Is Cartel Enforcement Effective? Evidence from the Stainless Steel Industry

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Abstract

This paper examines whether cartel enforcement restores competition or if collusion persists after a cartel's formal dissolution. We analyze the European stainless steel cartel, where collusion operated through adjustments to the parameters of a formula-based pricing system. The formulaic nature of pricing in this industry makes it possible to clearly distinguish collusive and competitive conduct. Following the cartel's detection, the European Commission imposed fines and directed firms to revise their formulas to eliminate the collusive changes. Using a novel, hand-collected dataset of prices during and after the cartel, we test whether collusion ended after the cartel's detection, as reflected in whether firms revised their pricing formulas as directed by the Commission. Results suggest that producers largely continued pricing according to the collusive formula after detection and, within a few years, modified the formula to further increase prices. Shortly after the cartel's dissolution in Europe, producers in the U.S., where no cartel existed, adjusted the parameters within their pricing formulas to match the values developed by European producers during and immediately after the cartel. The European pricing parameters appear to have served as focal points for tacit coordination in the U.S., suggesting a cross-market spillover of collusive practices to producers and markets uninvolved in the original conspiracy.

Keywords: collusion, cartels, post-cartel tacit collusion, antitrust

JEL Codes: L4, K2, C7

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1 Introduction

Price fixing represents one of the most egregious and harmful means of denying consumers the benefits of a competitive marketplace. To deter price fixing and restore competition, antitrust authorities impose large fines, prison sentences, and, in some cases, remedies[1] intended to prevent continued collusion. Determining whether these methods succeed in restoring competition to a market is challenging, as it is difficult to distinguish collusive from competitive behavior. Prices that remain constant, or even rise, after a cartel's detection may simply reflect competitive responses to shifting market conditions (e.g., changes in demand, costs, or market structure) rather than persistent collusion. In this study, we analyze post-cartel conduct after the detection of a price fixing conspiracy among stainless steel producers in Europe. Due to the industry's formula-based pricing system, collusive and competitive behavior can be clearly distinguished, making the setting particularly well suited for evaluating the effectiveness of cartel enforcement in restoring competition to a market.

Utilizing a novel, hand-collected dataset of prices during and after the cartel, we ask whether detecting the cartel and imposing a targeted behavioral remedy was effective in altering firm conduct and restoring competition. In the stainless steel industry, producers use a specific formula for calculating a component of final prices known as an alloy surcharge. The formula involves three crucial parameters known as trigger points. In the formula, a reduction (an increase) in a trigger point mechanically increases (reduces) surcharges. Collusion involved reducing the values of all three trigger points. After the conspiracy was detected, the European Commission (EC) required the firms to increase their trigger points, which would, by the structure of the methodology, reduce prices.[2] Therefore, testing whether post-cartel conduct was collusive, and therefore also a violation of the behavioral remedy, consists solely of testing whether these parameters were increased after the cartel's detection. In most studies of conduct after a cartel's dissolution, post-cartel conduct must be inferred indirectly from observed prices, which may reflect a mix of both changes in conduct and evolving market conditions including shifts in costs, demand, and market structure. In contrast, in this industry, collusion corresponds to a specific configuration of trigger-point values, enabling a direct test of post-cartel conduct by examining how those parameters change over time.

The analysis proceeds as follows. First, we estimate the trigger points underlying the surcharge pricing

[1] Remedies are measures designed to correct or prevent anticompetitive effects. Structural remedies typically involve altering the structure of a firm or market (e.g., divestitures), while behavioral remedies require firms to change or refrain from specific practices (e.g., modifying pricing formulas or contract terms).

[2] Strictly speaking, the wording of the EC's directive required only that firms cease using the collusive trigger points established during the cartel, without explicitly specifying the direction of any subsequent adjustment (Case IV/35.814 – Alloy surcharge, 1/21/1998, Commission Decision., hereafter "Alloy Surcharge Decision, 1998"; Joined Cases T-45/98 and T-47/98 – Krupp Thyssen Stainless and Acciai Speciali Terni v. Commission, Judgment of 13 December 2001, Court of First Instance., hereafter "Krupp Thyssen Judgment, 2001"). However, we interpret the behavioral remedy as requiring an upward adjustment of trigger points, at least to some extent, which is consistent with an objective of reducing surcharges rather than mandating firms charge prices exceeding collusive levels. See Subsection 2.2 for detailed discussion.

methodology both during and after the cartel. Trigger points are not directly revealed by firms, and must be estimated through maximum likelihood or non-linear least squares. Next, we formally test the hypothesis that stainless steel producers adjusted their trigger points, as dictated by the behavioral remedy imposed by the EC. Using both Wald and bootstrap-based tests, we find little evidence that producers meaningfully adjusted their trigger points in the year and a half immediately following the end of the cartel. Approximately one and a half years after the end of the cartel, results suggest that producers reduced at least one of the three trigger points, increasing surcharges above the levels that prevailed during explicit collusion. The null hypothesis that steel mills increased the three trigger points following the dissolution of the cartel is firmly rejected. These findings are consistent with continued collusion after the end of the cartel and a failure to comply with the EC's behavioral remedy. Next, we analyze surcharge pricing in the United States. U.S. producers were not involved in the cartel and were not accused of any collusive activity during this period. Consistent with a lack of involvement in the cartel, trigger points in the U.S. are significantly higher than European trigger points during the cartel period (implying lower surcharges in the U.S.). However, a few years after the end of the cartel, trigger point estimates for the U.S. reveal that American producers aligned their trigger points to those employed in Europe during and immediately after the cartel. The collusive trigger points developed during cartel activity in Europe may have served as focal points for tacit collusion among American producers.

This study highlights that collusive behavior may persist long after a cartel's formal end date, particularly when firms have developed formulaic pricing methodologies. After a detailed pricing methodology has been developed/adjusted, continued collusion may not require explicit communication as firms need only follow an established methodology to successfully and tacitly collude. Behavioral remedies directing former cartel members to depart from the collusive methodology appear warranted in these cases. However, the stainless steel case suggests behavioral remedies of this kind must be either coupled with extensive monitoring to ensure compliance, or be designed in a way that prioritizes transparency and ease of monitoring. Forbidding surcharges altogether would likely have been far easier to monitor and potentially more effective at eliminating collusion. Additionally, results from the U.S. suggest that pricing parameters within firms' methodologies can serve as focal points for tacit coordination. These focal points can cause collusion to spill over into separate markets, extending the harm from collusion to customers of firms unconnected to the original conspiracy. Generally, our findings suggest that formula-based collusion may be particularly harmful due to its persistence and elevated risk of spreading to additional markets.

Related Literature This study contributes to three distinct strands of literature: research analyzing the impact of cartel dissolution on prices and conduct, literature studying collusion on surcharges, and studies examining the effectiveness of post-cartel remedies.

Prior empirical literature exploring the impact of a cartel's detection and/or penalization on market prices has found mixed results. For example, Erutku and Hildebrand (2010) and Clark and Houde (2013) find that prices fell after the announcement of an investigation into a retail gasoline cartel in Canada. Hüschelrath, Leheyda and Beschorner (2010) show that prices in a Swiss road surfacing cartel fell after detection, though they began to rise again after a few years. In contrast, other studies find that cartel distortions persist or that prices even increase in the post-cartel period. Sproul (1993), analyzing 25 cartels, reports that prices typically rose in the four years following an indictment for price fixing. Asker (2010) finds similar evidence of persistent distortions in an international maritime chemical shipping cartel. Boswijk, Bun and Schinkel (2019) show that elevated cartel prices continued beyond the formal end date in the European sodium chlorate cartel, while Starc and Wollmann (2022) also find evidence of post-cartel tacit collusion after the discovery of a generic drug cartel. Consistent with the mixed results list above, Kovacic et al. (2007), in their study of pricing after the vitamins cartel, find that the prices of certain vitamins appeared to continue as if the conspiracy never ended while others returned to pre-conspiracy levels.

In the stainless steel industry, final prices consist of two parts: a surcharge and a base price. Base prices are privately negotiated between steel mills and buyers, while surcharges are applied uniformly to all customers. Collusion pertained only to surcharges. While simple, collusion of this kind seemingly suffers from an important flaw. Cartel members could charge the agreed upon surcharge, appearing to comply with the agreement, while secretly undercutting their rivals' base prices. A series of theoretical models demonstrate how surcharge-based collusion can be effective in increasing final prices despite this apparent flaw (Harrington and Ye, 2019; Chen, 2023; Harrington, 2024).

The present study also relates to prior literature analyzing the effectiveness of remedies imposed by antitrust authorities after a cartel. While behavioral or structural remedies are not typically applied during the penalization of price fixers, prior literature has called for a greater application of remedies in cartel cases (Harrington, 2018; Cosnita-Langlais, 2020). Miller (2010) analyzes the impact of a consent degree in the U.S. airline industry limiting firms' ability to communicate and coordinate prices through a shared fare database. She finds that the intervention, which could be considered a behavioral remedy, had a temporary effect on fares, at best. After the discovery of a Brazilian retail gasoline cartel, the government replaced the management of at least one firm with a government appointee to help prevent/stop continued collusion (Chaves and Duarte, 2021). Harrington (2023) proposes a specific remedy (the issuance of competitor coupons) designed to disrupt post-cartel collusion. Harrington (2017) shows that structural remedies after cartel cases may deter collusion more effectively than can fines and damages.

Finally, prior literature has examined the role of focal points in facilitating coordination. Schelling (1960) demonstrates that salient labels can serve as focal points that substantially increase the likelihood of successful coordination. Subsequent empirical research has found that price ceilings may act as focal points for collusion (Knittel and Stango, 2003; Genakos, Koutroumpis and Pagliero, 2018; Zhang et al., 2020), while pricing conventions such as round numbers have been shown to facilitate tacit collusion among gas stations (Lewis, 2015) and banks (Chan, Lin and Lin, 2025). The present study contributes to this literature by identifying a novel type of focal point for collusive behavior. Specifically, our results suggest that technical parameters embedded within firms' pricing formulas can serve as focal points for coordination between producers in an entirely separate geographic market.

The remainder of this article is organized as follows. Section 2 provides background information on the stainless steel industry, the operations of the cartel, and the surcharge pricing methodology. Section 3 introduces the dataset. Trigger point estimation procedures and hypothesis testing methodologies are introduced in Section 4. Trigger point estimates and testing results for Europe are presented in Section 5 while post-cartel pricing in the U.S. is analyzed in Section 6. Policy implications are discussed in Section 7. Section 8 concludes. Details regarding the dataset and its collection, supplementary analyses, and additional figures are presented in an online appendix.

2 Industry and Cartel Background

2.1 Industry Background

Stainless steel is a type of steel that contains chromium, which forms a protective surface layer that makes it highly resistant to rust, corrosion, and staining. Unlike regular steel, which can easily rust when exposed to moisture, stainless steel maintains its appearance and durability even in harsh environments, making it ideal for applications in construction, household appliances, medical tools, and food processing.[3]

There are over 150 grades of stainless steel, which differ primarily in their alloy composition. Differences in alloy content, particularly the levels of chromium, nickel, carbon, and molybdenum, lead to wide variations in strength, corrosion resistance, formability, and cost across grades. Stainless steel grades are typically identified using standards like the AISI (American Iron and Steel Institute) numbering system, which assigns a three-digit number to a particular grade of stainless steel (e.g., 304, 316, and 430 grades). 300 series (e.g., grade 304 and grade 316) stainless steels contain higher levels of nickel, which gives them excellent corrosion resistance, non-magnetic properties, and good weldability and ductility. They account for roughly 70% of global stainless steel production. In contrast, grades in the 400 series contain little or no nickel, making

[3]The industry background in this subsection is based on discussion in Case No COMP/M.6471 – Outokumpu/ INOXUM. 07/11/2012 (hereafter, "Outokumpu-Inoxum Merger Case, 2012"), Alloy Surcharge Decision (1998), Case COMP/F/39.234 – Alloy surcharge (readoption), 12/20/2006, Commission Decision. (hereafter, "Alloy Surcharge Readoption Decision, 2006"), Case COMP/M.2187 – Outokumpu/Avesta, 5/23/2001, Commission Decision. (hereafter, "Outokumpu-Avesta Merger Case, 2001"), Jefferies (2015), and Ambica (2021).

them magnetic, more affordable, and suitable for less demanding environments.

The most common grade of stainless steel is grade 304, which constitutes about 45% of European production. 304 grade stainless steel contains approximately 9% nickel, 18% chromium and no molybdenum. 304 grade is used for aerospace components, medical instruments, and hardware. The next most popular grades are 430 and 316, which each constitute about 15% of European production. 430 grade stainless steel, which contains 17% chromium, negligible amounts of nickel and no molybdenum, is used in the production of automotive trim and mufflers, industrial roofing, and refrigerator doors. 316 grade stainless steel, which contains 12% nickel, 18% chromium and 2.5% molybdenum, is used in marine equipment, medical devices, and commercial kitchens.

Stainless steel is produced by "mills" that combine the required alloying elements in furnaces and then form the material into specific shapes such as coils or sheets. The finished steel is sold both to distributors and directly to end users. For example, Proctor & Gamble regularly purchases stainless steel for producing razor blades. The majority of stainless steel is purchased by distributors or "stockers" who then resell the steel to downstream customers.

In the early 1990s, the European stainless steel industry was concentrated, with seven or eight major mills producing over 80% of total output. Over the next two decades, consolidation through mergers and acquisitions further reduced the number of dominant producers. By 2014, only three major mills remained. Over the same period, import competition, initially minimal, grew significantly. Imports from Asia, in particular, increased sharply, and by 2014, imported stainless steel accounted for approximately 30% of European demand.

Stainless steel prices consist of two main components: a base price and an alloy surcharge. The base price is negotiated directly between the customer and the mill at the time the order is placed. In contrast, the alloy surcharge is a standardized, non-negotiable component that applies uniformly across customers. It is designed to reflect the fluctuating costs of key alloying elements used in the production of a given stainless steel grade. While base prices are fixed at the time of order, the surcharge component for a stainless steel purchase is based on the prevailing alloy surcharge at the time of delivery.

In Europe, alloy surcharges for a grade j of stainless steel at time t are determined by the following formula:

$$f_j(\mathbf{w}_t;\theta) = \mathrm{Cr}_j \max\left\{0, w_t^{Cr} - \theta^{Cr}\right\} + \mathrm{Ni}_j \max\left\{0, w_t^{Ni} - \theta^{Ni}\right\} + \mathrm{Mo}_j \max\left\{0, w_t^{Mo} - \theta^{Mo}\right\}. \tag{1}$$

$\mathbf{w}_t = [w_t^{Cr}, w_t^{Ni}, w_t^{Mo}]$ is a vector of alloy prices in month t. Cr_j is the percentage of chromium in grade j of stainless steel (e.g., $\mathrm{Cr}_j = .17$ for grade 430). w_t^{Cr} denotes the price of a metric ton of ferrochrome alloy. In

Europe, this price was generally calculated as the average of the spot ferrochrome price two and three months prior to the current month.[4] Alloy prices (i.e., w_t^{Cr}, w_t^{Ni} and w_t^{Mo}) were often quoted in dollars. Thus, the mills converted these prices into euros or, prior to January 1999, European Currency Units (ECUs), for the purposes of surcharge calculation. θ^{Cr} represents the trigger point for chromium, a fixed threshold established by producers. The chromium component of the alloy surcharge is positive when the market price of ferrochrome exceeds this trigger, and zero when it falls below. Note that a reduction in the trigger point mechanically leads to a higher surcharge, as it increases the differential between the alloy price and the trigger. The nickel and molybdenum components of the alloy surcharge are defined analogously.

Some grades of stainless steel do not contain nickel (specifically, most grades in the 400 series, such as 430). Thus, $\mathrm{Ni}_j = 0$ for these grades. For grades that contain nickel, the nickel component was almost always the largest component of the alloy surcharge due to particularly high market prices for nickel since the early 1990s. Additionally, the majority of stainless steel grades do not contain any molybdenum. Thus, $\mathrm{Mo}_j = 0$ for the majority of grades of stainless steel. In 2004, producers added an iron/scrap component to the surcharge formula.[5] European producers revealed very little information regarding this component and its calculation. In subsequent years, European producers may have also added other components such as titanium, copper and manganese (Giuliodori and Rodriguez, 2015). Again, producers publicly released little to no information about these components, the raw material prices underlying their calculation, or the associated trigger points.

The surcharge system has faced widespread criticism from consumers for a number of reasons (Fastmarkets, 2012). First, large stainless steel mills often purchase raw alloy materials at a substantial discount relative to the prevailing spot prices used in the surcharge formula (Fastmarkets, 2012).[6] Second, although the surcharge formula is based on the cost of virgin raw materials, mills frequently rely on scrap metal, which can be substantially more affordable, for a significant share of their alloy requirements (MEPS, 2021, 2023). Third, producer profits systematically rise with alloy prices, implying that surcharge increases may directly drive up overall prices.[7] In 2018, mills increasingly shifted to quoting a single, all-inclusive price for stainless steel rather than a separate base price and surcharge. This change was possibly driven by competition from

[4]Since 2007, this price is calculated as the average of ferrochrome prices over the 30 days before the 20th of the previous month. "Until now the published alloy surcharge has been based on average raw material prices two and three months in the past. From now on it will be based on price movements in the 30 days before the 20th of the previous month" (ThyssenKrupp, 2007).

[5]"Stainless steel mills introduced a steel scrap component to the alloy surcharge during 2004 to compensate for the big increase in the scrap price" (Outokumpu, 2005).

[6]Also, "[t]he petitioners attest that while U&A Belgium claimed the alloy surcharge is based on LME nickel levels, the link between LME prices and actual manufacturing costs remains tenuous" (A-423-808 Administrative Review, Issues and Decisions for the Final Results of the Sixth Administrative Review of the Antidumping Duty Order on Stainless Steel Plate in Coils from Belgium (2006-2007).)

[7]"Every 5 USc/lb increase in the quarterly contract price for ferrochrome improves Group operating profit by some EUR 10 million on an annual basis" (Outokumpu, 2008). Also, "[r]espondents argue that a firm's profitability increases during periods when the prices of raw material inputs are high" (ITC, 2017).

Asian producers, who typically do not impose surcharges and instead offer a single unified price.[8]

2.2 Cartel Background

In 1991, alloy prices dropped below the trigger points that prevailed at that time and, as a result, mills stopped charging an alloy surcharge.[9] From that point until the beginning of the cartel in early 1994, no surcharges were levied. In early 1993, alloy prices again declined sharply and then began to rise again in September 1993. The major European producers, with the exception of the Finnish mill Outokumpu, agreed to hold a meeting in Madrid in December of 1993.[10] At the meeting, producers agreed to reduce the trigger points in the alloy surcharge formula as of February 1st, 1994. Specifically, the producers agreed to reduce the trigger point for Nickel to 3,750 European Currency Units (ECUs). The trigger point for chromium was reduced to 777 ECUs. The trigger point for molybdenum was changed to 5,532 European Currency Units (ECUs). Hereafter, these values are referred to as the Madrid values. The Madrid values were chosen because they were the alloy prices that prevailed in September 1993 when the nickel price reached its historical low. The mills notified customers of the change in the trigger points shortly after the Madrid meeting and, from February 1994 onwards, the producers uniformly[11] applied the methodology with the Madrid trigger points. After the Madrid meeting and a series of subsequent faxes and phone calls directly following the meeting, producers rarely, if ever, explicitly communicated. As the surcharge methodology was well understood and, by design, automatically adjusted to fluctuations in alloy prices, no further communication was necessary.

Producers did not fix base prices. Collusion was focused solely on alloy surcharges. Additionally, the mills did not change the structure of the formula in (1); they only changed the trigger points θ^{Cr}, θ^{Ni} and θ^{Mo}. By reducing the trigger points to levels below contemporaneous alloy prices in February of 1994, producers effectively reintroduced the alloy surcharge, now applying it at higher levels than when it was last in effect. The methodology was designed to be uniformly applied across producers, with any resulting variation in surcharges attributable primarily to minor differences in exchange rates, alloy prices, or rounding differences.

In 1995, the European Commission began receiving complaints from stainless steel customers regarding the price increase applied, with a high degree of uniformity, by producers across the industry in the previous

[8]"Traditionally, producers across Europe have utilised a "basis price plus alloy surcharge" mechanism when selling to their customers. However, since the middle of 2018 many sales have been concluded on effective or inclusive prices" (MEPS, 2021).

[9]The cartel background in this subsection is based on the Alloy Surcharge Decision (1998), Krupp Thyssen Judgment (2001), and Alloy Surcharge Readoption Decision (2006).

[10]Many of the producers involved in this cartel had also participated in an earlier infringement during the 1980s. That case concerned quota arrangements and concerted pricing practices, but did not involve directly fixing surcharges (Case 90/417/ECSC, 7/18/1990, Commission Decision).

[11]"In the course of inspections carried out under Article 47 of the ECSC Treaty and in certain letters to the Commission, the producers of stainless steel flat products stated that they had used the same formula for calculating the alloy surcharge, with the exception of the reference values (or 'trigger points')" (Alloy Surcharge Readoption Decision, 2006).

year. In response, the Commission requested information from the mills regarding the 1994 change in the alloy surcharge methodology. Based on the evidence obtained, it conducted inspections at the offices of major producers between July 1995 and December 1996. In January 1998, the Commission adopted a Decision against the major mills, excluding a Finnish producer named Outokumpu, finding that they had engaged in price-fixing contrary to Article 65 of the ECSC Treaty.[12] The EC imposed fines totaling over 25 million ECUs on the participating firms.

Executives from Outokumpu did not attend the Madrid meeting, but did receive faxes from the participants after the meeting and, based on this communication, appear to have adopted the measures decided at that meeting (i.e., the change in trigger points). As part of the EC's investigation into the cartel, Outokumpu's offices were inspected in 1996. Outokumpu was not charged by the European Commission, likely because it was the first to supply decisive evidence of the conspiracy and due to the fact that it did not attend the Madrid meeting.

In addition to imposing fines, Article 4 of the decision imposed a behavioral remedy on the participants:

> "The undertakings referred to in Article 1 shall refrain from repeating the acts or conduct specified in the said Article and from adopting any measure having an equivalent effect" (Alloy Surcharge Decision, 1998).

In a later 2001 judgement in response to an appeal by two of the cartel members, the EC clarified exactly what "acts and conduct" were forbidden:

> "[T]he infringement which the applicants are required to bring to an end is clearly defined in Article 1 of the Decision, namely the change to and application in a concerted manner of the reference values in the formula for calculating the alloy surcharge. It follows that, in order to comply with the Decision, the applicants should no longer apply the [trigger] values decided on at the Madrid meeting in December 1993" (Krupp Thyssen Judgment, 2001).

While a few mills initially protested the EC's instructions, the European Court of First Instance rejected their appeals. Regardless, producers claimed that they complied with the obligation to adjust their surcharge methodology in April 1998:[13]

> "The applicants [...], in their letters of 11 March 1998, [...] informed the Commission that

[12] The relevant provision for the coal and steel industries was Article 65 of the ECSC Treaty (in force 1952–2002), which prohibited restrictive agreements and concerted practices in those sectors. Article 65 closely resembled the general cartel prohibition contained in Article 85 of the EEC Treaty, and is generally regarded as a sector-specific application of the same competition law principles (Cohen, 1968).

[13] Also, "the applicants clearly understood the scope of their obligations since each of them applied new reference values as from 1 April 1998 for the purpose of calculating the alloy surcharge" (Krupp Thyssen Judgment, 2001).

they had decided to apply new [trigger] values for the alloying materials as from 1 April 1998[14] when calculating the alloy surcharge" (Krupp Thyssen Judgment, 2001).

In summary, the EC directed the cartel members to adjust their surcharge methodology and no longer apply the collusive trigger points agreed at the Madrid meeting.

Strictly speaking, the EC's directive required the mills to adjust their methodology/trigger points without specifying the direction of adjustment. We interpret this directive as requiring an increase in trigger points. A reduction in trigger points would mechanically increase surcharges and thereby intensify the collusive outcome. It appears unlikely that the EC, having just prosecuted these firms for cartel behavior, would issue a directive that effectively mandates higher prices than those achieved under collusion. The more plausible interpretation, likely implicit in the EC's language, is that firms were expected to raise trigger points, which would mechanically reduce surcharges. For the remainder of this study, we interpret the remedy as a directive to increase the trigger points.[15]

While the EC's investigation began as early as 1995, the participants, with the exception of a single firm (Avesta Sheffield), continued to utilize the Madrid trigger points throughout the investigation until at least April 1998, when the firms claimed to have adjusted their trigger points in response to the EC's directions to do so (Krupp Thyssen Judgment, 2001). As the mills continued to utilize the collusive Madrid values until at least March 1998, we consider the cartel to have been operational from February 1994 through March 1998. Hereafter, March 31st 1998 is considered the cartel's end date.

2.3 The Stainless Steel Industry in the United States

In this subsection, we discuss the stainless steel industry in the United States.[16] Alloy surcharges in the United States will also be analyzed as a comparison with the European market. In contrast to Europe, stainless steel producers in the U.S. have not been found guilty of, nor accused of, price-fixing activity. U.S. mills also charge their customers a formula-based alloy surcharge in addition to a base price.

There are five key differences between the U.S. alloy surcharge formula and the methodology used in Europe. First, most U.S. producers apply a yield factor of 1.2, intended to reflect the raw material losses that occur during the production process. Mathematically, this means each component of the surcharge formula in (1) is multiplied by 1.2. The yield factor scales up the surcharge to reflect the fact that mills must purchase more alloying material than is ultimately embodied in the finished product, since a portion

[14] The original text reads "1 April 1988," which is a typographical error; the correct year is 1998.

[15] Notably, our empirical analysis reveals that firms maintained trigger points highly similar to the collusive levels for approximately seventeen months following the EC's directive, suggesting non-compliance even under the most literal interpretation of the remedy that would require only a change (of some kind) in trigger points.

[16] Much of the content in this subsection is from U.S. International Trade Commission. Stainless Steel Sheet and Strip from China. Investigation Nos. 701-TA-557 and 731-TA-1312 (Final), USITC Publication 4676, March 2017. Washington, DC.

of the raw material is lost during processing. Second, U.S. mills use a two-month lag of raw material prices when calculating the surcharge, whereas European producers used the average of prices in the second and third months prior. Third, the relevant spot prices for certain alloys differed across the U.S. and Europe, reflecting distinct markets for the alloys in the two regions. Fourth, alloy surcharges in the U.S. are quoted in dollars per pound, rather than euros (or ECUs) per metric ton as in Europe. As raw material prices are generally quoted in dollars, currency conversion is unnecessary when calculating surcharges in the U.S. Finally, the alloy percentages employed by U.S. and European producers when calculating the surcharge differed slightly for certain grades. See Appendix A for additional details regarding alloy percentages. Due to the absence of prior antitrust scrutiny, U.S. producers are typically more transparent than their European counterparts regarding both the structure of their surcharge formula and the trigger points used. Specifically, U.S. producers release a greater amount of information regarding the calculation of surcharges in their annual reports, websites, and surcharge pricing lists.

3 Data

Table 1 describes the data sources. Data on alloy surcharges in Europe is compiled from multiple sources, including CRU (an independent industry research and consulting firm), Legierungszuschlag.info (a database maintained for informational purposes by a German steel distributor), and historical archives from stainless steel producers' websites (specifically, those of Outokumpu and ThyssenKrupp). The CRU and Legierungszuschlag data report average surcharges, while the producer website archives report surcharges imposed by the specific firm. Data preceding January 2001 are available exclusively for two grades, 304 and 430, sourced from CRU. These two grades account for the majority stainless steel production and consumption (ThyssenKrupp, 2023). Beginning in January of 2001 for Europe, surcharge data become available for a much broader set of stainless steel grades. Data on alloy surcharges in the U.S. are compiled from CRU (which reports an average surcharge across producers) and the websites of two producers (AK Steel and ATI), which provide surcharges imposed by the specific firm.

Across sources in each region, price dispersion is generally minimal (see Appendix C.1), so the main analysis uses average monthly surcharges across sources for each grade and region.[17] Robustness checks (see Appendix D.3) are conducted by re-estimating the main results using surcharge data from each source individually, rather than relying on the averaged values. Beginning with the addition of an iron component to the surcharge formula in early 2004, producers began adding additional components, such as titanium, copper, energy and manganese, to the surcharge methodology (Giuliodori and Rodriguez, 2015). The analysis

[17] Averaging also ensures that months with multiple sources do not generate multiple observations while other months contribute only a single observation, which would otherwise give uneven weight to certain periods.

Table 1: Data Sources in Europe and the U.S.

