that indicate a generally increasing demand in the market but do not specify the reasons for this reaction of the market. We may assume that often it is the result of a growing global economic situation, but we did not find evidence within the news items.

Finally, we identified events that did not directly influence demand or supply. Based on the relevant news items, we assume that these events directly influenced the resource price.

1. *Higher export duties*: We were able to identify several news items containing information about higher export duties and a resulting price change. Indeed, in the analyzed time frame, China regularly increased export duties for different metals to strengthen the domestic market. Therefore, this event directly leads to higher prices for the global market.
2. *Adaption of taxes*: We also found information about the adaption of taxes and its impact on the resource price. Higher taxes lead to higher prices, but on the other hand, unchanged taxes or even a suddenly announced rebate on taxes lead to an easing of the market and thus falling prices. Hence, these events have the same basis as export duties but are also relevant for the domestic market, as they are not restricted to exported metals.

In the "Findings", we will discuss to what degree these events are similar to events found in our theoretical analysis in the "Theoretical Analysis", and where possible differences lie.

We identified all the events mentioned and explained above with our empirical analysis, discussed within our research methodology in the "Hypotheses". We see the statistical effects of each event and metal in Tables 3, 4, 5. These results of our analysis are quite revealing in terms of our research questions. Nevertheless, their statistical validity has to be analyzed. Therefore, we used different testing methods.

As a first validation approach, the results of the precision and recall tests are given in Tables 6, 7, 8. Thus, with our methodology, on the recall side we find possible events for about 89% of the jumps for Nd, 97% for In, and 91% for Ga.

On the precision side, we analyzed, as described in the "Hypotheses", which ratio of events results in a price jump. As shown in Tables 6, 7, 8, we found a number of additional news items for each event. With this keyword search and the following analysis and adjustment of the resulting news items, we identified the number of events in Tables 6, 7, 8. Finally, we got a precision value often higher than 70% for frequently appearing events and very specific events and mean values above 50%.

This brings us to the intermediate conclusion that based on our data and methodology, events can be assigned to price movements in most cases, but especially rare events (like holidays or state stockpiling) lead partly by below 30% to significant price movements. This may be due to the small time frame and thus are rare occurring events. Although we get weak precision values for those events, we would at least regard them as possible indicator for short-term planning and purchasing.

As we described in the "Hypotheses", as a next step we tested whether the jumps resulting from the identified events could be just characteristics of random noise or whether they indeed represent a significant correlation. Hence, in the second test we compared the mean price change per day ("jump per day") for each event with the distribution of the mean height of all 1,173 price changes per day for each of the three metals. The results are given in Tables 9, 10, 11. As we can see, all events lead to price changes per day in the 10% level under the distribution of all price changes. Furthermore, the average value for Nd is 4.9%. For In, this value is 3.1%, and for Ga 2.0%.

To confirm the result of this basic test, we used two additional tests to compare the distribution of the jumps to the distribution of the remaining values, as described in the "Hypotheses". The results of the Mann–Whitney–Wilcoxon test can be also found in Tables 9, 10, 11. As nearly all events are significant at 5% level or higher, the Mann–Whitney–Wilcoxon test also proves our assumption of significant jumps.

Table 6. Results Precision Recall Test, Nd

Event	Number of Price Jumps	Recall in %	Number of Events Precision	Precision in %
Decreasing supply—restraining supply	17	18.89	21	80.95
Decreasing supply—lower export quotas	8	8.89	12	75.00
Rainy season	7	7.78	9	77.78
Decreasing demand—general	5	5.56	16	31.25
Decreasing demand—restraining demand	5	5.56	15	33.33
Increasing demand—positive outlook	5	5.56	10	50.00
Decreasing supply—closure of mines by government	5	5.56	6	83.33
Holiday	4	4.44	7	57.14
Higher export duties	4	4.44	11	36.36
Increasing supply—suppliers sell stocks	4	4.44	6	66.67
Holiday before/after	3	3.33	6	50.00
Decreasing demand—global crisis	3	3.33	5	60.00
Decreasing supply—governmental control over production	3	3.33	5	60.00
Increasing supply—new/more production	2	2.22	4	50.00
Decreasing supply—lower production	2	2.22	10	20.00
Decreasing supply—state stockpiling	2	2.22	4	50.00
Fire		1.11	1	100.00
No event found	10	11.11		
Sum/average over all jumps	90	100.00		57.75

