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Quantification of Harm*

Abstract

This paper provides a concise yet comprehensive treatment of the economic and econometric methods used to quantify harm caused by competition law infringements. Its central argument is that economic theory, both a market theory of how competitive outcomes arise and a theory of harm explaining how the conduct distorted competition, is an indispensable foundation for any credible quantification. Building on this framework, the paper characterises the types of harm caused by cartels and by exploitive and exclusionary abuse, and traces how harm propagates to the affected economic actors along and beyond the supply chain. The major methods for estimating price overcharges, namely econometric approaches and market simulation, are developed step by step using a single illustrative example of a bottled-water cartel. The analysis extends to umbrella effects, pass-on, harm from exclusionary conduct, apportionment, and the compounding and discounting of harm.

Keywords

Antitrust Damage; Damage Quantification; Counterfactual Analysis; Cartel Overcharge; Pass-On Effects; Umbrella Effects

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1. Introduction

The economically grounded quantification of harm caused by competition law infringements has grown substantially in practical importance over the past two decades. Where a claim for compensation is pursued, quantifying the harm suffered is not merely a technical step. It is the central evidentiary challenge, and the outcome of damages proceedings will often turn on the quality of the economic analysis presented. Quantification is not restricted to quantifying harm in competition law infringements but is a tool also used more widely whenever harm needs to be quantified such as for example in securities litigation or other litigious matters. Against this background, the present paper aims at providing a concise yet comprehensive treatment of the economic and econometric methods available for quantifying harm, and, crucially, the conceptual framework within which those methods must be situated.

A central departure of this paper from earlier treatments of this subject is its emphasis on the role of economic theory as an indispensable foundation for any quantification exercise. Econometric methods are powerful tools, but they do not operate in a vacuum. Two theoretical pillars must be established before any empirical analysis can be meaningfully conducted. First, market theory describes how prices and other competitive outcomes would have been determined absent the infringement. It is the core foundation to constructing a credible counterfactual. The second, the theory of harm, explains how specifically the unlawful conduct unfolded and how based on this, it could have distorted the competitive process and thereby caused the estimated effect. Without both, econometric analysis risks becoming a purely mechanical exercise. Statistically precise, but economically uninterpretable. The present paper treats those two foundations as prior to, and structurally inseparable from, the empirical methods that follow.

A second distinguishing feature of this paper is its practical, handbook-oriented approach. Rather than surveying methods in the abstract, the major econometric approaches to quantification of harm are introduced, developed, and compared using a single, consistent illustrative example: a hypothetical price-fixing cartel in the market for bottled water. This paper assumes that three major producers coordinated prices, selling through beverage wholesalers and food retailers to end consumers and gastronomy operators. A consistent dataset with weekly transaction price and cost data has been generated for a three-year observation window, with seasonal temperature serving as a proxy for demand. This case study is not merely a backdrop. It is progressively adapted throughout the core methodological section to reflect different cartel structures, alternative assumptions about the nature of harm, and varying data environments, making visible how methodological choices and underlying assumptions shape the quantification of harm. The methods and challenges developed through this example then serve as an analytical reference point for the discussion of further harm channels and infringement types, including umbrella effects, pass-on and exclusionary conduct.

The paper is structured as follows. Section 2 characterises the types of harm by anti-competitive conduct and identifies the range of economic actors that may be harmed. It covers harm caused by cartels and by abusive conduct, both exploitive and exclusionary, and traces the mechanism through which harm propagates along the supply chain, and into related markets. Section 3 forms the analytical core. It opens with a treatment of the role of economic theory before turning to the mechanics of counterfactual analysis and the range of available comparators. The central subsections develop the major econometric and economic approaches to estimating price overcharges step by step using the bottled water case study. The section then extends this analysis to umbrella effects, pass-on, and harm in exclusionary conduct cases. These are discussed conceptually and with reference to their specific methodological challenges. Further aspects of quantification are addressed before section 4 concludes.

2. Harm caused by anti-competitive conduct

The restriction of competition by a cartel or abusive conduct by a dominant firm harms purchasers, suppliers, and ultimately consumers of the products or services through increased prices, lower quality or reduced variety. If the functioning of competition between firms is impaired or eliminated by cartel agreements or by an abuse of a dominant position, the competitive mechanism no longer fulfils its allocative function. In addition to these allocative inefficiencies, competition law infringements lead to a redistribution of wealth from direct and indirect purchasers to the cartel and may also affect economic actors that are neither part of the supply chain nor purchasers of the goods or services provided by a cartel or directly affected by an abusive conduct.

From a conceptual point of view, harm is quantified by a comparison of the factual situation, that is, the situation in the presence of the conduct identified as competition law infringement, with a hypothetical situation, the so-called counterfactual or but-for scenario, a situation that would have prevailed absent the infringement.[1] The types of harm caused by cartels or abusive behaviour, as well as the affected parties – namely, the economic actors suffering negative impacts – are identified in the following subsections.

2.1. Types of harm

2.1.1. Harm caused by cartels

The primary goal of cartel agreements is to increase profits by softening or eliminating competition among rival firms. Such agreements can be based on different strategic parameters. The following main forms can be distinguished:

- In a price-fixing cartel, competitors collectively decide on the prices of their products, on price lists, or on the timing and magnitude of price increases. Bid-rigging cartels represent a specific variant in which firms coordinate the conditions of bids submitted in procurement auctions. In all such cases, the cartel aims at setting prices above the competitive level.
- In a quota cartel, a collective agreement is reached on quantities to be produced or marketed by each cartel participant. Rather than fixing prices directly, cartelists restrict supply in order to achieve a price increase indirectly.

[1] More details on how to establish the appropriate counterfactual are provided in section 3.2.

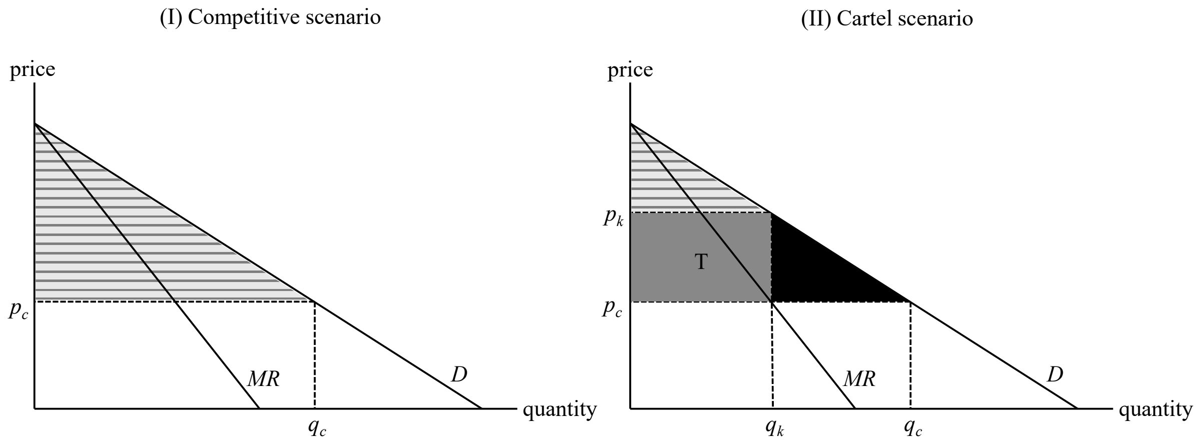
- Market-sharing arrangements allocate geographic markets, customer groups, or product segments to individual cartelists. A distinguishing feature of market-sharing cartels is that explicit price coordination is not required. Market-sharing agreements allocate markets to individual competitors, allowing each firm to act as a (local) monopolist, charging monopoly prices depending on the specific demand and cost condition they face in their respective market.[2]
- In a conditions cartel, competitors collectively agree on standard terms and conditions of trade, such as discount structures, rebate systems, payment terms, or delivery conditions, without directly fixing prices. By harmonising these parameters, cartelists reduce the effective degree of price competition and can achieve outcomes similar to a price-fixing cartel, as the agreed conditions constrain the scope for individual firms to compete on terms that would otherwise differentiate their offers.
- Another form of cartel involves information exchange, where firms share data on planned price increases, cost developments, or ongoing customer negotiations. While no price or quantity is directly agreed upon, the reduction in information asymmetry can facilitate implicit coordination, leading to price levels above those that would have prevailed under effective competition.

From an economic point of view, the cartelisation of a market leads to two types of effect that constitute harm from the perspective of affected actors: a transfer of wealth and allocative inefficiencies. To illustrate these, consider a cartel in final products market selling directly to end consumers.[3] Figure 1 depicts demand D and marginal revenues MR for this market. While Panel (I) illustrates the price, quantity, and economic rents under effective competition, Panel (II) depicts the same market when cartelised. The competitive pre-cartel price p_c and the cartel price of p_k are shown, where c stands for competition and k for cartel. The corresponding quantities sold in the competitive and the cartelised market are denoted by q_c and q_k.

[2] This has direct implications for the theory of harm and harm quantification, e.g. as a homogeneous overcharge cannot be assumed across cartelists. See Maier-Rigaud and Schwalbe (2023a) for a detailed analysis.

[3] Furthermore, it is assumed that all inputs of the cartel are produced in perfectly competitive markets so that no harm occurs upstream of the cartel. It is also assumed that there are no effects outside the supply chain, e.g. for producers of complements or buyers of substitutes. These assumptions are relaxed in section 2.2.1.

Figure 1: Transfers and (deadweight) welfare losses caused by cartelisation



Source: Own illustration based on Maier-Rigaud and Schwalbe (2013c). See also Maier-Rigaud and Schwalbe (2023b).

Based on a price p_c that would have prevailed under effective competition, that is, the counterfactual or but-for price (here assumed to be the perfectly competitive price[4]), Panel (I) illustrates the economic rents gained by customers in this market in the light grey rectangle. In Panel (II), the cartel increases the price to p_k. This gives rise to the two main effects through which a cartel harms its customers. The first is the price effect: On every unit they still buy, customers now pay p_k rather than p_c. This additional payment constitutes a redistribution of wealth from customers to the cartel in the form of a transfer of T (depicted as the dark grey square). The second effect is the quantity effect: because the price is higher, customers buy a smaller quantity q_k rather than q_c, so that transactions that would have taken place but for the cartel no longer occur. There are customers who would have been willing to pay a price p, that is $p_c < p < p_k$, for additional units of the product and there are firms that could have produced those units and still cover their costs. Because of the cartel, these mutually beneficial trades do not happen. The value lost in this way, measured across the market as a whole, is the deadweight welfare loss (DWL), an allocative inefficiency reflecting the gains from trade

[4] The price under effective competition is not necessarily the price that would prevail under perfect competition, as many markets are not characterised by perfect competition but instead operate under structurally imperfect conditions, including natural oligopolies or other concentrated market structures where competitive dynamics remain despite limited numbers of market participants. In particular, in oligopolistic markets, the price under effective competition may be substantially above the perfectly competitive price.

that are foregone on these transactions.[5] The DWL is shown as the black triangle.[6] Together, the price effect and the quantity effect are the main economic rationale for the prohibition of cartels under competition law.

The Transfer T, however, is a pure redistribution of wealth and does not, in itself, represent a welfare or efficiency loss. It depicts the economic rents captured by the cartel that would have been part of the consumer surplus under effective competition. As the additional expenditure for the quantity bought at the cartel-induced higher price is a loss to consumers, it must be considered a form of economic harm. This harm is known as the overcharge, or more generally, the price effect of a cartel. The total harm inflicted on consumers is thus the composed effect of the transfer T, that is, the price effect (dark grey square), and the welfare loss due to the quantity effect (black triangle), and is therefore higher than the economic efficiency loss and also higher than the extra profits generated by the cartel that correspond to the transfer T. A cartel typically causes both types of harm and there are no compelling economic grounds for prioritising one over the other when estimating total harm. In practice, it may, however, be more difficult to estimate quantity effects with a high degree of accuracy. This is due to the fact that it is usually easier to demonstrate that a higher price has been paid on units of the good bought in contrast to demonstrating that a certain number of goods were not bought but would have been had the price not increased. This holds in particular for those consumers who did not buy the product at the high cartel price at all but would have bought at the lower price under effective competition.

The magnitude of cartel-induced harm depends on a range of factors such as the duration and the market coverage of the cartel, as well as the magnitude of the price increase or the reduction in quantity. Obviously, given a certain price or quantity effect, the total harm due to a cartel is higher the longer the duration of the cartel. Economic theory has also shown that the size of the cartel, that is the share of the market covered

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5 The figure assumes that firms produce at constant marginal costs equal to p_c, so that the competitive price equals marginal cost throughout. This assumption implies that the entire area below p_c and above the quantity axis represents producer costs, with no producer surplus under effective competition. While this is a simplification – in practice, marginal costs may be increasing and firms in competitive markets may earn producer surplus – it has no bearing on the qualitative results. The distinction between price effect and quantity effect, and the identification of DWL as the efficiency loss from forgone transactions, holds under more general cost assumptions. The assumption of constant marginal costs does, however, affect the shape and magnitude of the areas depicted in the figure and should be borne in mind when applying the framework to markets where cost structures differ materially.

6 The quantity effect, in general, can be considered at two levels. Across the market as a whole, it appears as the deadweight welfare loss described here. At the level of an individual actor, however, it can take the form of the profit foregone by a party that sells fewer units, for instance, a direct purchaser that passes on the overcharge and therefore loses sales volume, or a supplier to the cartel whose input sales decline. These actor specific quantity effects are examined in section 2.2.

by the cartel, has a substantial impact on welfare effects. Generally speaking, the negative welfare effects, and therefore the harm, increase with market coverage.[7]

A further essential determinant of the harm is the extent of the price increase or the quantity reduction. This in turn depends on several factors, for instance, the intensity of competition that would have prevailed but for the cartel. Some markets are characterised by a relatively low intensity of competition even in the absence of a cartel, whereas other markets may be subject to fierce competition. In the first scenario, the harm created by the cartel would be relatively low as prices would have been comparatively high even in the absence of the cartel. In the second scenario, the harm is more significant because, without the cartel, prices would have been substantially lower due to the intense competition. An additional factor impacting the extent of the price increase is the degree of coordination in the cartel. Cartels are typically not able to achieve perfect coordination, implying that they are unable to fix the price or quantities at the level that maximises total cartel profits. Under certain circumstances, perfect coordination can also in theory not be achieved and only a partial coordination is feasible, so that prices will remain below the cartel profit-maximising price.[8] Holding other factors constant, harm is therefore expected to increase with the degree of coordination.[9] Finally, the slope of the demand curve has a substantial impact on the magnitude of the price increase and the welfare loss.[10] If consumers have only few options to substitute and can therefore not switch to alternative products once the price increases, the demand is inelastic with respect to price, implying that a cartel can charge substantially higher prices before reductions in quantity demanded become

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7 On welfare effects of cartels with partial market coverage see Schwalbe (2011). In this context, so called ‘umbrella effects’ are relevant, that is, price increases of firms active in the same relevant market but not participating in the cartel, which can also increase their prices under the umbrella of the higher cartel prices. See section 2.2.1 for a description of umbrella effects and section 3.4 for discussion on the quantification of umbrella effects.

8 The factors that contribute to a cartel being able to set the profit-maximising cartel price are the same as the factors that have been identified as facilitating coordinated effects in a merger context (see European Commission, 2004). Intuitively, firms with different variable costs will find it difficult to agree on the quantity that will equate marginal revenue with their respective marginal costs as those differ between firms.

9 Note, however, that the same factors that will enable a higher degree of coordination are also factors that would tend to soften competition in the market naturally, implying that cartel coordination may be high but the cartel mark-up over the competitive price is correspondingly low. See, e.g. Tirole (1988).

10 In the example of linear demand and constant marginal costs as shown in Figure 1, however, the cartel price p_k is independent of the slope of the demand curve, since the slope affects only the equilibrium quantity, while the price in joint profit maximisation, that is the monopoly price, simplifies to $p_k = (a + c)/2$, where a denotes the intercept of the (inverse) demand curve and c denotes constant marginal costs. Still within this benchmark framework, the slope of demand does not affect the monopoly price, but it does affect the magnitude of the welfare loss generated by monopoly power. In the more general case of increasing marginal costs or non-linear demand, this property no longer holds, as the elasticity of demand directly affects the monopoly mark-up and thus the equilibrium price.

important.[11] If consumers, however, have many possible substitutes at their disposal, demand is price elastic and a cartel will not increase the price substantially as it would otherwise only sell a much-reduced quantity.[12]

When quantifying harm, it is useful to consider what magnitude of effects would be expected from economic theory given the characteristics of the specific market and the anti-competitive conduct. This can provide a benchmark against which empirical estimates can be assessed.[13] Existing empirical studies on cartel harm – which have largely focused on price effects – suggest that overcharges in the range of 10 percent to 20 percent are not uncommon, though the variation is considerable across cases and industries such that each case must always be considered on its own merits.[14]

Such price increases, however, do not necessarily only harm direct purchasers. When downstream purchasers face higher input costs due to the price effect, they may partially or fully pass on that price increase to their own customers through higher prices. While this does not influence the magnitude of the harm, it redistributes the harm along the supply chain.[15]

In addition to the allocative inefficiencies described above, cartels may also give rise to productive and dynamic inefficiencies. Productive inefficiencies may arise because cartelists, due to the softening of competition, face reduced incentives to produce efficiently or to adopt the most cost-effective production technology.[16] A cartel can thus create a situation where inefficient firms producing at higher costs remain in the market, although they would have been forced to exit under effective competition.[17] If a cartel leads to higher costs, this should be taken into account when quantifying harm – particularly when cost-based methods are employed or cost functions need to be estimated.