Panel A: Europe

Source	Type	Num. Grades	Time Period
CRU	Data Provider	2	2/1994 - 1/2004
Legierungszuschlag.info	Informational Service	24	1/2001 - 1/2004
Outokumpu	Producer	35	6/2003 - 1/2004
ThyssenKrupp	Producer	31	1/2003 - 1/2004

Panel B: US

Source		Num. Grades	Time Period
CRU	Data Provider	2	2/1994 - 1/2004
AK Steel	Producer	30	1/2000 - 1/2004
Allegheny Technologies Incorporated (ATI)	Producer	36	1/2001 - 1/2004

Notes: This table describes available data sources for the European (Panel A) and American (Panel B) markets. For each source, the reported time range spans from the earliest available observation to the latest, across all stainless steel grades. For CRU, the two available grades (for both regions) are 304 and 430. For Europe, CRU data on 304 is available beginning in February 1994. CRU data on 430 is available beginning in August 1997. See Appendix A for additional details regarding the dataset and its collection.

in the main text focuses on the period before the introduction of an iron component to the surcharge formula, which began, both for the U.S. and Europe, in February 2004. This restriction serves two purposes. First, it ensures cleaner comparison between the cartel and post-cartel periods, as additional components, such as iron, were not present during the cartel period. Second, information regarding the structure of the iron component (as well as additional components like titanium) in Europe is sparse, complicating estimation in later years. However, data from after the introduction of the iron component (i.e., after January 2004) is available and is analyzed in Appendix C.3.[18] Information on the alloy composition of each stainless steel grade, including the proportions of nickel (Ni_j), chromium (Cr_j), and molybdenum (Mo_j), is obtained from ATI and AK Steel (for the U.S.) and the British Stainless Steel Association (for Europe). Supplementary data on alloy prices come from a wide array of sources, including the London Metal Exchange, *Platts Metals Week*, *Platts Metals Yearbook*, annual reports from Outokumpu, and the *USGS Minerals Yearbook*. Additional details regarding data collection can be found in Appendix A.

The following analysis examines trigger points both during and after the cartel period. Pre-cartel trigger points cannot be directly estimated because surcharge data are not available before the cartel's formation. However, EC documents pertaining to the cartel offer enough detail to infer an approximate estimate.[19]

[18]The analysis in Appendix C.3 incorporates a number of additional data sources (not described in Table 1) that are available exclusively for months after January 2004.

[19]EC documents report that producers applied a zero alloy surcharge between 1991 and 1993 (Alloy Surcharge Decision,

Hereafter, these values are referred to as the competitive trigger points. The competitive trigger points are €6,229 per metric ton for nickel and €834 per metric ton for chromium. As molybdenum price data are unavailable for the pre-cartel period, a corresponding trigger point cannot be defined for molybdenum. Details regarding the determination of pre-cartel/competitive trigger points can be found in Appendix B.

4 Methodology

In this section, we discuss how to estimate trigger points and formally test whether producers increased their trigger points (as directed by the EC) after the cartel. Crucially, stainless steel producers were not instructed to end their use of the surcharge methodology, only to adjust their trigger points (Krupp Thyssen Judgment, 2001; Alloy Surcharge Readoption Decision, 2006). The mills themselves maintained that they complied by modifying their trigger points rather than abandoning the methodology altogether (Krupp Thyssen Judgment, 2001). As a result, the surcharge methodology persisted after the cartel (LZ-Prognose, 2025), with the only area of uncertainty being the level of the trigger points. In other words, what is unknown in the surcharge formula are the trigger points, not the structure of the formula itself.

During the cartel period, all producers explicitly followed a nearly identical formula for calculating surcharges (Alloy Surcharge Decision, 1998; Alloy Surcharge Readoption Decision, 2006). Two pieces of evidence suggest the formula continued to be applied uniformly across firms after the cartel as well. First, the exceptionally low degree of inter-firm price dispersion after the cartel suggests there were not significant differences between the producer's surcharge calculations (see Appendix C.1). Second, separate firm-level estimations of the surcharge formula yield similar parameter estimates (see Appendix D.3). Accordingly, in what follows, we estimate a single common vector of trigger points rather than separate trigger points for each producer.

The notation we employ in the ensuing analysis includes the following: w_t^{Cr}, w_t^{Ni}, and w_t^{Mo} denote raw alloy prices for chromium, nickel and molybdenum, respectively. c denotes the cartel period (February 1994 – March 1998), pc denotes the post-cartel period (April 1998 – Jan 2004), pce denotes the early post-cartel period (April 1998 – Aug 1999) and pcl denotes the late post-cartel period (Sep 1999 – Jan 2004). θ_t^i denotes the trigger point for alloy $i \in \{\mathrm{Ni}, \mathrm{Cr}, \mathrm{Mo}\}$ in time period $t \in \{c, pc, pce, pcl\}$. $\hat{\theta}_t^i$ denotes the corresponding estimates of these trigger points. $\theta_t = \left[\theta_t^{Ni}, \theta_t^{Cr}, \theta_t^{Mo}\right]^T$ denotes a vector of trigger points in period $t \in \{pc, pcl\}$. $\theta_t = \left[\theta_t^{Ni}, \theta_t^{Cr}\right]^T$ denotes a vector of trigger points in period $t \in \{c, pce\}$ (a trigger point for molybdenum is not estimated for these time periods). $\hat{\theta}_t$ denotes the corresponding vector of estimates.

1998). Because the surcharge formula mechanically yields a zero surcharge only when all relevant raw material prices fall below their respective trigger points, the observed zero surcharge period implies that the trigger points exceeded the corresponding raw material prices over this period. The competitive trigger points are therefore inferred as the maximum observed raw material prices during this period, which provide an approximate lower bound on the pre-cartel trigger values.

$\Theta = [\theta_c, \theta_{pc}, \theta_{pce}, \theta_{pcl}]^T$ denotes a stacked vector of trigger points. $\hat{\Theta} = \left[\hat{\theta}_c, \hat{\theta}_{pc}, \hat{\theta}_{pce}, \hat{\theta}_{pcl}\right]^T$ denotes a stacked vector of trigger point estimates. $f_j(\mathbf{w_t}; \theta)$ represents the formula-implied surcharge for grade j when the alloy prices are $\mathbf{w_t}$ and the trigger points are θ (see Equation (1)). Ni_j, Cr_j, and Mo_j are the percentage of nickel, chromium and molybdenum, respectively, in grade j. S_{jt} denotes the random variable representing the alloy surcharge for grade j in month t. Let s_{jt} denote its realized (observed) value in the data. $Var(\hat{\Theta})$ is a 10×10 covariance matrix of the parameter estimates $\hat{\Theta}$. $1\{X \geq 0\}$ denotes an indicator function which is 1 if X is non-negative and 0 otherwise.

4.1 Trigger Point Estimation

Estimating trigger points requires first specifying the data-generating process for observed surcharges. The surcharges observed in the data will generally deviate, to some extent, from the values implied by the surcharge formula. These deviations are best interpreted as measurement error, arising from several sources. First, the exact raw material prices used by producers when setting surcharges (i.e., the w_t^{Ni}, w_t^{Cr} and w_t^{Mo} variables in (1)) are not directly reported. The nickel, chromium, and molybdenum prices employed in the following analysis are collected from a variety of sources (see Appendix A) and may differ slightly from the series actually used by the mills. Second, many alloy prices are quoted in U.S. dollars and must be converted into euros prior to their use in the formula. The exact exchange rate series used by the mills is unknown; the analysis employs monthly average rates from the Federal Reserve, whereas producers may have used rates from a different source or based on a specific day within the month.[20]

Third, although trade associations often report "typical" alloy percentages for a given stainless steel grade (or provide a range of acceptable alloy percentages), the actual composition may vary slightly by mill, leading to small systematic differences in calculated surcharges.[21] Fourth, many producers, especially early in the sample period, rounded the formula-implied surcharge before publication, sometimes substantially (e.g., from €12.30 to €10). In the analysis that follows, we estimate trigger points under two alternative specifications that differ in how measurement error is incorporated into the surcharge formula and in the distributional assumptions imposed on the error term.

[20]While producers did not report the exact exchange rate series used to convert raw material prices to euros, certain producers did report surcharges in both euros and dollars. In these cases, the producer's exchange rate can be inferred from the two price quotations. In all cases, the producer's exchange rate closely matched, but did not exactly equal, monthly average rates from the Federal Reserve.

[21]"The average proportions [of the respective alloys] are grade-specific and might slightly change from mill to mill depending on their manufacturing processes" (Montanstahl, 2019).

4.1.1 Additive Error Model (AEM)

The first specification incorporates measurement error as an additive term outside the surcharge formula. The surcharge S_{jt} for grade j in month t is then modeled as

$$S_{jt} = f_j(\mathbf{w_t}; \theta) + \varepsilon_{jt}, \tag{2}$$

where ε_{jt} captures the combined effect of the measurement errors discussed above. In this specification, ε_{jt} is assumed to satisfy $E[\varepsilon_{jt} \mid \mathbf{w_t}] = 0$, but no further distributional assumptions are imposed.

Estimation proceeds via nonlinear least squares (NLLS):

$$\min_{\theta \in \mathbb{R}^3} \sum_{j,t} \left[s_{jt} - f_j(\mathbf{w_t}; \theta)\right]^2. \tag{3}$$

The appeal of this specification lies in its simplicity, computational tractability, and minimal distributional assumptions. It can be estimated directly by NLLS and requires no parametric form for the distribution of the error term. A drawback of this approach is that the additive error specification implies a positive probability of infeasible surcharge values. For example, when $f_j(\mathbf{w_t}; \theta) = 0$ (i.e., when all raw material prices fall below their respective trigger points), the model still assigns positive probability to both strictly positive and strictly negative values of S_{jt} due to the support of ε_{jt}. In practice, negative surcharges are never observed, and the underlying formula $f_j(\cdot)$ is designed such that $f_j(\mathbf{w_t}; \theta) \geq 0$ for all $\mathbf{w_t}$. The additive error model therefore allocates positive probability mass to an outcome that is theoretically ruled out by the formula itself and never observed in practice. The next specification addresses this limitation by modifying the placement of the error term.

4.1.2 Component-Level Error Model (CLEM)

The component-level error model introduces measurement error at the component level within the surcharge formula rather than as a single additive term applied to the formula's output. Recall that $f_j(\mathbf{w_t}; \theta)$ consists of three alloy-specific components (nickel, chromium, and molybdenum) each of which enters as the positive part of the difference between the alloy price and its trigger point. In the CLEM, each of these components is augmented with its own measurement error term. Specifically, the surcharge for grade j at time t is modeled as

$$S_{jt} = \max\left\{0, \mathrm{Cr}_j \left[w_t^{Cr} - \theta_{Cr}\right] + 1\left\{\mathrm{Cr}_j > 0\right\} \epsilon_{jt}^{Cr}\right\} + \max\left\{0, \mathrm{Ni}_j \left[w_t^{Ni} - \theta_{Ni}\right] + 1\left\{\mathrm{Ni}_j > 0\right\} \epsilon_{jt}^{Ni}\right\} \tag{4}$$

$$+\max\left\{0, \mathrm{Mo}_j\left[w_t^{Mo} - \theta_{Mo}\right] + 1\left\{\mathrm{Mo}_j > 0\right\}\epsilon_{jt}^{Mo}\right\}$$

where ε_{jt}^{k} is the alloy-specific measurement error term for alloy $k \in \{\mathrm{Cr}, \mathrm{Ni}, \mathrm{Mo}\}$.

In this formulation, each measurement error term is directly associated with a specific component of the surcharge formula rather than being aggregated into a single disturbance term applied to the formula's output. This means, for example, that ϵ_{jt}^{Cr} directly reflects mis-measurement in chromium raw material prices or percentages, without being conflated with errors from other inputs. Each ε_{it}^{k} is assumed to be i.i.d. and normally distributed with mean zero. Formally, $\varepsilon_{jt}^{k} \overset{\text{i.i.d.}}{\sim} \mathcal{N}(0, \sigma_k^2)$ for $k \in \{\mathrm{Ni}, \mathrm{Cr}, \mathrm{Mo}\}$. In Appendix D.3, we show that results are robust to assuming a logistic distribution for error term, allowing for a correlation between the measurement errors, and allowing for the variance of the measurement error to depend on the alloy content (a form of heteroskedasticity).

Estimation proceeds by maximum likelihood. The full likelihood function is provided in Appendix D.1. The CLEM specification has the advantage of aligning the placement of the measurement error with one of its most plausible sources and allowing for the possibility that measurement error affects different components to different degrees. However, this flexibility comes at a cost: the number of parameters increases from three trigger points in the additive error model to six parameters here (three trigger points and three standard deviations), and a specific parametric functional form assumption for the distributions of the error terms is required.

4.2 Hypothesis Testing

We next test whether the mills, in line with the behavioral remedy imposed by the EC, raised their trigger points. The EC's instructions were imprecise: they did not clarify whether adjustments should apply to all or only a subset of trigger points, nor did they stipulate the new values. Consequently, no single hypothesis conclusively captures the EC's intent. We therefore implement a range of one-sided hypothesis tests designed both to reflect plausible interpretations of the directive and to provide a broader statistical assessment of post-cartel pricing behavior. The tests are of the following form:

$$H_0: \; R\Theta \; \geq \; r \quad \text{versus} \quad H_1: \; R\Theta \; < \; r$$

where Θ is a stacked 10×1 vector of trigger points across alloys and across the cartel, post-cartel, early post-cartel and late post-cartel time periods. R is a $M \times 10$ known selection matrix that maps the full parameter vector Θ into the linear combination(s) relevant for the restriction, and r is a known $M \times 1$ vector of constants that defines the hypothesized bounds. M is the number of inequality restrictions in the null hypothesis being tested. In the present setting, each row of R selects a parameter (or difference of parameters) from Θ, and the corresponding element of r provides the value against which that parameter is compared. For example, $R = [-1, 0, 1, 0, 0, 0, 0, 0, 0, 0]$ and $r = 0$ corresponds to a test of whether the nickel trigger point in the post-cartel period exceeds the trigger point during the cartel (i.e., $H_0: \theta_{pc}^{Ni} \geq \theta_c^{Ni}$).

$$R = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

and $r = [3750, 777, 5532]^T$ corresponds to a joint test of whether the post-cartel trigger points exceed the Madrid values (i.e., $H_0 : 3750 \leq \theta_{pc}^{Ni}$, $777 \leq \theta_{pc}^{Cr}$, and $5532 \leq \theta_{pc}^{Mo}$). The following subsections describe two alternative testing procedures: an asymptotic Wald test, and a bootstrap-based procedure that directly approximates the finite-sample distribution of the test statistics.

4.2.1 Wald Tests

For each component (nickel, chromium, and molybdenum), we conduct one-sided Wald tests of a variety of null hypotheses. The Wald test statistic is

$$T_W = \frac{R\hat{\Theta} - r}{\sqrt{R\widehat{Var}(\hat{\Theta})R^T}}$$

where $\widehat{Var}(\hat{\Theta})$ is a 10×10 covariance matrix estimate. Provided the nonlinear least squares and maximum likelihood estimators introduced in Subsection 4.1 satisfy standard regularity conditions, T_W is asymptotically standard normal. We conduct Wald tests for hypotheses involving single, but not multiple, inequality restrictions.[22] The primary advantage of this approach is computational simplicity: once parameter estimates and their estimated standard errors are available, the test statistic is straightforward to compute. The main drawbacks are its reliance on large-sample approximations and its limitation to testing one inequality at a time in this setting.

[22] In principle, it is possible to test multiple inequality restrictions jointly using chi-bar squared tests (see, e.g., Wolak (1987)). However, such procedures are substantially more complex to implement in applied work. They require simulating nonstandard asymptotic distributions that are mixtures of chi-squared distributions with weights depending on which subset of the inequality constraints are binding. Instead, multiple inequality restrictions are evaluated using a bootstrap procedure introduced in the next subsection, which is both more straightforward to implement and more reliable in small samples.

4.2.2 Bootstrap-Based Tests

The second hypothesis testing approach uses a residual bootstrap procedure to test inequality parameter restrictions. Unlike a Wald test, this procedure can accommodate both single and multiple inequality hypotheses.

Under the AEM, the bootstrap test is based on the statistic[23]

$$T_{BS} = \mathrm{SSE}_C - \mathrm{SSE}_U,$$

where SSE_C is the optimized sum of squared errors under the null hypothesis (i.e., imposing the relevant inequality constraints) and SSE_U is the optimized sum of squared errors from the unrestricted model. The residual bootstrap proceeds as follows. First, the model is estimated without any inequality restrictions, separately for the cartel and post-cartel periods, and the optimized total sum of squared errors is recorded as SSE_U. Second, the model is re-estimated under the null hypothesis (i.e., subject to the inequality restrictions defining the null). This restricted nonlinear least squares problem yields a set of constrained fitted values and residuals, and the corresponding optimized sum of squared errors is recorded as SSE_C.

Third, the constrained residuals (i.e., the difference between the observed surcharges and the constrained fitted values) are re-centered within grade, resampled with replacement, and added back to the constrained fitted values to generate a bootstrap sample.[24] Fourth, for each bootstrap sample, the model is estimated twice: once imposing the same null-hypothesis constraints and once without these constraints. This produces a bootstrap analogue of the test statistic, $T^*_{BS} = \mathrm{SSE}^*_C - \mathrm{SSE}^*_U$. Repeating this procedure B times yields an empirical distribution of T^*_{BS} under the null. Finally, the observed statistic $T_{BS} = \mathrm{SSE}_C - \mathrm{SSE}_U$ is compared with this empirical distribution. Because larger values of T indicate a greater deterioration in fit due to the imposed restrictions (and therefore greater evidence against the null) the one-sided bootstrap p-value is computed as the fraction of bootstrap draws satisfying $T^*_{BS} \geq T_{BS}$.

Intuitively, if the inequality restrictions imposed by the null hypothesis are true, then enforcing them should not materially worsen the model's fit. The constrained and unconstrained estimators will be nearly identical, and the increase in the objective function, $\mathrm{SSE}_C - \mathrm{SSE}_U$, will be small. Conversely, if the null is false, the constraints force the model away from the parameter values that best explain the data, causing the restricted fit to deteriorate and the difference in objective values to become large.

This residual bootstrap test has several advantages. Most importantly, it can directly test multiple

[23]The statistic T_{BS} is conceptually analogous to a likelihood ratio type test: it measures how much imposing the inequality restrictions worsens the model's fit.

[24]To maintain comparability, this step is implemented in a stratified manner. Specifically, residuals are resampled only within grades, preventing residuals from one grade from being added to observations from another.

inequality restrictions, unlike the Wald test introduced in Subsection 4.2.1. It also avoids reliance on large-sample normality approximations. The main limitation of the residual bootstrap is that it can only be implemented for the additive error model (AEM), where the disturbance term enters additively outside the surcharge formula. In the component-level error model (CLEM), the error terms enter inside the non-linear maximum operators, making it infeasible to extract and re-sample them in a meaningful way. For the CLEM, an alternative permutation-based testing procedure is conducted (see Appendix E.2).[25] Overall, the bootstrap-based tests complement the Wald tests: they allow for tests involving multiple inequality restrictions and avoid large-sample distributional assumptions, but are computationally more intensive and, in the residual bootstrap form, can only be conducted with the additive error model.

5 Post-Cartel Pricing in Europe

Figure 1 presents average surcharges (from CRU) in Europe for 304 grade stainless steel from February 1994 until the introduction of the iron component in February of 2004. Recall that 304 stainless steel contains both nickel and chromium, but no molybdenum. The blue line in Figure 1 depicts the actual observed surcharge in the data. Figure 1 also depicts the collusive (green) and competitive (red) surcharges. Recall that the collusive surcharge is the surcharge implied by the methodology utilizing the Madrid trigger points. The competitive surcharge is the surcharge implied by the methodology utilizing the competitive/pre-cartel trigger points. The vertical dashed black line depicts the date of the cartel's dissolution (March 31st, 1998). The observed surcharges closely match the collusive values throughout the cartel period (i.e., the blue and green lines closely track each other). This suggests the mills successfully and accurately implemented the change in trigger points agreed upon at the Madrid meeting. Minor differences between the collusive surcharge and the observed surcharge can be attributed to minor differences in alloy percentages, exchange rates, and raw material prices, as well as rounding. After the cartel, the observed surcharge continues to closely resemble the collusive surcharge. In fact, the observed surcharge slightly exceeds the collusive surcharge for reasons to be explained later in this section. However, this difference is minimal for grade 304.

[25] While more generally applicable, the permutation-based testing procedure has three drawbacks in the current setting. First, it cannot directly test inequality restrictions, only equality restrictions. Second, permutation-based tests can only test joint hypotheses corresponding to no change in all trigger points across time, not hypotheses pertaining to a single trigger point (e.g., $H_0 : \theta_{pc}^{Ni} \geq \theta_{c}^{Ni}$). Third, permutation-based tests require an assumption of exchangeability (Good, 2002).

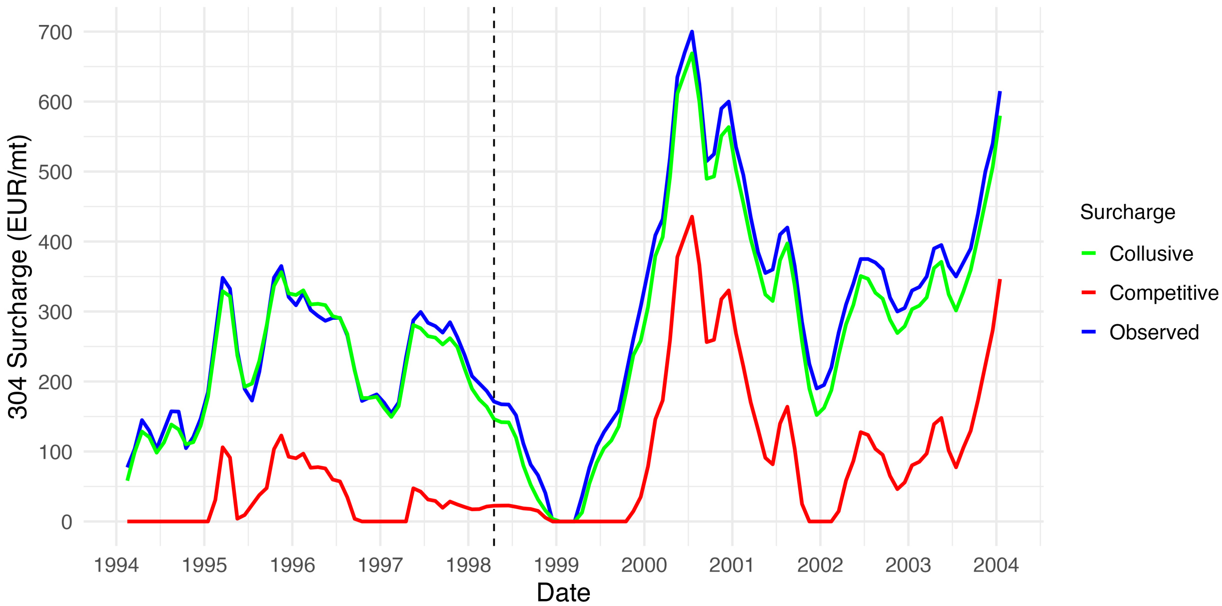

Figure 1: Alloy Surcharges in Europe for Grade 304 Stainless Steel

Notes: This figure depicts "observed" surcharges for grade 304 stainless steel in Europe in blue. The figure also depicts the surcharge implied by the methodology with the competitive (in red) and collusive/Madrid trigger points (in green). The variable on the x-axis is calendar time. The variable on the y-axis is the alloy surcharge in euros per metric ton. The data illustrated in this figure is from CRU. The vertical dashed black line indicates the date of the cartel's end (March 31st 1998). The data ranges from February of 1994 to January of 2004.

Figure 2 presents average surcharges (from CRU) in Europe for 430 grade stainless steel. Crucially, grade 430 stainless steel contains chromium, but neither nickel nor molybdenum. As with grade 304, the observed surcharges closely match the collusive surcharges during the cartel period and in the months immediately after the end of the cartel. Beginning in mid-1999, the observed surcharge begins to exceed the collusive surcharge by a significant margin. Additionally, during two distinct time periods (September 1999 – January 2000 and February 2002 – July 2003), the observed surcharge is positive while the collusive surcharge is 0. During these two periods, the collusive surcharge for grade 430 was 0 because the chromium raw material price had declined below the Madrid value of €777 per metric ton. The fact that the observed surcharge is positive implies that the trigger point for chromium was, at some point, reduced below the Madrid value.[26]

[26] Note that this pattern is most pronounced for grade 430 (Figure 2) as grade 430 contains only chromium. Grade 304 (Figure 1) also contains nickel which is significantly more expensive than chromium. When a stainless steel grade contains nickel, the majority of the surcharge is determined by the nickel component. For example, the nickel component is approximately 80-90% of the surcharge for grade 304. Thus, the impact of adjustments in the chromium trigger point are less pronounced visually in the figure for grade 304 as the chromium component makes up a relatively small share of the total surcharge.

Figure 2: Alloy Surcharges in Europe for Grade 430 Stainless Steel

Notes: This figure depicts "observed" surcharges for grade 430 stainless steel in Europe in blue. The figure also depicts the surcharge implied by the methodology with the competitive (in red) and collusive/Madrid trigger points (in green). The variable on the x-axis is calendar time. The variable on the y-axis is the alloy surcharge in euros per metric ton. The data illustrated in this figure is from CRU. The vertical dashed black line indicates the date of the cartel's end (March 31st 1998). The data ranges from August 1997 to January 2004.

5.1 Trigger Point Estimation

Table 2 presents trigger point estimates for the cartel period in Europe under both models, along with the estimated standard deviations of the error terms (for the CLEM).[27] For comparison, the table also reproduces the corresponding competitive and Madrid trigger points. The estimated trigger points are similar to the Madrid values, differing by no more than 2 percentage points for chromium and 2.5 percentage points for nickel. This suggests the cartel successfully implemented and maintained the change in trigger points agreed upon at the Madrid meeting.

Table 2 also reports post-cartel trigger point estimates, where the post-cartel period is defined as April 1998 through January 2004. For nickel, both models yield an estimate of approximately €3,650 per metric ton, which is slightly below the Madrid value and closely aligned with the cartel-period estimate. For chromium, the post-cartel estimates are approximately €650 per metric ton, significantly below the cartel-period estimate and the Madrid value. For molybdenum, no cartel-period estimate is available. However, the post-cartel estimate of roughly €3,800 per metric ton lies well below the Madrid value of €5,532 per metric ton. Overall, these results suggest little to no meaningful change in the nickel trigger point, a likely

[27]No estimate for the molybdenum trigger point is available during the cartel period because neither of the available grades during the cartel period contain molybdenum.

Table 2: Trigger Point Estimates for the Cartel (Feb 1994 - Mar 1998) and Post-Cartel (Apr 1998 - Jan 2004) Period in Europe

Parameter			Cartel Est.		Post-Cartel Est.	
	Comp. TPs	Madrid TPs	AEM	CLEM	AEM	CLEM
Nickel Trigger ($\hat{\theta}^{Ni}$)	6229	3750	3665.97	3664.96	3656.56	3640.43
			(28.77)	(31.75)	(12.35)	(10.45)
Chromium Trigger ($\hat{\theta}^{Cr}$)	834	777	786.68	778.91	658.79	672.41
			(15.49)	(14.49)	(6.35)	(3.84)
Moly Trigger ($\hat{\theta}^{Mo}$)		5532			3837.07	3821.15
					(52.88)	(65.84)
Nickel Error SD ($\hat{\sigma}_{Ni}$)				11.55		17.55
				(1.66)		(0.97)
Chromium Error SD ($\hat{\sigma}_{Cr}$)				4.73		9.28
				(2.03)		(0.42)
Moly Error SD ($\hat{\sigma}_{Mo}$)						25.01
						(1.85)
Num. Obs.			58	58	997	997
Num. Grades			2	2	42	42

Notes: This table presents trigger point estimates for the cartel period (Feb 1994 to Mar 1998) and post-cartel (Apr 1998 to Jan 2004) periods in Europe. Standard errors are in parentheses. The competitive trigger points and collusive/Madrid trigger points are also presented for comparison purposes.

reduction in the chromium trigger point, and, at least relative to the Madrid value, a substantial reduction in the molybdenum trigger point. A variety of robustness checks for the estimates in Table 2 are presented in Appendix D.3.[28]

The estimates in Table 2 are averaged over the entire post-cartel period of nearly six years (April 1998 – January 2004). Any changes in trigger points that occurred partway through this period would be masked by these averages. Several pieces of evidence suggest that such a change occurred and that it likely took place around September 1999. The clearest indication comes from a 2008 presentation to investors by ThyssenKrupp Stainless (a merged entity formed from three former cartel members), in which the company stated that the most recent adjustment to the trigger points occurred in September 1999, about a year and a half into the post-cartel period (ThyssenKrupp, 2008). While the statement does not specify the value of the trigger point (mills have revealed very little information regarding the methodology since the cartel ended (Montanstahl, 2019; LZ-Prognose, 2025)), it provides a concrete date for a change. Additional evidence

[28] Specifically, we show that results are robust to using only surcharges for grade 304 and 430 and estimating the trigger points separately for each data source.

Table 3: Trigger Point Estimates for the Early (Apr 1998 - Aug 1999) and Late (Sep 1999 - Jan 2004) Post-Cartel Period in Europe

Parameter			April 1998 – Aug 1999		Sep 1999 – Jan 2004	
	Comp. TPs	Madrid TPs	AEM	CLEM	AEM	CLEM
Nickel Trigger ($\hat{\theta}^{Ni}$)	6229	3750	3458.03	3492.84	3662.73	3658.5
			(11.14)	(5.53)	(12.67)	(10.17)
Chromium Trigger ($\hat{\theta}^{Cr}$)	834	777	765.55	759.87	654.31	660.51
			(5.05)	(6.66)	(6.63)	(3.3)
Moly Trigger ($\hat{\theta}^{Mo}$)		5532			3835.77	3819.1
					(53.72)	(66.06)
Nickel Error SD ($\hat{\sigma}_{Ni}$)				0.33		18.4
				(0.12)		(0.97)
Chromium Error SD ($\hat{\sigma}_{Cr}$)				5.15		8.02
				(0.9)		(0.35)
Moly Error SD ($\hat{\sigma}_{Mo}$)						24.69
						(1.89)
Num. Obs.			34	34	963	963
Num. Grades			2	2	42	42

Notes: This table presents trigger point estimates for the early (Apr 1998 – Aug 1999) and late (Sep 1999 – Jan 2004) post-cartel period in Europe. Standard errors are in parentheses. The competitive trigger points and collusive/Madrid trigger points are also presented for comparison purposes.

comes from a change-point detection analysis, reported in Appendix C.2, which identifies a structural break in the estimated surcharge relationship for chromium at approximately the same time.