Table 7. Results Precision Recall Test, In

Event	Number of Price Jumps	Recall in %	Number of Events Precision	Precision in %
Decreasing demand—general	11	15.28	13	84.62
Decreasing supply—restraining supply	9	12.50	11	81.82
Decreasing demand—global crisis		8.33	9	66.67
Increasing demand—general	6	8.33	9	66.67
Increasing supply—suppliers sell stocks	5	6.94	11	45.45
Decreasing supply—governmental control	5	6.94	9	55.56
Decreasing demand—restraining demand	5	6.94	9	55.56
Decreasing supply—less production	4	5.56	7	57.14
Decreasing demand—announcement export policy	3	4.17	4	75.00
Increasing demand—positive outlook	3	4.17	9	33.33
Holiday	2	2.78	5	40.00
Increasing demand—fill stocks after disaster	2	2.78	3	66.67
Higher taxes	1	1.39	4	25.00
Increasing supply—recycling	1	1.39	6	16.67
Increasing demand—innovation	1	1.39	6	16.67
Lower taxes	1	1.39	2	50.00
Unchanged taxes	1	1.39	4	25.00
Decreasing supply—general	1	1.39	2	50.00
Holiday before/after	1	1.39	8	12.50
Increasing demand—more LCD before FIFA	1	1.39	2	50.00
Decreasing demand—disaster	1	1.39	1	100.00
No Event found	2	2.78		
Sum/average over all jumps	72	100.00		51.16

As an additional validation, we implemented the Van der Waerden test, described in the "Hypotheses". The results of this test are also given in Tables 9, 10, 11. The compared distributions—event and random noise of the residual values—are significantly unequal for most of the events. We see that for both the Mann–Whitney–Wilcoxon and the Van der Waerden tests, nearly all events are significant with at least 5% level of significance. Moreover, the majority of events is

Table 8. Results Precision Recall Test, Ga

Event	Number of Price Jumps	Recall in %	Number of Events Precision	Precision in %
Decreasing supply—restraining supply	8	17.39	11	72.73
Decreasing demand—restraining demand	8	17.39	10	80.00
Increasing demand—positive outlook	4	8.70	8	50.00
Increasing demand—LED technology	4	8.70	5	80.00
Decreasing supply—low stocks	3	6.52	4	75.00
Decreasing supply—governmental control over production (power)	3	6.52	4	75.00
Higher export duties	2	4.35	2	100.00
Decreasing demand—global crisis	2	4.35	3	66.67
Holiday before/after	2	4.35	4	50.00
Increasing demand—announcement export duties	1	2.17	3	33.33
Decreasing supply—general	1	2.17	3	33.33
Decreasing demand—general	1	2.17	4	25.00
Decreasing demand—big stocks	1	2.17	2	50.00
Decreasing supply—state stockpiling	1	2.17	4	25.00
Holiday		2.17	5	20.00
No event found	4	8.70		
Sum/average over all jumps	46	100.00		55.74

Table 9. Results of Non-parametric Tests, Nd (*** = 0.1%, ** = 1%, * = 5%)