Cartels may also reduce incentives to innovate, both on the product side and with respect to production processes. The softening of competition reduces the pressure on firms to invest in research and development, potentially leading to substantial dynamic

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11 A low number of substitutes is only one reason for inelastic demand. Other reasons might be personal habits, brand loyalty, and other personal preferences, or high switching costs.

12 For a detailed discussion of elasticities and the factors driving the magnitude of cartel harm, see also Inderst et al. (2019).

13 See section 3.1 for the importance of economic theory for empirical analyses.

14 See, e.g. Posner (2001), OECD (2002), Werden (2004), Connor and Lande (2006) or Bolotova et al. (2009).

15 See section 2.2.1 for a more detailed description of pass-on effects and section 3.5 for a detailed discussion on the quantification of pass-on effects.

16 This type of inefficiency is known as X-inefficiency (Leibenstein, 1966) often associated with the ‘quiet life’ of a monopolist (Hicks, 1935).

17 In turn, a perfectly efficient cartel will imply that less efficient firms no longer produce and only receive transfers.

inefficiencies in the long run. Theoretical results on the impact of cartels on innovation are, however, ambiguous: higher cartel profits may in principle fund R&D investment, while at the same time reduced competitive pressure diminishes incentives for 'business stealing'.[18] In addition, cartels may reduce product variety, as a homogeneous product market is generally easier to cartelise and to monitor. All expenditures related to organising the cartel and to protecting cartelists from detection by competition authorities also represent welfare losses. Such productive and dynamic inefficiencies can give rise to after-effects that extend beyond the cartel period.[19]

2.1.2. Harm caused by abusive conduct

Abuse of a dominant position can take the form of exploitive or exclusionary conduct. Whereas an exploitive abuse directly increases the profits of a dominant firm through price increases,[20] exclusionary abuse increases profits indirectly.[21] The two forms differ fundamentally in their mechanism, their direct effects on the market, and the types of harm they generate – although both ultimately harm competition and the welfare of market participants.

2.1.2.1. Exploitive abuse

Exploitive abuses are characterised by the direct extraction of value from purchasers by a dominant firm, typically through the imposition of excessive prices, unfair trading conditions or price discrimination. In this respect, the welfare implications are similar to those arising in a cartel context. The prices are higher and quantities are lower than under effective competition, so that the resulting allocative inefficiencies take the form of profit or utility losses. Just as in a cartel context, there is also a transfer of economic rent from purchasers to the dominant firm.

The harm generated by exploitive abuses is therefore conceptually analogous to cartel harm, and the same counterfactual framework applies: the actual situation with the abuse is compared to a hypothetical situation that would have obtained in the absence of the abuse. The practical difficulties of establishing a competitive benchmark may,

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[18] See Schumpeter (1950) and Arrow (1962) for the two opposing views. Rather than a monotonic relationship, the evidence points to a non-monotonic, inverted-U pattern (Aghion et al., 2005), which in merger control implies that the innovation effect of a transaction depends on the market's position on this curve.

[19] See section 3.3.1.4.

[20] See OECD (2012a) for a detailed discussion of excessive prices.

[21] See Maier-Rigaud and Schwalbe (2013a) for a discussion of the quantification of harm in abuse of dominance cases.

however, differ considerably from cartel cases, particularly in the absence of suitable comparator markets or time periods.

One notable difference to cartels concerns the potential for price discrimination. A dominant firm may charge different purchasers different prices reflecting their different willingness to pay. Purchasers with more price-elastic demand generally benefit in this case compared to uniform price increases, while those with inelastic demand face a higher price. The net welfare effect of price discrimination may even be positive, in contrast to the unambiguously negative welfare effects of a cartel.

2.1.2.2. Exclusionary abuse

Exclusionary abuses differ fundamentally from both cartels and exploitive conduct in that their primary mechanism is indirect. Rather than raising prices directly, the dominant firm reduces competitive pressure by foreclosing the market to actual or potential competitors, or by limiting their ability to compete effectively. Practices such as predatory pricing, retroactive rebates, margin squeeze, refusal to deal, and exclusive dealing aim at reducing the competitiveness of rivals in order to strengthen the market position of the dominant firm.

The harm generated by exclusionary abuses is typically more complex and difficult to quantify than in cartel or exploitive abuse cases. Several features distinguish exclusionary from cartel conduct:

- First, the effects vary across phases. In the initial phase, the dominant firm may actually lower prices (e.g. via predatory pricing) or provide other benefits to purchasers as part of its exclusionary strategy. The harm to purchasers and consumers only becomes apparent once competitors have exited the market and the dominant firm starts to recoup its prior sacrifice through higher prices. The phased structure significantly increases the complexity of estimating total harm.
- Second, many exclusionary practices also entail pro-competitive effects. Tying, for instance, can be used to leverage market power from one market to another but might also entail substantial reductions in transaction costs for consumers.[22] The net effect on competition and welfare is therefore more ambiguous than in cartel cases, where the anti-competitive effects are essentially unilateral.
- Third, the primary victims differ. While cartel harm accrues mainly to (direct and indirect) purchasers, the bulk of harm from exclusionary abuse is typically borne by the excluded competitors, who suffer loss of revenues and ultimately profits as

[22] Of course, such efficiencies may be reached without anti-competitive effects by bundling instead of tying.

their market shares decline or as they are forced to exit the market. Purchasers are affected as secondary victims, primarily once the exclusionary strategy has succeeded and the dominant firm exploits the resulting reduction in competition through higher prices, lower quality, or reduced innovation.

Because of these features, the identification of an appropriate counterfactual scenario is considerably more difficult in exclusionary abuse cases than in cartel cases. As this issue is linked to the quantification methodology, it is addressed in detail in section 3.6.

The remainder of this section sets out in more detail the three phases through which exclusionary abuse typically unfolds and describes the types of harm that arise in each phase. In phase one, a competitor is forced to exit the market or marginalised. The increase in market power is then exploited by the dominant firm in phase two by higher prices and increased profits. In the following phase three, after the abusive behaviour has ceased, new or (re-)entry may occur. The phase is therefore characterised by a restoration of competitive conditions. An important aspect of phase three also concerns the remedies that the competition authority may impose. In contrast to cartel cases that typically end with a cease-and-desist order and the imposition of fines, abusive practices trigger behavioural or structural remedies.

Phase one

In the first phase of exclusionary abuse, the dominant firm engages in conduct designed to weaken or eliminate its competitors. As a result, the profits of competitors and their market shares decline. This phase continues until the competitor(s) leave(s) the market or, if there is no exit, until the market shares stabilise at a comparatively low level, implying the marginalisation of the competitor(s). The dominant firm can, depending on the strategy adopted, continue to earn profits as happens, for instance, in case of retroactive rebates. It is, however, also possible that the dominant firm is realising losses in the first phase, as would be the case under a predatory pricing strategy.[23]

The effects for purchasers in this phase depend on the type of abuse. In case of a predatory strategy, the effect on purchasers is in all likelihood positive. They pay lower prices for the products than they would have paid in the absence of the predatory pricing strategy. Similar arguments apply in case of a margin squeeze where low prices will also be observed. These effects can propagate and also reach indirect purchasers

[23] The question is not necessarily whether overall profits are positive or negative but rather whether there is a profit sacrifice that would require at least probabilistic future recoupment to make the strategy profitable, or whether exclusion may be compatible with profit maximisation considering only the first phase. Both scenarios are possible and depend on the abuse.

that would equally benefit from the predatory prices. Different effects for purchasers arise if the abuse is focusing on an increase in input prices (e.g. via raising rivals' costs) or refusal to deal. In such instances, the costs of competitors increase so that the price level on the downstream market tends to increase and purchasers pay higher prices than in the absence of the infringement. Repercussions for indirect purchasers are also possible in this case.

Phase two

In case the abuse leads to exit, the competitor is unable to realise any profits in the second phase and may under certain circumstances have to bear sunk costs.[24] The bulk of harm to the firm therefore comes from lost profits. In a case where the competitor remains in the market, albeit with lower market shares, it would be able to realise profits in the second phase, but these profits are substantially lower than those that would have been obtained absent the abuse. Also in this case, the harm takes the form of lost profits. The dominant firm, by contrast, has reached its goals in the second phase, that is a phase of exploitation, and is able to reap the benefits of increased market power by setting higher prices and earning higher profits.

Concerning repercussions for purchasers, direct and indirect purchasers pay higher prices. In addition, there is also harm in the form of reduced choice since in markets with differentiated products, the elimination of competitors reduces product variety and thereby reduces consumer welfare.[25] However, it is difficult to quantify such harm. Suppliers of the dominant company potentially face lower demand due to the reduced quantities supplied by the dominant firm, resulting in harm in the form of lost profits.[26]

Phase three

The third phase starts with the end of the abusive practice. In follow-on cases, this typically coincides roughly with the decision of the competition authority to terminate the infringement. The third phase is in some sense the reversal of the first, although the harm calculation in this phase is likely to be extremely difficult simply because of the added complication in the form of very likely behavioural or structural remedies

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24 It would, however, be incorrect to add sunk costs to a calculation of harm based on lost profits. The lost profits represent the returns the firm would have earned in the counterfactual scenario, which would have included the amortisation of the sunk costs over time. Adding the sunk costs separately would therefore amount to double counting.

25 See Fumagalli et al. (2010).

26 While demand for inputs certainly decreases in phase two compared to phase one, this does not necessarily apply when compared to a counterfactual scenario absent the abuse. Phase one itself could be characterised by higher demand due to lower prices, such that the decrease in demand in phase two re-establishes prior demand levels.

imposed by the competition authority. Generally speaking, the third phase will see a return to competitive conditions, implying the entry of new competitors or the re-entry of firms that exited, or the corresponding increase in market shares of the firms that were marginalised. As a result of these developments, the profits of the dominant firm decrease irrespective of any potential fine imposed by the competition authority, and the profits of competitors would increase. The third phase comes to an end once a situation is established that approximates the situation that would have existed in the absence of the infringement.[27]

In particular, outside the context of follow-on claims, the abusive practice may have resulted in permanent changes to the market structure that are not impacted by compensatory payment so that the third phase does not lead to an approximation of the situation prior to the infringement. Even if a decision by a competition authority exists, a dominant firm may have been able to build a reputation of fighting market entry with predatory prices.[28] In such a case, entry would not be observed immediately and may eventually occur only after a long time has passed.

A similar problem exists in cases of an exclusionary abuse that does not aim at foreclosure of a competitor already active in the market, but which targets potential competitors that are kept from considering entry. In such cases, potential competitors are harmed in the form of lost profits that they may have been able to realise after entry. Possibly this has led to entry in another, less lucrative market, where lower profits were realised.

2.2. Economic actors harmed

2.2.1. Actors harmed by cartels

The restriction of competition by a cartel does not affect all economic actors in the same way, nor is the harm confined to those who are in a direct transactional relationship with an infringer. Depending on the nature and scope of the infringement, a wide range

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[27] Once the competitive situation has been approximated, certain competition authorities, notably the European Commission, are obliged not only to terminate the infringement effectively but also to eliminate the risk of its future recurrence. This objective may preclude a full return to a situation as it existed prior the abuse. While it is not possible to develop the details concerning behavioural and structural remedies as well as the European Commission's mandate here, the European Commission has imposed structural remedies so far only in cases where behavioural remedies were unlikely to be effective in terminating the abuse and preventing any future recurrence of the abuse. As the situation prior to phase one clearly was not a situation that prevented future abuse, the Commission will be bound to choose remedies that exclude the possibility that the end of phase three results in the same situation as existed prior to phase one. Any remedy falling short of this can actually not be considered a suitable remedy. On the issue of remedies see Maier-Rigaud (2012).

[28] See Selten (1978).

of firms and consumers along the supply chain, as well as actors in related and neighbouring markets, may sustain harm.[29] Section 2.1.1 discussed the two basic effects through which firms or consumers can be harmed by anti-competitive conduct, namely price and quantity effects. This section will provide a more systematic analysis of downstream and upstream as well as horizontal and other cartel effects in order to clarify the mechanisms through which cartel harm percolates across the economy.

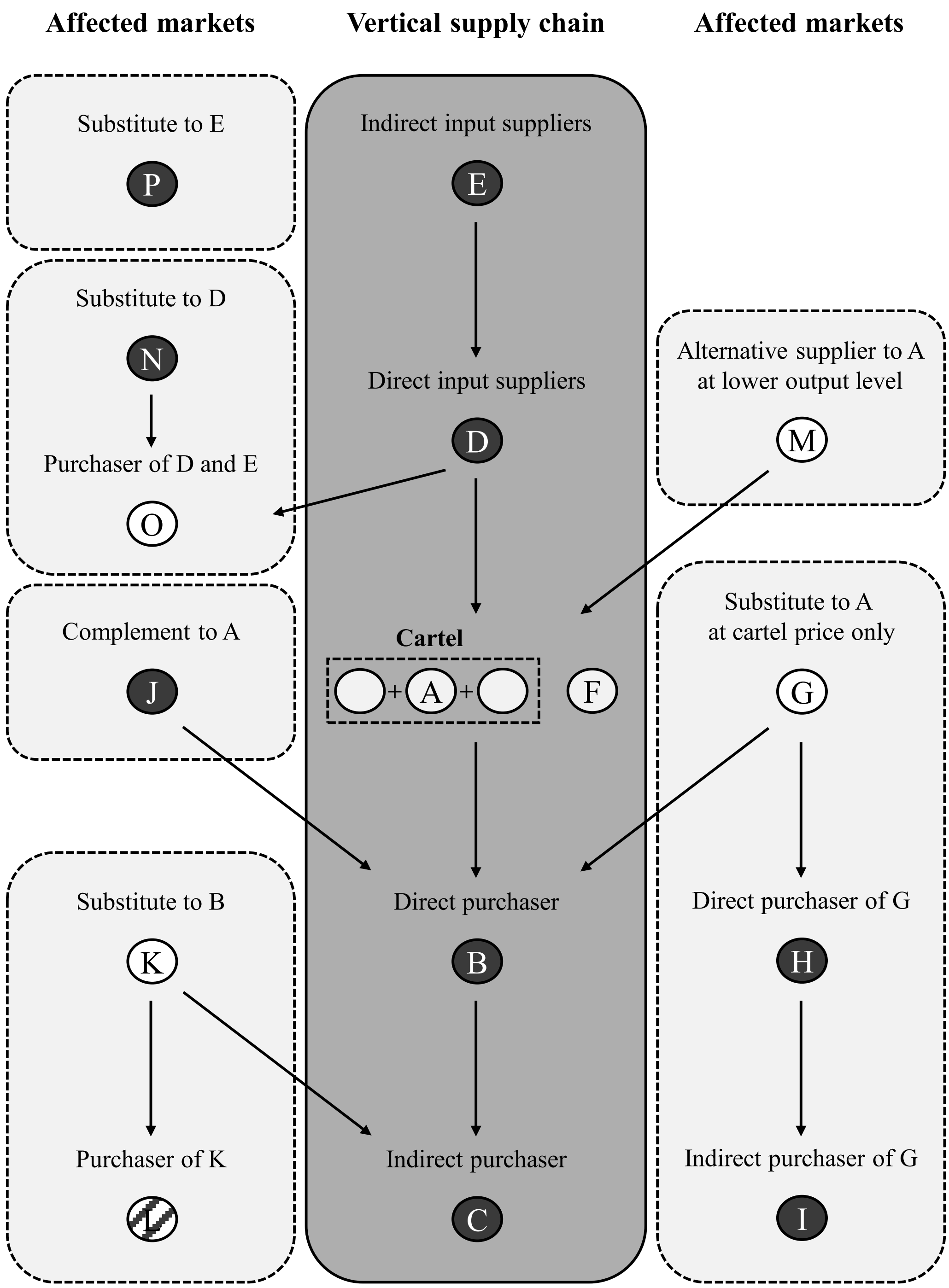
Downstream and upstream effects are vertical effects along the different levels of the production chain and concern firms providing direct and indirect inputs to the cartelised firms as well as firms and consumers that act as direct or indirect purchasers. Horizontal effects are generated on the same market and therefore concern all producers of cartelised goods and services irrespective of whether they take an active part in the cartel or not. Producers of products that consumers regard as substitutes only once cartel prices rise are also affected.[30] Other cartel effects, that are non-horizontal and non-vertical effects, apply, for instance, to firms that provide complements or firms and consumers purchasing from firms providing complements. Such effects also affect firms that purchase from some of the direct or indirect cartel input providers or some of the firms purchasing from firms offering substitutes to direct or indirect cartel inputs or firms offering substitutes to the products offered in the supply chain of the cartelists.