A third source of evidence is the set of rolling trigger point estimates shown in Appendix D.2, which display a clear shift in the chromium trigger point around late 1999. Neither the change-point analysis nor the rolling estimates indicate a comparable change for nickel, but both point to a discrete change for chromium. A final piece of evidence comes from Figure 2, which shows that in late 1999 (and again in late 2002–mid 2003) the observed surcharge for grade 430 remained positive while the collusive surcharge was zero due to the fact that chromium prices had fallen below the collusive (i.e., Madrid) trigger point. Without a reduction in the trigger point, the surcharge would have been zero, implying that any change must have occurred by late 1999. The same pattern (i.e., positive surcharges when the Madrid values would result in a surcharge of zero) prevails for other grades of stainless stain containing only chromium (see Figure 13 in Appendix A).[29]

[29] Alloy prices plummeted to record lows in early 1999 (see Appendix A) with nickel reaching its lowest price since prior to

Taken together, this evidence suggests that at least one trigger point (likely chromium) was adjusted around September 1999. This motivates re-estimating the trigger points separately for an "early" post-cartel period (April 1999 – August 1999) and a "late" post-cartel period (September 1999 – January 2004) to isolate the effects of this (possible) adjustment. Results from this analysis are presented in Table 3. The early post-cartel estimates should be interpreted with caution: they are based on only 34 observations covering two grades, and in many cases the surcharges are zero (particularly for grade 430). With that caveat in mind, the early post-cartel estimates suggest a slight dip in the nickel trigger point relative to the cartel period. Chromium, by contrast, shows no meaningful difference relative to the cartel period in this short window.[30]

In the late post-cartel period, where many more observations and grades are available, the estimates are more stable. Here, the nickel trigger point is largely consistent with the cartel-period, while the chromium trigger point is approximately 17% lower than during the cartel. These estimates provide more concrete evidence of a downward shift in the chromium trigger point around September 1999.

5.2 Hypothesis Tests

Using the trigger point estimates from the preceding section, we next formally test whether the mills, in line with the behavioral remedy mandated by the EC, raised their trigger points after the cartel ended.

Table 4 reports results from Wald tests and bootstrap-based tests.[31] For nickel, the hypothesis that the post-cartel trigger point is greater than or equal to the cartel period trigger point ($H_0 : \theta_c^{Ni} \leq \theta_{pc}^{Ni}$) cannot be rejected (under both Wald and bootstrap-based tests). However, the data reject the nulls that the nickel trigger was increased by 2.5% ($H_0 : 1.025 \left(\theta_c^{Ni}\right) \leq \theta_{pc}^{Ni}$) and 5% ($H_0 : 1.05 \left(\theta_c^{Ni}\right) \leq \theta_{pc}^{Ni}$). These results are consistent with the interpretation that nickel was left essentially unchanged.

Turning to chromium, the null hypothesis that the post-cartel trigger point is greater than or equal to the trigger point during the cartel period ($H_0 : \theta_c^{Cr} \leq \theta_{pc}^{Cr}$) is rejected under both Wald and bootstrap-based tests. The null hypothesis that the post-cartel chromium trigger point exceeds the Madrid value ($H_0 : 777 \leq \theta_{pc}^{Cr}$), the null hypothesis that the chromium trigger point was increased by 2.5% ($H_0 : 1.025 \left(\theta_c^{Cr}\right) \leq \theta_{pc}^{Cr}$), and the null hypothesis that the chromium trigger point was increased by 5% ($H_0 : 1.05 \left(\theta_c^{Cr}\right) \leq \theta_{pc}^{Cr}$) are all rejected. The hypothesis that the late post-cartel period trigger point is greater than or equal to the cartel period

the cartel's formation and chromium reaching its lowest price since 1994. This caused zero surcharges in early 1999 because the alloy prices were below the trigger points. Such a situation last occurred in 1993, just prior to the Madrid meeting and the formation of the cartel. The abrupt decline in alloy prices in early 1999 (and the resulting zero surcharges) may have served as an impetus for an adjustment in the trigger points, just as it had in 1993 when the cartel began.

[30] Even under a literal interpretation of the wording in the EC's directive (see Subsection 2.2), under which firms were merely required to change their trigger points to values different from those employed during the cartel, the estimates in Table 3 suggest that the mills did not meaningfully comply with the remedy in practice. For approximately seventeen months following the cartel's detection, firms continued to apply trigger points that closely resemble the Madrid values.

[31] In Appendix E.1, we show that hypothesis testing results are robust to using only surcharges for grades that appear in both the cartel and post-cartel period (i.e., grade 304 and 430).

trigger point ($H_0 : \theta_c^{Cr} \leq \theta_{pcl}^{Cr}$) is rejected. However, the hypothesis that the early post-cartel period trigger point is greater than or equal to the cartel period trigger point ($H_0 : \theta_c^{Cr} \leq \theta_{pce}^{Cr}$) is either not rejected or only marginally rejected at the 10% level. These findings are consistent with the narrative that the chromium trigger declined around September 1999.

As data from grades containing molybdenum are not available during the cartel period, fewer tests of the molybdenum trigger point can be conducted. However, the null that the molybdenum trigger point in the post-cartel period exceeds the Madrid value ($H_0 : 5532 \leq \theta_{pc}^{Mo}$) is rejected. Turning to joint hypotheses tests, the null that both trigger points were increased ($H_0 : \theta_c^{Ni} \leq \theta_{pc}^{Ni}$ and $\theta_c^{Cr} \leq \theta_{pc}^{Cr}$) is firmly rejected. Similarly, the null that both trigger points were increased in the early post-cartel period ($H_0 : \theta_c^{Ni} \leq \theta_{pce}^{Ni}$ and $\theta_c^{Cr} \leq \theta_{pce}^{Cr}$) and the null that trigger points in the late post-cartel period exceed those of the cartel period ($H_0 : \theta_c^{Ni} \leq \theta_{pcl}^{Ni}$ and $\theta_c^{Cr} \leq \theta_{pcl}^{Cr}$) are both rejected. Finally, the null that all three trigger points were increased above the Madrid values is also rejected ($H_0 : 3750 \leq \theta_{pc}^{Ni}$, $777 \leq \theta_{pc}^{Cr}$, and $5532 \leq \theta_{pc}^{Mo}$).

The graphical analysis, trigger point estimates, and formal hypothesis tests in this section point toward a similar conclusion: there is little indication that the mills meaningfully increased their trigger points after the cartel, contrary to the behavior remedy imposed by the EC. For nickel, the results suggest the trigger point remained largely unchanged. For chromium, the balance of evidence indicates a reduction, or, at a minimum, no increase. For molybdenum, the estimates do not support an increase above the Madrid value. Joint tests likewise provide little support for the view that producers raised their trigger points.

Taken together, these findings suggest that the mills are unlikely to have fully implemented the behavioral remedy imposed by the Commission. While the results cannot establish non-compliance with certainty, they consistently point toward little to no upward adjustment of trigger points, and in the case of chromium, possibly even a downward shift.

Table 4: Hypothesis Testing Results for Europe

	Null Hypothesis	Wald P-value		Bootstrap P-value
		AEM	CLEM	AEM
Nickel Tests:	$H_0 : \theta_c^{Ni} \leq \theta_{pc}^{Ni}$	0.431	0.231	0.550
	$H_0 : 1.025\left(\theta_c^{Ni}\right) \leq \theta_{pc}^{Ni}$	0.035*	$<$ .001***	0.004**
	$H_0 : 1.05\left(\theta_c^{Ni}\right) \leq \theta_{pc}^{Ni}$	$<$ .001***	$<$ .001***	$<$ .001***
	$H_0 : \theta_c^{Ni} \leq \theta_{pce}^{Ni}$	$<$ .001***	$<$ .001***	$<$ .001***
	$H_0 : \theta_c^{Ni} \leq \theta_{pcl}^{Ni}$	0.459	0.423	0.629
	$H_0 : 3750 \leq \theta_{pc}^{Ni}$	$<$ .001***	$<$ .001***	$<$ .001***
Chromium Tests:	$H_0 : \theta_c^{Cr} \leq \theta_{pc}^{Cr}$	$<$ .001***	$<$ .001***	$<$ .001***
	$H_0 : 1.025\left(\theta_c^{Cr}\right) \leq \theta_{pc}^{Cr}$	$<$ .001***	$<$ .001***	$<$ .001***
	$H_0 : 1.05\left(\theta_c^{Cr}\right) \leq \theta_{pc}^{Cr}$	$<$ .001***	$<$ .001***	$<$ .001***
	$H_0 : \theta_c^{Cr} \leq \theta_{pce}^{Cr}$	0.097*	0.116	0.095*
	$H_0 : \theta_c^{Cr} \leq \theta_{pcl}^{Cr}$	$<$ .001***	$<$ .001***	$<$ .001***
	$H_0 : 777 \leq \theta_{pc}^{Cr}$	$<$ .001***	$<$ .001***	$<$ .001***
Moly Tests:	$H_0 : 5532 \leq \theta_{pc}^{Mo}$	$<$ .001***	$<$ .001***	$<$ .001***
Joint Tests:	$H_0 : \theta_c^{Ni} \leq \theta_{pc}^{Ni}$ and $\theta_c^{Cr} \leq \theta_{pc}^{Cr}$			$<$ .001***
	$H_0 : \theta_c^{Ni} \leq \theta_{pce}^{Ni}$ and $\theta_c^{Cr} \leq \theta_{pce}^{Cr}$			$<$ .001***
	$H_0 : \theta_c^{Ni} \leq \theta_{pcl}^{Ni}$ and $\theta_c^{Cr} \leq \theta_{pcl}^{Cr}$			$<$ .001***
	$H_0 : 3750 \leq \theta_{pc}^{Ni}$ and $777 \leq \theta_{pc}^{Cr}$			$<$ .001***
	$H_0 : 3750 \leq \theta_{pc}^{Ni}$, $777 \leq \theta_{pc}^{Cr}$, and $5532 \leq \theta_{pc}^{Mo}$			$<$ .001***

Notes: This table presents hypothesis testing results for Europe. The bootstrap p-values are calculated using a residual bootstrap procedure. Bootstrap-based tests are conducted using 10,000 bootstrap replications. θ_c^j denotes the trigger point for the cartel period for alloy $j \in \{\text{Ni}, \text{Cr}, \text{Mo}\}$. θ_{pc}^j denotes the trigger point for the post-cartel period for alloy $j \in \{\text{Ni}, \text{Cr}, \text{Mo}\}$. θ_{pce}^j denotes the trigger point for the early post-cartel period for alloy $j \in \{\text{Ni}, \text{Cr}, \text{Mo}\}$. θ_{pcl}^j denotes the trigger point for the late post-cartel period for alloy $j \in \{\text{Ni}, \text{Cr}, \text{Mo}\}$. *** indicates the null is rejected at a .001 level. ** indicates the null is rejected at a .01 level. * denotes the null is rejected at a .1 level.

6 Surcharge Pricing in the United States

In this section, we present trigger point estimates for the U.S. stainless steel market. Recall that U.S. producers were not accused of involvement in the cartel, nor were they required to adjust their trigger points in any way. Figure 3 depicts alloy surcharges for grade 304 in the U.S., along with two benchmark surcharge series constructed for comparison.[32] These benchmarks are not observed prices. Rather, they are hypothetical surcharges calculated using the U.S. surcharge formula under alternative trigger points. The "collusive" benchmark is calculated using the Madrid trigger points from Europe (converted to dollars per pound), while the "competitive" benchmark is calculated using the competitive European trigger points.[33]

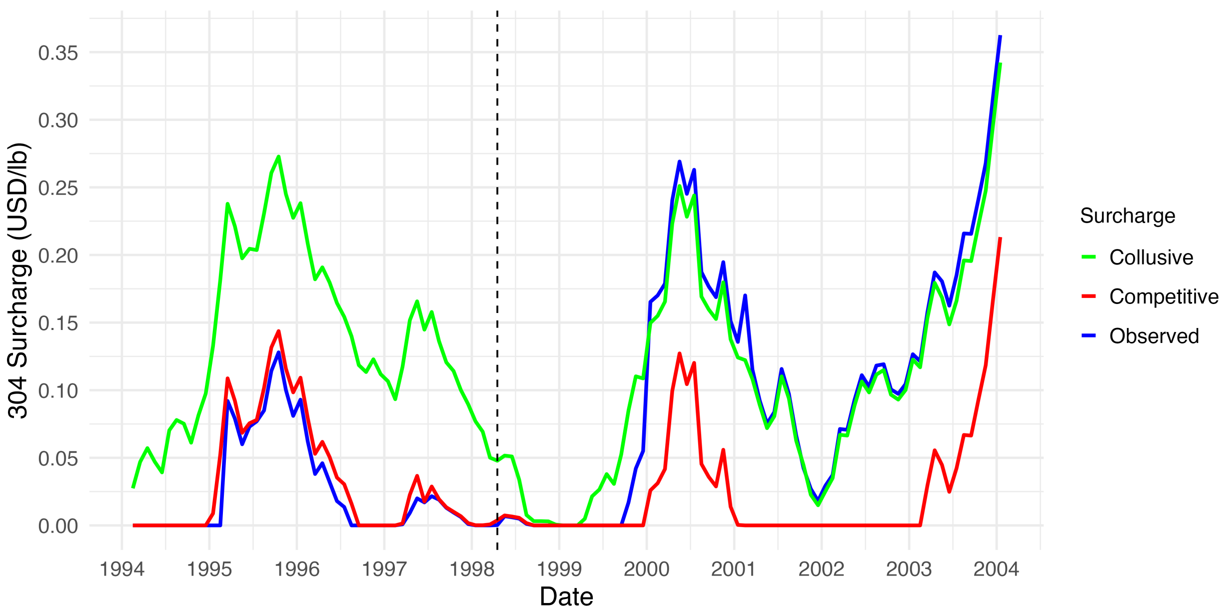

Figure 3: Alloy Surcharges in the United States for Grade 304 Stainless Steel

Notes: This figure depicts "observed" surcharges for grade 304 stainless steel in the United States in blue. The figure also depicts the surcharge implied by the methodology with the competitive European trigger points (in red) and collusive/Madrid trigger points (in green). These trigger points are convented from EUR/metric ton to USD/lb. The variable on the x-axis is calendar time. The variable on the y-axis is the alloy surcharge in dollars per pound. The data illustrated in this figure are from CRU. The vertical dashed black line indicates the date of the cartel's end (March 31st 1998). The data ranges from February of 1994 to January of 2004.

The figure indicates a striking pattern. Until the final months of 1999, the observed surcharge closely tracks the competitive benchmark. However, toward the end of 1999, the observed surcharge begins to align with the collusive benchmark instead. This suggests that U.S. producers may have initially employed trigger points similar to the European competitive values but then shifted to values resembling those developed by

[32] A corresponding figure for grade 430 is presented in Appendix A.

[33] When converting trigger points, we use the exchange rates agreed upon by European producers at the Madrid meeting: 1.179 USD/EUR for nickel, 1.182 USD/EUR for chromium, and 1.171 USD/EUR for molybdenum (Alloy Surcharge Decision, 1998). Because the U.S. and European methodologies differ (see Subsection 2.3), these two hypothetical price series are not equivalent to those in Figure 1, even after currency conversion.

the European cartel.

Motivated by these observations, we estimate U.S. trigger points separately before and after January 2000. Table 5 reports the results. Table 5 also includes, for comparison, the Madrid trigger points, the European competitive trigger points, and late post-cartel European estimates from the AEM (all of which are converted to dollars per pound). The estimates suggest that, prior to January 2000, the nickel trigger point in the U.S. was around \$3.50 per pound and the chromium trigger point about \$0.45 per pound. These values are close to the competitive European triggers, particularly for chromium. In January 2000, the estimated nickel trigger point falls to \$2.00, the chromium trigger falls to \$0.35, and the molybdenum trigger is approximately \$3.00. The estimated nickel trigger point of \$2.00 and the estimated molybdenum trigger point of \$3.00 are almost identical to the Madrid trigger points. Additionally, the chromium trigger estimate of \$0.35 closely resembles the trigger point in the late post-cartel period in Europe. Finally, rolling estimates for chromium and nickel, presented in Appendix D.2, provide further visual evidence of a sharp downward adjustment in both the chromium trigger (from \$0.45 to \$0.35) and the nickel trigger (\$3.50 to \$2.00) around late 1999.[34]

Documents released by U.S. producers further support this narrative. Specifically, multiple producers have publicly revealed that the trigger points were changed around January 2000.[35] Additionally, two major U.S. producers, AK Steel and ATI, have, at various times, publicly disclosed their trigger points on their websites or within their pricing lists to consumers (the earliest of which dates to May 2004). In every instance, they reported a nickel trigger point of \$2.00, a chromium trigger point of \$0.35, and a molybdenum trigger point of \$3.00 (see Appendix A), which is highly consistent with the estimates (from January 2000 to January 2004) presented in Table 5. Finally, a change point detection analysis (presented in Appendix C.2) provides further evidence that trigger points in the U.S. were adjusted in January of 2000.

Taken together, the evidence is consistent with U.S. producers initially employing trigger points resembling the European competitive levels then revising them at the end of 1999 to match trigger points from Europe. Specifically, evidence suggests U.S producers adjusted the nickel and molybdenum trigger point to match the Madrid value developed by the cartel 6 years prior. The chromium price was adjusted to

[34]The trigger points in Table 5 (for the U.S.) are more precisely estimated than trigger points in Europe (Table 2 and Table 3). This could reflect a greater degree of conformity with the methodology across U.S. producers. Indeed, U.S. producers typically published a greater amount of information about their methodologies than European producers, perhaps due to a lesser degree of antitrust scrutiny historically. A greater degree of information sharing by producers may lead to greater compliance with the methodology. The greater degree of precision in the U.S. estimates relative to Europe may also reflect the fact that U.S. producers did not need to convert raw material prices from dollars to euros. This eliminates any variation caused by differences in exchange rates across producers.

[35]Carpenter Technology reports that the "1999 base values" are currently in use (Carpenter Technologies, 2025). Allegheny Technologies Incorporated (ATI) stated in its 2000 annual report that "[o]perating profit increased [...] in 2000 primarily due to revised raw material surcharge base levels" (ATI, 2000). Universal Stainless and Alloy Products likewise reported that price increases were implemented in "September 1999" (Universal Stainless and Alloy Stainless and Products, 2000). Finally, a ThyssenKrupp presentation indicates that trigger points in the U.S. were changed in January 2000 (ThyssenKrupp, 2008).

Table 5: Trigger Point Estimates for Feb 1994 - Dec 1999 and Jan 2000 - Jan 2004 Periods in the United States

Parameter	Comp. TPs (\$/lb)	Madrid TPs (\$/lb)	Late PC EU TPs (\$/lb)	Feb 1994 - Dec 1999		Jan 2000 - Jan 2004	
				AEM	CLEM	AEM	CLEM
Nickel Trigger ($\hat{\theta}^{Ni}$)	3.331	2.0054	1.9588	3.5263	3.5194	2.0083	1.9988
				(0.0203)	(0.069)	(0.00097)	(0.00048)
Chromium Trigger ($\hat{\theta}^{Cr}$)	0.447	0.4166	0.3508	0.4469	0.4483	0.3518	0.355
				(0.0046)	(0.0017)	(0.00067)	(.0007)
Moly Trigger ($\hat{\theta}^{Mo}$)		2.9383	2.0374			2.9572	2.9996
						(0.018)	(0.0015)
Nickel Error SD ($\hat{\sigma}_{Ni}$)					0.0309		0.00068
					(0.005)		(5.7e-05)
Chromium Error SD ($\hat{\sigma}_{Cr}$)					0.0024		0.0048
					(0.00026)		(0.00011)
Moly Error SD ($\hat{\sigma}_{Mo}$)							2.7e-05
							(2.8e-06)
Num. Obs.				142	142	2208	2208
Num. Grades				2	2	53	53

Notes: This table presents trigger point estimates, for both the CLEM and AEM, for two periods: Feb 1994 to Dec 1999 and Jan 2000 to Jan 2004. Standard errors are in parentheses. The competitive European trigger points, Madrid (i.e., collusive) trigger points, and late post-cartel period trigger point estimates (from the AEM in the EU), converted to dollars per pound, are also presented for comparison purposes.

match the trigger point employed by European producers beginning in September 1999.[36] Trigger point estimates using additional data from after the introduction of the iron component in early 2004 suggest that the adjustments made in early 2000 were maintained for at least 18 years (see Appendix C.3).

For at least two reasons, the evidence presented in this section suggests that the reduction in U.S. trigger points in January 2000 is unlikely to reflect purely competitive, unilateral conduct. Instead, the pattern is more consistent with producers tacitly coordinating a reduction in trigger points, using the European trigger points as focal points. First, the new U.S. triggers match the European cartel's values almost exactly, despite the fact that the two markets faced distinct cost and demand conditions. If the changes were driven by independent competitive forces, one would not expect such precise alignment. Second, differences in surcharge methodology, most notably the 1.2 yield factor used in the U.S., mean that adopting identical trigger points did not simply harmonize surcharges across regions. Thus, U.S. producers were coordinating on the same numerical triggers, not merely responding to similar cost structures or engaging in parallel price matching. Taken together, these factors indicate that the European cartel's trigger points may have served

[36] As in Europe, alloy prices in the U.S. reached exceptionally low levels in early 1999 (see Appendix A). The abrupt decline in alloy prices in early 1999 resulted in the removal of surcharges for many stainless steel grades, as the methodology dictated. This may have caused producers to consider lowering their trigger points in order to re-activate (and increase) the alloy surcharges.

as focal points for tacit coordination among U.S. producers.

7 Discussion and Policy Implications

The evidence presented in Section 5 suggests that, following the European Commission's detection and dissolution of the stainless steel cartel, mills continued to apply pricing formulas consistent with the collusive regime for at least six years. This persistence implies that while explicit coordination ceased, tacit collusion effectively preserved supra-competitive outcomes. This finding provides several broader implications for antitrust enforcement and policy design.

7.1 The Durability of Formulaic Collusion

The risk of persistent tacit collusion appears particularly acute when explicit coordination establishes a detailed pricing formula tied to observable market variables. Several prominent cases exhibit this structure: the air cargo cartel linked fuel surcharges to jet fuel spot prices,[37] the steel abrasives cartel tied scrap surcharges to metal scrap price indices,[38] and ferry operators coordinated currency surcharges based on published exchange rates.[39] In contrast to cartels requiring repeated explicit communication to adjust prices in response to changing market conditions, formula-based schemes automatically adapt to cost fluctuations. Once the methodology is established/adjusted through explicit coordination, which exposes participants to antitrust liability, firms may sustain collusion simply by adhering to the agreed formula without further communication.

Traditional cartel enforcement focuses on detecting and penalizing explicit communication. However, when collusion involves a self-executing pricing formula, breaking up the conspiracy and imposing fines may be insufficient to end collusion, as the underlying pricing mechanism remains intact, available, and effective.

7.2 Designing Behavioral Remedies

Given the elevated risk of post-cartel tacit collusion in formula-based cases, behavioral remedies (measures requiring firms to alter specific business practices) appear warranted. In the stainless steel case, the European Commission imposed such a remedy, requiring mills to increase their trigger points in 1998. The empirical evidence suggests, however, that the remedy was ignored: trigger points did not increase and, for chromium, actually decreased.

[37] CASE AT.39258 – Airfreight. 11/09/2010.
[38] CASE AT.39792 – Steel Abrasives. 5/25/2016.
[39] Commission Decision 97/84/EC, 1997 O.J. (L 26) 23 (IV/34.503 — Ferry operators — Currency surcharges).

Non-compliance appears to have gone undetected by the EC, purchasers, and industry observers. Crucially, the EC's resources are severely limited. A recent audit found that, "due to limited resources, capacities for monitoring of markets and own detection of antitrust cases were limited." Additionally, some complaints and possible infringements cannot be pursued due to limited staff and resources (European Court of Auditors, 2024).[40] Additionally, detecting a violation of the remedy in this case was particularly challenging. Trigger points are not publicly disclosed, making compliance verification substantially more complex than observing prices or comparing published price lists. Verification required: (1) obtaining proprietary alloy price data, (2) determining alloy percentages and exchange rates used in calculations, and (3) estimating trigger points using econometric methods similar to those employed in this study. Consumers and third-party observers likely did not possess sufficient incentives or resources to regularly undertake this analysis.

A more transparent approach of forbidding the use of alloy surcharges altogether would have offered two advantages. First, it would have rendered the collusive trigger points irrelevant, forcing firms to compete on base prices which, as they are negotiated privately with customers, are difficult to coordinate tacitly. Second, it would have been simple for customers and authorities to observe compliance.[41] Both the EC and customers could immediately detect whether firms continued charging separate surcharges. Such a remedy carries trade-offs. Forbidding surcharges altogether might limit firms' ability to respond quickly to cost changes and would reduce price transparency for consumers. However, widespread customer dissatisfaction with the surcharge system (Fastmarkets, 2012) suggests the competitive benefits may outweigh these costs. Moreover, Asian producers operate successfully without separate alloy surcharges (Giuliodori and Rodriguez, 2015), demonstrating that the practice is not essential to a mill's operations.

More broadly, the stainless steel case suggests that the effectiveness of behavioral remedies depends critically on the ease of monitoring compliance. Remedies should be designed either with robust monitoring mechanisms or, preferably, in forms where violations are immediately observable to customers, competitors, and enforcers. Complex, opaque remedies may prove unenforceable and ineffective in practice.

[40]"With the remaining staff available, DG COMP is not in a position to pursue all complaints received but has to set priorities" (European Court of Auditors, 2024). Similarly, "[a]s regards to the potential infringements that are brought to its attention, the Commission is not in a position, due to its limited resources, to pursue all potential infringements of EU antitrust rules" (European Court of Auditors, 2024).

[41]A more interventionist approach has precedent: in the E-Books case (Case COMP/39.847), the Commission required publishers to abandon the very contractual framework that enabled coordination (i.e., agency agreements with most favored nation (MFN) clauses) in order to restore competition and prevent the re-emergence of coordination, rather than simply adjusting parameters within the framework, as in the stainless steel case.

7.3 Legal Status of Post-Cartel Conduct

Even absent the behavioral remedy, the mills' continued use of collusive trigger points may have constituted a violation of EU competition law at that time:[42]

> "[T]he Commission contends that, in any event, it is clear from the case-law on Article 85(1) of the EC Treaty [the general cartel prohibition] that that article is applicable if parallel conduct by certain undertakings, originally deriving from an agreement, continues even after the agreement has come to an end" (Krupp Thyssen Judgment, 2001).

If the mills' post-cartel pricing methodologies derived from parameters established at the Madrid meeting, their conduct could be characterized as a continuation of price fixing. Indeed, the Court applied precisely this logic when determining the cartel's duration, finding that because producers "did not cease applying the [trigger] values agreed at the Madrid meeting before the adoption of the Decision, the Commission was entitled to take the view that the infringement had lasted until that date" (Krupp Thyssen Judgment, 2001). The same reasoning applies to the post-decision period.[43]

7.4 Cross-Market Spillovers and Focal Point Adoption

Trigger point estimates from the U.S. suggest an unanticipated channel through which cartels harm consumers: collusive pricing parameters can migrate across markets as focal points for tacit coordination. U.S. stainless steel producers, who were not parties to the European cartel and faced no antitrust scrutiny, adjusted their trigger points around January 2000 to align with the collusive values established in Europe. The nickel and molybdenum triggers almost exactly matched the Madrid values, while the chromium trigger matched the post-September 1999 European level. Such spillover effects are difficult to prevent. When resources permit, antitrust authorities may wish to proactively monitor not only the markets directly affected by a conspiracy, but also related markets where similar pricing structures exist. However, such monitoring faces an important limitation: because the resulting coordination may be tacit rather than explicit, it may fall outside the scope of antitrust liability altogether. U.S. producers violated no antitrust laws; they simply

[42] The relevant price-fixing law governing steel producers evolved over the years during and after the cartel. Between 1952–2002, Article 65 of the ECSC Treaty forbid these practices in the coal and steel industries. After the ECSC Treaty expired in 2002, coal and steel were brought fully under the general EU competition regime, first under Article 81 EC, renumbered from Article 85 by the Treaty of Amsterdam in 1999, and subsequently under Article 101 TFEU following the Treaty of Lisbon in 2009. However, each of these articles contains similar language forbidding agreements, decisions, and concerted practices that restrict competition.