Event	Quantile in %	*P* Value Recall (Wilcoxon)	*P* Value Recall (van der Waerden)	*P* Value Precision (Wilcoxon)	*P* Value Precision (der Waerden)
Decreasing supply—restraining supply	5.70	0.00000***	0.00000***	0.00000***	0.00000***
Decreasing supply—lower export quotas	4.90	0.00000***	0.00000***	0.00213**	0.00006***
Rainy season	5.80	0.01462*	0.00509**	0.03971*	0.01226*
Decreasing demand—general	3.30	0.00002***	0.00001***	0.00053***	0.00042***
Decreasing demand—restraining demand	6.10	0.00007***	0.00004	0.00178**	0.00059***
Increasing demand—positive outlook	9.10	0.00229**	0.00206**	0.06090	0.01995*
Decreasing supply—closure of mines by government''	4.90	0.00206**	0.00016	0.00591**	0.00066***
Holiday	3.80	0.00017***	0.00112**	0.00080***	0.00151**
Higher export duties	5.40	0.01029*	0.01102*	0.22893	0.09847
Increasing supply—suppliers sell stocks	4.30	0.00017***	0.00086***	0.00080***	0.00182**
Holiday before/after	4.20	0.01286*	0.00109**	0.13545	0.02002*
Decreasing demand—global crisis	3.20	0.00023	0.00032***	0.10491	0.00070***
Decreasing supply—governmental control over production	1.40	0.00428**	0.00000	0.03532*	0.00077***
Increasing supply—new/more production	7.40	0.00062***	0.00918**	0.00486**	0.01346*
Decreasing supply—lower production	1.00	0.04655*	0.03829*	0.68894	0.46623
Decreasing supply—state stockpiling	8.40	0.07097	0.06893	0.24916	0.15744
Fire	7.10	0.08874	0.01648*	0.08874	0.01648*
Average	4.9				

significant to 0.1% level. We see this especially for events with higher frequencies.

Finally, we implemented the two tests for each event with the precision values of jumps. Therefore, we added 0% jumps for all additionally occurring events not resulting in a price jump. Consequently, we can see that the test values are less significant than for the original recall values.

DISCUSSION

Per our literature analysis in the ''Hypotheses'' and our empirical analysis in the ''Findings'', we now discuss the results considering the hypotheses from the ''Theoretical Analysis''.

We formulated hypothesis H1 to analyze whether events identified from the literature survey (see

Table 10. Results of Non-parametric Tests, In (*** = 0.1%, ** = 1%, * = 5%)

Event	Quantile (%)	*P* Value Recall (Wilcoxon)	*P* Value Recall (van der Waerden)	*P* Value Precision (Wilcoxon)	*P* Value Precision (van der Waerden)
Decreasing demand—general	3.9	0.00000***	0.00000***	0.00000***	0.00000***
Decreasing supply—restraining supply	3.4	0.00000***	0.00000***	0.00001***	0.00000***
Decreasing demand—global crisis	1.7	0.00000***	0.00000***	0.00008***	0.00000***
Increasing demand—general	2.6	0.00020***	0.00000***	0.00147**	0.00000***
Increasing supply—suppliers sell stocks	4.9	0.00009***	0.00010***	0.00476**	0.00051***
Decreasing supply—governmental control	2.6	0.00311**	0.00004***	0.01589*	0.00031***
Decreasing demand—restraining demand	4.8	0.00129**	0.00018***	0.00766**	0.00040***
Decreasing supply—less production	4.7	0.00004***	0.00002***	0.00150**	0.00012***
Decreasing demand—announcement export policy	2.2	0.00012***	0.00000***	0.00082***	0.00000***
Increasing demand—positive outlook	4.5	0.00583**	0.00117**	0.08630	0.00649**
Holiday	1.2	0.00034***	0.00000***	0.02227*	0.00100***
Increasing demand—fill stocks after disaster	4.8	0.04496*	0.02628*	0.07357	0.03069*
Higher taxes	0.8	0.08920	0.00035***	0.40329	0.07714
Increasing supply—recycling	0.6	0.00060	0.00012***	0.15317	0.10694
Increasing demand—innovation	2.5	0.08380	0.00149**	0.45824	0.14093
Lower taxes	2.6	0.00057***	0.00161**	0.01513*	0.00901**
Unchanged taxes	0.9	0.00062***	0.00033***	0.08340	0.06775
Decreasing supply—general	4.1	0.10598	0.04745*	0.23238	0.10925
Holiday before/after	4.6	0.10295	0.05194	0.53022	0.21045
Increasing demand—more LCD before FIFA	1.8	0.09607	0.00169**	0.24187	0.02722*
Decreasing demand—disaster	5.0	0.00188**	0.14825	0.00188**	0.14825
Average	3.1				