Figure 2 below illustrates these effects in a stylised manner. The figure shows that cartel effects extend well beyond the cartelists themselves and reach a wide range of actors both inside and outside the vertical supply chain. The vertical structure in the centre of the figure depicts five separate layers of the production chain. On the third layer, a competition law infringement, here in the form of a three-firm cartel labelled as A, takes place. Two layers are downstream of the cartel (direct purchasers labelled as B and indirect purchasers labelled as C) and two layers are upstream (direct input suppliers labelled as D and indirect input suppliers labelled as E). Actors in related markets, including producers of substitutes and complements, are shown to the left and right of the vertical chain. The figure indicates for each actor whether the cartel has a positive effect (white) or a negative effect, i.e. causes harm (dark grey). The remainder of the section discusses each of these effects in turn.

[29] See Maier-Rigaud (2014a), Maier-Rigaud (2014b) and Maier-Rigaud (2017).

[30] In that sense, horizontal effects may also arise outside the relevant market as is intuitively clear if one considers the cellophane fallacy.

Figure 2: Stylised vertical industry structure and related markets



Source: Own illustration based on Maier-Rigaud and Schwalbe (2013c). See also Maier-Rigaud (2017) and Maier-Rigaud and Schwalbe (2023b).

For a more intuitive understanding, Table 1 translates the abstract actors in Figure 2 into the context of the bottled water case study introduced in section 1. The case study concerns a hypothetical cartel among the three largest producers of bottled water, that are A, whose products are purchased by beverage wholesalers and food retailers B, which in turn supply end consumers and gastronomy operators C. Table 1 maps each actor in the figure to their counterpart in that market and indicates whether they profit or suffer from the cartel effect.

Table 1: Actors in Figure 2 and their counterparts in the bottled water case study

Role in Figure 2		Effect	Effect in the bottled water case study
A	Cartel members	+	The three major bottled water producers: coordinate prices and realise above-competitive profits
B	Direct purchasers of the cartelised product	–	Beverage wholesalers and food retailers: pay higher procurement prices; harmed by price overcharge and quantity effects
C	Indirect purchasers of the cartelised product	–	End consumers and gastronomy operators: harmed by passed-on price increases and quantity effects
D	Direct input suppliers to the cartel	–	Operators of mineral springs and deep wells: suffer reduced demand for raw water as cartel sales volumes fall (quantity effect)
E	Indirect input suppliers to the cartel	–	Manufacturers of bottling and filling equipment: harmed indirectly through reduced demand from spring operators (D)
F	Non-cartelised producer of the same or closely substitutable product	+	Regional, non-cartelised bottled water producers: benefit from increased prices via the umbrella effect of the cartel
G	Producer of products that become substitutes only at the cartel price	+	Producers of substitute beverages (e.g. juices, soft drinks, tap water filters): benefit from demand diversion and umbrella pricing
H	Direct purchaser of substitute producer G	–	Retail chains sourcing from juice and soft drink producers (G): pay higher prices as G raise prices
I	Indirect purchaser of substitute producer G	–	End consumers buying substitute beverages from H: harmed by higher prices for substitute products induced by umbrella effect
J	Producer of complementary products to the cartelised good	–	Manufacturers of flavoured syrups or CO_2 cartridges: demand falls with reduced bottled water sales, despite having no direct link to the cartel
K	Producer of substitutes to direct purchaser B	+	Producers of substitutes to direct purchaser (e.g. other retail chains that did not source from the cartel) may gain marginally as demand for J's products falls
L	Purchaser of K	–	Consumers purchasing from K: harmed by higher prices as K faces additional demand from purchasers switching away from J
M	Alternative input supplier becoming competitive at lower output levels	+	Smaller or technologically distinct well operators or water suppliers: may enter the market as D's output falls and previously uncompetitive supply becomes viable
N	Producer of substitutes to direct input suppliers D	–	Suppliers of alternative water-sourcing inputs (e.g. industrial water treatment systems): harmed as D lowers prices in response to reduced demand, squeezing N's pricing scope
O	Purchaser of inputs from both D and N	+	Industrial users of spring or processed water (e.g. cosmetics, pharmaceuticals): benefit from lower D input prices as cartel reduces competition for raw water
P	Producer of substitutes to indirect input suppliers E	–	Manufacturers of alternative bottling equipment: harmed as E reduces prices in response to lower demand, limiting P's own pricing scope

Source: Own illustration.

As can be seen, a whole range of economic actors can principally be affected by anti-competitive conduct. General equilibrium theory shows that all actors in an economy can be positively or negatively affected by a cartel. By increasing the price of the cartelised product, the cartel changes relative prices and thus causes substitution and income effects that can affect the whole economy, similar to how a stone that is thrown into a pond will generate waves that will spread across the entire pond.[31]

To realise that effects accrue not only downstream in the supply chain is important because much of the literature has focused on direct and indirect purchaser standing, which may have obfuscated this point. In EU cartel damages cases, all harmed parties have standing to claim damages regardless of their position in (or outside) the supply chain. This is in contrast to the approach taken at the federal level in the US, where damages claims are restricted to direct purchasers, who are consequently allowed to claim total downstream harm based on price effects only.[32] Even if the impact of cartels on upstream suppliers is considered, the simplified concept of a supply chain rather than a complex supply network may have led to the impression that harm caused by a cartel is confined only to a very limited, isolated part of the economy.

2.2.1.1. Downstream effects

Downstream of the cartel are direct purchasers B as well as indirect purchasers C. The direct purchasers of bottled water might be beverage wholesalers and food retailers that are obviously affected by the cartel as they have to pay higher prices for bottled water. To the degree that they pass-on all or part of the higher prices to their own customers, they reduce the price effect. As this increase in price implies a reduction in demand for their own products, they are harmed by a quantity effect. In turn, if pass-on by the direct purchaser takes place, the indirect purchasers C, e.g. final customers or gastronomy operators, have to pay higher prices and are thus potentially harmed by price and quantity effects as well.[33]

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[31] From a practical point of view, damages claims will realistically only be brought by a small subset of those actors affected. Similar to the small pond metaphor, however, where the height of the wave is normally greatest near the point where the stone sank into the water but also depending on the depth topology of the pond, the economic effects or harm are not necessarily greater for direct as opposed to indirect purchasers or those that are even further removed from the actual economic dealings of the cartel. Indeed, there are – empirically probably rare – constellations where direct purchasers may even benefit from the cartel to the further detriment of indirect purchasers.

[32] See Maier-Rigaud (2017) for a critical economic comparison of the US and the EU damages claim regimes.

[33] The distribution of harm between direct and indirect purchasers depends critically on the competitive conditions prevailing at each level of the supply chain. This can be illustrated with a stylised example in which a cartel sells to a direct purchaser operating in a perfectly competitive downstream market, which in turn sells to a monopolist who serves final consumers. In this constellation, the direct purchaser, facing perfect competition, is unable to absorb the cartel-induced cost increase and passes it on entirely to the downstream monopolist. The direct purchaser therefore suffers no harm, or more precisely, suffers only a quantity effect with no profit impact, while the harm concentrates entirely at the level of the monopolist and final consumers. This also illustrates that the

The producer of substitutes to direct purchaser B, that is K, is positively affected as indirect purchasers partially substitute consumption away from the direct purchasers to K, which in turn sells a higher quantity at a higher price. The direct purchasers L that were buying before from K are harmed in this case as the price is higher than in the absence of the cartel due to the fact that K is now also facing demand from an indirect purchaser of the cartelised product C.[34]

2.2.1.2. Upstream effects

A cartel-induced price increase leads to a reduction in the demand of the cartelised product and therefore also reduces the demand of the cartelised firms for direct inputs to produce the cartelised product, generating an upstream quantity effect.[35]

As a result of this reduction in demand for the direct input, the profits of direct input suppliers D are reduced.[36] In the bottled water case study, such direct input suppliers might be operators of mineral springs and deep wells that face a reduced demand and adapt prices accordingly. This has a negative impact on producers of substitutes to direct input suppliers' products N, in the bottled water example, for instance, producers of alternative water sourcing inputs such as industrial water treatment systems. They find it profitable to adjust their price downward in a reaction to the price decrease of the operators of mineral springs and deep wells.[37] The lower prices charged by direct input suppliers benefit firms such as O, a purchaser of inputs from both D and N, for whom the input provided by direct input suppliers now becomes an attractive substitute. In

overcharge, which in this case corresponds to the illegal gain of the cartel, substantially underestimates the total harm: the losses accruing to the monopolist and to final consumers considerably exceed the cartel's profits. More generally, harm need not accrue to direct purchasers and may concentrate at lower levels of the supply chain, depending on the degree of competition and market power at each stage. Quantity effects can only be ignored if the cartelised product affects only fixed costs of the downstream purchaser, or if the downstream market is perfectly competitive. In the latter case, however, there is no harm to direct purchasers to begin with.

34 Alternatively, one may envision that this increased demand allows K to produce at lower cost due to some increasing returns to scale technology. If that is the case, the price may go down so that consumers L are benefiting from the cartel.

35 It should be noted that the decrease in input prices due to the reduction in demand is an aggregate effect and that indeed firms not participating in the cartel but producing the same products (F) or producers of substitutes to the cartelised product (G) – to the extent that G requires the same inputs – may actually increase their production. This increase will, however, not compensate for the reduction in input quantities demanded by the cartelists.

36 The profit-maximising response of direct input suppliers results in a reduction of their own prices, thereby mitigating the negative effect of the cartel.

37 This should be viewed as a type of umbrella effect. Whereas umbrella effects classically are based on producers of substitutes of the cartelised product increasing their prices under the pricing umbrella opened up by the cartel induced price increase, this effect rests on the more limited pricing scope of the producer of substitutes to direct inputs of the cartelised products as a result of a reduction in prices by direct input suppliers.

the bottled water case study, this might be industrial users of spring or processed water (e.g. for cosmetics or pharmaceuticals) that benefit from lower input prices.

Direct input suppliers D are, however, not only negatively affected by the reduction in demand induced by the cartel but may be further harmed if, for instance, this industry was experiencing economies of scale prior to the drop in demand. This may lead to firms such as M that use a different production technology and that were not competitive at pre-cartel production levels, becoming attractive suppliers of substitutes.[38]

Thus, the cartel causes harm to direct suppliers and, potentially, their competitors (such as N) that did not supply the cartelists. A similar logic applies to indirect suppliers E and producers of substitutes to indirect inputs P, who also suffer harm from the cartel.

2.2.1.3. Horizontal effects

The cartel also has an effect on firms such as F that are part of the same market as the cartelised firms and G, producing products that only become substitutes to the cartel products at the higher cartel price.[39] Translated to the bottled water case study, this might be regional, non-cartelised producers of bottled water (F) or producers of substitute beverages (e.g. juices and soft drinks) that only become substitutes as the prices for bottled water increase (G). These firms do not participate in the cartel and may not even be aware of its existence but benefit from umbrella effects.[40] The cartel-induced price increase leads to a diversion of demand to non-cartelised firms producing products that are substitutes of the cartelised product only at higher cartel prices. The increase in demand causes these firms to also raise prices of their products and to increase their supply.[41] As firms such as F and G are sometimes perceived as

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[38] An alternative explanation could be that with lower utilisation levels of the machine park of the cartelists, suddenly inputs become interesting that are cheaper but require more maintenance, for which time is available at lower utilisation rates.

[39] F is the example of a partial cartel where not all firms in the relevant market are cartelised (see Schwalbe, 2011). G in contrast, is a firm that would not be part of the relevant market on the basis of a proper SSNIP test taking the competitive prices as a starting point for the analysis of substitution. In other words, G is only part of the relevant market, i.e. producing substitutes for the cartelised products, at cartel prices. This is known as the cellophane fallacy: when a SSNIP test is applied to prices that are already elevated above the competitive level, products that would not be substitutes under competitive conditions appear as substitutes, leading to an overly broad market definition. While the fallacy implies an inappropriate definition of the relevant market, such effects can of course be present, implying umbrella effects beyond the relevant market. See, e.g. OECD (2012b).

[40] On umbrella effects see Inderst et al. (2014).

[41] In the case of homogeneous products and no capacity constraints, the umbrella effect induced by the cartel leads to a price increase by the same amount as the cartel price, that is, the harm that accrues to customers of non-cartelised firms is the same as for customers of the cartel as both pay the same price. If products are differentiated, the increases in price and supply under the umbrella of the higher cartel price depend on the amount of demand diverted from the cartel to non-cartelised producers of substitutes. The higher the degree of differentiation, the

contributing to the negative cartel effects, it should be noted that their reaction is actually mitigating the harm caused by the cartel. The economic mechanisms that lead firm F and G to react to an increase in demand are equivalent to a reaction to other shortages and constitute the very reason for which competition law exists, that is, to ensure an efficient allocation of resources.[42]

Thus, there is an increase in prices by firms F and G compared to the counterfactual price that prevailed absent the cartel even though they are not involved in the cartel. Therefore, the direct customers of firm G, that is H, such as retail chains sourcing from juice and soft drink producers, and customers of this direct customer I are harmed by having to pay a higher price and therefore are buying a reduced quantity of the product.

2.2.1.4. Effects on producers of complements

Further effects of the cartel accrue for J, a producer of complementary products. With a reduced demand for cartel products, the demand for complements also decreases despite a profit-maximising reaction, consisting of a lowering price to partially offset the quantity effect.[43]

In the bottled water example, producers of complementary products J may include manufacturers of flavoured syrups. These firms have no contractual or supply relationship with the bottled water producers, yet they suffer a reduction in demand as fewer units of bottled water are sold.

2.2.1.5. Summary of effect analysis

The discussion has shown that while the total net effects of a cartel are necessarily negative due to the resulting welfare losses, the cartelisation of an industry can have

less pronounced the reaction of the non-cartelised producers of competitors will be. In addition, the relative magnitude of that effect crucially depends on the reaction of the indirect purchasers C as will be seen in the discussion below. In anticipation of that reaction, direct purchasers unintentionally mitigate negative effects of the cartel by not increasing prices as much as the increase in input cost would seemingly warrant, simply in order to maximise profits.

[42] F and G would react exactly in the same manner if instead of being cartel induced, the shortage was the exogenous result of a severe drought in certain regions of the world. For example, one could think of the cartelists as bottled water producers in region A, where a severe drought has reduced the amount of water that can be extracted, thereby decreasing supply. In that case, sales of bottled water producers in region B, which was not affected by the drought, would increase. This would ensure that appropriate substitution patterns are triggered among those most sensitive to price, so that demand equals supply at a new price.

[43] Note that price reductions will be more significant if the complement is not sold in a fixed proportion to the cartelised product. If it is, the price reduction will be more mitigated as quantity reactions will only depend on the price ratio of the complement and the cartelised product.

positive effects for some consumers and firms while having negative effects for others.[44] It should also be clear that the notion of ‘passing-on’ harm is misguided as the cartel does not produce a certain ‘quantity of harm’ that is then passed up and down different levels of the supply chain. Rather, by changing relative prices, the cartel triggers responses up and down the supply chain and also outside vertical and horizontal relationships. These responses, while solely induced by profit-maximising behaviour, spread the harm caused by the cartel across a wide range of economic actors rather than confining it to direct purchasers.[45]

As price effects are pure transfers, the sum of all price effects is equal to the overcharge. From an economic point of view, the concepts of overcharge and passing-on are at best complicated methods of deriving price effects: they neither provide a basis for calculating total harm nor capture effects upstream of the cartel or outside the vertical supply chain.

2.2.2. Actors harmed by abusive conduct

While exploitive and exclusionary abuse share the legal classification as abusive conduct, the circle of harmed parties differs substantially between the two forms. In exploitive abuse, the affected actors largely mirror those in cartel cases, since the mechanism of harm is again the elevation of the price charged by the dominant firm. By contrast, exclusionary conduct primarily harms a different category of actors, namely the actual and potential competitors of the dominant firm and, to a lesser extent, their suppliers. Purchasers of the dominant firm are affected in both forms of abusive conduct, but the timing, magnitude and sign of this effect varies considerably between exploitive and exclusionary conduct.

2.2.2.1. Exploitive abuse

In case of an exploitive abuse, the circle of harmed parties broadly mirrors that of a cartel situation. The direct and indirect purchasers as well as the direct and indirect suppliers are affected, as are the producers of complementary products and the purchaser of substitutes. The mechanisms through which harm arises, i.e. price effects, quantity effects and the ripple effects along the supply chain and into adjacent markets, are conceptually the same as those described in section 2.2.1.

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[44] This is actually inherent in the notion of transfer, although the figures show that such transfers not only accrue to the cartelists but that there are transfers that benefit consumers or firms that are not in the cartel and may not even be active in the same industry.

[45] See Maier-Rigaud (2014a) and (2014b).