[43] The European Court of Justice (ECJ) had earlier adopted the same principle in EMI Records (Case 51/75), holding that "for Article 85 to apply to a case ... of agreements which are no longer in force it is sufficient that such agreements continue to produce their effects after they have formally ceased to be in force." This same legal rule has been reaffirmed by the ECJ under Article 101 TFEU (the current E.U. cartel prohibition), the court treats continued post-agreement effects as extending an infringement's duration (Koivusalo, 2024).

adopted pricing parameters that had been publicly disclosed (revealed in publicly available court documents) in another jurisdiction.[44]

Prior literature has emphasized the role of focal points based on price ceilings (Knittel and Stango, 2003; Genakos, Koutroumpis and Pagliero, 2018; Zhang et al., 2020) and round numbers (Lewis, 2015; Chan, Lin and Lin, 2025) in facilitating collusion. The stainless steel case reveals that technical parameters embedded in pricing formulas, especially those publicized through cartel enforcement proceedings, can serve the same coordinating function across geographically and legally separate markets. This cross-jurisdictional spillover effect provides additional justification for treating formula-based collusion with particular severity. When cartels establish explicit pricing formulas, they create durable focal points that can facilitate coordination beyond the original conspiracy's scope.

8 Conclusion

We have analyzed post-cartel pricing behavior in the European stainless steel industry. Despite directions from the European Commission to increase their trigger points (which would reduce prices), evidence suggests steel producers actually maintained or reduced their trigger points after the end of the cartel. This finding is consistent with producers continuing to collude tacitly after the cartel's dissolution.

The results of this study have a number of implications for cartel policy. First, the detection of a cartel, and the subsequent imposition of fines, may be insufficient to restore competition to the market, as firms may continue to tacitly collude after the cartel's dissolution. Second, the risk of post-cartel tacit collusion appears particularly pronounced when the cartel involves the development/adjustment of a specific pricing formula (Turner, 2024). Firms can simply collude by continuing to follow the pricing formula developed/revised during the cartel, without any need to communicate. Given the elevated risk of post-cartel tacit collusion in cases involving formulaic pricing, a more aggressive intervention than fines, such as a behavioral remedy, appears warranted. Such a behavioral remedy was imposed on producers in the stainless steel case. However, our findings suggest this behavioral remedy was largely unsuccessful due to a lack of compliance. To prevent this outcome, compliance with behavioral remedies must be closely monitored by antitrust authorities or, alternatively, the remedy must be designed such that consumers and third-parties can readily observe violations of the remedy. Finally, pricing patterns in the U.S. suggest that pricing methodologies developed through collusion in one market can act as focal points for successful tacit collusion in another market. This finding provides further justification for treating formula-based collusion more severely than traditional car-

[44] European producers sent letters to their customers after the Madrid meeting informing them of a change in the trigger points (Alloy Surcharge Decision, 1998). While these letters were often vague regarding the exact level of the revised trigger points, U.S. producers may have first learned the values of the (revised) European trigger points through these communications or another channel, rather than court documents published by the EC.

tels: in addition to enabling persistent coordination within the original market, formula-based collusion can spillover into distinct markets in ways that are challenging to prevent or penalize under existing antitrust frameworks.

A few caveats to the preceding analysis merit consideration. First, the foregoing analysis does not include firm-level surcharge data from all relevant producers (although it does include averages). Thus, the analysis does not imply all producers failed to comply with the behavioral remedy, nor that all producers continued to collude tacitly after the cartel's detection.[45] Second, the empirical analysis has utilized only data on surcharges, rather than base prices, because the cartel only fixed surcharges, not base prices. Thus, our findings do not imply that collusion led to higher final prices for the mills' customers. However, a growing theoretical literature has demonstrated that artificially inflating a portion of final prices (e.g., surcharges) can increase final prices (Harrington and Ye, 2019; Chen, 2023; Harrington, 2024). Finally, the analysis in the main text restricts attention to conduct prior to the introduction of the iron component to the surcharge methodology in early 2004. The introduction of the iron component complicates the identification of trigger points. However, evidence presented in Appendix C.3 suggests the introduction of the iron component raised surcharges and therefore may represent an enhancement/adjustment of the collusive methodology, rather than a breakdown of collusion.

[45] Appendix C.1 examines inter-firm price dispersion and shows that surcharge levels are exceptionally similar across producers (both in Europe and the U.S.), suggesting that industry averages (and data from a subset of producers) may be representative of surcharge levels throughout the industry. This analysis incorporates data from additional producers for whom surcharge data are available only after the introduction of the iron component (see Appendix A). The surcharges imposed by these producers closely match industry averages and those of the producers available in the pre-iron period.

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Technical Appendix for "Is Cartel Enforcement Effective? Evidence from the Stainless Steel Industry"

Daniel A. Garcia and Douglas C. Turner

A Data Appendix

In this section, we provide additional details regarding the dataset. The analysis in the main text only uses data from prior to the introduction of the iron component in February 2004. Additional data and sources are available after the introduction of the iron component, and these are analyzed in later sections of this appendix. Thus, the full dataset (including these additional sources/data) are discussed in this section. Table 6 summarizes all available data.

CRU Data: CRU International is a global commodity market intelligence and consulting firm. CRU provided surcharge data for both the U.S. and Europe for grades 304 and 430. Data for grade 304 in both regions are available from January 1994 to December 2019. Data for grade 430 in Europe are available only from August 1997 to December 2019, while 430 data for the U.S. span February 1994 to December 2019. Alloy surcharges from CRU are monthly prices based on a weighted average of spot transactions (deals that are neither contract-based nor for forward delivery) concluded in Germany. Germany represents the largest stainless steel market in Europe (ThyssenKrupp, 2008), and German surcharges are generally considered representative of prices in Europe (Giuliodori and Rodriguez, 2015). Moreover, prices across Europe are highly correlated (Giuliodori and Rodriguez, 2015).

Legierungszuschlag Data: Legierungszuschlag.info is an informational service provided by Norder Band AG, a German steel distributor. The service provides surcharges for a variety of grades (in Europe) between January 2001 and December 2019. The service states that these surcharges are "based on the prices published by home producers in Germany."

European Outokumpu Data: Outokumpu, a large Finnish producer, publishes surcharge data on its website. Historical data are collected from archived versions of its website (stored on https://web.archive.org). Specifically, data is collected from archives of monthly surcharge reports that list the alloy surcharge for various grades. More recent surcharges are downloaded from https://www.outokumpu.com/en/surcharges/stainless-steel-alloy-surcharges-europe.

ThyssenKrupp Data: Data for ThyssenKrupp, a large German producer, are collected from archived versions of its website (stored at https://web.archive.org). Specifically, data are obtained from archived

Table 6: Data Sources in Europe and the U.S. (Full Dataset)

Panel A: Europe

Source	Type	Num. Grades	Time Period
CRU	Data Provider	2	2/1994 - 12/2019
Legierungszuschlag.info	Informational Service	25	1/2001 - 12/2019
Outokumpu	Producer	38	6/2003 - 12/2019
ThyssenKrupp	Producer	31	1/2003 - 12/2012
Aperam/ArcelorMittal	Producer	19	1/2008 - 12/2019

Panel B: US

Source		Num. Grades	Time Period
CRU	Data Provider	2	2/1994 - 12/2019
AK Steel	Producer	30	1/2000 - 12/2019
Allegheny Technologies Incorporated (ATI)	Producer	66	1/2001 - 12/2019
North American Stainless	Producer	18	1/2014 - 12/2018
Outokumpu North America	Producer	22	7/2016 - 12/2019

Notes: This table describes available data sources for the Europe (Panel A) and American (Panel B) markets. For each source, the reported time range spans from the earliest available observation to the latest, across all stainless steel grades.

yearly surcharge reports listing the alloy surcharge for a variety of grades.

Aperam/ArcelorMittal Data: ArcelorMittal, a large Luxembourg-based steel producer, spun off its stainless steel division (Aperam) in 2011 (Aperam, 2011). Accordingly, surcharges from ArcelorMittal (before 2011) and Aperam (2011 onward) are treated as a single data source. This series begins in 2008 and is therefore not included in the main-text analysis. The data are collected from archived versions of Aperam and ArcelorMittal websites. More recent surcharges are available at https://www.aperam.com/alloys-surcharge/.

AK Steel Data: AK Steel is a large American producer. Surcharges are collected from archived versions of its website (http://www.aksteel.com/markets_products/stainless_surcharges.asp), specifically from monthly reports. These reports also contain alloy prices for each month and, at times, the trigger points themselves. Crucially, AK Steel's surcharge reports decompose the alloy surcharge by component, reporting not only the total surcharge for each grade but also the value of each component separately.

ATI Data: Allegheny Technologies Incorporated (ATI) is another large American producer. Historical surcharges for ATI are downloaded from their website.[46] ATI's current trigger points can also be found on

[46]http://www.atimaterials.com/specialtyrolledproducts/Pages/surcharge-history.aspx

its website.[47]

North American Stainless Data: Surcharges for North American Stainless, a U.S. producer, are obtained from the website of Stanch Stainless Steel (https://www.stanch.com/msg/message-2014-35.htm), a steel finisher. North American Stainless' surcharge reports also decompose the alloy surcharge by component.

U.S. Outokumpu Data: Surcharges for Outokumpu in the Americas are downloaded from its website (https://www.outokumpu.com/en/surcharges/stainless-steel-alloy-surcharges-americas). Note that Outokumpu applies different surcharges in Europe and the Americas.

Alloy Percentages: For Europe, the percentages of each alloy in a stainless steel grade (e.g., the percentages of nickel, chromium, and molybdenum) are taken from the British Stainless Steel Association (BSSA) and the websites of various producers. For grades 304 and 316, the alloy percentages were reported directly in the surcharge decision (Alloy Surcharge Decision, 1998). For the United States, alloy percentages are obtained from the websites and surcharge reports of ATI and AK Steel. ATI directly reports the alloy percentages for the grades it produces (https://myati.atimaterials.com/marketsurcharge/SurCalc.asp?type=Steel). Because AK Steel reports the value of each component separately, alloy percentages can be directly inferred from its surcharge reports. We allow alloy percentages to differ slightly across regions, as available data suggest that while percentages for a given grade are generally similar, small regional differences exist.

Alloy Prices: We collected pricing data for the metals involved in the formula for calculating the alloy surcharge (primarily nickel, chromium, and molybdenum) for both Europe and the United States. Using Automeris, an online data-mining tool, we extracted European chromium prices from 1994 to 2019 from graphs in Outokumpu's annual and quarterly reports. As these are the prices quoted by Outokumpu (a large Finnish mill), they are likely to reflect the prices used in the calculation of their surcharges. Outokumpu's reports cited various sources. From 1994 to 2000, Outokumpu referenced prices from Metal Bulletin under the category "lumpy Cr charge, basis 52% Cr, free market"; in 2001, they referenced prices from Metal Bulletin under the category "lumpy 52%"; from 2002 to 2004, they referenced prices from CRU under the category "US Imported 50-55% high Carbon Cr"; from 2005 to 2010, they referenced prices from Metal Bulletin under the category "Ferrochrome lumpy chrome charge, basis 52% chrome"; and from 2011 to 2019, they referenced prices from contracts agreed between South African producers of chromium and European buyers. From 1994 to 2010, this price was detailed monthly; after 2011, it was detailed quarterly. Similarly, to collect chromium prices for the United States, we gathered pricing data from documents published by North American stainless steel producers. We gathered chromium prices from Universal Steel, NAS, and primarily, AK Steel surcharge reports. In 2006, 2007, 2018, and 2019, we were unable to locate surcharge reports from these companies and therefore collected chromium prices from other sources. Instead, chromium pricing data

[47]https://myati.atimaterials.com/marketsurcharge/SurCalc.asp?type=Steel

for 2018 and 2019 was extracted from the 2019 Acerinox annual report, as it aligned with collected prices before 2018 and after 2019. In 2006 and 2007, chromium prices are from the U.S. Geological Survey (USGS) Minerals Yearbooks.

We collected European molybdenum pricing data in a similar fashion to chromium, obtaining molybdenum prices from graphs available in Outokumpu annual reports. Outokumpu referenced prices from Metal Bulletin under the category "molybdenum oxide, Europe" as well as monthly prices provided by the London Metal Exchange. From 2013 onwards, Outokumpu referenced prices from Metal Bulletin under the category "Molybdenum Drummed molybdic oxide. Free market $ per lb Mo in warehouse." To collect molybdenum pricing data for the United States, we again used prices referenced by North American stainless steel producers in their surcharge reports, as well as the USGS Minerals Yearbook.

The nickel prices in our dataset, for both Europe and the United States, are from the London Metal Exchange (LME). This data aligned with European nickel prices provided by Outokumpu in their annual and quarterly reports, prices quoted in surcharge reports of American producers, and with the yearly financial reports of North American stainless steel producers.

Prior to 2011, U.S. producers employed a two month lag of alloy prices in the surcharge formula. From 2011 onwards, U.S. producers used the one month lags of alloy prices. In Europe, the mills used the average of the two and three month lags of alloy prices in the surcharge formula until 2007. From 2007 onwards, they used a weighted average of alloy prices in the 30 days before the 20th of the previous month. Figures 4-9 depict alloy prices in both regions over time.

Exchange Rates: Exchange rates are needed for converting raw alloy prices, which are often quoted in dollars, into euros before insertion into the alloy surcharge formula. We use exchange rates from Board of Governors of the Federal Reserve System (US).[48] These are non-seasonally adjusted monthly averages of daily exchange rates. Note that surcharges were quoted in European Currency Units prior to January 1999 and were quoted in euros from January 1999 onwards. Thus, the ECU to USD exchange rate is used prior to January 1999 and the EUR to USD exchange rate is used beginning in January 1999.

Grade Selection: The number of stainless steel grades varies across source/producer. This is the case for two reasons. First, some producers produce a larger number of grades than others. Second, when compiling the set of available grades from each source, certain grades were excluded under specific conditions. First, grades were dropped if their names were ambiguous, making it difficult to determine the exact alloy composition. Second, producer-specific or highly specialized grades were removed. For example, precipitation-hardening grades such as 17-4PH or 15-5PH were excluded because their specialized production processes make it unclear whether the alloy surcharge formula was intended to apply to them.

[48] https://fred.stlouisfed.org/series/EXUSEU and https://fred.stlouisfed.org/series/EXUSEC

Grades were also removed when their designation could not be reliably matched to a known stainless steel grade. For example, AK Steel lists surcharges for a grade called "430TIX," which does not appear in other sources and for which no reliable composition could be identified. This suggests it may be a proprietary grade or an uncommon label for an existing alloy. Similarly, ATI includes a grade simply called "9" which is a designation inconsistent with established numbering systems such as EN or AISI. To remain conservative, such cases were excluded.

As a result of this filtering process, sources that provide clear and descriptive grade names in their surcharge documents end up with a larger set of usable grades than those that rely on less descriptive or more ambiguous labels. Tables 7-13 indicate the available grades for each source.

Stainless steel grades are identified using either AISI or EN designations, depending on data availability. The two systems are broadly comparable but not equivalent: many EN grades (particularly modern duplex and high-molybdenum steels) have no direct AISI counterpart, while some AISI grades correspond to multiple EN variants differing in carbon or nitrogen content. Because of this lack of one-to-one correspondence, and because firms and data sources often report grades under different systems, EN numbers are used (in parentheses) where AISI designations are ambiguous or unavailable, and vice versa.

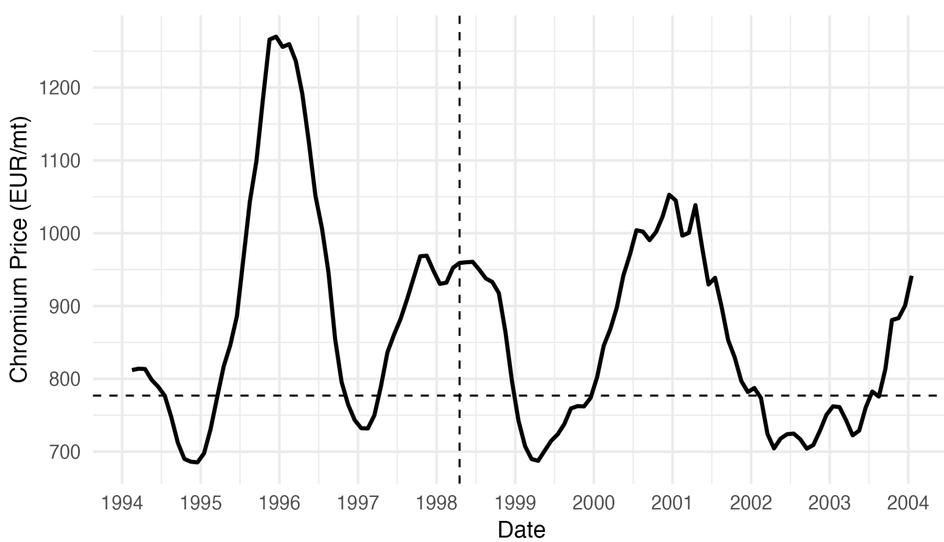


Figure 4: Average of Two and Three Month Lags of Chromium Prices in Europe

Notes: This figure depicts the average of the two and three month lags of chromium prices in Europe in euros per metric ton. The vertical dashed black line indicates the date of the cartel's end (March 31st 1998). The horizontal dashed line represents the Madrid nickel trigger.

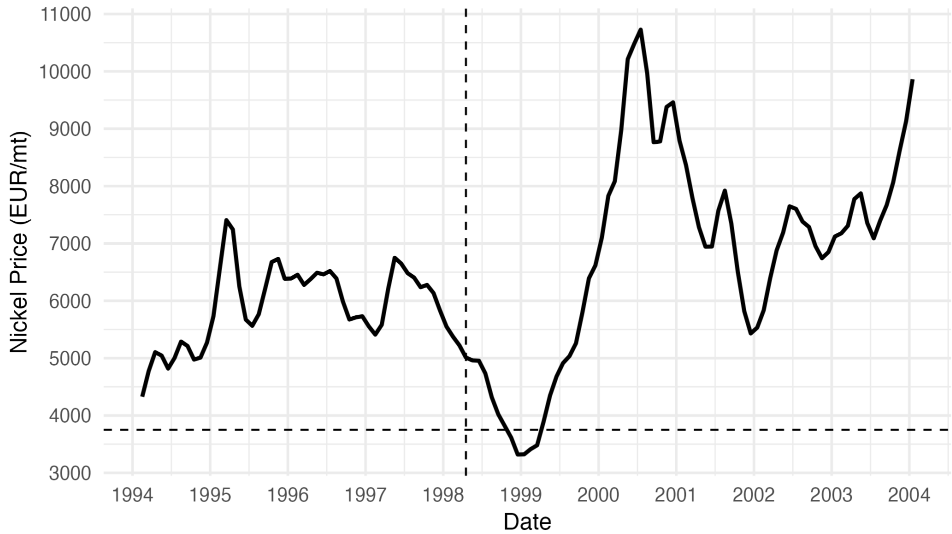


Figure 5: Average of Two and Three Month Lags of Nickel Prices in Europe

Notes: This figure depicts the average of the two and three month lags of nickel prices in Europe in euros per metric ton. The vertical dashed black line indicates the date of the cartel's end (March 31st 1998). The horizontal dashed line represents the Madrid nickel trigger.

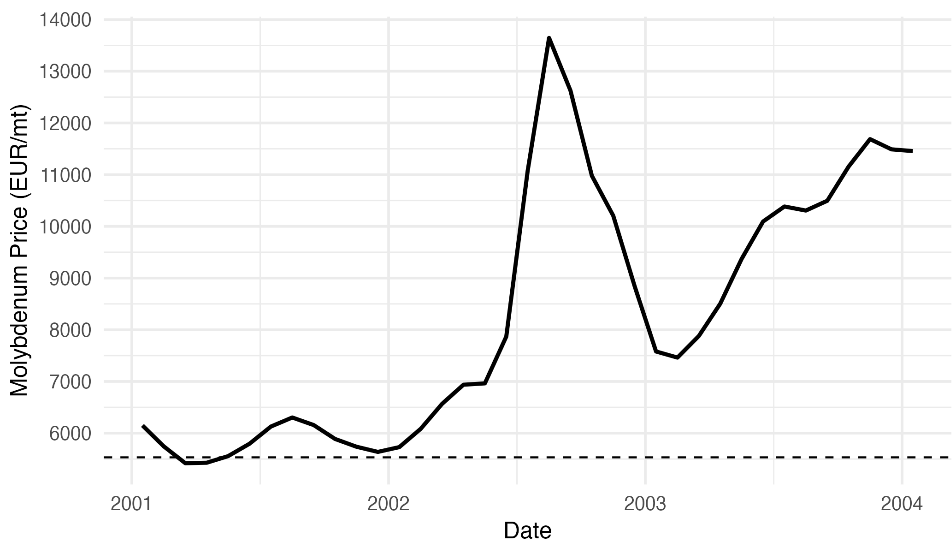


Figure 6: Average of Second and Third Month Lags of Molybdenum Prices in Europe

Notes: This figure depicts the average of the two and three month lags of molybdenum prices in Europe in euros per metric ton. The horizontal dashed line represents the Madrid molybdenum trigger.

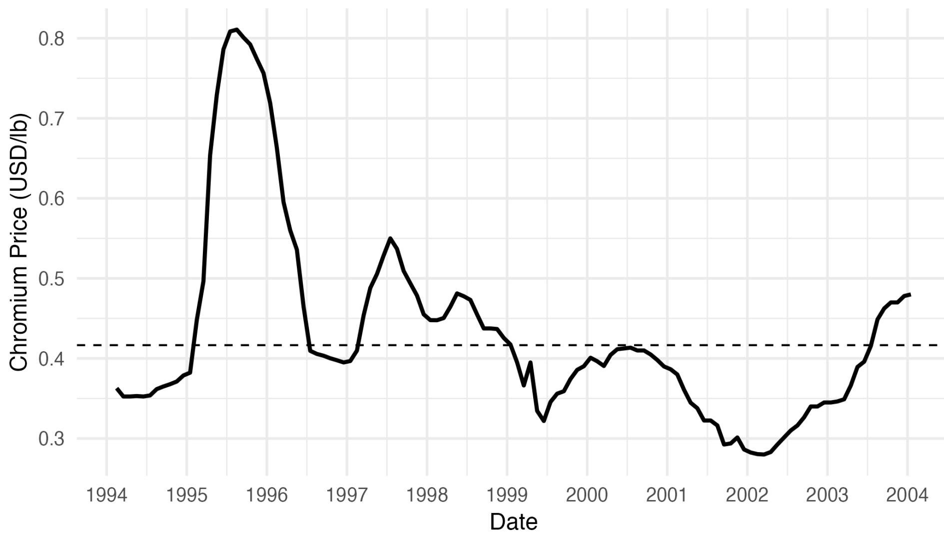


Figure 7: Two Month Lag of Chromium Prices in the U.S.

Notes: This figure depicts the two month lag of chromium prices in the U.S. in dollars per pound. The horizontal dashed line represents the European Madrid chromium trigger for reference.

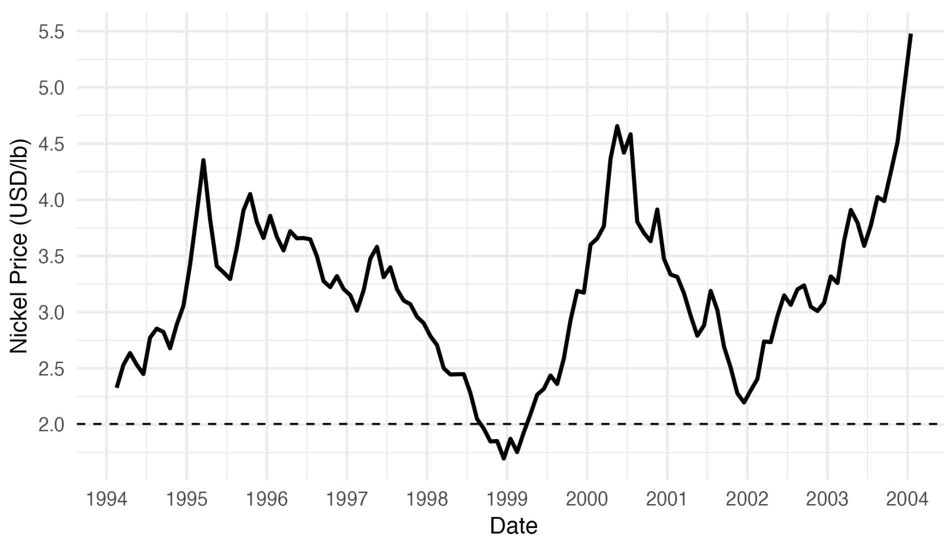


Figure 8: Two Month Lag of Nickel Prices in the U.S.

Notes: This figure depicts the two month lag of nickel prices in the U.S. in dollars per pound. The horizontal dashed line represents the European Madrid nickel trigger for reference.

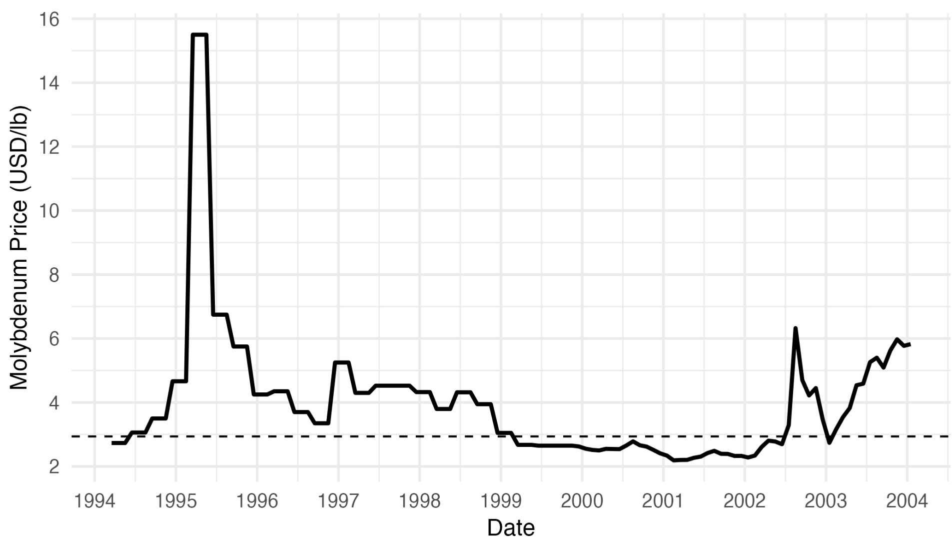


Figure 9: Two Month Lag of Molybdenum Prices in the U.S.

Notes: This figure depicts the two month lag of molybdenum prices in the U.S. in dollars per pound. The horizontal dashed line represents the European Madrid molybdenum trigger for reference.

Figure 10 depicts two sample monthly surcharge reports published by AK Steel (one for November 2000 and one for May 2004). Note that the May 2004 surcharge report lists the "Base Rate" or trigger point for each alloy while the November 2000 report does not. Also, note that the surcharge is broken down by component. Finally, the surcharge report includes alloy prices (see the "Actual Rate").

Figure 11 presents a screenshot of the website of Allegheny Technologies Incorporated (ATI). The screenshot depicts a surcharge calculation tool provided by ATI which allows customers to calculate the alloy surcharge themselves for various alloy prices. The trigger points are also depicted in this screenshot.

Figure 12 presents surcharges in the U.S. for grade 430 during the cartel and post-cartel period.

For Orders Promised for Shipment **November 1, 2000 through December 2, 2000**

Grade	Chrome	Nickel	Moly	Total
Average Monthly Costs	$.3981	$3.9200	$2.5180	
Nitronic 19D	$.0121	$.0230	$-	$.0351
Nitronic 30	$.0089	$.0507	$-	$.0596
201	$.0092	$.0806	$-	$.0898
201LN	$.0094	$.0922	$-	$.1016
2205	$.0127	$.1210	$-	$.1337
301,301LN (6.00)	$.0092	$.1382	$-	$.1474
301,301L (7.00)	$.0092	$.1613	$-	$.1705
302	$.0104	$.1843	$-	$.1947
304, 304L (8.00)	$.0104	$.1843	$-	$.1947
304, 304L (8.50)	$.0104	$.1958	$-	$.2062
304, 304L (9.00)	$.0104	$.2074	$-	$.2178
304, 304L (9.25)	$.0104	$.2131	$-	$.2235
304, 304L (9.50)	$.0104	$.2189	$-	$.2293
304LN	$.0104	$.1935	$-	$.2039
305	$.0098	$.2419	$-	$.2517
309S	$.0127	$.2765	$-	$.2892
316,316L,316LN,316Ti	$.0092	$.2304	$-	$.2396
321,321LA	$.0098	$.2074	$-	$.2172
15-5PH	$.0081	$.0806	$-	$.0887
PH 15-7MO	$.0081	$.1498	$-	$.1579
17-4PH	$.0089	$.0691	$-	$.0780
17-7PH	$.0092	$.1498	$-	$.1590
400	$.0069	$-	$-	$.0069
400CB	$.0063	$-	$-	$.0063
409, Aluminized 409	$.0061	$-	$-	$.0061
409NI	$.0062	$.0173	$-	$.0235
41003	$.0062	$.0069	$-	$.0131
410,410H,410S	$.0066	$-	$-	$.0066
420, 420HC	$.0069	$-	$-	$.0069
430	$.0092	$-	$-	$.0092
430LI	$.0096	$-	$-	$.0096
430TI	$.0113	$-	$-	$.0113
430TIX	$.0104	$-	$-	$.0104
431L	$.0092	$.0207	$-	$.0299
434	$.0092	$-	$-	$.0092
435-Mod	$.0110	$-	$-	$.0110
436	$.0092	$-	$-	$.0092
436LM	$.0115	$-	$-	$.0115
436MT	$.0098	$-	$-	$.0098
439, Aluminized 439	$.0098	$-	$-	$.0098
440A	$.0092	$-	$-	$.0092
444	$.0101	$-	$-	$.0101
11CrCb	$.0063	$-	$-	$.0063
12SR	$.0068	$-	$-	$.0068
18CrCb	$.0101	$-	$-	$.0101
18SR	$.0098	$-	$-	$.0098

All totals are rounded to 4 decimal places. Surcharges for grades with non-standard alloy content will be calculated based upon the minimum content specified.
Note: The effective dates on this announcement supercede all previous effective dates.