Table 11. Results of Non-parametric Tests, Ga (*** = 0.1%, ** = 1%, * = 5%)

Event	Quantile (%)	*P* Value Recall (Wilcoxon)	*P* Value Recall (van der Waerden)	*P* Value Precision (Wilcoxon)	*P* Value Precision (van der Waerden)
Decreasing supply—restraining supply	3.2	0.00003***	0.00000***	0.00028***	0.00000***
Decreasing demand—restraining demand	1.6	0.00000***	0.00000***	0.00000***	0.00000***
Increasing demand—positive outlook	3.2	0.00293**	0.00037***	0.02875*	0.00120**
Increasing demand—LED technology	3.2	0.00498**	0.00082***	0.00982**	0.00108**
Decreasing supply—low stocks	0.3	0.01150*	0.00382**	0.02386*	0.00472**
Decreasing supply—governmental control over production (power)	3.8	0.00979**	0.00107	0.02402*	0.00161**
Higher export duties	1.9	0.02003*	0.00014***	0.02003*	0.00014***
Decreasing demand—global crisis	1.4	0.00028***	0.00000***	0.00252**	0.00001***
Holiday before/after	3.8	0.05154	0.03362*	0.13598	0.04599*
Increasing demand—announcement export duties	1.8	0.08433	0.00138**	0.36337	0.03608*
Decreasing supply—general	0.9	0.08976	0.00005***	0.35876	0.01487*
Decreasing demand—general	0.7	0.00060***	0.00001***	0.07153	0.01047*
Decreasing demand—big stocks	2.1	0.00103**	0.05984	0.01445*	0.05772
Decreasing supply—state stockpiling	3.8	0.12008	0.04777*	0.46862	0.10415
Holiday	2.1	0.00147**	0.10913	0.10059	0.08939
Average	2.0				

Table 1) may result in price movements. Based on our empirical analysis, we were able to identify a number of events already mentioned in the literature that can be linked to price movements in our data. For instance, previous studies and the present analysis lead to environmental effects as possible influencing factors for the supplied quantity (Stiglitz 1993). Regarding the area of demand, we found factors like the economic situation (for instance, a global crisis) and technological progress within both analyses (e.g., Schulze 1974; Stiglitz 1993). We identified this technological progress especially for new and growing technologies like LED or solar technology on the demand side. Furthermore, events

like governmental intervention (e.g., Makhija 1993) and restraining supply and demand in close contact to storage activities can be found within both analyses. We identified many governmental interventions and regulations in China, which were implemented to increase the price. With the statistical test, we calculated precision values mostly greater than 60% and thus were able to confirm the possible influence of most of these determinants.

However, we did not discover events like exploration activities as mentioned in Deshmukh and Pliska (1980), extraction costs, ore quality (Krautkraemer 1998), and mine output depending on its period in the life cycle in our empirical study. We also did not find events concerning co-products. This might be due to the news items we selected for the Nd, Ga, and In and could be part of further research by including news items of co-products. Moreover, events related to the price of substitutes and complements (Stiglitz 1993) could not be found in our empirical data, probably because there are no economically suitable substitutes for the minor metals.