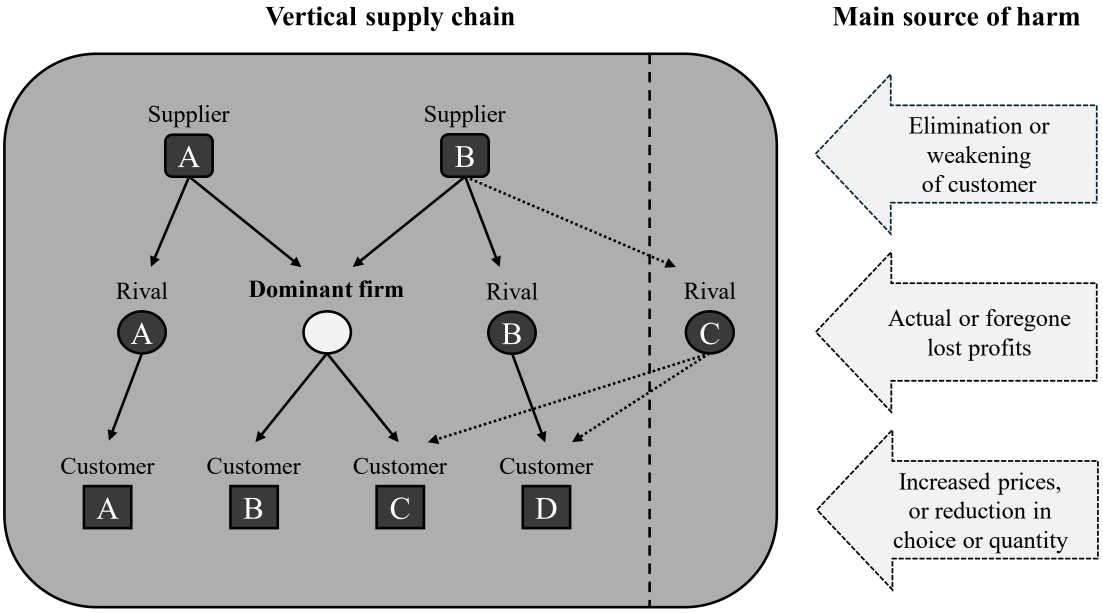
One important difference, however, concerns the distribution of harm among purchasers. A cartel-induced price increase typically affects all purchasers of the cartelised product uniformly, even if the downstream consequences for individual purchasers may differ considerably depending on their own market position. Under exploitive conduct, by contrast, a dominant firm may engage in price discrimination, charging different prices to different (categories of) purchasers. If there are, for instance, two groups of customers, one with elastic demand and the other with a less elastic demand for the product, customers with an elastic demand will stand to benefit and those with an inelastic demand will stand to lose compared to a uniform price. The total welfare effect of price discrimination may even be positive, which further distinguishes exploitive abuse from cartel conduct where no such offsetting effects arise.

2.2.2.2. Exclusionary abuse

The distribution of harm in exclusionary conduct cases looks somewhat different from that in cartel and exploitive abuse cases. In contrast to section 2.2.1, where the cartel-induced price and quantity effects generate harm primarily along the vertical supply chain, the primary victims of exclusionary conduct are the actual and potential competitors of the dominant firm. Similar to cartel and exploitive abuse, direct and indirect purchasers are also harmed. Depending on the phase of the abuse and the type of conduct, however, purchasers may even temporarily benefit from the exclusionary practice, as set out in section 2.1.2.2. Finally, suppliers of the dominant firm and of its rivals can also be among the victims. Figure 3 below provides a stylised overview of the typical constellation of actors potentially affected by exclusionary conduct.[46]

[46] The figure presents a simplified depiction. As in cartel cases (see section 2.2.1), exclusionary conduct may also affect further categories of economic actors.

Figure 3: Economic actors potentially harmed by exclusionary conduct



Source: Own illustration based on Ormosi et al. (2026).

The competitors of the dominant firm are typically the principal victims of exclusionary conduct. In Figure 3, Rival A and Rival B suffer harm because they are forced to leave the market or because their shares are marginalised throughout the exclusionary practice. This is the case, for instance, with retroactive rebate schemes or predatory pricing, which have a direct bearing on the revenues of competitors. This is associated with substantial profit loss, which may also persist in the long run. Even after the abusive conduct has ended, network effects, economies of scale, reputational effects or other structural changes may prevent the marginalised rivals from reaching the position they would have held absent the abuse. In addition to actual competitors, potential competitors such as Rival C in the figure may also be harmed. They would have entered the market in the absence of the abuse but are deterred by the exclusionary conduct from doing so. The harm takes the form of foregone profits that Rival C would have earned upon entry. Where Rival C entered a less lucrative alternative market instead, the harm corresponds to the difference between the profits it would have earned in the foreclosed market and the profits actually realised in the alternative market.

The suppliers of the dominant firm as well as of foreclosed or marginalised competitors may be among the victims. In the figure, Supplier A and Supplier B sell inputs not only to the dominant firm but also to Rival A and Rival B. As the rivals lose market share or are forced out of the market, the quantities sourced from the suppliers decline, which translates into lost profits for the suppliers concerned.[47] Furthermore, suppliers can be harmed because potential customers such as Rival C do not enter the market in the first place, foreclosing a demand source that would otherwise have existed. A further channel of harm arises where the exclusionary conduct strengthens the bargaining position of the dominant firm vis-á-vis its own remaining suppliers. With weaker downstream competition, the dominant firm can potentially negotiate lower input prices, which further reduces the suppliers' margins.

While the bulk of the harm thus accrues to competitors, purchasers of the dominant firm are also affected, albeit typically with a delay and in a manner that depends on the phase of the abuse. Once the exclusionary strategy has succeeded and the dominant firm is able to exploit the reduction in competitive pressure, purchasers such as Customer A, Customer B and Customer C in the figure are harmed by higher prices, reduced quantities, lower quality and/or less innovation. If the abusive conduct is terminated before competitors lose substantial market share, the harm to purchasers may be limited and they may even have benefited from the intensified competition during the initial phase of the abuse.[48] Customers can also be harmed because a potential rival is deterred from entering the market, as illustrated by Customer D in the figure. Customer D would have sourced from Rival C in the absence of the exclusionary conduct, and the foregone entry reduces choice for this group of customers.

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47 It should be noted, however, while the quantities demanded by rivals of the dominant firm decline, the quantity demanded by the dominant firm typically increases as its market share rises. The additional quantity demanded by the dominant firm may partly (or in some cases even fully) offset the loss in forgone sales of suppliers.

48 Note that this crucially depends on whether the abusive practice involves a profit sacrifice or not. This is the case with predatory pricing but may as well be the case under retroactive rebate schemes or other abusive practices such as refusal to deal. For a discussion whether rebate schemes involve a sacrifice, see Maier-Rigaud and Schwalbe (2013b).

3. Quantification of harm caused by anti-competitive conduct

3.1. Role of economic theory

3.1.1. No statistical analysis without theory

The quantification of antitrust harm typically relies on statistical and econometric methods that infer counterfactual prices, quantities or profits from observed market data. These methods are indispensable tools in the quantification of antitrust harm. Yet they do not operate in a vacuum. A statistical model does not, by itself, tell the analyst which price should be examined, which observations can validly be compared, which explanatory variables belong in an empirical analysis, or whether a statistically significant estimate can be interpreted as evidence of harm. These questions are answered by economic theory. In harm quantification, theory plays a double role. First, market theory helps reconstruct the competitive benchmark and guides the choice of comparators as well as the specification of an empirical or economic model. Second, a theory of harm explains how the unlawful conduct unfolded and how it could have distorted the competitive process and thereby caused the estimated effect.[49] Without this dual theoretical foundation, econometric analysis risks becoming a purely mechanical exercise.

A classic illustration demonstrating the role of theory is the well-known storks-and-babies example. In some datasets, there is a positive correlation between the number of stork nests in a region and the local birth rate.[50] Taken in isolation, the statistical relationship may be robust. Yet nobody would infer from this that storks cause babies. The reason is not that statistics suddenly cease to matter, but that independent knowledge about the underlying causal mechanism exists. The example captures a simple but fundamental point: correlation is not causation, and no amount of statistical sophistication can transform an implausible mechanism into a convincing causal account.

A common response is that the correlation arises only because other relevant factors have not been accounted for in the statistical analysis. But that response already confirms the importance of theory. Without theory, the analyst would not know which additional factors should be controlled for in the first place nor that additional factors need to be controlled for to begin with. In the stork example, it is theory that suggests

[49] Bantle et al. (2026).

[50] See Höfer et al. (2004).

that rurality, housing conditions, or family size may explain both a larger stork population and a higher birth rate. And even if the statistical relationship between storks and births were to persist once such factors were accounted for, it would still not make the causal story credible. Theory does not merely refine statistical analysis after the fact; it is what makes statistical analysis meaningful in the first place.

The same logic applies to antitrust harm quantification. A statistically significant increase in prices, margins, or bids does not by itself establish that the infringement caused an overcharge. One must first understand how prices would normally have been formed in the relevant market and how the conduct at issue could have interfered with that process. Only then can the empirical analysis be specified and interpreted in a meaningful way. This is the sense in which there is no implication from a statistical analysis without theory.

3.1.2. Market theory

Any quantification of harm is necessarily counterfactual. It asks what would have happened absent the infringement. Constructing that counterfactual requires a theory of competition in the relevant market. Market theory addresses how prices, quantities, discounts, and other terms of trade are determined under lawful competitive conditions. Are prices generated through tenders or auctions, through bilateral negotiations, through list prices combined with rebates, or in a more decentralised posted-price environment? Are products homogeneous or differentiated? Are markets local, national, or customer-specific? Are firms capacity-constrained? Do transport costs and switching costs, transparency, or long-term commercial relationships shape the bargaining process? These questions are not merely descriptive background. They define the competitive benchmark against which any harm is measured.

For purposes of econometric quantification, the most immediate contribution of market theory lies in the identification of the relevant market determinants or suitable comparator markets for counterfactual analysis. A regression model that seeks to explain the competitive price must control for the factors that would have affected the price even absent the infringement.[51] Depending on the market, these may include input costs, capacity utilisation, transport distance, product characteristics, project size, timing, local demand conditions, bargaining power, or the number and identity of competing suppliers. In practical terms, market theory primarily disciplines which factors must be accounted for in the empirical analysis. It distinguishes variables that

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[51] See section 3.3.1.1 for a short introduction into regression analysis.

genuinely belong in the model from those that are irrelevant, redundant, or merely rough proxies for underlying economic mechanisms.

This is true regardless of whether the analyst relies on a time-based comparison, a benchmark approach, or a difference-in-differences design. None of these methods is theory-free. Each of them presupposes an account of what the competitive price would have depended on and which sources of variation can plausibly be treated as informative about the counterfactual. Without such an account, the choice of controls or comparator markets is arbitrary. The risk that the estimate is distorted by relevant factors that have been omitted from the analysis, or by factors that should not have been part of it, cannot be meaningfully assessed, and the interpretation of the estimate of interest becomes uncertain.

Market theory is equally essential when the counterfactual is constructed from a comparator market rather than from the affected market itself. A different geographic region or a substitute product market can serve as a credible proxy for the counterfactual only if the underlying mechanism of price formation in that comparator market is sufficiently similar to that in the affected market. Market theory provides the criteria for that judgement by identifying the structural features, e.g. demand conditions, cost structure, competitive interactions, and institutional setting, that must align between the two markets, and the features those differences must be controlled for. A comparator that looks superficially similar but operates under a fundamentally different pricing mechanism is not a valid basis for the counterfactual.

Market theory further disciplines what exactly is being measured in the empirical analysis. In many harm quantification analyses, and in particular in price overcharge estimations, the variable of interest is the price. Where the analysis focuses on prices, the economically relevant magnitude is the transaction price, that is, the amount actually paid by the customer to the supplier for the product or service in question. How this transaction price is formed, however, varies considerably across markets. In some markets, list prices are themselves the transaction prices. In others, the transaction price emerges only after rebates, discounts, portfolio negotiations, or subsequent contractual adjustments have been applied. In the latter case, list prices may not be relevant for the harm analysis, even if they are the most readily available information, because they do not capture the price through which the alleged infringement actually operated. Market theory provides the criterion for identifying the economically relevant transaction price in a given market.[52] Market theory also informs the level of aggregation at which the data should be analysed. If prices are negotiated bilaterally, potential customer-specific heterogeneity should not be averaged away through aggregation across customers. If products are differentiated, aggregating across products may conceal rather than reveal the relevant price effect. If competition takes place tender by tender, the natural unit of analysis is often the project or bid, not an annual average price covering multiple independent tenders. Conversely, aggregation may be justified only where the theory of the market supports the assumption of sufficiently homogeneous pricing mechanisms and effects at the chosen level. The same logic applies to the question of which systematic differences between units, for instance, firms, products, regions, or customers, must be absorbed by the empirical model to isolate the infringement effect. In practice, many disagreements between experts stem less from the nominal choice of the econometric method than from an insufficiently theorised treatment of the data structure.

Where data for empirical analysis is scarce, the counterfactual may be constructed from an economic model of how the affected market would have operated under effective competition.[53] Here, too, market theory is what determines the structure of the analysis. It indicates which model of competitive interaction is appropriate: Would competition have operated through prices, quantities, capacities, bids, or contract terms? Are products sufficiently homogeneous to support a single-product model or is a system describing substitution across differentiated products more plausible? Furthermore, capacity constraints or bargaining structures must be built into the counterfactual. These modelling choices are not interchangeable. Different competitive models can produce materially different counterfactual prices from the same underlying data. Market theory is therefore not only the guide for empirical specification but also the basis on which a simulated counterfactual is built.

Finally, market theory is essential for assessing the scope and transferability of any estimate. An overcharge estimated for one set of products, one customer group, or one supplier cannot automatically be transferred to others. Transferability is not a matter of statistical convenience; it is an economic claim that must be justified by the similarity of the underlying pricing mechanisms. A sound market theory therefore does not merely supplement econometrics. It determines which data, variables, and units of

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[52] In some harm quantification analyses, the relevant variables of interest may be profits, margins, or quantities instead of prices. In these cases, the same logic applies, such that market theory identifies the correct variable of interest.

[53] See section 3.3.2.

observation can support a method of analysis in order to get a meaningful estimate at all.

3.1.3. Theory of harm

If market theory describes how competition would have worked absent the infringement, the theory of harm explains how the infringement could have distorted that competitive process. This distinction is crucial. A general account of the market is not yet a theory of how harm arose. The theory of harm must identify the mechanism that links the specific unlawful conduct to the alleged overcharge or other loss. In follow-on actions, the competition authority's infringement decision will often provide the natural starting point. It may identify whether the case concerns price coordination, bid rigging, market sharing, quota arrangements, information exchange, or some combination of these forms of conduct, and it may indicate the products, customers, regions, firms, and periods that were affected.

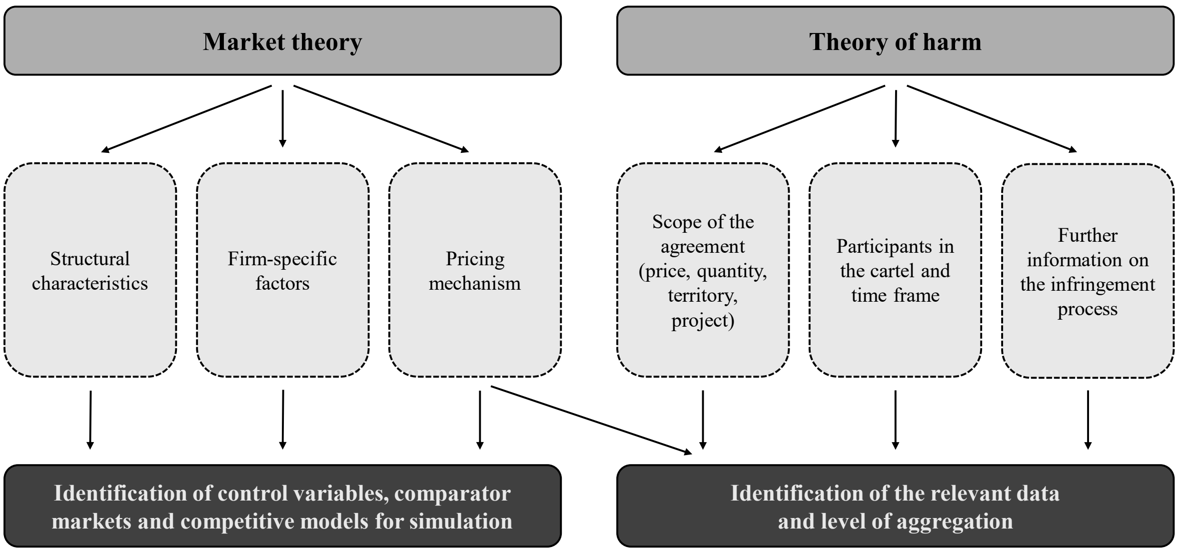
But translating those findings into a harm analysis requires more than repeating the legal characterisation of the infringement. The analyst must ask how the conduct could have influenced actual transaction prices. A cartel that coordinates list-price announcements may affect negotiated prices only if list prices serve as credible focal points in subsequent bargaining. A bid-rigging arrangement may affect only those tenders that were actually allocated or strategically covered. A market-sharing agreement may generate different price effects across territories, customer groups, or product categories. An information exchange may matter only where transparency, repeated interaction, and punishment mechanisms make coordination sustainable. The theory of harm therefore tells the analyst where to look for effects, when effects should begin, where they should be strongest, and where one should not expect to find them at all.