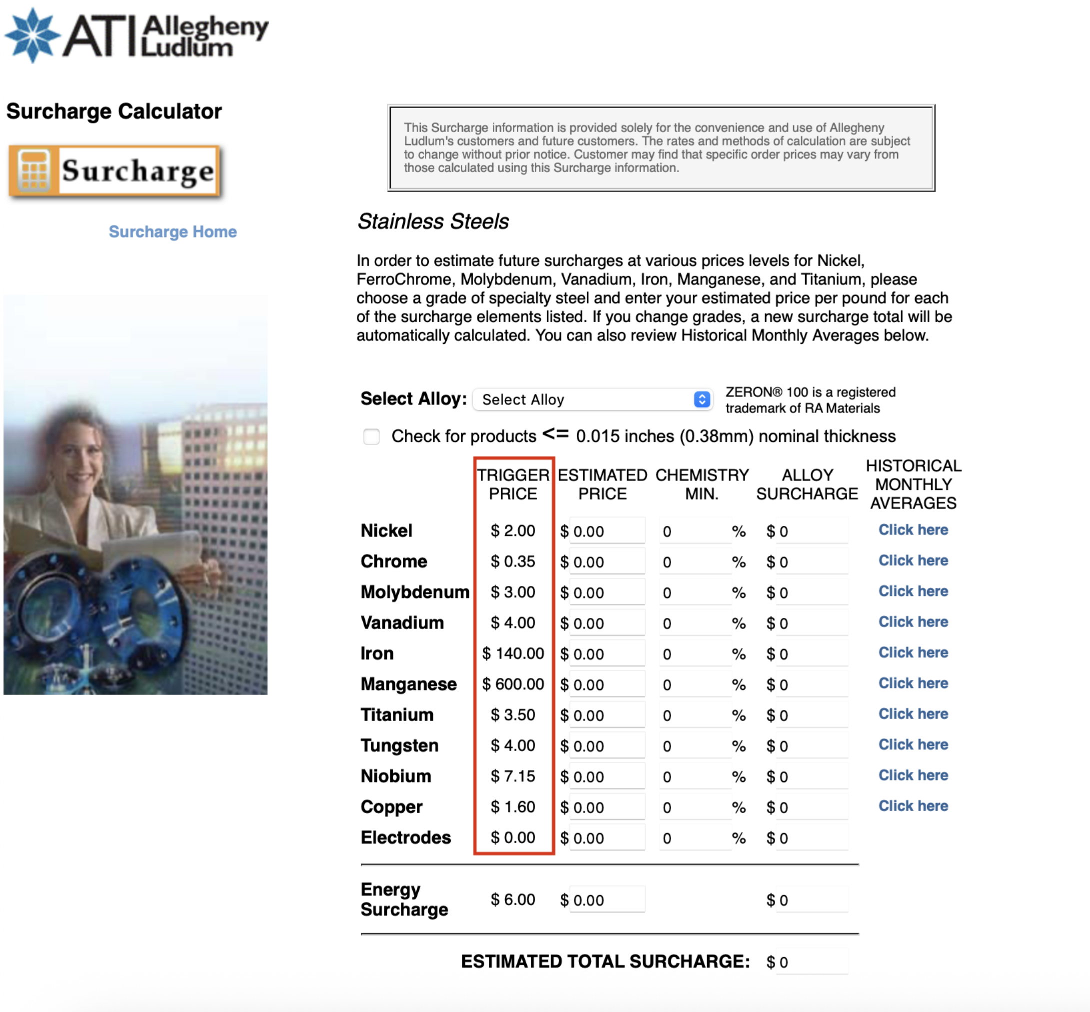
For Orders Promised for Shipment **May 2, 2004** through **May 29, 2004**
Revised April 29, 2004

Grade	Chrome $/lb	Nickel $/lb	Moly $/lb	Mn $/GT	Iron $/GT	Total
Base Rate	**$.3500**	**$2.0000**	**$3.0000**	**$600**	**$140**	
Actual Rate	**$.6970**	**$6.2245**	**$9.1000**	**$1,377**	**$300**	
Rates per pound below will be added to invoice at time of shipment.						
Nitronic 19D	$.0874	$.0507	$-	$.0253	$.0509	$.2143
Nitronic 30	$.0645	$.1115	$-	$.0454	$.0513	$.2727
201 (3.5)	$.0666	$.1774	$-	$.0320	$.0518	$.3278
201 (4.0), 201LN	$.0677	$.2028	$-	$.0347	$.0509	$.3561
201 (5.0)	$.0666	$.2535	$-	$.0336	$.0505	$.4042
2205	$.0916	$.2535	$.2196	$-	$.0486	$.6133
301 (6.00)	$.0666	$.3042	$-	$-	$.0543	$.4251
301,301L (7.00)	$.0708	$.3549	$-	$-	$.0529	$.4786
301LN	$.0729	$.2915	$-	$.0120	$.0518	$.4282
302	$.0750	$.4056	$-	$-	$.0514	$.5320
304, 304L (8.00)	$.0750	$.4056	$-	$-	$.0514	$.5320
304, 304L (8.50)	$.0750	$.4309	$-	$-	$.0511	$.5570
304, 304L (9.00)	$.0750	$.4562	$-	$-	$.0507	$.5819
304, 304L (9.25)	$.0750	$.4689	$-	$-	$.0505	$.5944
304, 304L (9.50)	$.0750	$.4816	$-	$-	$.0504	$.6070
304LN	$.0750	$.4258	$-	$-	$.0511	$.5519
305	$.0708	$.5323	$-	$-	$.0504	$.6535
309S	$.0916	$.6083	$-	$-	$.0457	$.7456
316,316L,316LN,316Ti	$.0666	$.5069	$.1464	$-	$.0500	$.7699
321,321LA	$.0708	$.4562	$-	$-	$.0514	$.5784
15-5PH	$.0583	$.1774	$-	$-	$.0575	$.2932
PH 15-7MO	$.0583	$.3295	$.1464	$-	$.0539	$.5881
17-4PH	$.0645	$.1521	$-	$-	$.0568	$.2734
17-7PH	$.0666	$.3295	$-	$-	$.0539	$.4500
400	$.0500	$-	$-	$-	$.0614	$.1114
400CB	$.0458	$-	$-	$-	$.0621	$.1079
409, Aluminized 409	$.0437	$-	$-	$-	$.0625	$.1062
409NI	$.0448	$.0380	$-	$-	$.0618	$.1446
41003	$.0450	$.0152	$-	$-	$.0621	$.1223
410,410CB,410H,410S	$.0479	$-	$-	$-	$.0618	$.1097
420, 420HC	$.0500	$-	$-	$-	$.0614	$.1114
430	$.0666	$-	$-	$-	$.0586	$.1252
430LI	$.0695	$-	$-	$-	$.0581	$.1276
430TI	$.0812	$-	$-	$-	$.0561	$.1373
430TIX	$.0750	$-	$-	$-	$.0571	$.1321
431L	$.0666	$.0456	$-	$-	$.0579	$.1701
434	$.0666	$-	$.0549	$-	$.0580	$.1795
435-Mod	$.0791	$-	$-	$-	$.0564	$.1355
436	$.0666	$-	$.0549	$-	$.0580	$.1795
436LM	$.0833	$-	$.0659	$-	$.0551	$.2043
436MT	$.0708	$-	$.0549	$-	$.0573	$.1830
439, Aluminized 439	$.0708	$-	$-	$-	$.0579	$.1287
440A	$.0666	$-	$-	$-	$.0586	$.1252
444	$.0729	$-	$.1281	$-	$.0563	$.2573
11CrCb	$.0458	$-	$-	$-	$.0621	$.1079
12SR	$.0489	$-	$-	$-	$.0616	$.1105
18CrCb	$.0729	$-	$-	$-	$.0575	$.1304
18SR	$.0708	$-	$-	$-	$.0579	$.1287

All totals are rounded to 4 decimal places. Surcharges with non-standard alloy content will be calculated based upon the minimum content specified.
Note: The effective dates on this announcement supercede all previous effective dates.

Figure 10: AK Steel Surcharge Report from November of 2000 (left) and May of 2004 (right)

Notes: Both tables are monthly surcharge reports published by AK Steel, breaking down the surcharge applied to each grade by the components of its alloy. The May 2004 report (on the right) lists trigger points (written as "Base Rates") for metals in the alloys, while the November 2000 report (on the left) does not.



ATI Allegheny Ludlum

Surcharge Calculator

Surcharge

Surcharge Home

This Surcharge information is provided solely for the convenience and use of Allegheny Ludlum's customers and future customers. The rates and methods of calculation are subject to change without prior notice. Customer may find that specific order prices may vary from those calculated using this Surcharge information.

Stainless Steels

In order to estimate future surcharges at various prices levels for Nickel, FerroChrome, Molybdenum, Vanadium, Iron, Manganese, and Titanium, please choose a grade of specialty steel and enter your estimated price per pound for each of the surcharge elements listed. If you change grades, a new surcharge total will be automatically calculated. You can also review Historical Monthly Averages below.

Select Alloy: Select Alloy

ZERON® 100 is a registered trademark of RA Materials

Check for products <= 0.015 inches (0.38mm) nominal thickness

	TRIGGER PRICE	ESTIMATED PRICE	CHEMISTRY MIN.	ALLOY SURCHARGE	HISTORICAL MONTHLY AVERAGES
Nickel	$ 2.00	$ 0.00	0 %	$ 0	Click here
Chrome	$ 0.35	$ 0.00	0 %	$ 0	Click here
Molybdenum	$ 3.00	$ 0.00	0 %	$ 0	Click here
Vanadium	$ 4.00	$ 0.00	0 %	$ 0	Click here
Iron	$ 140.00	$ 0.00	0 %	$ 0	Click here
Manganese	$ 600.00	$ 0.00	0 %	$ 0	Click here
Titanium	$ 3.50	$ 0.00	0 %	$ 0	Click here
Tungsten	$ 4.00	$ 0.00	0 %	$ 0	Click here
Niobium	$ 7.15	$ 0.00	0 %	$ 0	Click here
Copper	$ 1.60	$ 0.00	0 %	$ 0	Click here
Electrodes	$ 0.00	$ 0.00	0 %	$ 0	
Energy Surcharge	$ 6.00	$ 0.00		$ 0	

ESTIMATED TOTAL SURCHARGE: $ 0

Figure 11: ATI Surcharge Calculator as of October 2025

Notes: The surcharge calculator is a tool available on the ATI website allowing customers to calculate surcharges for different alloy prices and grades of stainless steel.

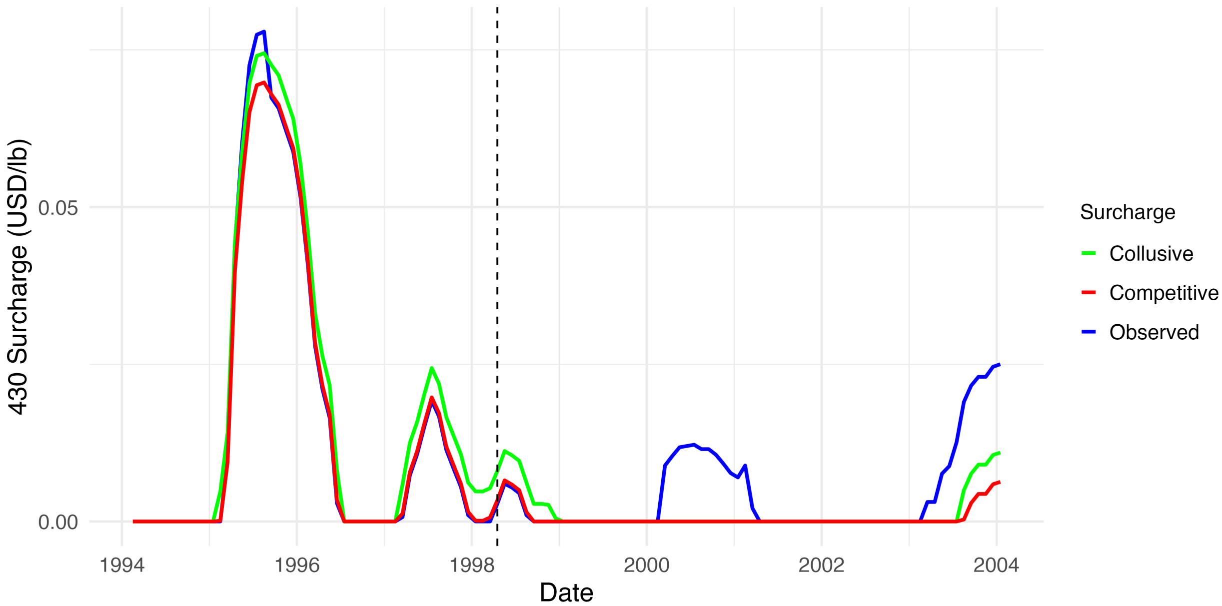


Figure 12: Alloy Surcharges in the United States for Grade 430 Stainless Steel

Notes: This figure depicts "observed" surcharges for grade 430 stainless steel in the United States in blue. The figure also depicts the surcharge implied by the methodology with the competitive European trigger points (in red) and collusive/Madrid trigger points (in green). These trigger points are converted from EUR/metric ton to USD/lb. The variable on the x-axis is calendar time. The variable on the y-axis is the alloy surcharge in dollars per pound. The data illustrated in this figure are from CRU. The vertical dashed black line indicates the date of the cartel's end (March 31st 1998). The data ranges from February of 1994 to January of 2004.

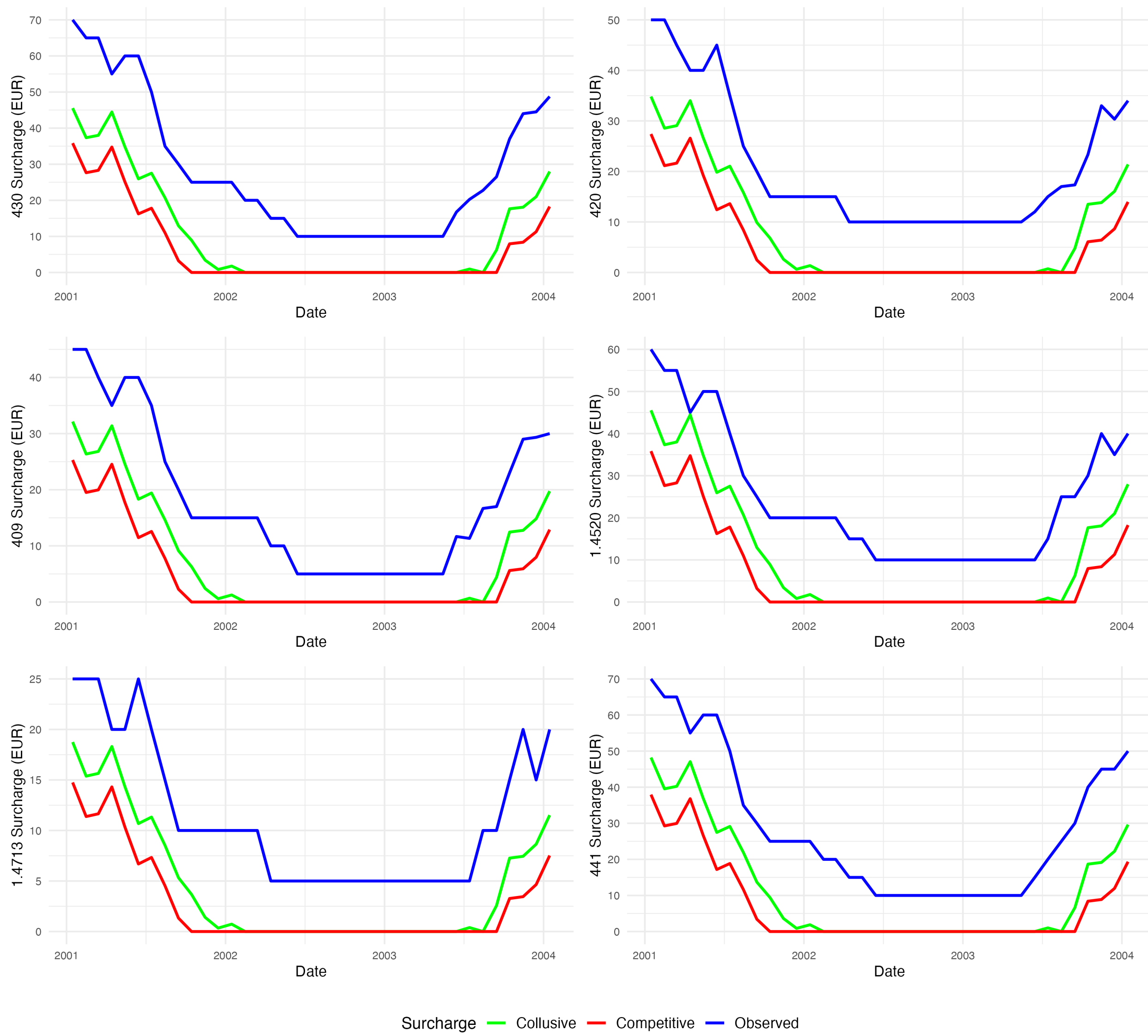


Figure 13: Selected 400-Series Surcharges in Europe from January 2001 to January 2004

Notes: These figures depict "observed" surcharges for various 400-series grades of stainless steel (430, 420, 409, 1.4520, 1.4713, 441) in Europe in blue. The figures also depict the surcharge implied by the methodology with the competitive European trigger points (in red) and collusive/Madrid trigger points (in green). The variable on the x-axis is calendar time. The variable on the y-axis is the alloy surcharge in EUR/metric ton. The data illustrated in these figures are from January of 2001 to January of 2004.

Table 7: Steel Grades by Source

Grade	Source								
	AK Steel	Aperam	ATI	CRU	Legier	NAS	Outokumpu	Outokumpu U.S.	Thyssen
(1.4003)		X			✓		X		✓
(1.4307)		X			✓		✓		✓
(1.4520)					✓				✓
(1.4713)					✓				✓
201		X					✓		
201 3.5			X			X		X	
201 4			X			X		X	
201 4.3			✓						
201LN	✓		✓						
2205	✓		X				✓		✓
225			✓						
301		X			X		✓		✓
301 6	✓		✓			X		X	
301 6.5			X					X	
301 6.6			X			X		X	
301 7	✓		✓			X			
301 7.3			X						
301LN		X					✓		✓
302	✓		X						
303			✓				✓		
304	✓	X	✓	✓	✓	X	✓	X	✓
304 8	✓		✓	✓		X		X	
304 8.5	✓		✓			X		X	
304 9.25	✓								
304 9.5	✓		✓			X		X	
304L		X			✓		✓		✓
304LN	✓		X				✓		✓

Notes: This table presents available stainless steel grades by source. Grades listed as a number within a parentheses (e.g. (1.4003)) reflect European Standard (EN) grading; grades listed with three digits (e.g. 304, 430, 904L) reflect AISI (American Iron and Steel Institute) grading. Checkmarks represent grades with data available prior to the inclusion of the iron component to the alloy surcharge; Xs represent grades with data available only after the inclusion of the iron component of the alloy surcharge.

Table 9: Alloy Grades by Source Cont.

Grade	Source								
	AK Steel	Aperam	ATI	CRU	Legier	NAS	Outokumpu	Outokumpu U.S.	Thyssen
305	✓	X	X		✓	X	✓	X	✓
309	✓		✓		✓	X	X		✓
309S		X					✓		
310			✓			X	✓		✓
310 MoLN							✓		
314					✓		✓		✓
316	✓	X	✓		✓	X	✓		✓
316 2.5			✓					X	
316 2.75			X						
316 11			X					X	
316 12.5			X						
316 16.25			X						
316 16.5			X						
316L					✓		✓		✓
316L (1.4435)		X			✓				✓
316 LN			X						
317			X						
317 14			X						
317 LMN			X		✓		✓		✓
317L							✓		✓
320					✓		✓		✓
321	✓	X	X		✓	X	✓	X	✓
330							✓		
332			✓						
332M			X						
334			✓						

Notes: This table presents available stainless steel grades by source. Grades listed as a number within a parentheses (e.g. (1.4003)) reflect European Standard (EN) grading; grades listed with three digits (e.g. 304, 430, 904L) reflect AISI (American Iron and Steel Institute) grading. Checkmarks represent grades with data available prior to the inclusion of the iron component to the alloy surcharge; Xs represent grades with data available only after the inclusion of the iron component of the alloy surcharge.

Table 11: Alloy Grades by Source Cont.

Grade	Source								
	AK Steel	Aperam	ATI	CRU	Legier	NAS	Outokumpu	Outokumpu U.S.	Thyssen
334M			X						
347			✓				✓	X	
400	✓								
403			✓						
404			✓						
405			✓						
406			✓						
408			X						
409	✓	X	✓		✓	X	✓	X	✓
410	✓		✓				✓	X	
410 MOD							✓	X	
413			X						
416			X						
418 S			✓						
420	✓		✓		✓		✓		✓
420 (1.4021)		X			✓		✓		✓
420 (1.4028)		X					✓		X
425 MOD			✓						
430	✓	X	✓	✓	✓	X	✓	X	✓
430F							✓		
431	✓						✓		
433			✓						
434	✓		✓		✓		✓	X	✓
435M	✓								
436	✓								
436LM	✓								

Notes: This table presents available stainless steel grades by source. Grades listed as a number within a parentheses (e.g. (1.4003)) reflect European Standard (EN) grading; grades listed with three digits (e.g. 304, 430, 904L) reflect AISI (American Iron and Steel Institute) grading. Checkmarks represent grades with data available prior to the inclusion of the iron component to the alloy surcharge; Xs represent grades with data available only after the inclusion of the iron component of the alloy surcharge.

Table 13: Alloy Grades by Source Cont.

Grade	Source								
	AK Steel	Aperam	ATI	CRU	Legier	NAS	Outokumpu	Outokumpu U.S.	Thyssen
436S			✓						
439	✓	X	✓		✓	X		X	✓
440	✓		✓						
440C							✓		
441		X	✓		✓	X		X	✓
444	✓	X	✓		✓		✓	X	✓
447			X						
453			X						
468			✓						
904L					✓		✓		✓
Alloy 2003			✓						

Notes: This table presents available stainless steel grades by source. Grades listed as a number within a parentheses (e.g. (1.4003)) reflect European Standard (EN) grading; grades listed with three digits (e.g. 304, 430, 904L) reflect AISI (American Iron and Steel Institute) grading. Checkmarks represent grades with data available prior to the inclusion of the iron component to the alloy surcharge; Xs represent grades with data available only after the inclusion of the iron component of the alloy surcharge.

B Competitive trigger points

According to the 1998 surcharge decision, producers applied a zero alloy surcharge from some point in 1991 up until the cartel began.[49] Recall that a zero surcharge is applied only when all raw material prices fall below their respective trigger points. Thus, the highest observed alloy prices during that period serve as a lower bound on the pre-cartel trigger points. The maximum nickel price from December 1991 to December 1993 was 6,229 ECUs, and the maximum chromium price was 834 ECUs. These values are therefore chosen as the competitive trigger points. As molybdenum price data are unavailable for this pre-cartel period, a corresponding trigger point cannot be defined for molybdenum.

These estimates are likely conservative (i.e., the true competitive trigger points may have been higher) for two reasons. First, the EC decision doesn't specify exactly when in 1991 producers began charging zero surcharges. To be cautious, we use price maxima from December 1991 to December 1993. If surcharges dropped to zero earlier in 1991, this window may underestimate the actual pre-cartel trigger points. Second, statements by the European Commission suggest that the pre-cartel trigger points (which were set in 1988) may have been, at least partly, collusive.[50] If so, the true competitive trigger points would be higher than even these conservative estimates.

C Additional Analyses

C.1 Inter-Firm Price Dispersion

In this subsection, we demonstrate that inter-firm price dispersion was relatively low throughout the cartel and post-cartel period. Specifically, we show that surcharges do not typically vary significantly between sources.[51] This feature supports the use of the average surcharge (across sources) in the main analysis. Additionally, this finding provides additional evidence that producers' surcharges methodologies were, for the most part, highly similar.

Figure 14 plots alloy surcharges for grade 304 in Europe by source across time. Figure 15 plots alloy surcharges for grade 430. The analyses in this subsection use all available data, including data from after the introduction of the iron component. Figures 14 and 15 illustrate the lack of price dispersion across sources. Figure 15 (for 430) indicates a slightly higher degree of price dispersion than Figure 14 (for 304). This is due to the fact that surcharges for grade 304 are generally higher than surcharges for grade 430

[49] "Such a situation occurred between 1991 and 1993, when alloy prices fell below the trigger points and producers applied a zero alloy surcharge" (Alloy Surcharge Decision, 1998).

[50] "The use of an identical calculation method by all the Community producers for their sales in Western Europe dates back approximately to 1988. There is reason to believe, therefore, that the agreement dates back to the same period and that the concerted modification of the reference values in 1994 is only a development thereof" (Alloy Surcharge Decision, 1998).

[51] Recall that distinct sources do not always correspond to distinct firms. See Table 6.

due to the presence of nickel in grade 304. Crucially, the plots do not suggest an abrupt increase in price dispersion across time. A sharp increase in price dispersion would indicate at least one source/producer deviated significantly from the methodology. Analogous plots for the U.S. are presented in Figures 16 and 17.

To further explore the extent of price dispersion throughout the sample, we calculate two summary statistics for each grade. First, the sample is restricted to grade–month combinations that have at least two distinct data sources. For each grade and month, we compute two dispersion measures: the coefficient of variation (standard deviation divided by mean, times 100) and the normalized range (maximum minus minimum, divided by mean, times 100). Finally, we average these dispersion measures across months for each grade to obtain mean values by grade. These statistics are reported in Table 15. Across grades, the average coefficient of variation is 1.767%. The average normalized range is approximately 3%. Table 15 indicates an exceptionally low degree of price dispersion across sources. The average number of sources for each grade is also reported in Table 15.

Finally, Table 18 presents trigger point estimates in Europe decomposed by data source. Trigger point estimates are broadly consistent across sources, again supporting the argument that surcharge methodologies did not vary meaningfully across producers.

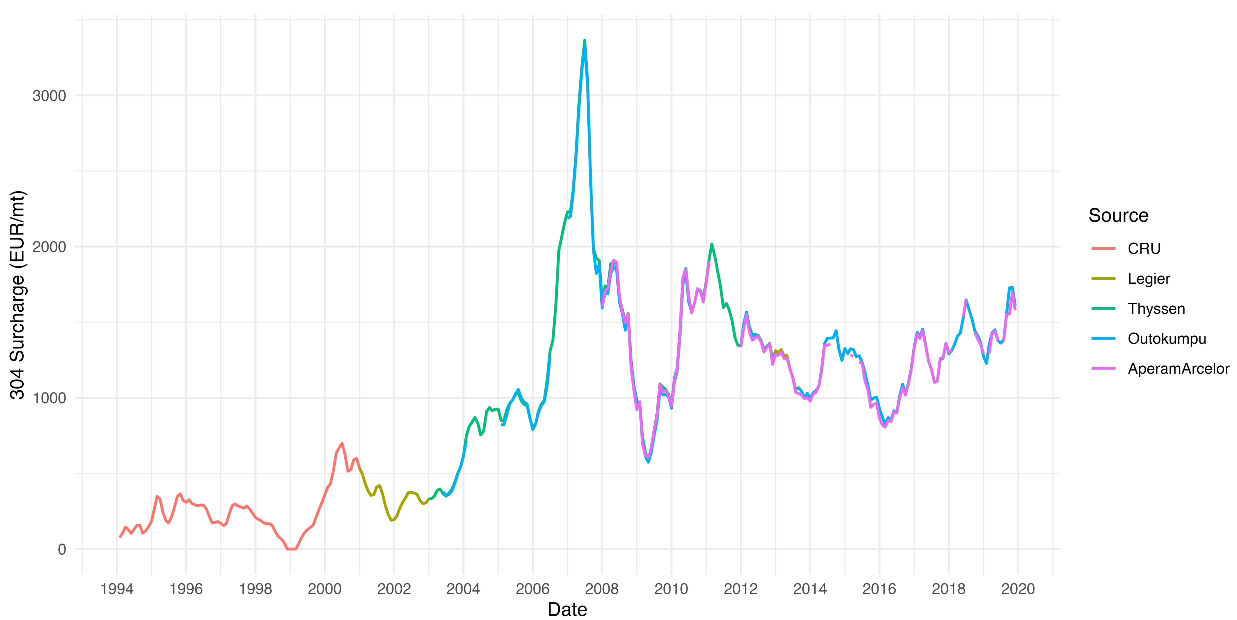


Figure 14: Surcharges for Grade 304 in Europe by Source

Notes: This figure depicts alloy surcharges for grade 304 in Europe by source from (month) 1994 to (month) 2000. Each color represents surcharge data derived from a specific source (i.e. lines in blue depict surcharges sourced from Outokumpu). The variable on the x-axis is calendar time. The variable on the y-axis is the alloy surcharge in EUR/metric ton.