With hypothesis H2, we tested whether all price movements coincide with the determinants identified in the literature. We found relevant events for about 90% of the price jumps. However, not all events can be found in the literature. Indeed, we identified different regional, political, environmental, and geographical events that can be assigned to a market reaction, visible as a price movement. For instance, we identified determinants like the growing demand before and after the Chinese holidays, the sluggish market during these holidays and the summer slowdown, the shutdown of mines by governmental force, the decreasing output based on governmental pollution regulations, and finally the regularly appearing rainy season in China. All these events are also important possible determinants or at least indications for price movements that have not yet been analyzed in detail.

As we found several events that have not been considered in the literature, we can examine hypotheses H3 and H4. With these hypotheses, we wanted to find out to what extent all identified events can be assigned to resource price movements. With hypothesis H3, we wanted to analyze whether price jumps can be assigned to coinciding events. We can accept this hypothesis with a precision test within our empirical study, as we were able to find coinciding events for about 90% of the price jumps.

We only selected events from news items that could doubtless be connected contextually and temporarily to a specific price jump. In several cases, we identified more than one event from our news items. With the results, we found at least indications that most of the price movements for minor metals are determined by one or more specific events.

However, for this analysis, we used a number of assumptions that we mention here again. Firstly, the prices we use, have been published by Metal-Pages and are based on surveys. Although the data sources are widely used and the procedure is accepted, there is always possibility of wrong or biased prices. Yet, as there is no exiting regulated market to this time, we assume to have at least an appropriate indication for the spot prices with signaling effect. Moreover, we have to mention that these prices do not reflect the prices of possible closed long-term contracts, although these contracts may implicit influence spot transactions as they are often constructed as forward-contracts with a delivery at the expiration date. Furthermore, as most of the published events are also short-termed, we assume this fact to be negligible for our short-term-oriented event study. Secondly, the event items are based on reports and surveys from market participants reporting to Metal-Pages and thus one single source. As described above, it might further be possible that events which are crucial for price jumps are not reported for various reasons. Yet, as our data source is one of the biggest news, price, and information databases for worldwide metals and delivers reliable news items, we can consider this limitation justifiable and for this analysis we assume the Metal-Pages news to be appropriate as they present their reports and source transparently. Thirdly, the definition of a price jump had an impact on the number of jumps and on their length and height. Here, we accepted each daily price change with a value other than 0 as a price jump. Moreover, we connected two jumps within 5 days to one coherent price movement. Although these two assumptions for the definition of a price jump used in this paper seem to be adequate for the analyzed metals, we could of course modify the parameters and get, for instance, more and thus smaller jumps. Yet, as we saw within the analysis of the news items, it is quite difficult to match events and news to an exact point of time. As we did with our assumption of coherent jumps within 5 days, we got this high value of coinciding events that could be matched clearly to a price jump. The last assumption we have to mention is the treatment of confounding events. We treated each event as responsible for the price jump, as it was not possible to tell apart these events suitably. Furthermore, we did not exclude these confounding events from the analysis, which is a common practice in the empirical literature, especially event studies, as this would have diminished our sample radically. Considering our research questions, we can justify these assumptions, as we wanted to find out what kinds of determinants can be indicated to drive minor metal prices or at least coincide with a price movement.

In the next step, we wanted to analyze to what extent all events lead to price movements following hypothesis H4. We have described the findings within the precision test in the ''Findings'' and ''Discussion''. Here, we see that for some events we got recall values over 70%. Hence, given an event, for example, from news items or other sources, we can assume a price change in the near future. Although we found few events (like holidays or state stockpiling) with low precision values, we would regard these determinants at least as possible indicators for further price movements. This information can help to enable better decision making for industry and politics, at least for short-term planning. With our analysis, we identified about 20% of events from news items that temporally followed price jumps. This result is not contradictory to our findings, as these news items contained information about events that were chronological before the relevant price jump. In common event studies there is risk that news items link to the most obvious event, and reporters were able to find, what might be a misleading conclusion. Yet, as mentioned above, with the survey of Metal-Pages, based on interviews with market insiders, we assume this risk to be existent, but low. Moreover, the time frame between information and market reaction is quite small, and thus information has to be provided in time and has to be screened effectively. Only under these circumstances can the benefits mentioned above be realized profitably. Finally, we can accept this hypothesis, as we identified various events coinciding to price movement, especially for events occurring often within our analyzed time frame.