This is the second major role of theory in econometric work. The theory of harm disciplines the empirical design by identifying the treated transactions, the likely channels of effect, the expected heterogeneity of any overcharge, and the relevant period of impact. It also helps determine the appropriate level of aggregation. If the alleged mechanism operates at the level of specific tenders, customers, regions, or product groups, a uniform market-wide estimate may be economically uninformative even if it is statistically precise. Conversely, where the theory of harm indicates a broadly common mechanism, a more aggregated approach may be defensible. The key point is that the data design and the causal narrative must match.

Equally important, the theory of harm provides the framework within which empirical results can be plausibility-checked. An estimated overcharge is not self-validating merely because it is statistically significant.[54] A large and uniform overcharge estimate may be difficult to reconcile with a theory of harm that predicts only partial, uneven, or short-lived implementation. By the same token, a zero or statistically insignificant estimate is not necessarily evidence of a failed empirical method. It may be entirely consistent with an infringement that was ineffective, inconsistently applied, offset by discounts, or confined to a limited subset of transactions.[55] Econometrics can reveal patterns in the data, but only the theory of harm can establish whether those patterns can be linked to the alleged mechanism of harm.

Figure 4 below summarises the two theoretical foundations and the empirical decisions they discipline. As described above, market theory shapes the identification of relevant price determinants in empirical analysis, the selection of comparator markets, and the choice of the competitive model in an economic simulation model. The theory of harm guides which data are relevant, the level at which the analysis should be conducted, and the period and scope of expected effect.

Figure 4: The role of economic theory in harm quantification



Source: Own illustration based on Bantle et al. (2026).

The central message is straightforward: Economic theory is not an optional preface to econometric harm quantification. It is what gives econometric analysis its meaning. Market theory identifies the competitive benchmark and the variables required to

[54] Statistical significance and the related parameters are introduced in section 3.3.1.1.

[55] By contrast, if the theory of harm suggests a substantial price increase due to the infringement, estimates of zero or a statistically insignificant amount might indicate a misguided empirical analysis. The same applies to implausibly high estimates where the theory of harm suggests zero or minimal effects.

explain lawful price formation. The theory of harm explains how the infringement could have altered that process and why the estimated effect should be interpreted as harm. The more clearly these two theoretical foundations are articulated, the more credible the subsequent empirical estimate will be. The econometric methods discussed in the remainder of this paper should therefore be understood as tools whose reliability depends on a prior and explicit account of both the market and the mechanism of harm.

3.2. Basics of counterfactual analysis

3.2.1. Comparing factual to counterfactual scenarios

Building on the theoretical considerations set out in section 3.1, the quantification of antitrust harm rests on a single organising principle. The actual market outcome as affected by the infringement is compared with a hypothetical market outcome that would have prevailed had the infringement not taken place. This hypothetical scenario is referred to as the counterfactual scenario (or sometimes but-for scenario). Harm is defined as the difference between the two:

$$\text{Harm} = \text{Factual outcome} - \text{Counterfactual outcome}$$

The factual outcome is, in principle, observable. It is the price, quantity, or other market parameter actually recorded during the infringement period. The counterfactual outcome, in contrast, is inherently unobservable. It describes a market scenario that, by definition, did not exist and cannot be read off from the data directly. Establishing a credible counterfactual is therefore the central methodological challenge in any harm quantification exercise.[56]

In practice, the counterfactual is estimated in reference to a comparator. A comparator is an observable market situation that is used as a proxy for the hypothetical competitive outcome. It may be drawn from the same market at a different point in time, from a different geographic or product market that was not affected by the infringement or may be constructed from an economic model. In each case, the comparator provides the empirical foundation from which the counterfactual price or quantity is derived.

The selection and interpretation of a comparator cannot be separated from the theoretical foundations discussed in section 3.1. A comparator is only credible if economic theory supports the assumption that the observed market situation it is

[56] The concept of the counterfactual is well established in the practice of EU competition damages assessments. The European Commission's Practical Guide on Quantifying Harm in Actions for Damages (SWD(2013)205) sets out the counterfactual as the central methodological reference point for quantifying harm.

drawn from follows similar or identical patterns to the counterfactual absent the infringement. Market theory identifies the factors that would have driven prices competitively, and the theory of harm explains how the infringement distorted them. Both are required to assess whether a given comparator is a valid basis for the counterfactual and to specify how differences between the comparator and the affected market must be accounted for.

3.2.2. Typical comparators for counterfactual analysis

All methods employed to estimate antitrust harm are comparator-based in a broad sense. The main distinguishing feature between approaches is whether the comparator is derived from an existing, observable market or constructed from an economic model. In practice, the time-based comparison and the difference-in-differences method are the approaches most frequently employed in litigation, with simulation-based methods applied in specific cases where market-based comparators are unavailable. These approaches are therefore discussed in further detail in section 3.3. There are, however, a whole range of approaches to establish comparators that are broadly introduced in this section.

3.2.2.1. Market-based comparators

In a time-based comparison, the comparator consists of prices observed in the same affected market during a period before and/or after the infringement.[57] These pre- and post-infringement prices serve as a basis from which the counterfactual price is estimated, adjusted where necessary for differences over time in supply and demand, or other price determinants that are unrelated to the infringement.[58] The approach has the advantage that the firms observed in both scenarios are the same and, therefore, largely identical, so that the comparator is a close institutional match to the affected market. Its principal limitation lies in identifying sufficiently long and undisturbed comparison periods. In practice, the start of the infringement may be uncertain, pre-infringement conditions may themselves be distorted, and post-infringement prices may be affected by after-effects or structural market changes. It is mainly used if relevant data for the infringement period, for a non-infringement period as well as for necessary control variables is available.

In a cross-sectional comparison, in contrast, the comparator is a different geographic region or a substitute product market that was not affected by the infringement. Prices

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[57] See section 3.3.1.2 for further details.

[58] As set out in section 3.1.2, market theory guides the selection of relevant price determinants.

observed in that unaffected market during the infringement period serve as a proxy for the counterfactual price in the affected market. This approach requires that the comparator market is sufficiently similar in terms of cost structure, demand conditions, and competitive dynamics. Remaining differences must be accounted for by appropriate adjustments. A practical difficulty is that a comparator market producing close substitutes may itself be affected through umbrella effects. Apart from that, a market that is truly similar to the affected one may face similar incentives to engage in the same conduct, so that the comparator itself cannot be assumed to be genuinely unaffected.

The difference-in-differences method, or DiD for short, combines temporal and cross-sectional variation.[59] The comparator is the price development observed over time in a comparable and unaffected market. This price development is used as a proxy for the price development that would have occurred in the affected market absent the infringement. The cartel effect is then estimated as the difference between the change in price over time in the affected market and the corresponding change in the comparator market. By taking differences this way, the method controls both for time-invariant characteristics of the affected market and for common time trends. The key identifying assumption requires that, absent the infringement, prices in the affected market and in the comparator market would have developed in a similar way.[60]

3.2.2.2. Simulation-based comparators

Simulated comparator markets are often used where no suitable real-world comparator is available. In this case, the counterfactual can be constructed using a structural model from industrial organisation theory.[61] The comparator in this case is an artificially simulated market equilibrium rather than an observable market. Drawing on demand data, information on costs and quantities, and assumptions about the competitive market structure, such models simulate prices and quantities that would have prevailed absent the infringement. Standard model types include oligopoly models with homogeneous or differentiated goods and quantity competition (Cournot models), oligopoly models with price competition (Bertrand models), and auction models.[62] The

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59 See section 3.3.1.3 for further details.

60 The validity of the parallel trend assumption cannot be tested directly for the counterfactual period by definition. It can, however, be assessed empirically for pre-cartel or post-cartel periods in which both markets are observed, and it must be supported by a coherent economic theory of price formation in both markets. See section 3.3.1.3 below.

61 See section 3.3.2 for further details.

62 On Cournot and Bertrand models and their use in antitrust analysis, see Tirole (1988). The use of such models in the context of cartel harm is discussed in detail in section 3.3.2 below.

principal conceptual challenges are the calibration of the degree of coordination achieved by the cartel and the identification of the competitive intensity that would have prevailed in its absence.

Rather than drawing the comparator from an observable market or a simulated equilibrium, the cost-based approach constructs the counterfactual price directly from the cost structure of the infringing firms. Variable production costs are taken as a starting point, and a 'normal' competitive mark-up is added to derive the counterfactual price. The mark-up may be estimated from comparable competitive markets or derived from economic theory. A practical difficulty is that the infringing firms' costs may themselves be distorted by the infringement, for instance through X-inefficiencies[63] or inflated input costs arising from reduced output and the associated loss of scale economies.

Instead of focusing on prices, profitability-based approaches use the profitability of the infringing firms as an indicator of the harm caused. The comparator in this case is a benchmark level of profitability considered 'normal' under competitive conditions. Two general approaches are available: An accounting approach assesses profitability based on the return on capital employed (ROCE). A finance approach draws on the capital asset pricing model (CAPM) and is based on net present value (NPV) and the internal rate of return (IRR). An alternative is to examine price-cost margins directly, typically using long-run average incremental costs (LRAIC) as the relevant concept.[64] Changes in profitability relative to the competitive benchmark may serve as an indicator of the transfer of wealth caused by the infringement.

3.3. Quantification of price overcharges

Price overcharges arise where an infringement causes prices paid by direct purchasers to exceed the prices that would have prevailed under effective competition. This type of harm is particularly relevant in cartel cases and in cases of exploitive abuse, most notably excessive pricing. As set out in section 3.2, the quantification of a price overcharge therefore requires estimating the counterfactual price that would have been charged absent the infringement, and measuring the difference to the price actually observed.

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63 X-inefficiency describes a situation in which firms due to less competitive pressure do not produce at lowest possible costs. For details, see Leibenstein (1966).

64 See OECD (2012a).

From the basics of counterfactual scenario analysis as set out in section 3.2.1, it follows that the observed price in a cartel scenario, that is the factual price, can be decomposed into a counterfactual price and a cartel-induced price effect capturing the harm component. The goal of the empirical analysis is to isolate this cartel-induced price effect by estimating the counterfactual scenario as credibly as possible. The focus in this section is purely on the price effect suffered by direct purchasers. Quantity effects, that is, harm arising from reduced purchases at inflated prices, fall outside the scope of price overcharge analyses and are not addressed here.

This section provides a detailed treatment of the econometric and simulation-based approaches regularly used to estimate price overcharges. The methodologies developed here, however, are not limited to direct cartel effects. They apply equally to the estimation of umbrella effects and pass-on effects, which are discussed in sections 3.4 and 3.5 respectively. In those sections, the methods will not be presented afresh. Instead, the focus will be on how the same framework applies and where specific adjustments are required.

3.3.1. Econometric estimation of comparators

3.3.1.1. Econometric foundations

Fundamentals of regression analysis

The estimation of a price overcharge requires isolating the price effect attributable to the infringement from all other influences on prices. The standard tool for this purpose is regression analysis. A regression model is a statistical method that identifies and quantifies the relationship between a variable of interest, referred to as the dependent variable, and one or more factors that may explain it, referred to as the explanatory or independent variables.[65] In the context of price overcharge estimation, the observed price is the natural dependent variable. It is modelled as a function of the infringement effect, which is the relationship the analysis seeks to estimate, a set of economically relevant price determinants such as costs and demand, and a random error term that captures all remaining unexplained variation.

The fundamental challenge in any empirical analysis is to isolate the causal effect of the cartel from all other influences on prices.[66] A well-specified regression model achieves

[65] For a more detailed introduction to regression analysis, see Wooldridge (2020) or Gujarati (2002).

[66] The goal of regression analysis is to identify causal effects, not mere correlations. A correlation between two variables does not imply that one causes another. Only a correctly specified model grounded in economic theory (as described in section 3.1) can support a causal interpretation.

this, for instance, by explicitly accounting for the factors that would have driven prices even in the absence of the infringement.[67] The cartel effect can then be estimated as the portion of the observed price variation that cannot be explained by those other factors.

To illustrate the basic mechanics of a regression, however, consider first a simple example in which prices depend on a single explanatory variable, costs. The linear regression model takes the following form:

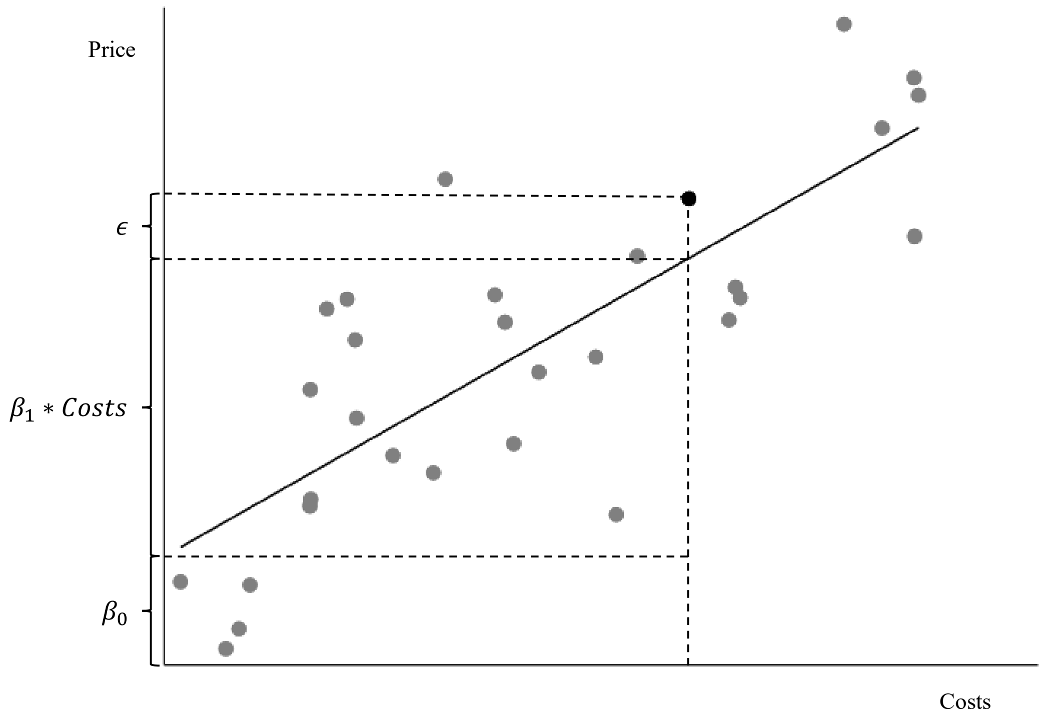
$$Price = \beta_0 + \beta_1 * Costs + \epsilon$$

Three components make up this model: The constant β_0, also referred to as the intercept, is the estimated baseline price when the explanatory variables take a value of zero. In the illustrated case above, it describes the price that would prevail if costs were equal to zero. In most applications, however, it has no direct economic interpretation but is typically included to ensure correct model specification. The regression coefficient β_1 measures the change in the dependent variable, here $Price$, associated with a one-unit increase in the explanatory variable, here $Costs$. The error term ϵ captures all variation in prices that is not explained by the included explanatory variables. It reflects both genuine random fluctuations and the influence of any other factors not explicitly included in the model.

Figure 5 below illustrates this simple regression graphically. Each dot represents a single price observation at a given cost level. The regression line is the best-fitting straight line through these observations. The line is estimated by ordinary least squares (OLS), a method that chooses the intercept and slope coefficients to minimise the sum of the squared (vertical) distances between each data point and the line. As can be seen, the intercept, that is the constant β_0, describes at which level of the dependent variable, the regression line starts if the explanatory variable takes on a value of zero. The coefficient β_1 describes the slope of the regression line. For any given observation, the vertical distance between the data point and the regression line is the residual captured in the error term ϵ of the model.

[67] This describes isolating the cartel effect by preventing bias caused by omitted variables. In practice, however, there are other forms of endogeneity that could bias the estimation of a cartel effect, such as simultaneity and measurement error, which must be taken into account in order to correctly isolate the cartel effect. See section 3.3.1.4 for further details.

Figure 5: Stylised illustration of a simple regression of prices on costs



Source: Own illustration.

In practice, a regression model for price overcharge estimation will always contain more than one explanatory variable, which is called a multivariate framework. At a minimum, it will include a variable capturing the infringement effect and a set of control variables accounting for other relevant determinants of the price. Each explanatory variable has its own regression coefficient. That coefficient measures the isolated effect of the respective variable on the dependent variable, assuming no change in any other of the included variables. This is known as the *ceteris paribus* condition, meaning all else is held constant. It is the core principle underlying the interpretation of regression coefficients in a multiple regression framework.[68]

Dependent variables

In a price overcharge estimation, the dependent price usually is the observed transaction price. Before specifying the regression model, the analyst must make

[68] In a price overcharge estimation, the *ceteris paribus* condition is precisely what makes the infringement coefficient interpretable as a measure of harm. Suppose, for example in a time-based comparison, that costs increased during the infringement period. Without controlling for this costs development, a comparison of prices during and outside the infringement period would confound the infringement effect with the cost effect. By including costs as a control variable in the regression, the model holds costs constant when isolating the infringement's contribution to the price increase. The infringement coefficient then captures only the price effect attributable to the infringement and not the simultaneous effect of cost movements or other market developments.

several choices about how to measure prices. The first concerns the unit of observation. Prices may be observed at the level of individual transactions, or, for instance, as weekly or monthly averages by product, or at firm level.[69] The choice affects the variation that is available to identify the cartel effect and how control variables must be specified.