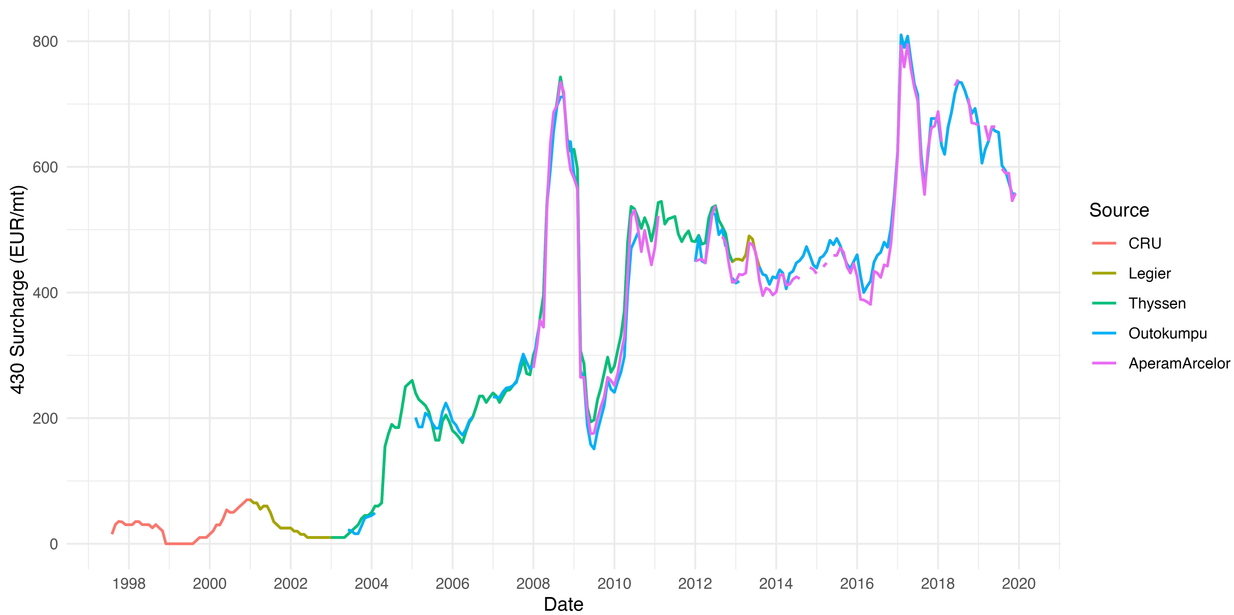


Figure 15: Surcharges for Grade 430 in Europe by Source

Notes: This figure depicts alloy surcharges for grade 430 in Europe by source from (month) 1998 to (month) 2020. Each color represents surcharge data derived from a specific source (i.e. lines in blue depict surcharges sourced from Outokumpu). The variable on the x-axis is calendar time. The variable on the y-axis is the alloy surcharge in EUR/metric ton.

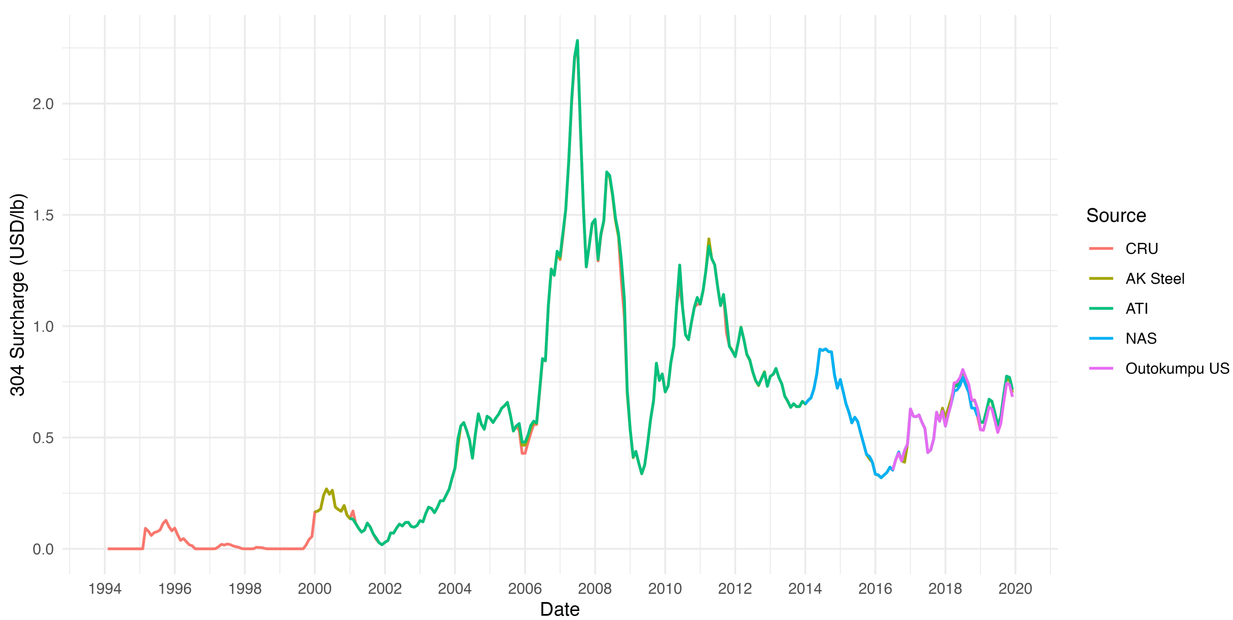


Figure 16: Surcharges for Grade 304 in the U.S. by Source

Notes: This figure depicts alloy surcharges for grade 304 in the U.S. by source from (month) 1994 to (month) 2020. Each color represents surcharge data derived from a specific source (i.e. lines in blue depict surcharges sourced from NAS). The variable on the x-axis is calendar time. The variable on the y-axis is the alloy surcharge in USD/lb.

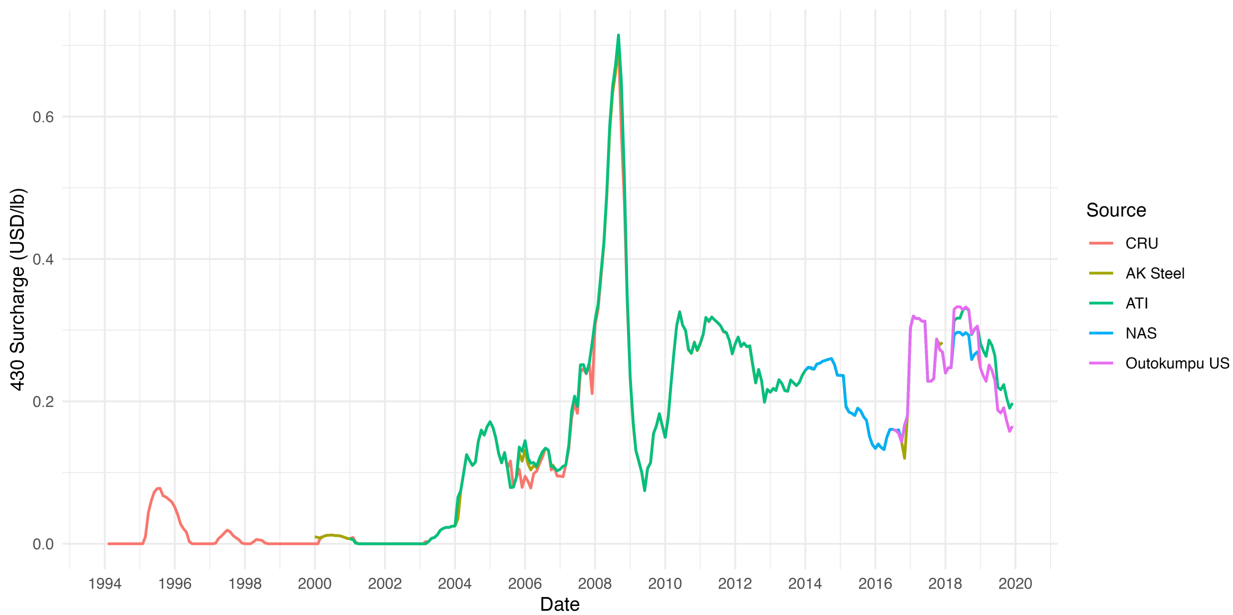


Figure 17: Surcharges for Grade 430 in the U.S. by Source

Notes: This figure depicts alloy surcharges for grade 430 in the U.S. by source from (month) 1994 to (month) 2020. Each color represents surcharge data derived from a specific source (i.e. lines in blue depict surcharges sourced from NAS). The variable on the x-axis is calendar time. The variable on the y-axis is the alloy surcharge in USD/lb.

C.2 Change-Point Detection Analysis

Documentary evidence discussed in the main text, graphical patterns in Figure 2, trigger point estimates in Table 3, and rolling trigger point estimates in Figure 25 and 26 all suggest that trigger points in Europe were adjusted in late 1999. In this subsection, we conduct a change-point detection analysis to provide further evidence on the timing and existence of a trigger point adjustment in Europe following the cartel's dissolution.

For each month m, the data are split into two periods. The first period includes observations prior to month m, and the second includes observations during or after month m. Separate trigger point estimates are then obtained for each period. The optimized objective values (defined as the sum of squared residuals for the AEM and the log-likelihood value for the CLEM) are added together to form a single measure of fit for a split at month m. For the CLEM, the month that maximizes the total log-likelihood is identified as the most likely change point, while for the AEM, the month that minimizes the total sum of squared residuals is identified as such. The same procedure is repeated under the restriction that only the chromium trigger point may differ across periods.

A buffer of four periods is imposed so that each potential change point leaves at least four observations (non-zero surcharges) on both sides of the split, ensuring that parameters can be estimated with sufficient precision. When estimating changes in both the chromium and nickel trigger points, additional structure is required: the split must also occur late enough for data on multiple grades to be available, since both trigger points cannot typically be identified from data on a single grade. In practice, this implies that valid splits can occur no earlier than August 1997, when data on grade 430 first becomes available. Grades with molybdenum are excluded from the analysis to ensure comparability of the models in the two periods (recall that data on grades containing molybdenum are only available beginning in January 2001).

Figure 18 plots the total non-linear least squares objective function in the AEM (y-axis) for various splits (x-axis) in Europe. The minimum of the total NLLS objective function occurs in April 1999, both when nickel and chromium triggers are allowed to change across periods and when only the chromium trigger changes. Figure 19 plots the total maximized log-likelihood (y-axis) for various splits (x-axis) in Europe. The maximum of the total log-likelihood occurs in October 1999, both when the nickel and chromium triggers are allowed to change and when only the chromium trigger changes. Recall that a 2008 ThyssenKrupp presentation to investors stated the trigger points in Europe were last changed in September 1999 (ThyssenKrupp, 2008).

Figure 20 plots the total non-linear least squares objective function in the AEM (y-axis) for various splits (x-axis) in the U.S. The minimum of the total NLLS objective function occurs in January 2000, both when nickel and chromium triggers are allowed to change across periods and when only the chromium trigger changes. Figure 21 plots the total maximized log-likelihood (y-axis) for various splits (x-axis) in the U.S. The maximum of the total log-likelihood also occurs in January 2000, both when the nickel and chromium triggers are allowed to change and when only the chromium trigger changes. Recall that a 2008 ThyssenKrupp presentation to investors stated the trigger points in the U.S. were last changed in January 2000 (ThyssenKrupp, 2008). Results for both regions are summarized in Table 16.

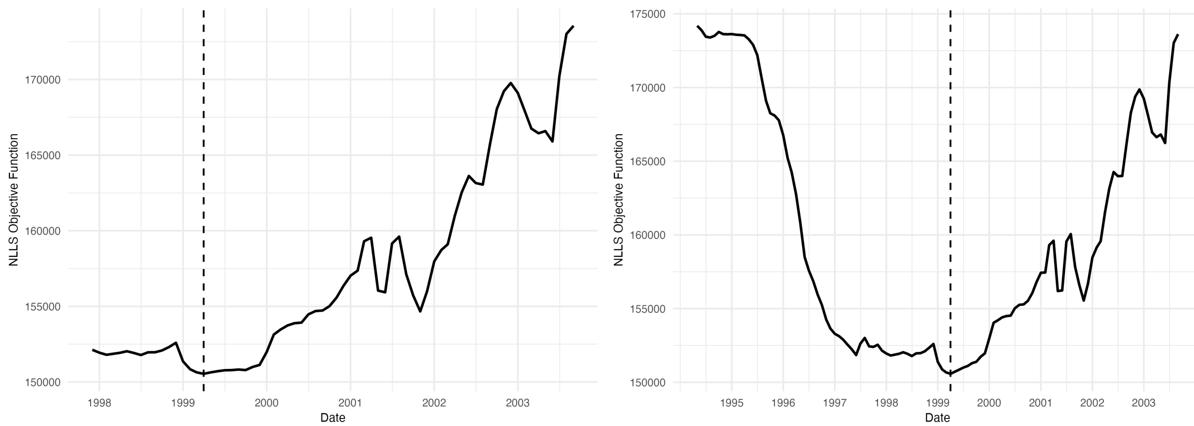


Figure 18: Change Point Detection in the AEM for Europe (Left: Both Trigger Points Changing, Right: Only Chromium Trigger Changing)

Notes: The change point detection analysis in Europe allowing for both trigger points changing is conducted only for splits from December 1997 onwards, as data for both 304 and 430 is only available from August 1997 onwards. Data on both grades is necessary to estimate both trigger points. The variable on the x-axis is calendar time. The variable on the y-axis is the value of the non-linear least squares objective function. The minimum of the non-linear least squares objective function suggests the most likely date for a trigger point adjustment. The figure on the left depicts results from an analysis allowing both the nickel and trigger points to change; the figure on the right depicts results from an analysis that holds the nickel trigger point constant.

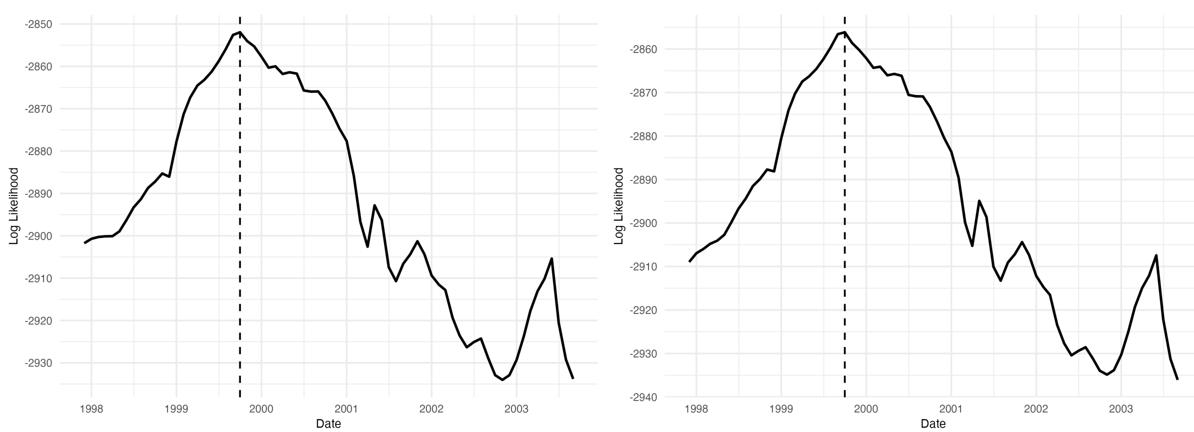


Figure 19: Change Point Detection in the CLEM for Europe (Left: Both Trigger Points Changing, Right: Only Chromium Trigger Changing)

Notes: The change point detection analysis in Europe allowing for both trigger points changing is conducted only for splits from December 1997 onwards, as data for both 304 and 430 is only available from August 1997 onwards. Data on both grades is necessary to estimate both trigger points. The variable on the x-axis is calendar time. The variable on the y-axis is the total maximized log-likelihood. The maximum of the total maximized log-likelihood suggests the most likely date for a trigger point adjustment. The figure on the left depicts results from an analysis allowing both the nickel and trigger points to change; the figure on the right depicts results from an analysis that holds the nickel trigger point constant.

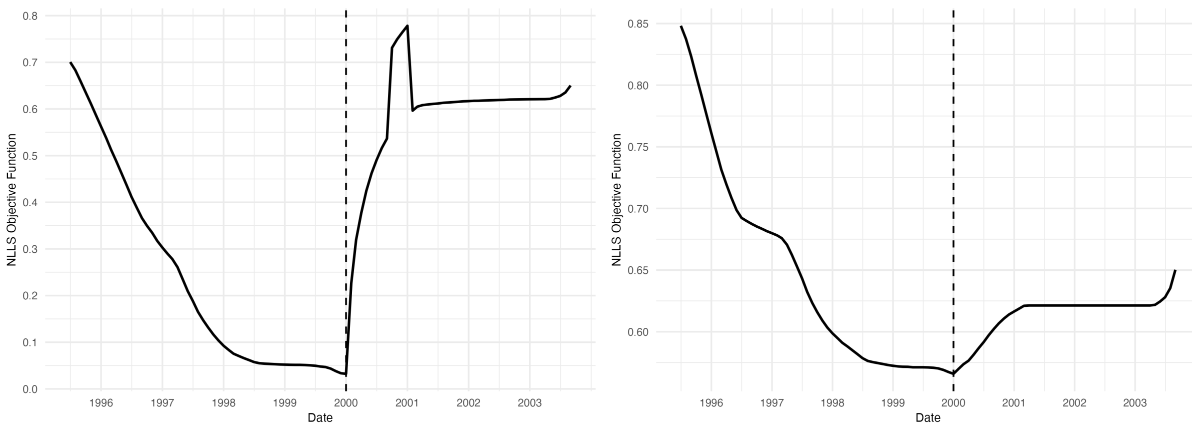


Figure 20: Change Point Detection in the AEM for the U.S. (Left: Both Trigger Points Changing, Right: Only Chromium Trigger Changing)

Notes: The change point detection analysis in the U.S. allowing for both trigger points changing is conducted only for splits from July 1995 onwards, as surcharges in the U.S. are zero until February 1995. Data on both grades is necessary to estimate both trigger points. The variable on the x-axis is calendar time. The variable on the y-axis is the value of the non-linear least squares objective function. The minimum of the non-linear least squares objective function suggests the most likely date for a trigger point adjustment. The figure on the left depicts results from an analysis allowing both the nickel and trigger points to change; the figure on the right depicts results from an analysis that holds the nickel trigger point constant.

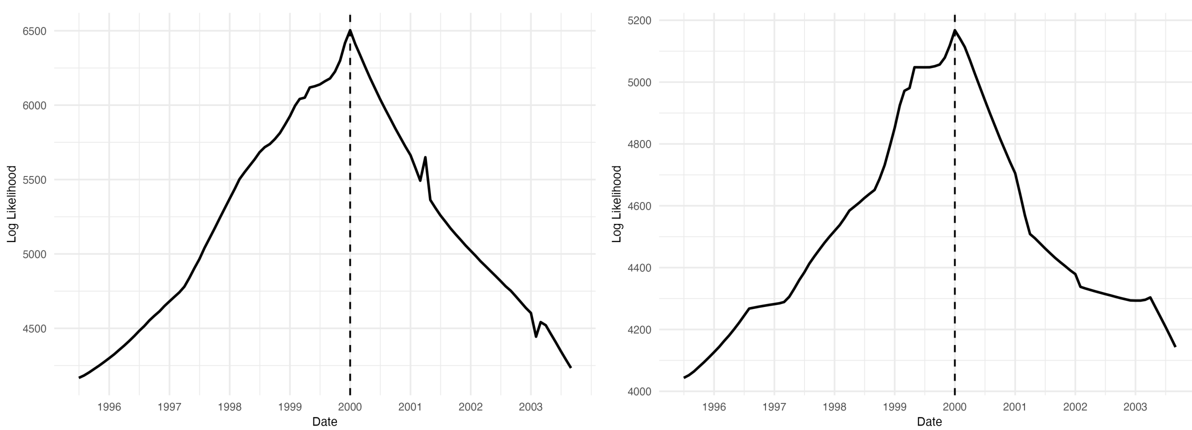


Figure 21: Change Point Detection in the CLEM for the U.S. (Left: Both Trigger Points Changing, Right: Only Chromium Trigger Changing)

Notes: The change point detection analysis in the U.S. allowing for both trigger points changing is conducted only for splits from July 1995 onwards, as surcharges in the U.S. are zero until February 1995. Data on both grades is necessary to estimate both trigger points. The variable on the x-axis is calendar time. The variable on the y-axis is the total maximized log-likelihood. The maximum of the total maximized log-likelihood suggests the most likely date for a trigger point adjustment. The figure on the left depicts results from an analysis allowing both the nickel and trigger points to change; the figure on the right depicts results from an analysis that holds the nickel trigger point constant.

C.3 Surcharges after the Introduction of the Iron Component

In this subsection, we analyze surcharges after the introduction of the iron component in both the U.S. and Europe. The introduction of the iron component in February of 2004 added a fourth component to the surcharge methodology. In subsequent years, additional components including titanium, copper, manganese, and energy were added. We present evidence suggesting that the introduction of these components caused further increases in surcharges above the collusive levels achieved during the cartel (and in the years immediately afterwards). The data does not suggest that the trigger points for nickel, chromium, and molybdenum were meaningfully increased upon the introduction of these additional components.

Note that, for both regions, the dataset ends in December 2019 for two key reasons. First, the COVID-19 pandemic (in 2020) introduced extreme volatility in alloy prices and disrupted global stainless steel supply chains. Second, around 2019, the traditional alloy surcharge pricing model began to break down, likely due to increasing competitive pressure from Asian producers who do not use the surcharge mechanism (Giuliodori and Rodriguez, 2015).

In Europe, little information is available about the additional components added to the methodology beginning in 2004, the relevant trigger points, or the materials prices used in their calculation. Thus, it is infeasible to directly estimate trigger points after February of 2004. However, plots of surcharges in Europe suggest the iron component led to substantially higher surcharges. Figure 22 depicts average surcharges in Europe for grade 304 from February of 1994 to December of 2019. Figure 22 also depicts collusive surcharges (i.e., the surcharge implied by the surcharge methodology using the collusive trigger points without any additional components) and competitive surcharges (i.e., the surcharge implied by the surcharge methodology using the competitive trigger points without any additional components). After the introduction of the iron component (the dashed line), observed surcharges generally exceed the collusive surcharges by a significant and growing margin. A similar pattern prevails for grade 430, which is depicted in Figure 23.

Next, we examine the percentage deviation in the alloy surcharge relative to the surcharge implied by the collusive trigger points. Specifically, for each grade, we calculate the differences between the observed surcharge and the collusive surcharge, divided by the collusive surcharge. This quantity represents the percentage by which the observed surcharge exceeds the collusive surcharge. Positive values for this statistic indicate the mills set surcharges in excess of collusive levels. Figure 24 depicts results separately for grades in the 300 and 400 series of stainless steel grades. In these figures, each line represents a distinct grade of stainless steel. For both series, the percentage deviation in the alloy surcharge is positive for the vast majority of grades and months.

These figures indicate that the introduction of iron component appears to have led to further increases in the surcharge above the collusive level. While it is not possible to estimate trigger points in Europe for nickel, chromium or molybdenum over this period, the fact that surcharges increased (sometimes significantly) above the collusive levels suggests these trigger points were not meaningfully increased between 2004 and 2019. However, as estimates of trigger points cannot be obtained after the introduction of the iron component, this possibility cannot be entirely ruled out.

While trigger points for nickel, chromium, and molybdenum cannot be estimated for Europe after early 2004, they can be estimated for the United States. This is because several U.S. producers (specifically, AK Steel and North American Stainless) report alloy surcharges broken down by component (see Figure 10). By summing the nickel, chromium, and molybdenum components, it is possible to reconstruct a simplified surcharge that excludes later-added elements such as iron, manganese, titanium, and copper. This reconstructed surcharge can be used to estimate nickel, chromium, and molybdenum trigger points after 2004. Crucially, this approach avoids the need to estimate trigger points for the additional components (which would require raw material price data and alloy proportions that producers do not disclose and that are difficult to identify reliably). Focusing on the three core components thus makes it possible to continue estimating trigger points in the post-2004 period for the United States, even as additional components were gradually incorporated into the surcharge formula.

Table 17 presents trigger point estimates for February 2004 to December 2018 (after the introduction of the iron component) in the United States. These estimates are based on the average, across producers, of the simplified surcharge discussed in the preceding paragraph.[52] Trigger point estimates for January 2000 to January 2004 are also presented for comparison. For both the AEM and CLEM models, the trigger point estimates for February 2004 to December 2018 and January 2000 to January 2004 are very similar. This suggests that the mills did not adjust the nickel, chromium, or molybdenum trigger points between January 2000 and December 2018. Thus, the reduction in the trigger points made in January 2000 (which aligned trigger points in the U.S. with the collusive trigger points developed in Europe) was maintained for almost 20 years.

[52]Two producers disaggregate surcharges by component: AK Steel and North American Stainless. Thus, the estimates for February 2004 to December 2018 in Table 17 are based on the average simplified surcharge across these two producers. Surcharge reports (disaggregated by component) are not available for 2019. Thus, the estimates in Table 17 do not include data from 2019.

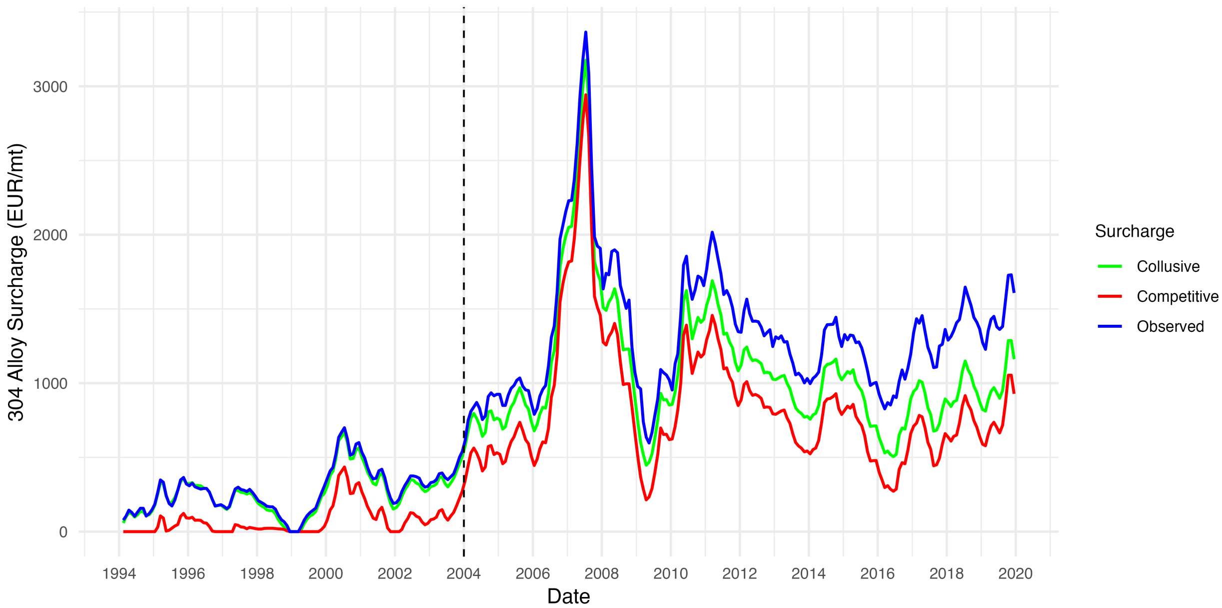


Figure 22: Surcharges for Grade 304 in Europe

Notes: This figure depicts average "observed" surcharges for grade 304 in Europe in blue. The figure also depicts the surcharge implied by the methodology with the competitive European trigger points (without any additional components, in red) and collusive/Madrid trigger points (without any additional components, in green). The variable on the x-axis is calendar time. The variable on the y-axis is the alloy surcharge in EUR/metric ton. The vertical dashed black line indicates the date of introduction of the iron component to the alloy surcharge. The data ranges from February of 1994 to December of 2019.