Furthermore, we wanted to analyze whether our identified price movements are significantly different from the average price development. Using the Wilcoxon–Mann–Whitney test, we showed that about 90% of our price jumps for Nd, In, and Ga are significant at a level of 5% or higher. The van der Waerden test proved these results with a value of about 80% significant price jumps at a level of significance of 5% or higher. Furthermore, we identified that many events, like the speculation for higher prices, even showed a significance of 0.1%. Even the results for the tests with recall values show a majority of significant events. Finally, we can confirm our results, as our price jumps are significantly different from average price development for most of the events. Regarding the assumption about our definition of price jumps above, we consider that these statistical results also confirm this assumption.

With hypotheses H5a and H5b, we finally wanted to analyze whether the impacts of equal determinants show the same direction. As discussed in the ''Findings'' and shown in Tables 3, 4, 5, we can prove the assumption from the literature analysis, as increasing (decreasing) demand leads to higher (lower) prices and increasing (decreasing) supply leads to lower (higher) prices (Stiglitz 1993). Thus, we accept these hypotheses for our analysis.

Overall, we have identified several determinants that can be assigned to relevant price movements within the market of the examined minor metals. Not all of these possible determinants have been analyzed in the literature reviewed. Hence, with our analysis, we show that in small and local markets, most price movements can be traced back to different incidents and thus new information in the market that may control supply and demand.

CONCLUSION AND OUTLOOK

Regarding our research question, with this paper we wanted to analyze whether price developments of minor metals are the result of fundamental determinants. Through our literature analysis, we discovered several possible determinants from general as well as resource-specific studies. As these determinants were quite general or had been analyzed only for resources like crude oil or copper, we presented an empirical analysis for determinants of minor metals. With this analysis, we identified price jumps for neodymium, indium, and gallium and coinciding events, which in most cases may be matched to these price jumps. We discovered much overlap between the results of our literature survey and our empirical analysis, but many differences, too. The regional events in China, in particular, like the rainy season or holidays, quite often could be assigned to price movements, even if these factors were not mentioned or analyzed in the existing literature. With different statistical tests, we showed that if an event occurs, we often can identify a coinciding price movement (precision).

With the results of this paper, we can contribute to the explanation of the determinants of resource prices by regarding the specific markets for neodymium, indium, and gallium. Due to their specific market features, we were able to find indications for direct relationships between fundamental determinants and price movements. Our results may support industries which are dependent on these high-tech-metals in their planning. Especially for short-term purchasing, it is important to know when there are indications for price drops or price increases. This is supported by our analysis, as information about most of the events, identified in this analysis, is easy to get. Nevertheless, our results may stimulate the debate on resource-specific information publishing by reliable institutions, which could be interesting for the mentioned industries. These institutions like for instance USGS in the United States or BGR in Germany have to be supported in delivering specific market environment observations of these strategic resources for companies and governments. Therefore, we hope that these findings can not only support companies but also make a small contribution on the way to a well informed and long-term-oriented utilization of our natural resources.

As the number of de facto available events is quite small for each of the analyzed metals, it would be beneficial to analyze other metals or non-renewable resources in a similar way in further research to test and compare our findings. Especially, the comparison with less rare metals with different market conditions like copper would be beneficial. Furthermore, we could extend the time period back to the past, where other events could possibly have occurred, and choose more and other data sources for the news items. For further analysis and forecasts, we could use other sources like local newspapers to indicate these events in time, which of course would be possible, for instance, for events like holidays or a rainy season. For a more specific analysis, we also plan to build an algorithm to analyze news items automatically for keywords and importance.

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