The second choice concerns the functional form. Prices may be used in their natural units, referred to as levels, or transformed into logarithms.[70] When log prices are used as a dependent variable the infringement coefficient is interpreted as a relative, that is percentage, price overcharge rather than an absolute one. The correct choice of the functional form of the dependent variable as well as of explanatory variables depends on the nature of the cartel agreement and the market structure as set out by economic theory and the theory of harm.[71]

Control variables

Control variables are explanatory variables included in the regression to account for factors other than the cartel that influence prices. Their selection is one of the most consequential steps in building a reliable estimation model. The following criteria guide that selection:

- *Economic relevance:* Only variables that genuinely influence prices in the relevant market should be included. Including irrelevant variables reduces the precision of the estimated coefficients and can obscure the cartel effect.
- *Exogeneity:* A core assumption of OLS is that explanatory variables are not correlated with the error term. This exogeneity assumption can be violated in different ways. First, it is violated in case relevant variables that influence the dependent price and correlate with the variable of interest[72] without being causally impacted by the infringement are omitted from the model. Such variables are referred to as confounders and must be included as control variables to avoid omitted variable bias.[73] Second, when an included variable may itself be correlated with the error term, for instance through simultaneity or measurement error.

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[69] For a discussion on potential problems arising in regression analyses when observing aggregated mean prices, see section 3.3.1.4.

[70] On the choice of functional form, See Gujarati (2002).

[71] Suppose that a cartel agreed on a uniform absolute price increase. In this case, a level specification is appropriate. If the cartel agreement was to raise prices by a certain percentage, or if competitive prices themselves vary proportionally with costs, a log specification is more suitable. The choice of the functional form has important practical consequences and is discussed in further detail in section 3.3.1.2.

[72] Throughout this section, the main variable of interest is an indicator for the infringement. In a simple cartel case, this would usually be a dummy variable indicating prices that are set by the cartel.

[73] See section 3.3.1.2 for an example of how omitted variable bias affects regression estimates.

Such variables are referred to as endogenous and should be excluded to avoid biased estimates.[74]

- *Bad Controls:* Variables that are themselves influenced by the infringement should not be included as control variables. Such variables transmit part of the infringement's effect on prices, so that including them as control variables absorbs part of that effect rather than removing an independent influence in prices.[75]
- *Data quality and availability:* Variables should be reliably measured and consistently available across all units and time periods included in the dataset. In practice, proxy variables are often used when the ideal variable is not directly observable. A publicly available energy price index may, for instance, serve as a proxy for production costs when firm-level costs are energy intensive but not available.[76]
- *Parsimony:* A regression model should not include an unnecessarily large number of variables. Including too many controls can make results unstable and difficult to interpret, particularly in datasets with limited variation in prices or with a relatively small number of observations.

Panel data and fixed effects

In practice, datasets used for price overcharge estimation often contain multiple prices observed across different firms, products, or customers over time. This data structure is called panel data. Panel data typically increases the number of observations available for estimation, which improves statistical precision. It does, however, require additional modelling choices.

When multiple units are observed over time, prices of different units may systematically differ from one another for reasons that are constant over time. A premium brand may always charge more than a standard product, regardless of cost or demand developments. A firm operating in a particular region may face structurally different demand conditions that are unrelated to the infringement. If these time-invariant differences are not accounted for, they remain in the error term and may bias the cartel coefficient.

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74 Endogeneity is discussed in more detail in section 3.3.1.4.

75 A typical example in cartel cases are the prices of non-cartelised competitors that may be elevated via umbrella effects. Such prices can have an influence on the prices set by the cartel and might appear to be a relevant control. However, since they are themselves a consequence of the cartel, including them as controls would absorb part of the cartel effect through the umbrella channel and lead to an underestimation of the true overcharge. Other mechanism can also give rise to bad controls, including more subtle cases involving so-called collider bias. For a comprehensive overview see Cinelli et al. (2024).

76 See section 3.3.1.4 for a discussion on the importance of robustness analyses, especially in the context of the selection of control variables.

Fixed effects address this problem by including separate intercepts for each unit in the dataset. This controls for all time-invariant, unit specific differences in price levels, whether directly observed or not.[77] The cartel coefficient is then identified from variation within units over time rather than from differences across units, which is generally a more credible basis for estimating a causal price effect.

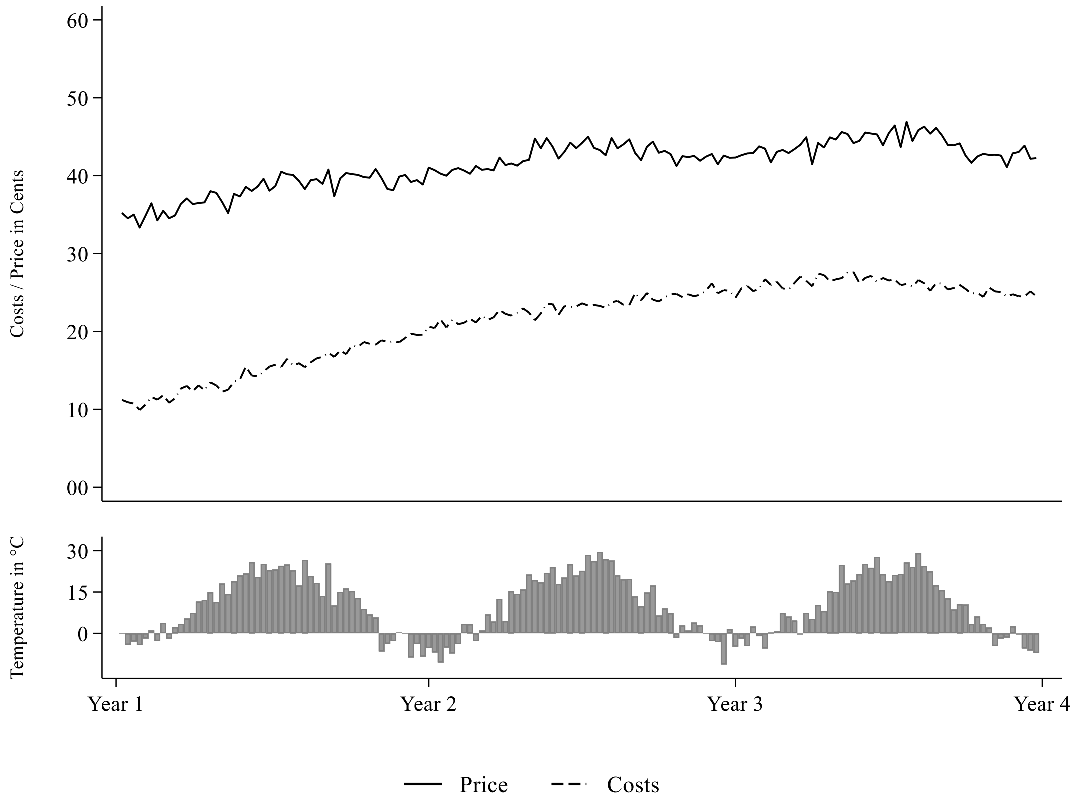
Estimating regression models

The concepts introduced above are illustrated throughout the remainder of this paper using the stylised case study of a cartel in the market for bottled water introduced in section 1.[78] The market assumed in this case study is structured as follows: Several firms each offer a single product, bottled water, and set prices independently at the beginning of each week. Prices are posted prices, i.e. customers either accept the offered price or do not purchase. Two factors drive prices in the competitive scenario. The first is production costs, which vary across firms and time. The second is temperature measured as weekly averages in degree Celsius, which serves as a proxy for demand. Higher temperatures are assumed to increase consumer demand for bottled water and are therefore expected to push prices upwards. Weekly price and cost data in cents per bottle are available for all firms over three years, covering 156 weeks. Figure 6 below shows the development of (competitive) prices, costs, and temperature over the full observation period for one firm.

[77] With respect to the regression line, one can think of fixed effects as a unit-specific adjustment of the constant, which leads to a parallel shift of the regression line downwards or upwards depending on the time-invariant difference in price levels of several units. The use of fixed effects is discussed in detail with empirical examples in sections 3.3.1.2 and 3.3.1.3.

[78] The case study is used throughout sections 3.3.1.2 to 3.3.1.4 to illustrate progressively more complex estimation approaches. All regression output shown in those sections use the same underlying data and market structure introduced here.

Figure 6: Weekly (competitive) prices, costs and temperature in the stylised bottled water case study



Source: Own illustration.

The figure shows that prices and costs both trend upward over the observed period. Temperature follows a clear seasonal pattern with peaks in summer and lows in winter. The relationship between these variables and prices provides the empirical basis for the regression model. Given the competitive market structure described above, the regression model for the bottled water market under effective competition takes the form described below. For illustrative purposes, the regression model uses prices per bottle for one firm only.[79]

$$Price_t = \beta_0 + \beta_1 * Costs_t + \beta_2 * Temperature_t + \epsilon_t$$

In this regression model, water bottle prices per week t are explained using weekly costs and temperatures as well as an error term ϵ_t. Usually, such regression models are estimated by running statistical software. As a result, the software often generates a regression table with the estimates of the coefficients and further statistical

[79] This assumption is relaxed in the further subsections of the paper.

measurements. Figure 7 below shows the regression output for the regression model described above.

Figure 7: Example regression output using the statistical software Stata

Source	SS	df	MS			
				Number of obs	=	156
				F(2, 153)	=	4853.03
Model	.655961215	2	.327980607	Prob > F	=	0.0000
Residual	.010340139	153	.000067583	R-squared	=	0.9845
				Adj R-squared	=	0.9843
Total	.666301354	155	.004298718	Root MSE	=	.00822

Price	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
Costs	1.206479	.0132186	91.27	0.000	1.180364	1.232593
Temperature	.001988	.0000601	33.06	0.000	.0018692	.0021068
_cons	.169358	.0029364	57.67	0.000	.1635568	.1751592

Source: Own estimation. Regression output generated by Stata.

The key elements of the output are as follows. The estimated coefficient on costs is 1.206. This means that a one-cent increase in production costs is associated, on average, with a price increase of approximately 1.2 cents per bottle, holding temperature constant.

The coefficient on temperature is 0.002, indicating that a one-degree increase in temperature is associated with a price increase of 0.002 cents, holding costs constant. In other words, an increase in temperature of 20 degrees Celsius therefore corresponds to a price increase of approximately 0.04 cents on average. The coefficient of the constant, that is the intercept, is 0.169.[80]

The regression is estimated on 156 weekly average price observations, covering the three years of data for one firm. The number of observations is relevant for several other elements of the regression output. A larger sample generally yields smaller standard errors and more reliable results. It also determines the degrees of freedom[81] available for estimation, which affects the reliability of all reported test statistics. As a common rule of thumb, a regression model should have at least ten to twenty independent observations per estimated parameter to produce reliable results.

80 Technically that would be the estimated price if temperature is at 0° Celsius and costs were equal to zero. As discussed above, the coefficient of the constant has no direct economic interpretation in many applications.

81 Degrees of freedom refer to the number of independent pieces of information available for estimating the unknown parameters of the model. In a regression with N observations and k explanatory variables plus a constant, the degrees of freedom for the residuals are $N - k - 1$. Each additional explanatory variable consumes one degree of freedom. With fewer observations relative to the number of parameters, the remaining degrees of freedom are small, which inflates standard errors and reduces the reliability of the estimate coefficients (see Wooldridge, 2020). In the present example, with 156 observations and two explanatory variables, the degrees of freedom are 153, which is sufficiently large to support precise estimation.

The standard error measures the precision of the estimated coefficient. A smaller standard error indicates a more precise estimate. The 95 percent confidence interval translates this precision into a range: the cost coefficient of 1.206, with a standard error of 0.013, yields a 95 percent confidence interval of [1.180, 1.233]. This means that the true cost coefficient is expected to fall in the interval from 1.180 to 1.233 with a 95 percent probability.[82]

The p-value measures the statistical significance of an estimated coefficient. Statistical significance addresses the question of whether an estimated effect is likely to reflect a genuine relationship in the data or whether it could plausibly have arisen by chance in a sample of finite size. Statistical significance does not, however, indicate economic relevance or magnitude. The starting point to obtain p-values is the null hypothesis, which generally posits that the true value of the coefficient is zero, that is, that the variable in question has no effect on the dependent variable.[83] The p-value then gives the probability of observing an estimated coefficient as large as the one obtained, or larger, if the null hypothesis were true.[84] A small p-value therefore indicates that the observed estimate would be unlikely to arise by chance if there were no true effect, which provides evidence against the null hypothesis. By convention, an effect is considered statistically significant if the p-value falls below a certain threshold, typically 5 percent.[85] In the example above, both coefficients have p-values reported as 0.000 in the Stata output, indicating that the true p-value is rounded down because it is smaller than 0.0005. The coefficients are thus statistically significant at the 1-percent level, which is a common threshold used to indicate a very high statistical significance.

The R-squared is a widely used statistical measure of ‘goodness of fit’ that describes the proportion of variation in the dependent variable that is explained by the model. An R-squared of 0.9845 indicates that the regression model captures 98.45 percent of the variation in prices. A higher R-squared, thus, generally indicates a better fitting model,

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[82] The exact technical interpretation is that for a large number of independent data samples, in approximately 95 percent of cases the confidence interval covers the true coefficient.

[83] The standard regression output assumes a two-sided test against the null hypothesis that the coefficient equals zero. Other formulations are possible, such as one-sided tests or tests against non-zero values, but are less common in the present context.

[84] More precisely, the p-value is the lowest significance level at which the null hypothesis can be rejected given the observed data. A significance level of 5 percent means that one accepts a 5 percent probability of incorrectly rejecting a true null hypothesis, known as a Type-I-error (see Wooldridge, 2020). A useful analogy is a medical diagnostic test: a Type-I-error corresponds to a false positive result, where the test indicates that a patient has a disease when they are in fact healthy. In regression analysis, the equivalent error is concluding that an explanatory variable indeed affects the dependent variable when in truth it does not.

[85] In regression output tables, significance levels are commonly indicated using asterisks: *** for $p < 0.01$, ** for $p < 0.05$, and * for $p < 0.1$.

but a high R-squared alone does not guarantee that coefficients are correctly estimated.[86] As for mathematical reasons, the R-squared typically increases via the inclusion of control variables (irrespective of their economic relevance), in practice the adjusted R-squared is often used. It penalises for the inclusion of additional variables and is useful for comparing models with different numbers of control variables.

The F-statistic tests whether the regression model as a whole has explanatory power, that is, whether at least one of the included explanatory variables has a statistically significant relationship with the dependent variable. The reported F-statistic of 4,853.03 with a corresponding p-value of 0.000 indicates that the model has significant explanatory power. In practice, the F-statistic is most informative when it is low or borderline significant, which would signal that the included variables jointly explain little to none of the variation in prices. In the present case, however, the high value simply indicates that some of the included variables have more explanatory power than what would be expected from variables with random influences.

Figure 7 above contains several further statistics and elements that can be used to interpret the regression output. In practice, however, regression output tables are often reported in a condensed form, showing only the relevant estimated coefficients, standard errors, asterisks for statistical significance, the number of observations, and the (adjusted) R-squared. Sometimes, the F-statistic is included as well. This condensed format is used in the remainder of this paper.

3.3.1.2. Time-based comparison

In many cases it is appropriate to use a comparison in time to estimate price effects of anti-competitive conduct. The time-series comparison, also referred to as the before-and-after method, uses prices observed in the same affected market before and/or after the infringement as the comparator for the counterfactual price. It is the most widely used approach in practice and is applicable whenever a sufficiently long time series of price data are available for periods that are clearly separable from the infringement period, when the cartel period can be identified with reasonable precision, and when no suitable comparison market is available for a difference-in-differences analysis. The core identifying assumption is that prices in the comparison periods provide a reliable guide to what prices would have been during the infringement absent the infringement. Such an approach has the advantage that the firms in the factual and counterfactual

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86 A high R-squared is not required for identification, which depends on isolating exogenous variation in the variable of interest rather than explaining total variation in the dependent variable. A high R-squared may in some cases even signal simultaneity or other forms of endogeneity.

scenario are mostly the same, so that the counterfactual is a good comparator at least in that respect. In contrast it has the disadvantage that any unobserved time-varying influences cannot be controlled for and are therefore assumed to be zero.

The following subsections develop the approach of a time-based comparison step by step using the bottled water case study introduced in sections 1 and 3.3.1.1. To allow for a concrete illustration, the case study is now extended to include a cartel. In year 2, that is weeks 53 to 104, all firms in the market agreed to raise their prices by a fixed amount of 5 cents per bottle above the competitive level, a straightforward price-fixing agreement resulting in a uniform absolute overcharge.[87] It is further assumed that the cartel lasted until the end of year 2 and prices fell to the competitive level with the beginning of year 3.[88] Starting from this scenario, the subsections below work through progressively more sophisticated estimation approaches, each motivated by a specific econometric challenge that arises in practice.