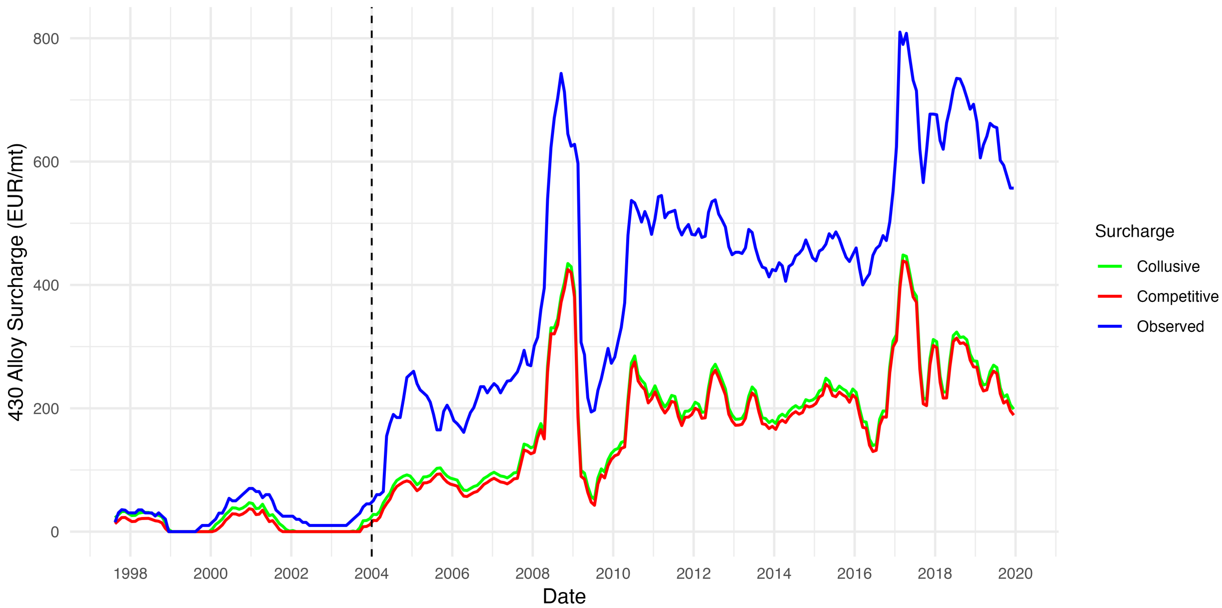


Figure 23: Surcharges for Grade 430 in Europe

Notes: This figure depicts average "observed" surcharges for grade 430 in Europe in blue. The figure also depicts the surcharge implied by the methodology with the competitive European trigger points (without any additional components, in red) and collusive/Madrid trigger points (without any additional components, in green). The variable on the x-axis is calendar time. The variable on the y-axis is the alloy surcharge in EUR/metric ton. The vertical dashed black line indicates the date of introduction of the iron component to the alloy surcharge. The data ranges from August 1997 to December 2019.

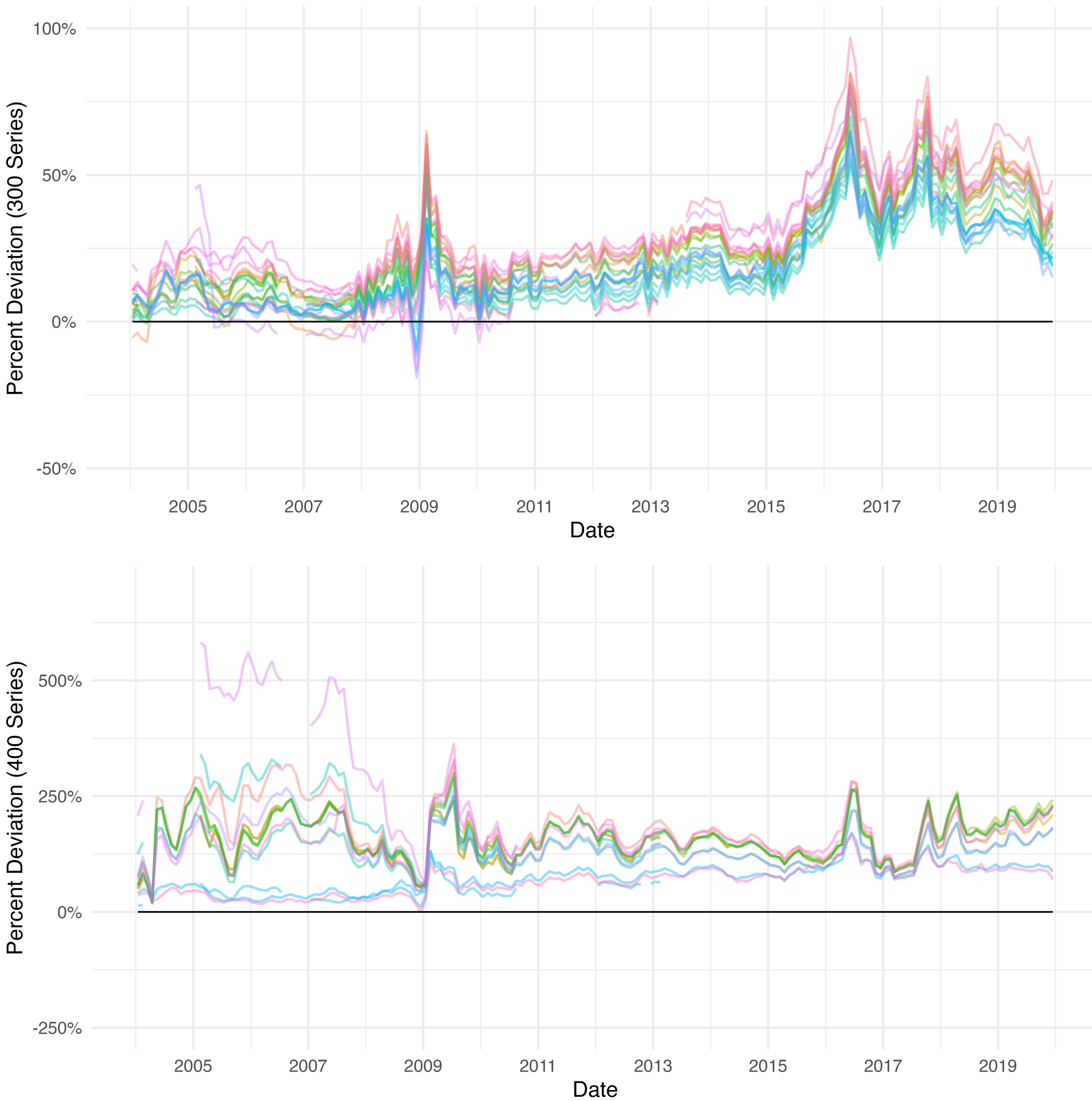


Figure 24: Percentage Deviation in Surcharges Relative to the Collusive Surcharge 300 Series (top) and 400 Series (bottom) in Europe

Notes: The percentage deviation in surcharges relative to the collusive surcharge is calculated by dividing the difference between the observed and collusive surcharges by the collusive surcharge. Each line in the figures represents a unique grade of stainless steel. The top figure depicts results for grades in the 300 series of stainless steel; the bottom figure depicts results for grades in the 400 series of stainless steel. The variable on the x-axis is calendar time. The variable on the y-axis is percent deviation. Calculations range from (January?) 2004 to (December?) 2019.

Table 15: Price Dispersion by AISI in Europe

AISI	Average CV (%)	Average Normalized Range (%)	Number of Sources
(1.4003)	2.7	4.6	2.67
(1.4307)	0.9	1.6	2.98
(1.4520)	0	0	2
(1.4713)	0	0	2
201	2.6	3.7	2
2205	3.5	4.9	2
301	1.9	3.5	2.88
301LN	4	6.4	2.28
304	0.7	1.4	3.77
304L	0.6	1.1	2.43
304LN	1.4	1.9	2
305	2.1	3.9	3.01
309	0	0	2
309S	1.5	2.1	2
310	1.5	2.2	2
314	1.5	2.6	2.42
316	0.8	1.4	2.99
316L	0.4	0.6	2.42
316L (1.4435)	0.7	1	2.26
317 LMN	0.7	1.2	2.69
317L	2.6	3.6	2
320	0.3	0.6	2.42
321	0.8	1.5	2.99
409	4.3	7.8	2.98
420	2.5	4.2	2.42
420 (1.4021)	3	5.5	2.99
420 (1.4028)	3.7	6.1	2.28
430	2.4	4.8	3.78
434	1.3	2.2	2.42
439	1.8	2.9	2.27
441	2.5	5.2	2.79
444	2.4	4.6	2.97
904L	0.5	0.8	2.45
Average	1.685	2.845	2.532

Notes: This table reports the coefficient of variation, range percentage and number of sources by AISI. The reported statistics are averages over all available months. Only grade-month combinations with at least two available sources are considered.

Table 16: Change Point Detection Results

Region	Changing Triggers	Change Point in AEM	Change Point in CLEM
Europe	Nickel and Chromium	April 1999	October 1999
	Chromium	April 1999	October 1999
United States	Nickel and Chromium	January 2000	January 2000
	Chromium	January 2000	January 2000

Notes: This table reports the detected change point for both regions under both the AEM and CLEM.

Table 17: Trigger Point Estimates After the Iron Component in the United States

Parameter	Comp. TPs ($/lb$)	Madrid TPs ($/lb$)	Late PC TPs ($/lb$)	Jan 2000 - Jan 2004		Feb 2004 - Dec 2018	
				AEM	CLEM	AEM	CLEM
Nickel Trigger ($\hat{\theta}^{Ni}$)	3.331	2.0054	1.9588	2.0083	1.9988	1.981	1.98
				(0.00097)	(0.00048)	(0.0037)	(0.0026)
Chromium Trigger ($\hat{\theta}^{Cr}$)	0.447	0.4166	0.3508	0.3518	0.355	0.3488	0.349
				(0.00067)	(7e-04)	(0.0016)	(0.00038)
Moly Trigger ($\hat{\theta}^{Mo}$)		2.9383	2.0374	2.9572	2.9996	3.003	3.0124
				(0.018)	(0.0015)	(0.022)	(0.0092)
Nickel Error SD ($\hat{\sigma}_{Ni}$)					0.00068		0.013
					(5.7e-05)		(0.00019)
Chromium Error SD ($\hat{\sigma}_{Cr}$)					0.0048		0.002
					(0.00011)		(4.2e-05)
Moly Error SD ($\hat{\sigma}_{Mo}$)					2.7e-05		4.8e-07
					(2.8e-06)		(1.9e-10)
Num. Obs.				2208	2208	3355	3355
Num. Grades				53	53	38	38

Notes: This table presents trigger point estimates, for both the CLEM and AEM, for two periods: January 2000 to January 2004 and February 2004 to December 2018. Standard errors are in parentheses. The competitive European trigger points, Madrid (i.e., collusive) trigger points, and late post-cartel trigger point estimates (from the AEM in Europe), converted to dollars per pound, are also presented for comparison purposes. These estimates are based on an average (across sources) of simplified surcharges calculated from nickel, chromium and molybdenum components from surcharge reports of AK Steel and North American Stainless.

D Trigger Point Estimation

D.1 Likelihood Function in the CLEM

The component level error model (CLEM) is estimated with maximum likelihood estimation. The surcharge for grade j in time t is

$$S_{jt} = \max\left\{0, \mathrm{Cr}_j\left[w_t^{Cr} - \theta_{Cr}\right] + 1\left\{\mathrm{Cr}_j > 0\right\}\epsilon_{jt}^{Cr}\right\} + \max\left\{0, \mathrm{Ni}_j\left[w_t^{Ni} - \theta_{Ni}\right] + 1\left\{\mathrm{Ni}_j > 0\right\}\epsilon_{jt}^{Ni}\right\}$$

$$+\max\left\{0, \mathrm{Mo}_j\left[w_t^{Mo} - \theta_{Mo}\right] + 1\left\{\mathrm{Mo}_j > 0\right\}\epsilon_{jt}^{Mo}\right\}$$

where $\varepsilon_{it}^{k} \overset{\text{i.i.d.}}{\sim} \mathcal{N}(0, \sigma_k^2)$ for $k \in \{\mathrm{Ni}, \mathrm{Cr}, \mathrm{Mo}\}$. Let f denote the PDF of a standard normal random variable. Let F denote the CDF. The likelihood function is

$$L(\theta, \sigma) = \prod_j \prod_t l(\theta, \sigma | s_{jt})$$

where s_{jt} is the observed surcharge for grade j in month t. $\theta = [\theta_{Cr}, \theta_{Ni}, \theta_{Mo}]$ and $\sigma = [\sigma_{Cr}, \sigma_{Ni}, \sigma_{Mo}]$. $L(\theta, \sigma | s_{jt})$ is the likelihood contribution from a surcharge s_{jt}.

For a grade containing only chromium (i.e., $\mathrm{Cr}_j > 0$ and $\mathrm{Ni}_j = \mathrm{Mo}_j = 0$),

$$L(\theta, \sigma | s_{jt}) = 1\left\{s_{jt} > 0\right\} f\left(\frac{s_{jt} - \mathrm{Cr}_j\left[w_t^{Cr} - \theta_{Cr}\right]}{\sigma_{Cr}}\right) + 1\left\{s_{jt} = 0\right\} F\left(-\frac{\mathrm{Cr}_j\left[w_t^{Cr} - \theta_{Cr}\right]}{\sigma_{Cr}}\right).$$

There are no grades containing only molybdenum or nickel. For a grade only containing chromium and nickel (i.e., $\mathrm{Cr}_j > 0$, $\mathrm{Ni}_j > 0$ and $\mathrm{Mo}_j = 0$),

$$L(\theta, \sigma | s_{jt}) = 1\left\{s_{jt} > 0\right\}\left\{f\left(\frac{s_{jt} - \mathrm{Cr}_j\left[w_t^{Cr} - \theta_{Cr}\right]}{\sigma_{Cr}}\right) F\left(-\frac{\mathrm{Ni}_j\left[w_t^{Ni} - \theta_{Ni}\right]}{\sigma_{Ni}}\right)\right.$$

$$+ f\left(\frac{s_{jt} - \mathrm{Ni}_j\left[w_t^{Ni} - \theta_{Ni}\right]}{\sigma_{Ni}}\right) F\left(-\frac{\mathrm{Cr}_j\left[w_t^{Cr} - \theta_{Cr}\right]}{\sigma_{Cr}}\right)$$

$$\left.+ f\left(\frac{s_{jt} - \mathrm{Ni}_j\left[w_t^{Ni} - \theta_{Ni}\right] - \mathrm{Cr}_j\left[w_t^{Cr} - \theta_{Cr}\right]}{\sqrt{\left(\sigma_{Ni}\right)^2 + \left(\sigma_{Cr}\right)^2}}\right)\right\} + 1\left\{s_{jt} = 0\right\}\left\{F\left(-\frac{\mathrm{Cr}_j\left[w_t^{Cr} - \theta_{Cr}\right]}{\sigma_{Cr}}\right) F\left(-\frac{\mathrm{Ni}_j\left[w_t^{Ni} - \theta_{Ni}\right]}{\sigma_{Ni}}\right)\right\}.$$

The likelihood contribution for grades containing only chromium and molybdenum are defined analogously. There are no grades containing only nickel and molybdenum. For a grade containing chromium, nickel and molybdenum (i.e., $\mathrm{Cr}_j > 0$, $\mathrm{Ni}_j > 0$ and $\mathrm{Mo}_j > 0$),

$$
\begin{aligned}
L(\theta, \sigma | s_{jt}) = 1\left\{s_{jt} > 0\right\} \Bigg\{ & f\left(\frac{s_{jt} - \mathrm{Cr}_j\left[w_t^{Cr} - \theta_{Cr}\right]}{\sigma_{Cr}}\right) F\left(\frac{-\mathrm{Ni}_j\left[w_t^{Ni} - \theta_{Ni}\right]}{\sigma_{Ni}}\right) F\left(\frac{-\mathrm{Mo}_j\left[w_t^{Mo} - \theta_{Mo}\right]}{\sigma_{Mo}}\right) \\
& + f\left(\frac{s_{jt} - \mathrm{Ni}_j\left[w_t^{Ni} - \theta_{Ni}\right]}{\sigma_{Ni}}\right) F\left(\frac{-\mathrm{Cr}_j\left[w_t^{Cr} - \theta_{Cr}\right]}{\sigma_{Cr}}\right) F\left(-\frac{\mathrm{Mo}_j\left[w_t^{Mo} - \theta_{Mo}\right]}{\sigma_{Mo}}\right) \\
& + f\left(\frac{s_{jt} - \mathrm{Mo}_j\left[w_t^{Mo} - \theta_{Mo}\right]}{\sigma_{Mo}}\right) F\left(\frac{-\mathrm{Cr}_j\left[w_t^{Cr} - \theta_{Cr}\right]}{\sigma_{Cr}}\right) F\left(-\frac{\mathrm{Ni}_j\left[w_t^{Ni} - \theta_{Ni}\right]}{\sigma_{Ni}}\right) \\
& + f\left(\frac{s_{jt} - \mathrm{Ni}_j\left[w_t^{Ni} - \theta_{Ni}\right] - \mathrm{Cr}_j\left[w_t^{Cr} - \theta_{Cr}\right]}{\sqrt{\left(\sigma_{Ni}\right)^2 + \left(\sigma_{Cr}\right)^2}}\right) F\left(-\frac{\mathrm{Mo}_j\left[w_t^{Mo} - \theta_{Mo}\right]}{\sigma_{Mo}}\right) \\
& + f\left(\frac{s_{jt} - \mathrm{Ni}_j\left[w_t^{Ni} - \theta_{Ni}\right] - \mathrm{Mo}_j\left[w_t^{Mo} - \theta_{Mo}\right]}{\sqrt{\left(\sigma_{Ni}\right)^2 + \left(\sigma_{Mo}\right)^2}}\right) F\left(-\frac{\mathrm{Cr}_j\left[w_t^{Cr} - \theta_{Cr}\right]}{\sigma_{Cr}}\right) \\
& + f\left(\frac{s_{jt} - \mathrm{Mo}_j\left[w_t^{Mo} - \theta_{Mo}\right] - \mathrm{Cr}_j\left[w_t^{Cr} - \theta_{Cr}\right]}{\sqrt{\left(\sigma_{Mo}\right)^2 + \left(\sigma_{Cr}\right)^2}}\right) F\left(-\frac{\mathrm{Ni}_j\left[w_t^{Ni} - \theta_{Ni}\right]}{\sigma_{Ni}}\right) \\
& + f\left(\frac{s_{jt} - \mathrm{Ni}_j\left[w_t^{Ni} - \theta_{Ni}\right] - \mathrm{Cr}_j\left[w_t^{Cr} - \theta_{Cr}\right] - \mathrm{Mo}_j\left[w_t^{Mo} - \theta_{Mo}\right]}{\sqrt{\left(\sigma_{Ni}\right)^2 + \left(\sigma_{Cr}\right)^2 + \left(\sigma_{Mo}\right)^2}}\right) \Bigg\} \\
+ 1\left\{s_{jt} = 0\right\} \Bigg\{ & F\left(-\frac{\mathrm{Cr}_j\left[w_t^{Cr} - \theta_{Cr}\right]}{\sigma_{Cr}}\right) F\left(-\frac{\mathrm{Ni}_j\left[w_t^{Ni} - \theta_{Ni}\right]}{\sigma_{Ni}}\right) F\left(-\frac{\mathrm{Mo}_j\left[w_t^{Mo} - \theta_{Mo}\right]}{\sigma_{Mo}}\right) \Bigg\}.
\end{aligned}
$$

The maximum likelihood estimates are

$$
\left(\hat{\theta}, \hat{\sigma}\right) = \underset{(\theta, \sigma)}{\operatorname{argmax}}\ L(\theta, \sigma)
$$

$$
\text{subject to } \sigma > 0.
$$

D.2 Rolling Estimates

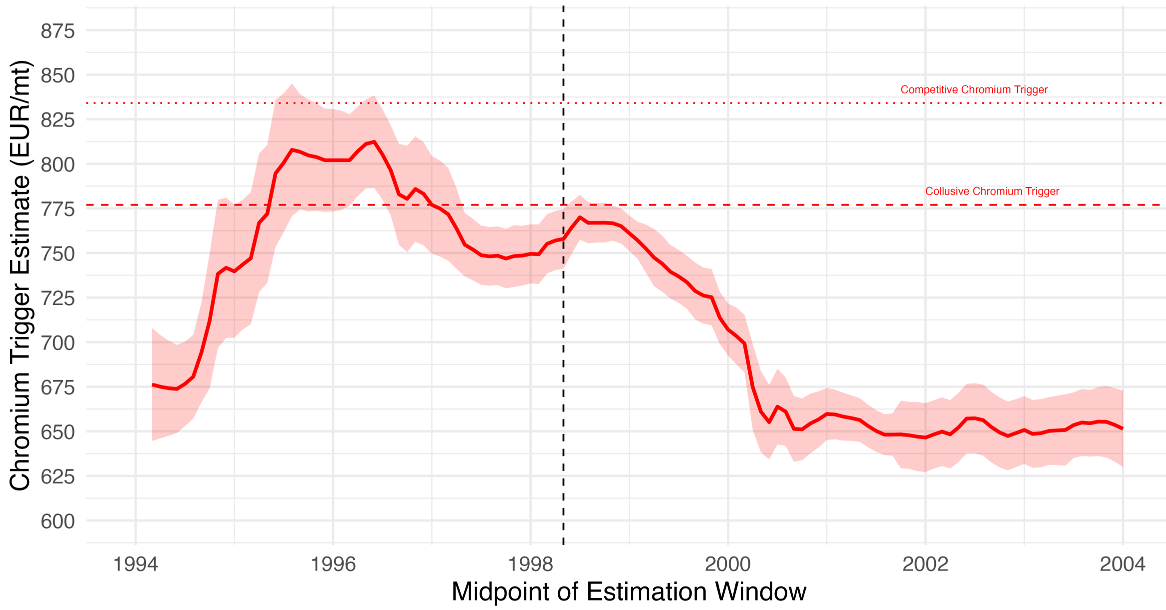


Figure 25: Rolling Estimates of the Chromium Trigger Point in Europe.

Notes: This figure depicts rolling estimates of the trigger point for chromium in Europe using the AEM. Each trigger point estimate uses data from 10 months before and 10 months after the midpoint of the estimate window. The horizontal dotted line depicts the competitive chromium trigger point. The horizontal dashed line represents the collusive/Madrid chromium trigger point. The variable on the x-axis is the midpoint of the estimation window. The variable on the y-axis is the chromium trigger point estimate in euros per metric ton. The vertical dashed black line indicates the date of the cartel's end (March 31st, 1998). The error bars represent a 95% confidence interval around the point estimate. See Appendix D.2 for additional details regarding the estimation of rolling trigger points.

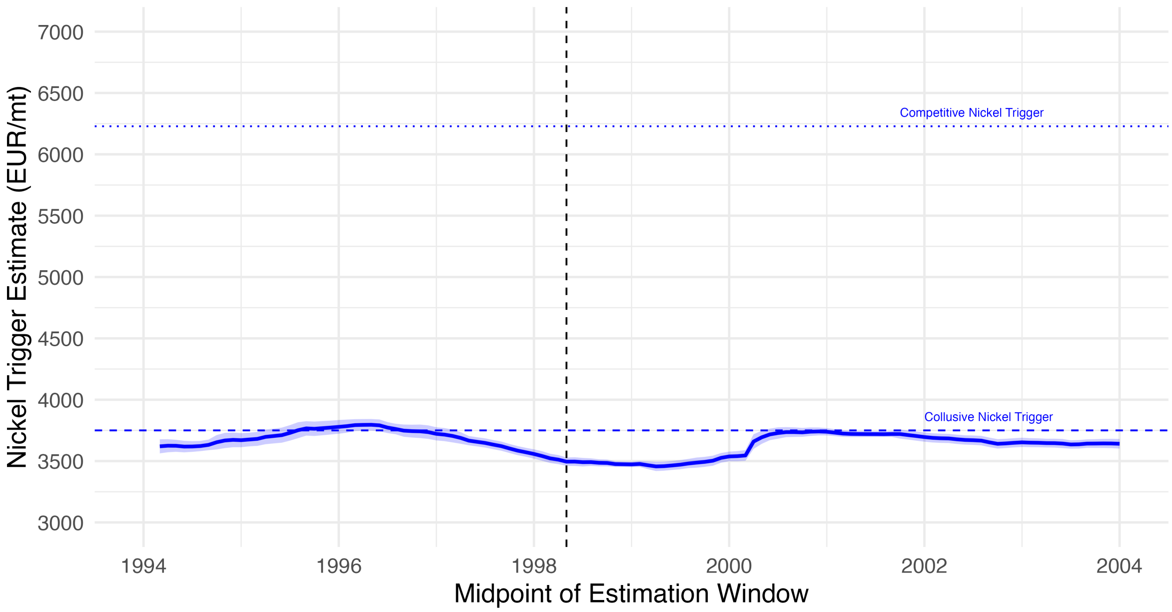


Figure 26: Rolling Estimates of the Nickel Trigger Point in Europe.

Notes: This figure depicts rolling estimates of the trigger point for nickel in Europe using the AEM. Each trigger point estimate uses data from 10 months before and 10 months after the midpoint of the estimate window. The horizontal dotted line depicts the competitive nickel trigger point. The horizontal dashed line represents the collusive/Madrid nickel trigger point. The variable on the x-axis is the midpoint of the estimation window. The variable on the y-axis is the nickel trigger point estimate in euros per metric ton. The vertical dashed black line indicates the date of the cartel's end (March 31st, 1998). The error bars represent a 95% confidence interval around the point estimate. See Appendix D.2 for additional details regarding the estimation of rolling trigger points.

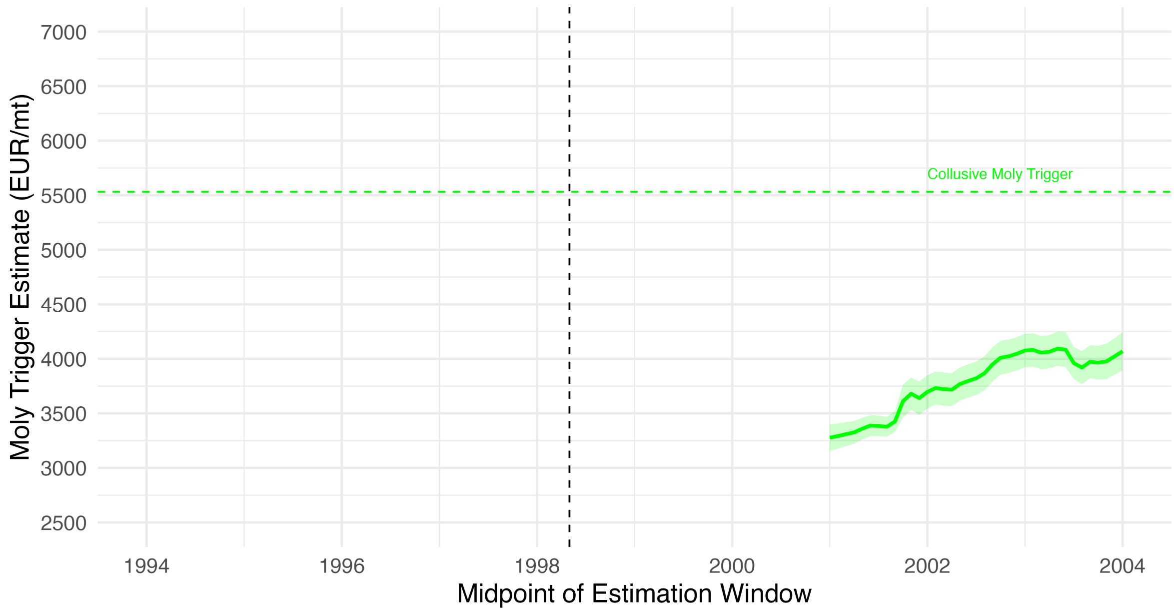


Figure 27: Rolling Estimates of the Moly Trigger Point in Europe.

Notes: This figure depicts rolling estimates of the trigger point for molybdenum in Europe using the AEM. Data from grades containing molybdenum are available only for 2001 onwards. Each trigger point estimate uses data from 10 months before and 10 months after the midpoint of the estimate window. The horizontal dotted line depicts the competitive chromium trigger point. The horizontal dashed line represents the collusive/Madrid molybdenum trigger point. The variable on the x-axis is the midpoint of the estimation window. The variable on the y-axis is the molybdenum trigger point in EUR per metric ton. The vertical dashed black line indicates the date of the cartel's end (March 31st 1998). The error bars represent a 95% confidence interval around the point estimate.

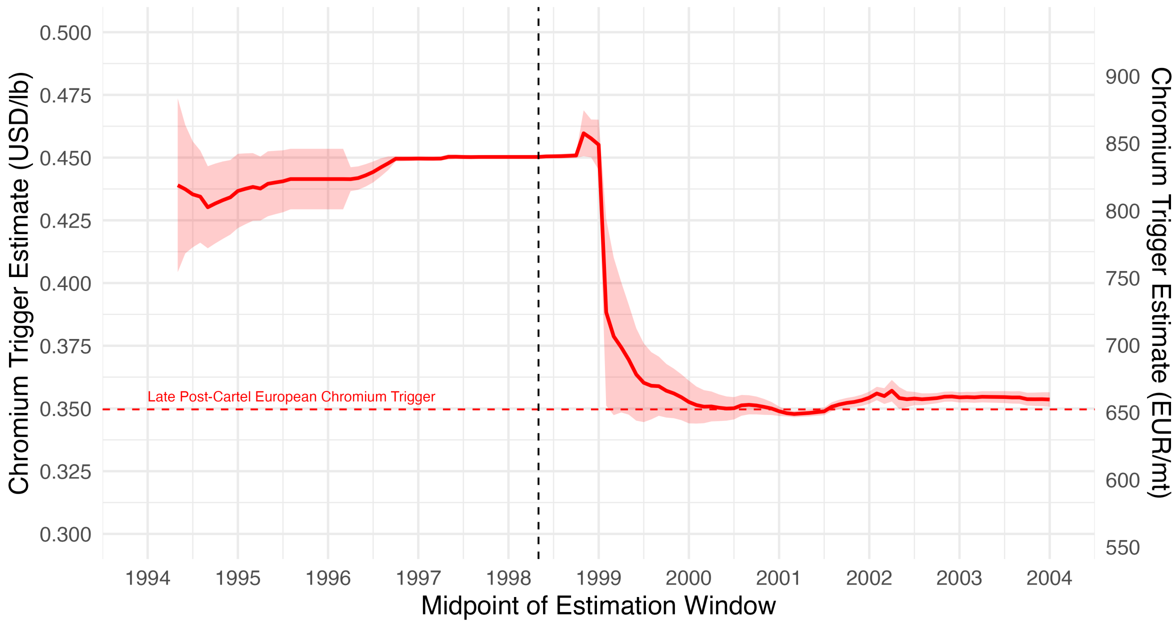


Figure 28: Rolling Estimates of the Chromium Trigger Point in the United States.

Notes: This figure depicts rolling estimates of the trigger point for chromium in the U.S. using the AEM. Each trigger point estimate uses data from 12 months before and 12 months after the midpoint of the estimate window. The larger estimation relative to Figures 25 and 29 is necessary due to the large number of zero surcharges in the U.S. The variable on the x-axis is the midpoint of the estimation window. The variable on the primary y-axis is the chromium trigger point in USD per pound. The variable on the secondary y-axis is the chromium trigger estimate in euros per metric ton based on an exchange rate of 1.182 USD/EUR. The vertical dashed black line indicates the date of the cartel's end (March 31st 1998). The error bars represent a 95% confidence interval around the point estimate. The horizontal dashed line represents the European chromium trigger estimate (from the CLEM) from the late post-cartel period (converted to dollars per pound). See Appendix D.2 for additional details regarding the estimation of rolling trigger points.

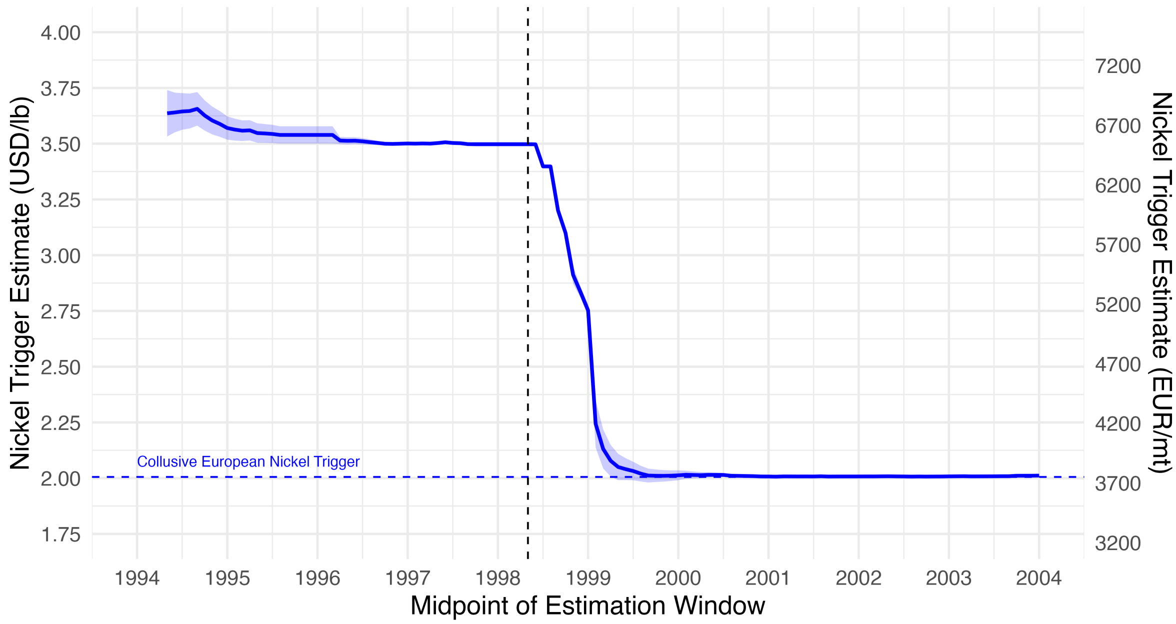


Figure 29: Rolling Estimates of the Nickel Trigger Point in the United States.

Notes: This figure depicts rolling estimates of the trigger point for nickel in the U.S. using the AEM. Each trigger point estimate uses data from 12 months before and 12 months after the midpoint of the estimate window. The larger estimation relative to Figures 25 and 29 is necessary due to the large number of zero surcharges in the U.S. The variable on the x-axis is the midpoint of the estimation window. The variable on the primary y-axis is the nickel trigger point in USD per pound. The variable on the secondary y-axis is the nickel trigger estimate in euros per metric ton based on an exchange rate of 1.179 USD/EUR. The vertical dashed black line indicates the date of the cartel's end (March 31st 1998). The error bars represent a 95% confidence interval around the point estimate. The horizontal dashed line represents the collusive/Madrid nickel trigger point in Europe (converted to dollars per pound). See Appendix D.2 for additional details regarding the estimation of rolling trigger points.

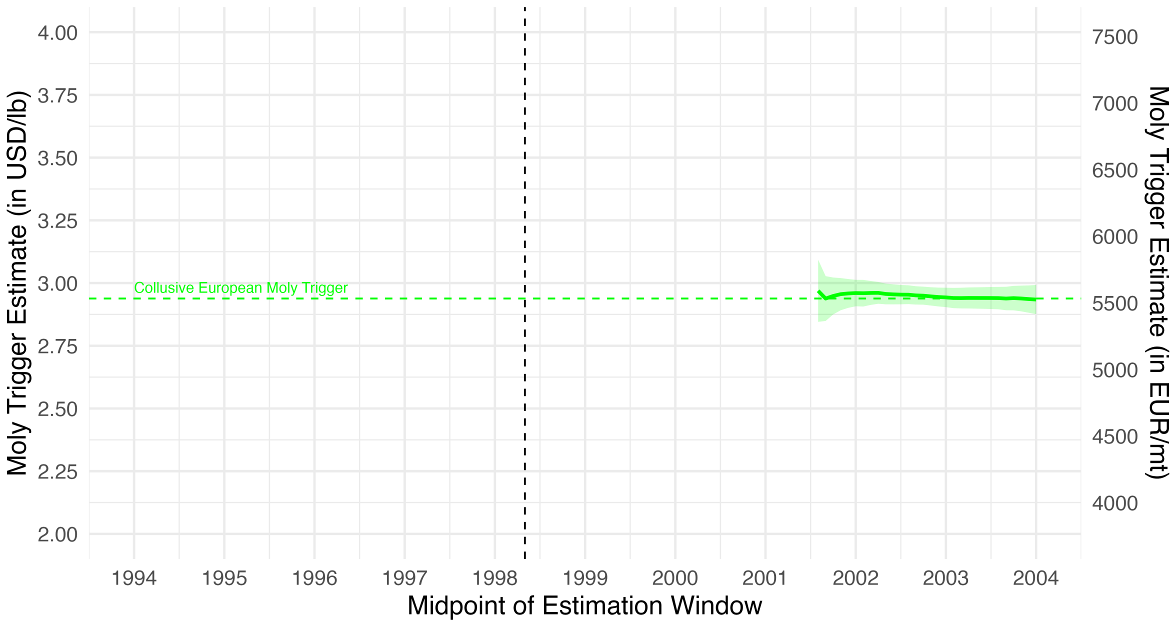


Figure 30: Rolling Estimates of the Moly Trigger Point in the U.S.

Notes: This figure depicts rolling estimates of the trigger point for moly in the U.S. using the AEM. Each trigger point estimate uses data from 12 months before and 12 months after the midpoint of the estimate window. The larger estimation relative to Figures 25 and 29 is necessary due to the large number of zero surcharges in the U.S. The variable on the x-axis is the midpoint of the estimation window. The variable on the primary y-axis is the molybdenum trigger point in USD per pound. The variable on the secondary y-axis is the molybdenum trigger estimate in euros per metric ton based on an exchange rate of 1.171 USD/EUR. The vertical dashed black line indicates the date of the cartel's end (March 31st 1998). The error bars represent a 95% confidence interval around the point estimate. The horizontal dashed line represents the collusive/Madrid molybdenum trigger point in Europe (converted to dollars per pound).

Rolling estimates of trigger points in Europe are depicted in Figures 25, 26, and 27. These rolling estimates are constructed as follows. For each month, data is selected from a window of 10 months before and after that month. Any observations within that window (regardless of grade) are used for estimation under the AEM.

Prior to August 1997, data is only available for grade 304 (from CRU). With only a single grade, both trigger points are typically not identifiable. To enable estimation of trigger points for periods prior to August 1997, we impute the Madrid trigger point for one trigger point and estimate the other trigger point. To illustrate, consider the chromium estimates depicted in Figure 25. For surcharges from before August 1997, we fix the trigger point of nickel at €3,750 (the Madrid value) and estimate the chromium trigger point freely. Formally, the observed surcharge S_{jt} from before August 1997 for 304 is adjusted to

$$\tilde{S}_{jt} = S_{jt} - \mathrm{Ni}_j \, max\left\{0, w_t^{Ni} - 3750\right\}.$$

Next, the remaining chromium trigger point is estimated. Formally, the following model is estimated with non-linear least squares:

$$\tilde{S}_{jt} = \mathrm{Cr}_j\ max\left\{0, w_t^{Cr} - \theta_{Cr}\right\} + \varepsilon_{jt}.$$

An analogous procedure is followed to obtain estimates of the nickel trigger points for months before August 1997. Figure 27 presents rolling trigger estimates for molybdenum in Europe. Recall that data from grades including molybdenum is available only for 2001 onwards in Europe.

Rolling estimates of trigger points in the U.S. are depicted in Figures 28, 29, and 30. The procedure for estimating trigger points in the U.S. mirrors the procedure outlined in the previous paragraph for Europe with two modifications. First, rolling estimates in the U.S. use 12 months (rather than 10) before and after each month. This is due to the fact that surcharges are zero in a larger number of months in the U.S. As a result, additional data is needed to accurately identify surcharges in certain months. Second, as data on both 304 and 430 are available in the U.S. throughout the sample, the imputation step outlined above is not necessary in the U.S.

Finally, molybdenum trigger point estimates in the U.S. are available only from July 2001 onwards. This is the case as 1) data from grades containing molybdenum are only available for 2000 onwards, and 2) the raw material price for molybdenum is below the molybdenum trigger point between January of 2000 and July of 2001. When a raw material price is below the relevant trigger point, the surcharge component is zero and the trigger point cannot be identified.

D.3 Trigger Point Estimate Robustness

Table 18 presents trigger point estimates in Europe, disaggregated by data source. The analysis in the main text uses the average surcharge across these sources (for each month and grade). All estimates in Table 18 pertain to the post-cartel period as only a single data source (CRU) is available during the cartel period. Each estimate is obtained using the AEM.

Because CRU provides data only for grades 304 and 430, no molybdenum trigger point is available for this source. Trigger point estimates are broadly consistent across sources. In particular, the chromium trigger point in the post-cartel period is lower than during the cartel period for every source. The nickel trigger point, by contrast, shows no meaningful increase following the cartel's dissolution. For all sources, molybdenum trigger point estimates are significantly less than the Madrid trigger point of €5,532 per metric ton. This robustness check establishes that results are not driven by a single data source. An analogous robustness check is conducted for trigger point estimates from the U.S. Results are presented in Table 21.

Table 19 reports trigger point estimates (from the AEM) using only data for grades 304 and 430 in Europe, averaging across sources where multiple are available. Recall that grades 304 and 430 (along with

316) account for the vast majority of stainless steel production. The resulting estimates are closely aligned with those in the main text, which incorporate all available grades. This robustness check confirms that the findings in the main text are not driven by the inclusion of less common stainless steel grades.

Table 20 presents a variety of robustness checks for the CLEM in Europe. First, we estimate trigger points supposing the error terms are distributed according to a logistic distribution instead of a normal distribution. Formally, the surcharge for grade j at time t is modeled as

$$S_{jt} = \max\left\{0, \mathrm{Cr}_j \left[w_t^{Cr} - \theta_{Cr}\right] + 1\left\{\mathrm{Cr}_j > 0\right\} \epsilon_{jt}^{Cr}\right\} + \max\left\{0, \mathrm{Ni}_j \left[w_t^{Ni} - \theta_{Ni}\right] + 1\left\{\mathrm{Ni}_j > 0\right\} \epsilon_{jt}^{Ni}\right\} \quad (5)$$

$$+\max\left\{0, \mathrm{Mo}_j \left[w_t^{Mo} - \theta_{Mo}\right] + 1\left\{\mathrm{Mo}_j > 0\right\} \epsilon_{jt}^{Mo}\right\}$$

where ε_{jt}^k is the alloy-specific measurement error term for alloy $k \in \{\mathrm{Cr}, \mathrm{Ni}, \mathrm{Mo}\}$. Unlike the model in the main text, each ε_{it}^k is assumed to be i.i.d. and follows a logistic distribution with mean zero. Formally, $\varepsilon_{it}^k \overset{\text{i.i.d.}}{\sim} Logistic(0, \sigma_k)$ where $k \in \{\mathrm{Ni}, \mathrm{Cr}, \mathrm{Mo}\}$. Note that the variance of ε_{it}^k is $\sigma_k^2 \frac{\pi^2}{3}$. Unlike the CLEM with normally distributed errors, the estimates in Table 20 are consistent with the CLEM estimates in the main text (see Table 2).

In the main text, we assumed the errors in the CLEM were independent. We next estimate trigger points in a model that allows for a correlation between the measurement errors. This robustness check uses only data from grades that do not contain molybdenum. Including grades containing molybdenum would require estimating three separate correlation coefficients (one between the nickel and chromium error, one between the nickel and molybdenum error and another between the chromium and molybdenum error) which would increase the total number of parameters to 9. Instead, we estimate a simpler model that includes only grades without molybdenum. Thus, we estimate a single correlation between the nickel error ϵ_{it}^{Ni} and the chromium error ϵ_{it}^{Cr}. This correlation is denoted ρ. Table 20 presents results. Allowing for a correlation between the errors does not significantly change the trigger point estimates from the main text.

Finally, we conduct a robustness check that allows for a form of heteroskedasticity in the CLEM. In the main text, the error terms are homoskedastic, meaning the variance of (for example) the nickel component error is the same across all grades. This assumption may be unrealistic if, for example, measurement error is driven by differences between the alloy prices employed in estimation and the alloy prices used by firms when calculating surcharges. Measurement error of this kind would have a larger impact on grades that contained a larger amount of that alloy (recall that alloy prices are multiplied by the percentage of the relevant alloy in that grade within the surcharge formula). To account for heteroskedasticity of this kind, we conduct a robustness check where the variance of the errors varies with the percentage of the alloy in a

Table 18: Trigger Point Estimates in Europe Decomposed by Source

Parameter	Comp. TPs	Madrid TPs	Post-Cartel Est. (AEM) CRU	Legier	ThyssenKrupp	Outokumpu
Nickel Trigger ($\hat{\theta}^{Ni}$)	6241	3750	3586.89	3692.85	3691.92	3602.34
			(15.84)	(12.34)	(26.93)	(27.48)
Chromium Trigger ($\hat{\theta}^{Cr}$)	821	777	664.43	651.79	652.39	646.25
			(5.76)	(6.3)	(14.35)	(15.61)
Moly Trigger ($\hat{\theta}^{Mo}$)		5532		3832.28	3821.07	4245.81
				(50.9)	(101.94)	(122.81)
Num. Obs.			106	780	317	260
Num. Grades			2	24	31	35

Notes: This table presents post-cartel period (April 1998 to Jan 2004) estimates for Europe decomposed by the data source, using the AEM. Standard errors are in parentheses. The competitive trigger points and collusive/Madrid trigger points are also presented for comparison purposes.

particular grade. Specifically, $Var(\epsilon_{jt}^{Ni}) = Ni_j\sigma_{Ni}^2$, $Var(\epsilon_{jt}^{Cr}) = Cr_j\sigma_{Cr}^2$, and $Var(\epsilon_{jt}^{Mo}) = Mo_j\sigma_{Mo}^2$. Results are presented in Table 20. The trigger point estimates are highly similar to the estimates in the main text (under homoskedastic errors).

Table 19: Trigger Point Estimates in Europe for Grade 304 and 430 Only

Parameter	304/430 Only (AEM)			
	Cartel Est.	PC Est.	Early PC Est.	Late PC Est.
Nickel Trigger ($\hat{\theta}^{Ni}$)	3665.97	3545.86	3458.03	3584.41
	(28.77)	(15.46)	(11.14)	(15.82)
Chromium Trigger ($\hat{\theta}^{Cr}$)	786.68	687.89	765.55	665.49
	(15.49)	(5.5)	(5.05)	(5.75)
Num. Obs.	58	140	34	106
Num. Grades	2	2	2	2

Notes: This table presents trigger point estimates in Europe using only data on grade 304 and 430. The cartel period is February 1994 - March 1998. The post-cartel period is April 1998 - January 2004. The early post-cartel period is April 1998 - August 1999. The late post-cartel period is September 1999 - January 2004. Standard errors are in parentheses. The competitive trigger points and collusive/Madrid trigger points are also presented for comparison purposes.

Table 20: Robustness Checks for Trigger Point Estimates in Europe for the CLEM

Parameter	Logistic Errors		Correlations		Heteroskedasticity	
	Cartel Est.	PC Est.	Cartel Est.	PC Est.	Cartel Est.	PC Est.
Nickel Trigger ($\hat{\theta}^{Ni}$)	3671.68	3643.57	3652.51	3659.92	3612.84	3625.4
	(22.27)	(8.2)	(36.12)	(9.9)	(30.51)	(10.86)
Chromium Trigger ($\hat{\theta}^{Cr}$)	770.58	670.46	782.91	666.86	810	669.45
	(8.58)	(2.63)	(17.37)	(3.43)	(17.93)	(3.18)
Moly Trigger ($\hat{\theta}^{Mo}$)		3833.74				3873.3
		(31.55)				(68.8)
Nickel Error SD ($\hat{\sigma}_{Ni}$)	6.87	9.89	9.42	22.9	24.18	53.44
	(0.79)	(0.2)	(2.68)	(1.59)	(7.99)	(2.91)
Chromium Error SD ($\hat{\sigma}_{Cr}$)	2.39	4.22	5.13	9	24.89	21.49
	(0.67)	(0.19)	(2.38)	(0.39)	(6.08)	(0.87)
Moly Error SD ($\hat{\sigma}_{Mo}$)		11.73				131.14
		(0.21)				(10.74)
Correlation ($\hat{\rho}$)			0.48	-0.63		
			(0.53)	(0.13)		
Num. Obs.	58	997	58	691	58	997
Num. Grades	2	42	2	31	2	42

Notes: This table presents a variety of robustness checks for the CLEM estimates for Europe. The "Logistic Errors" estimates are from a model where the measurement errors are from a logistic distribution instead of a normal distribution. The "Correlations" estimates are from an extension of the CLEM that allows for correlations between the errors. These estimates use only data from grade 304 and 430. The "Heteroskedastic" estimates allow for heteroskedasticity in the measurement errors terms in the CLEM model. The cartel period is February 1994 - March 1998. The post-cartel period is April 1998 - January 2004. Standard errors are in parentheses. The competitive trigger points and collusive/Madrid trigger points are also presented for comparison purposes.

Table 21: Trigger Point Estimates in the U.S. Decomposed by Source

Parameter	Competitive TPs ($/$lb$)	Madrid TPs ($/$lb$)	Late PC TPs ($/$lb$)	Post-Cartel Est. (AEM) CRU	ATI	AK Steel
Nickel Trigger ($\hat{\theta}^{Ni}$)	3.331	2.0054	1.9588	1.9925	2.0109	1.9981
				(0.0073)	(0.0014)	(3e-04)
Chromium Trigger ($\hat{\theta}^{Cr}$)	0.447	0.4166	0.3508	0.3479	0.3578	0.3497
				(0.0033)	(0.0013)	(1e-04)
Moly Trigger ($\hat{\theta}^{Mo}$)		2.9383	2.0374		2.9139	2.9948
					(0.0244)	(0.0044)
Num. Obs.				98	1242	1419
Num. Grades				2	36	30

Notes: This table presents post-cartel period (April 1998 to Jan 2004) estimates for the U.S. decomposed by the data source, using the AEM. Standard errors are in parentheses. The competitive European trigger points, Madrid (i.e., collusive) trigger points, and late post-cartel trigger point estimates (from the AEM in Europe), converted to dollars per pound, are also presented for comparison purposes.

E Hypothesis Testing

E.1 Hypothesis Tests using Grade 304 and 430 Only

Although trigger points are common across grades, most grades in the dataset appear only in the post-cartel period. Recall that grade 304 and 430 are the only grades for which data are available in the cartel period. In the main analysis, we use all available grades to estimate trigger points to exploit the full set of post-cartel observations. However, because the bootstrap resampling procedure is stratified by grade, grades that exist only in the post-cartel period contribute variation solely within that period. To verify that results are not driven by grades observed only after the cartel ended, we re-estimate the test using only grade 304 and 430 (the two grades that appear in both the cartel and post-cartel periods). Table 22 presents results from both wald and bootstrap-based tests. As neither grade 304 nor 430 contains molybdenum, tests involving the molybdenum trigger point cannot be conducted using solely data on grade 304 and 430. The results are qualitatively similar to those of the main text, confirming that hypothesis testing results are not sensitive to the inclusion of grades that are present only in the post-cartel period.

E.2 Permutation Test Procedure

The residual bootstrap procedure employed in the main text cannot be applied to the CLEM. This is the case as residuals in the CLEM are inside non-linear maximum operators. Thus, the residuals for each component can't be recovered and subsequently resampled. However, an alternative permutation-based test can be conducted using the CLEM. However, as permutation-based tests rely on relabeling observations across periods, they are valid only for null hypotheses that imply no systematic difference between the cartel and post-cartel period (i.e., equality null hypotheses). Thus, the null hypotheses in this subsection will be of the form

$$H_0 : \theta_{pc}^{Ni} = \theta_c^{Ni} \text{ and } \theta_{pc}^{Cr} = \theta_c^{Cr}.$$

The permutation-based testing procedure proceeds as follows. First, maximum likelihood estimates of the CLEM are obtained separately for the pre and post-cartel period. The respective maximized likelihoods for these two models are added together to obtain a test statistic L^*. Second, observations are randomly assigned (i.e., permuted) to the cartel and post-cartel period. This assignment is done in a stratified manner. Specifically, the random assignment is done such that the number of observations of each grade assigned to the post-cartel period is the same as in the original data.[53] Thus, the random assignment does not change the number of observations from each grade in the cartel and post-cartel period. Third, the CLEM estimated

[53] As the CLEM is considerably more computationally burdensome than the AEM, permutation-based tests use only data on grade 304 and 430.

separately on the (new) post-cartel and cartel periods. The sum of the maximized likelihoods from these two models is saved. Fourth, steps 2-4 are repeated B times to generate a distribution for the maximized likelihood under the null hypothesis. Finally, the test statistic L^* is compared with its empirical distribution under the null hypothesis. If the observed estimates lie in the upper tail of the bootstrap distribution, the null is rejected.

For comparison, an analogous permutation-based procedure is applied to the AEM, which is estimated using nonlinear least squares (NLLS). In this case, the objective function represents the sum of squared errors (SSE). Thus, smaller values indicate a better model fit. The test therefore proceeds identically to the above case, except that the statistic of interest is the minimized SSE rather than the maximized log-likelihood. Because a smaller SSE corresponds to a better fit, the null hypothesis is rejected if the observed statistic lies in the lower tail of the null distribution.

Table 23 presents results. For both the AEM and CLEM, the null hypothesis of no change in trigger points is decisively rejected. The null hypotheses of no difference between the cartel and early post-cartel periods, and between the cartel and late post-cartel periods, are also rejected. Because these permutation-based tests assess only equality of trigger points, rejection indicates that the trigger points changed over time but do not indicate the direction of change. Taken together with the estimates presented in the main text, showing a clear decline in the chromium trigger point and little or no increase in the nickel trigger point, these results suggest that trigger points not only changed but did so in a manner consistent with a downward adjustment following the cartel's dissolution.

Table 22: Hypothesis Testing Results for Europe using 304/430 Only

	Null Hypothesis	Wald P-value		Bootstrap P-value
		AEM	CLEM	AEM
Nickel Tests:	$H_0 : \theta_c^{Ni} \leq \theta_{pc}^{Ni}$	$<$ .001***	$<$ .001***	$<$ .001***
	$H_0 : 1.025\left(\theta_c^{Ni}\right) \leq \theta_{pc}^{Ni}$	$<$ .001***	$<$ .001***	$<$ .001***
	$H_0 : 1.05\left(\theta_c^{Ni}\right) \leq \theta_{pc}^{Ni}$	$<$ .001***	$<$ .001***	$<$ .001***
	$H_0 : \theta_c^{Ni} \leq \theta_{pce}^{Ni}$	$<$ .001***	$<$ .001***	$<$ .001***
	$H_0 : \theta_c^{Ni} \leq \theta_{pcl}^{Ni}$	0.006**	0.013*	$<$ .001***
	$H_0 : 3750 \leq \theta_{pc}^{Ni}$	$<$ .001***	$<$ .001***	$<$ .001***
Chromium Tests:	$H_0 : \theta_c^{Cr} \leq \theta_{pc}^{Cr}$	$<$ .001***	$<$ .001***	$<$ .001***
	$H_0 : 1.025\left(\theta_c^{Cr}\right) \leq \theta_{pc}^{Cr}$	$<$ .001***	$<$ .001***	$<$ .001***
	$H_0 : 1.05\left(\theta_c^{Cr}\right) \leq \theta_{pc}^{Cr}$	$<$ .001***	$<$ .001***	$<$ .001***
	$H_0 : \theta_c^{Cr} \leq \theta_{pce}^{Cr}$	0.097*	0.116	0.095*
	$H_0 : \theta_c^{Cr} \leq \theta_{pcl}^{Cr}$	$<$ .001***	$<$ .001***	$<$ .001***
	$H_0 : 777 \leq \theta_{pc}^{Cr}$	$<$ .001***	$<$ .001***	0.007**
Joint Tests:	$H_0 : \theta_c^{Ni} \leq \theta_{pc}^{Ni}$ and $\theta_c^{Cr} \leq \theta_{pc}^{Cr}$			$<$ .001***
	$H_0 : \theta_c^{Ni} \leq \theta_{pce}^{Ni}$ and $\theta_c^{Cr} \leq \theta_{pce}^{Cr}$			$<$ .001***
	$H_0 : \theta_c^{Ni} \leq \theta_{pcl}^{Ni}$ and $\theta_c^{Cr} \leq \theta_{pcl}^{Cr}$			$<$ .001***
	$H_0 : 3750 \leq \theta_{pc}^{Ni}$ and $777 \leq \theta_{pc}^{Cr}$			$<$ .001***

Notes: This table presents hypothesis testing results for Europe. The bootstrap p-values are calculated using a residual bootstrap procedure. Tests in this table include only data on grade 304 and 430. Bootstrap-based tests are conducted using 10,000 bootstrap replications. θ_c^j denotes the trigger point for the cartel period for alloy $j \in \{\mathrm{Ni}, \mathrm{Cr}, \mathrm{Mo}\}$. θ_{pc}^j denotes the trigger point for the post-cartel period for alloy $j \in \{\mathrm{Ni}, \mathrm{Cr}, \mathrm{Mo}\}$. θ_{pce}^j denotes the trigger point for the early post-cartel period for alloy $j \in \{\mathrm{Ni}, \mathrm{Cr}, \mathrm{Mo}\}$. θ_{pcl}^j denotes the trigger point for the late post-cartel period for alloy $j \in \{\mathrm{Ni}, \mathrm{Cr}, \mathrm{Mo}\}$. *** indicates the null is rejected at a .001 level. ** indicates the null is rejected at a .01 level. * denotes the null is rejected at a .1 level.

Table 23: Hypothesis Testing Results for Europe: Permutation-Based Tests

	Null Hypothesis	Permutation p-value	
		AEM	CLEM
	$H_0 : \theta_c^{Ni} = \theta_{pc}^{Ni}$ and $\theta_c^{Cr} = \theta_{pc}^{Cr}$	$< .001$***	$< .001$***
Joint Tests:	$H_0 : \theta_c^{Ni} = \theta_{pce}^{Ni}$ and $\theta_c^{Cr} = \theta_{pce}^{Cr}$	$< .001$***	$< .001$***
	$H_0 : \theta_c^{Ni} = \theta_{pcl}^{Ni}$ and $\theta_c^{Cr} = \theta_{pcl}^{Cr}$	$< .001$***	$< .001$***

Notes: This table presents hypothesis testing results for Europe under a permutation test. Permutation tests involve only data on grade 304 and 430. Permutation tests are conducted using 10,000 bootstrap replications. θ_c^j denotes the trigger point for the cartel period for alloy $j \in \{\text{Ni}, \text{Cr}, \text{Mo}\}$. θ_{pc}^j denotes the trigger point for the post-cartel period for alloy $j \in \{\text{Ni}, \text{Cr}, \text{Mo}\}$. θ_{pce}^j denotes the trigger point for the early post-cartel period for alloy $j \in \{\text{Ni}, \text{Cr}, \text{Mo}\}$. θ_{pcl}^j denotes the trigger point for the late post-cartel period for alloy $j \in \{\text{Ni}, \text{Cr}, \text{Mo}\}$. *** indicates the null is rejected at a .001 level. ** indicates the null is rejected at a .01 level. * denotes the null is rejected at a .1 level.