Comparison of mean prices

To introduce the approach of a time-based comparison, first the simplest possible implementation is considered: a comparison of average prices of the infringement period and the non-infringement period. In the case study, the firms agreed to raise prices by a fixed amount of 5 cents per bottle above the competitive level in year 2. Figure 8 below illustrates the weekly prices of one firm throughout the observation period. The solid black line shows the pre- and post-cartel prices, as well as the counterfactual price during the cartel period. The dotted line shows the cartelised price in year 2, while the grey area indicates the price increase. Additionally, the figure displays the average pre- and post-infringement price, as well as the average price during the cartel period.

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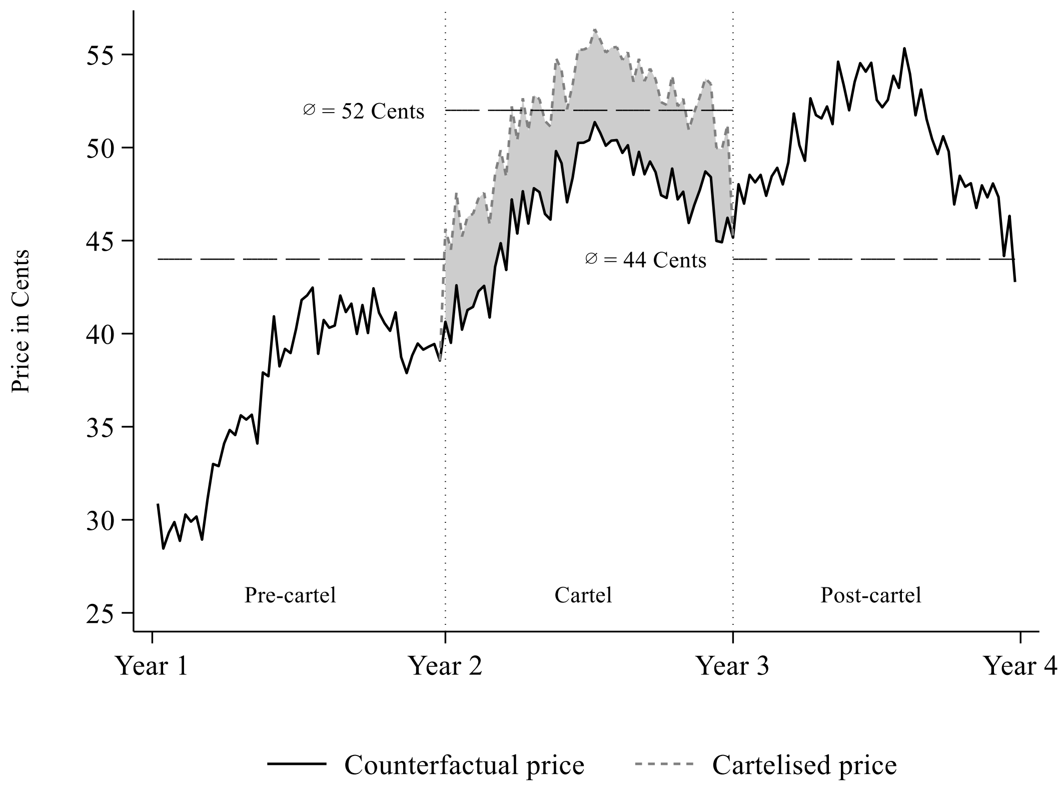
87 Throughout this case study, the true cartel effect is known because the underlying data were simulated for illustrative purposes. In practice, the true overcharge is of course unobservable. Its estimation is precisely the purpose of the analysis. The known true effects serve here only as a benchmark against which the performance or different estimation approaches can be assessed.

88 The main assumption here is that there have not been any after-effects of the cartel and the infringement period is clearly defined. In practice, the clear definition of the period in which prices have been affected by the cartel may be more complex. See section 3.3.1.4 for further details.

Figure 8: Weekly prices and period averages in the bottled water case study



Source: Own illustration.

The average price during the cartel period is 52 cents, while the average price during the pre- and post-cartel period is 44 cents. A naive comparison of means would therefore suggest a cartel overcharge of 8 cents. The true overcharge is, however, only 5 cents. The simple mean comparison overstates the cartel effect because prices also rose over time for reasons that have nothing to do with the infringement. Neither of these factors is accounted for by comparing average prices across periods.

A first step towards a more systematic approach is to express the comparison as a regression model. In its simplest version, regressing prices on a cartel dummy and a constant is mathematically equivalent to comparing average prices across groups or time periods. The cartel dummy takes on the value of one during the infringement period and zero otherwise. The regression model is the following:

$$Price_t = \beta_0 + \beta_1 * Cartel\ period_t + \epsilon_t$$

It is now assumed that price data for one of the firms that participated in the cartel during year 2 is available. If the simple regression model above is run for the price data of this firm, the regression output is shown in Table 2.[89]

Table 2: Naïve regression for a time-based comparison without control variables in the bottled water case study

Variables	
Cartel period	0.081***
	(0.011)
Constant	0.436***
	(0.006)
Observations	156
Adjusted R-squared	0.262

Note: *Standard errors in parentheses.* $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.
Source: *Own estimation.*

The constant of 0.436 corresponds to the average price outside the cartel period, that is, roughly 44 cents. The cartel coefficient of 0.081 implies an estimated overcharge of approximately 8 cents. This result reproduces the mean comparison from Figure 8 above, as a regression without any control variables is simply a more formal econometric representation of a group-wise mean comparison. Since the underlying true cartel effect in the data is 5 cents by definition, the estimate of 8 cents is an overestimate. The estimate is biased upwards because systematic cost and demand developments during the cartel period are attributed entirely to the infringement. The low adjusted R-squared of 26.2 percent confirms that the model explains only a quarter of the variation in prices.

Simple regression model

As was shown, a simple comparison of mean prices over time may lead to an incorrect estimate of the cartel effect. The bias in the estimate above is an instance of omitted variable bias. It arises when a variable that both influences prices and correlates with the cartel dummy is not included in the regression.[90] In the bottled water example, production costs increase strongly in year 1 and 2 and remain nearly constant in year 3.[91] Average production costs are thus systematically higher during the cartel period than

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[89] For the remainder of this paper, only a condensed form of the regression output table in line with standard practices is used to summarise the main elements.

[90] As explained in section 3.3.1.1 such variables are confounders and should be included in the model.

[91] See Figure 6 in section 3.3.1.1 for a description of cost development in the bottled water case study.

outside of it. Because the regression without controls cannot distinguish the effect of rising costs on prices from the effect of the cartel, it attributes part of the cost-driven price increase to the infringement.

The remedy is to include the relevant price determinants as control variables. In the bottled water market, these are production costs and temperature. Adding both variables to the regression model yields:

$$Price_t = \beta_0 + \beta_1 * Cartel\ period_t + \beta_2 * Costs_t + \beta_3 * Temperature_t + \epsilon_t$$

The cartel dummy, again, takes on a value of one for weeks 53 to 104 and zero otherwise. Costs and Temperature are included as controls and capture the price-relevant developments that are independent of the infringement. The regression is estimated for one of the cartelised firms over all three years jointly. Table 3 shows the respective regression output.

Table 3: Simple regression controlling for costs and temperature in the bottled water case study

Variables	
Cartel period	0.049***
	(0.001)
Costs	1.210***
	(0.014)
Temperature	0.002***
	(0.000)
Constant	0.169***
	(0.003)
Observations	156
Adjusted R-squared	0.988

Note: *Standard errors in parentheses.* *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: *Own estimation.*

The cartel dummy is now 0.049, indicating that the estimated price effect of the cartel is approximately 4.9 cents, holding all else constant. This effect is statistically significant at the 1-percent level as the three asterisks indicate a p-value below 1 percent.[92] By controlling for costs and temperature, the regression isolates the cartel's contribution to the price increase from cost- and demand-driven components. In the result, the estimated cartel effect of 4.9 cents is very close to the underlying true cartel

[92] See section 3.3.1.1 for the interpretation of p-values.

overcharge of 5 cents.[93] The adjusted R-squared of 98.8 percent confirms that the model explains almost all variation in prices across observation periods.

The estimated overcharge per unit can be translated directly into a total harm amount. If the cartel affected one million units sold during the infringement period, the total harm to a direct purchaser amounts to $€0.049 * 1{,}000{,}000 = €49{,}000$.

Choice of functional form

The regression above assumes that the cartel caused a fixed absolute price increase in cents per bottle. This is appropriate when the cartel agreement was to raise prices by a uniform absolute amount. In many cases, however, the nature of the cartel agreement or the competitive market structure suggests that the overcharge is better described as a percentage of the counterfactual price. A cartel that coordinates a common mark-up, or that exploits market power by charging a proportional premium above competitive costs, will produce a relative rather than an absolute overcharge. Translated to the bottled water case study, it is now assumed that the cartel increased prices in year 2 by 10 percent rather than by a fixed amount of 5 cents.

To estimate this relative overcharge, the dependent variable is transformed into its natural logarithms. This ensures that the cartel coefficient can be interpreted as a relative change in percent rather than an absolute overcharge. The regression model becomes:

$$ln(Price_t) = \beta_0 + \beta_1 * Cartel\ period_t + \beta_2 * Costs_t + \beta_3 * Temperature_t + \epsilon_t$$

In this log-linear regression specification, the cartel coefficient β_1 is interpreted as a relative price effect. To obtain the percentage overcharge, the coefficient β_1 must be transformed using the formula $100 * \left(e^{\beta_1} - 1\right)$.[94] Assume now that the cartel in the bottled water case study agreed to raise prices by 10 percent rather than by 5 cents. Table 4 reports the regression results both for the previous linear specification as well as for the log-linear mode. Column (I) uses prices in levels as the dependent variable and Column (II) uses log prices. Both regressions are estimated on data for one of the cartelised firms whereas the true overcharge is 10 percent:

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[93] This case illustrates the role of statistical uncertainty. Although the model is statistically well-specified and yields a high degree of accuracy, it does not recover the exact value of 5 cents. Econometric models do not aim to identify exact deterministic values. Rather, they provide estimates that are close to the true parameter within a margin of statistical uncertainty. This distinction should be kept in mind when interpreting the results. Importantly, the fact that such models do not reproduce exact values should not be taken as a reason to dismiss them, as their value lies in providing consistent and informative approximations of underlying relationships.

[94] For small values of β_1, the percentage overcharge can be approximated as $100 * \beta_1$.

Table 4: Log-linear regression model in the bottled water case study

Variables	(I)	(II)
	Lin Prices	Log Prices
Cartel period	0.045***	0.100***
	(0.002)	(0.004)
Costs	1.213***	2.903***
	(0.014)	(0.040)
Temperature	0.002***	0.005***
	(0.000)	(0.000)
Constant	0.168***	-1.485***
	(0.003)	(0.009)
Observations	156	156
Adjusted R-squared	0.986	0.981

Note: *Standard errors in parentheses.* *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: *Own estimation.*

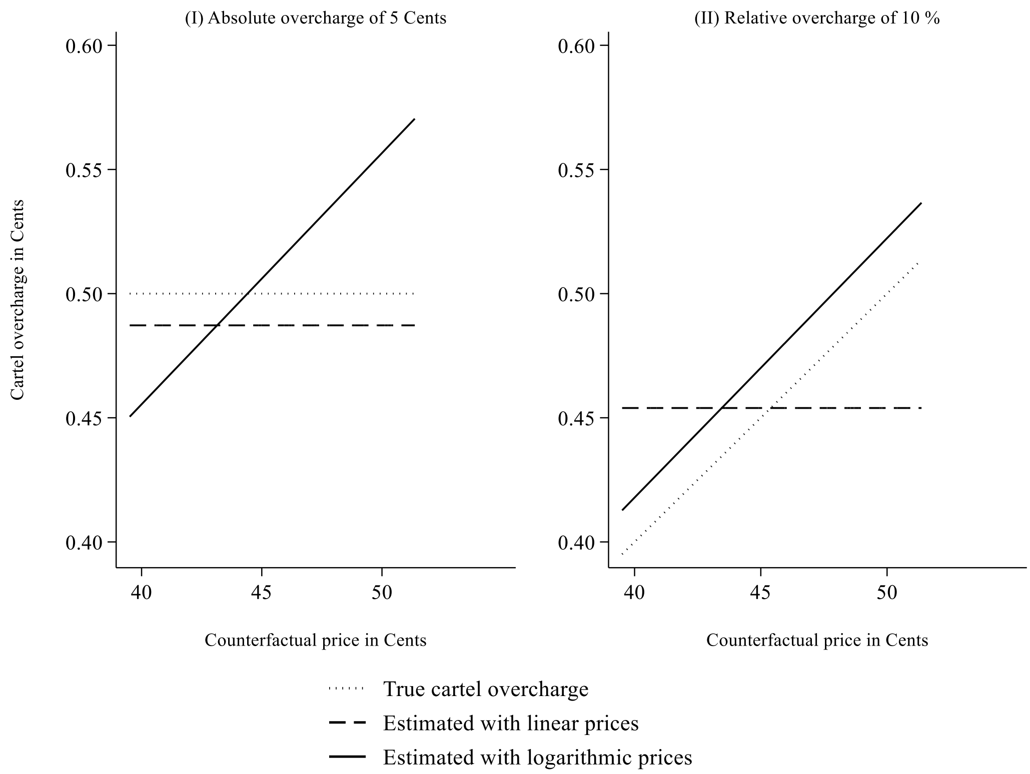
The cartel coefficient in Column (I) is 0.045 suggesting an absolute price increase of approximately 4.5 cents per bottle, holding all else constant. This estimate is constant across all price levels by construction of the linear model. Regardless of whether the counterfactual price is 40 cents or 50 cents, the model always attributes the same absolute overcharge induced by the cartel. The cartel coefficient in Column (II) is 0.100, which translates to an estimated overcharge of 10.5 percent using the formula for interpreting coefficients in a log-linear model described above, closely matching the true overcharge of 10 percent.[95] The log-linear specification correctly captures a proportional effect that scales with the price level, which is precisely what a percentage overcharge requires.

The importance of choosing the correct functional form is illustrated in Figure 9 below which compares the estimated overcharge in cents for each counterfactual price using different functional forms with the underlying true overcharge. The left Panel (I) shows the case of a true absolute overcharge of 5 cents. The right Panel (II) shows a case of a true relative overcharge of 10 percent as estimated in the regressions in Table 4 above.

[95] To derive the absolute per-unit harm in this case, the estimated percentage overcharge represents a mark-up on the counterfactual price, not a share of the observed cartelised price. For a given cartelised price P_{Cartel} and an estimated relative overcharge of r, the counterfactual price is $P_{Cartel}/(1 + r)$ and the absolute per-unit overcharge is the difference of the cartelised price and the derived counterfactual price. For example, if the observed cartelised price is 52 cents and the estimated overcharge is 10.5 percent, the counterfactual price is 52 cents / $(1 + 0.105) \approx 47$ cents. The absolute per-unit overcharge is thus 5 cents. As can be seen, in relative terms the share of the price increase to the cartelised price is less (5 cents / 52 cents $\approx$ 9.6 percent) than the 10.5 percent overcharge. To calculate total absolute harm, the absolute per-unit overcharge for each transaction must be multiplied by the corresponding quantity purchased and summed up across all transactions during the infringement period. Alternatively, total harm can be calculated by deriving the counterfactual total revenue as observed revenue divided by $(1 + r)$ and subtracting it from observed revenue, which yields the same result.

As Figure 9 reveals, the linear price estimate almost matches the true cartel overcharge on the left Panel (I) whereas the logarithmic price estimate almost matches the true percent price overcharge in Panel (II) on the right.

Figure 9: Estimated vs. true cartel overcharge for different functional form specifications



Source: Own illustration.

The choice of the functional form encodes an assumption about the nature of the cartel overcharge. A linear specification assumes that the cartel caused a fixed absolute price increase, independent of the counterfactual price level. A log-linear specification, in contrast, assumes a proportional overcharge that scales with the counterfactual price level. Panel (I) of Figure 9 shows the true constant overcharge of 5 cents. The correctly specified linear estimator deviates only slightly from the true overcharge, with the small gap reflecting ordinary statistical estimation error rather than a systematic bias. The log-linear specification, by contrast, cannot reproduce this constant absolute effect and instead produces an estimated overcharge that rises with the counterfactual price, overstating the harm at high price levels and understating it at low ones. Panel (II) shows the case of a true overcharge of 10 percent relative to the counterfactual price. Here the correctly specified log-linear estimation tracks the true overcharge closely, again with only small deviations attributable to random noise in the data. The linear specification, however, cannot reproduce this proportional effect and instead estimates a constant overcharge, which understates the true harm when the counterfactual price is high and overstates it when it is low. In both cases the bias introduced by the wrong functional form is not random but systematic and directional, which reinforces the importance of grounding the choice of specification in the economic theory of the cartel agreement before estimation begins.[96]

The choice of functional form for the dependent variable does not only affect the interpretation of the cartel coefficient. It also changes the assumed relationship between prices and all other explanatory variables included in the model, and therefore the interpretation of their coefficients as well. When moving from a level to a logarithmic specification of the dependent variable, it is worth considering whether the functional form of the control variables should be adjusted accordingly.

To illustrate this, consider the relationship between prices and costs. In a linear specification where prices are used in levels, the cost coefficient measures the absolute price change associated with a one-unit increase in costs. When the dependent variable is expressed in logarithms, but costs are still entered in levels, the coefficient measures the approximate relative change in prices associated with a one-unit increase in costs. In many markets, however, the relationship between costs and prices is more naturally described in proportional terms. If firms apply a constant percentage mark-up on costs, a one-percent increase in costs leads to a one-percent increase in prices. This elasticity relationship is captured by taking the natural logarithm of both, the dependent variable and the cost variable, yielding a log-log specification. Table 5 summarises the interpretation of regression coefficients for the four standard combinations of level and log specifications.

96 See section 3.1.3 for the importance of the theory of harm in harm quantification.

Table 5: Interpretation of regression coefficients under different functional form combinations

Functional form	Dependent variable	Explanatory variable	Interpretation of the coefficient β
lin - lin	Price	Costs	+ 1 unit increase in costs → β units increase in prices
lin - log	Price	Ln(Costs)	+ 1 % increase in costs → β / 100 units increase in prices
log - lin	Ln(Price)	Costs	+ 1 unit increase in costs → **approximately** 100 · β % increase in prices for small values of β → **exactly** 100 · (e^{β} - 1) % increase in prices
log - log	Ln(Price)	Ln(Costs)	+ 1 % increase in costs → β % increase in prices

Source: Own illustration.

The choice of the functional form for control variables is governed by the same principles as the choice for the dependent variable. It should reflect the economic relationship between the variable in question and the price as suggested by market theory.[97] In practice, the choice of the functional form for control variables follows widely accepted standards:

- Costs and other price-relevant input variables are typically entered in logarithms when a proportional relationship with prices is economically plausible, for instance when firms charge prices on percentage mark-up basis.
- Dummy variables and categorical variables are always used in a linear form, as a logarithmic transformation is not meaningful for binary indicators.
- Percentage variables or normalised indices are generally entered in levels, as their unit of measurement already implies a relative interpretation.
- Variables that can take zero or negative values must be entered in levels, as the natural logarithm is not defined for zero and non-positive numbers.

Applying these principles to the bottled water case study, the cartel is now assumed to have succeeded in raising prices by 10 percent, so logarithmic prices are used as the dependent variable. Costs are entered in logarithms because competitive pricing in this market is assumed to be based on a proportional mark-up on costs, implying an elasticity relationship. Temperature measured in degree Celsius is entered in levels,

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97 This again shows the importance of economic theory, here market theory, for empirical analyses as described in section 3.1.2.

because it can take negative values and because its effect on demand, and thereby on prices, is as assumed to be a linear one. The baseline regression model for the remainder of this paper is therefore:

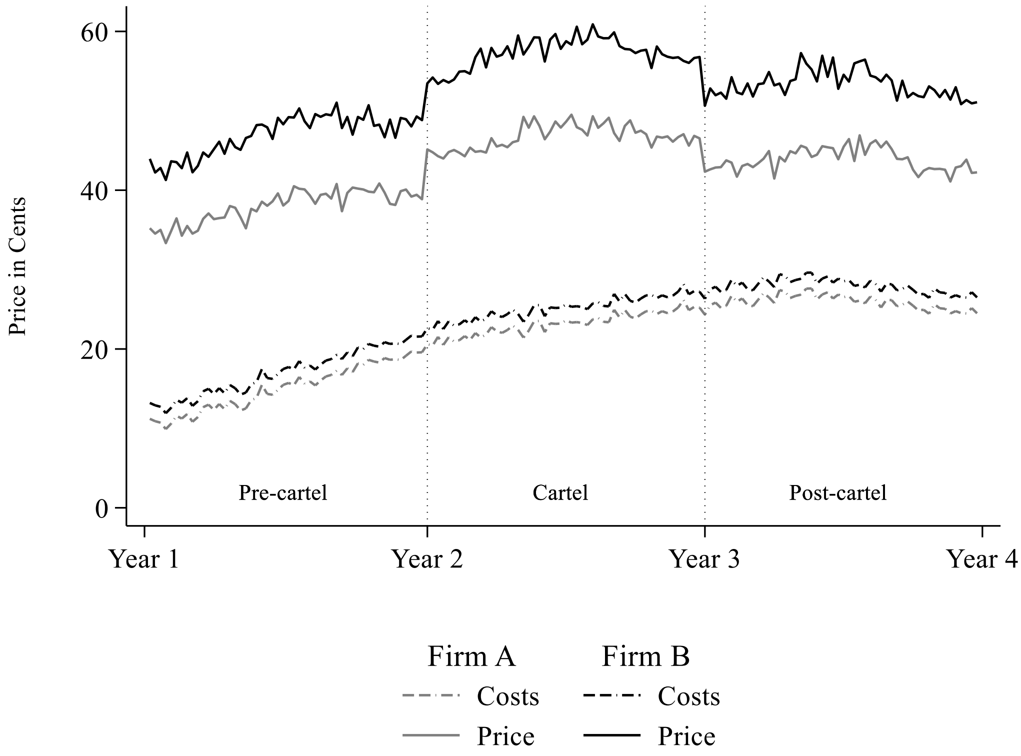
$$ln(Price_t) = \beta_0 + \beta_1 * Cartel\ period_t + \beta_2 * ln(Costs_t) + \beta_3 * Temperature_t + \epsilon_t$$

Panel data and fixed effects

So far, the analysis has focused on price observations from a single product of a single firm over time. In practice, price overcharge estimations are typically conducted using larger datasets that contain prices from multiple firms, products or customers observed over the same period. Such panel data structures offer important advantages. A large number of observations increases statistical precision through reduced standard errors, thereby improving the reliability of the estimated cartel effect. They also allow for a richer set of modelling approaches, including the use of fixed effects.

To illustrate this, the case study is now extended to include a second firm. Firm B is structurally similar to Firm A but has somewhat higher production costs and charges prices at a consistently higher level, e.g. as the product of Firm B is perceived as a more premium product. Both firms participate in the cartel and both raised prices by 10 percent in year 2. Figure 10 below shows prices and costs of both firms across the observation period.

Figure 10: Weekly prices and costs for Firm A and Firm B in the bottled water case study under homogeneous cartel effects



Source: Own illustration.

The figure shows that costs and prices of Firm B are consistently higher than those of Firm A. Part of the observed price premium may therefore be explained by cost differences, while the remaining component reflects a consistent firm-specific effect. This residual premium is not accounted for by the cost and demand variables included in the model and may capture time-invariant characteristics such as a perceived quality advantage or stronger brand recognition. If both firms are pooled in a single regression without controlling for these fixed differences, the firm-specific component will be absorbed into the error term, potentially biasing the estimated coefficients.[98]

[98] Whether the omission of fixed effects biases the cartel coefficient depends on whether time-invariant unit-specific price differences are correlated with the cartel dummy. If all firms are observed throughout the entire sample period, including both the infringement and the comparison periods, a time-invariant price premium does not necessarily bias the cartel coefficient, since it affects prices equally in all periods and is thus not correlated with the cartel period. However, even in this case a bias can arise if the composition of observed units changes over time in a way that is correlated with the cartel period, for instance because a firm entered or exited the market, or because certain products are only sold seasonally. If units observed during the cartel period systematically differ in their price level from units observed outside it, failing to control for these differences will cause the cartel coefficient to partially capture compositional rather than cartel-induced price changes. This is discussed further in the context of composition effects in section 3.3.1.4.

Firm fixed effects can be used to address this by including a separate intercept for each firm in the regression. The firm fixed effects absorb all time-invariant, firm specific differences in price levels, leaving only within-firm variation over time to identify the coefficients. The regression model with firm fixed effects is:

$$ln(Price_{it}) = \beta_1 * Cartel\ period_t + \beta_2 * ln(Costs_{it}) + \beta_3 * Temperature_t + \mu_i + \epsilon_{it}$$

The subscript i denotes the firm and t the week. The term μ_i represents the firm fixed effect, which captures all time-constant, firm-specific influences on prices, such as persistent differences in product quality or brand positioning, that are not explicitly included as control variables. Unlike the standard regression model introduced in the sections above, this specification does not include a common intercept β_0. Instead, the firm fixed effect plays the role of a firm-specific intercept that replaces the single common intercept of the pooled model. Prices and costs are now firm-specific in each period as indicated by the double subscript. The cartel dummy and temperature are only indexed by the time subscript because both are the same for all firms in any given week.[99]

Table 6 reports four regressions. Columns (I) and (II) estimate the baseline regression model separately for each firm. Column (III) pools both firms without firm fixed effects. Column (IV) estimates the regression for both firms as well, but includes firm fixed effects.

[99] This holds true only for the stylised example, in which the dataset is generated with a common temperature variable for all firms. As temperature is used as a proxy variable for demand, it is assumed that changes in demand are equal for both firms. In practice, it could be possible that temperature (or demand) varies for each firm at different points in time. In that case, firm-specific data on temperature should be used and a firm-specific subscript i should be added to the regression model.

Table 6: Time-series regression results: Separate, pooled, and pooled with firm fixed effects

Variables	(I)	(II)	(III)	(IV)
	Firm A	Firm B	Firm A & B	Firm A & B (FE)
Cartel period	0.093***	0.096***	0.084***	0.095***
	(0.003)	(0.003)	(0.011)	(0.002)
Ln(Costs)	0.253***	0.253***	0.322***	0.253***
	(0.006)	(0.006)	(0.020)	(0.004)
Temperature	0.002***	0.002***	0.002***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	-0.502***	-0.327***	-0.305***	-0.504***
	(0.010)	(0.009)	(0.034)	(0.007)
Observations	156	156	312	312
Adjusted R-squared	0.965	0.968	0.575	0.984
Firm fixed effects	No	No	No	Yes

Note: Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Own estimation.

Columns (I) and (II) yield cartel coefficients of 0.093 and 0.096 respectively, corresponding to estimated overcharges of approximately 9.7 percent and 10.1 percent, both close to the true overcharge of 10 percent. Column (III), the pooled regression without fixed effects, produces a coefficient of 0.084, equivalent to approximately 8.8 percent. The underestimation reflects the fact that the persistent price premium of Firm B, which is unrelated to the cartel, introduces noise that attenuates the cartel effect. The adjusted R-squared is markedly lower than in the single-firm regressions, confirming that a substantial portion of price variation remains unexplained by the regression model. Column (IV), adding firm fixed effects, recovers a cartel coefficient of 0.095, approximately 10 percent, and raises the adjusted R-squared to 98.4 percent. By absorbing the time-invariant firm level price premium, the fixed effects model restored the precision of the estimate while exploiting the additional statistical power of the pooled dataset.[100]

In this example, firm fixed effects were used to control for time-invariant differences in price levels across firms. In practice, the relevant unit for which fixed effects should be included depends on the structure of the data and the market. Fixed effects, for instance, can be applied at the level of individual products, customers, distribution channels, or

100 It is worth noting that Columns (I) and (II) are equally valid estimations of the cartel effect for each respective firm than the estimate of column (IV). Column (IV) is nevertheless the more efficient specification overall: by pooling both firms, it uses 312 rather than 156 observations to estimate the coefficients on the control variables, which reduces their standard errors and makes the overall model more reliable. As price variation unrelated to the cartel is estimated more precisely in Column (IV), also the estimation of the cartel effect is more precise which can be seen in the lower standard error.

geographic regions, depending on which unit drives the systematic price variation that is unrelated to the infringement. In some cases, multiple fixed effects are combined, for instance, customer fixed effects and production facility fixed effects to account for time-invariant price differences that are due to differences in delivery distance. Which fixed effects are appropriate in a given case is not a purely statistical question. It depends on the market theory developed in section 3.1.2 since understanding the competitive determinants of prices in a relevant market is a prerequisite for identifying which sources of systematic price variation must be controlled for and at what level of aggregation.

Heterogeneous cartel effects

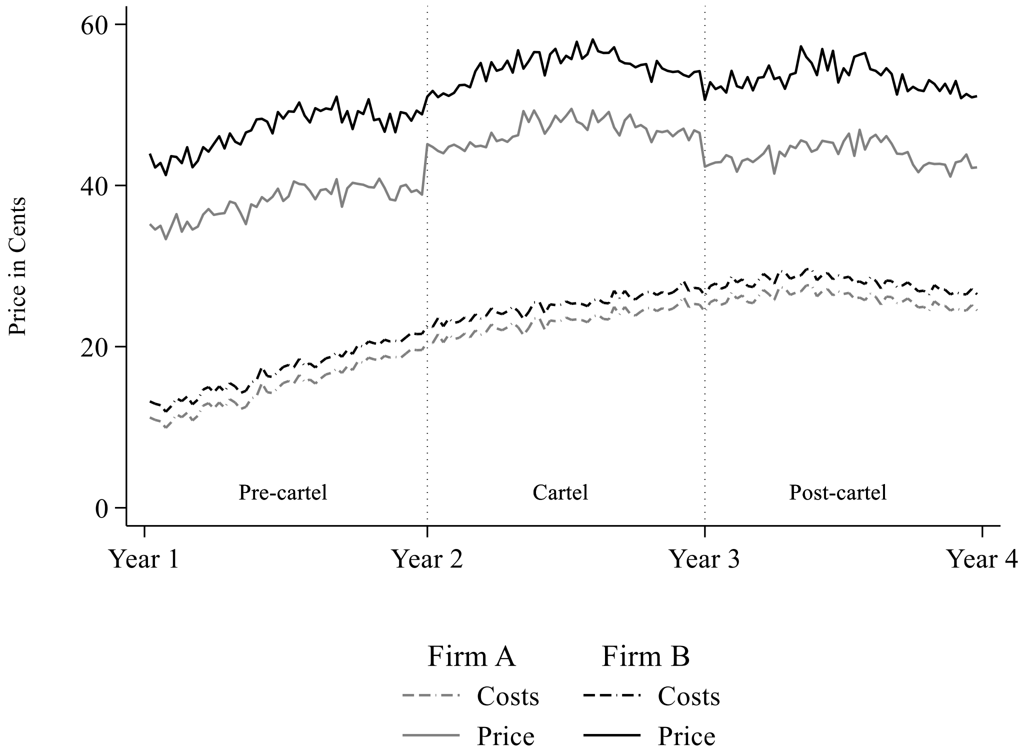
The regressions above assume that the cartel effect is the same for all firms included in the estimation. This assumed homogeneity is appropriate when the infringement operated symmetrically across all cartelists. In many cases, however, the theory of harm suggests that the cartel overcharge may have differed across firms, products, or customer groups. This may occur, for example, where the cartel did not fix prices uniformly but allocated markets geographically or by product, or where participating firms had different starting prices such that a common pricing agreement implied different percentage effects.[101]

The case study is thus adapted to illustrate this scenario. The firms no longer agreed on a uniform price increase. Instead, they divided the market geographically. Firm A supplied only the south and Firm B only the north, allowing each to act as a regional monopolist. Firm A raised prices by 10 percent during the cartel period. Firm B, whose pre-cartel prices were already at a higher level, raised prices by only 5 percent.[102] Figure 11 below shows the resulting price developments.

[101] Whether the cartel effect is homogeneous or heterogeneous across firms, products, or customer groups, is itself an empirical question that should be guided by the theory of harm (see section 3.1.3). A market-sharing cartel will almost by definition produce heterogeneous overcharges across market segments, whereas a straightforward price-fixing agreement may produce more uniform effects. In either case, the structure of the estimation model must be consistent with the economic theory of how the infringement operated.

[102] The fact that both firms in this scenario realise different price overcharges, results from the fact that each firm sets its prices independently from the other firm. As monopolists in each region, they set prices only in regard to region-specific costs and demand. See Maier-Rigaud and Schwalbe (2023a) for a detailed analysis.

Figure 11: Weekly prices and costs for Firm A and Firm B in the bottled water case study under heterogeneous cartel effects



Source: Own illustration.

If both firms are pooled in a single regression with a common cartel dummy, the estimated coefficient will be a (weighted) average of the two firm-specific effects, which does not accurately represent the overcharge of either firm. Two approaches are available to allow for heterogeneous effects. First is to estimate the cartel effect separately for each firm using individual regressions. The second is to include interaction terms in the pooled regression in order to estimate individual cartel effects for each firm. An interaction term is the product of two variables, here the cartel dummy and a firm indicator.[103] The interaction term ($Cartel\ period_t * Firm\ A$) takes on a value of one for all observations of Firm A during the cartel period and zero otherwise;

[103] Where heterogeneity in cartel effects cannot or should not be fully resolved through interaction terms or sample splits, for instance because the data structure does not allow for sufficiently precise unit-specific estimates or because the analysis aims at an aggregate measure of harm, the choice of weighting scheme determines how the individual effects contribute to the estimated average. See section 3.3.1.4 for a discussion of weighting in this context.

$(Cartel\ period_t * Firm\ B)$ operates analogously for Firm B.[104] The regression model with interaction terms is:

$$ln(Price_{it}) = \beta_1 * (Cartel\ period_t * Firm\ A) + \beta_2 * (Cartel\ period_t * Firm\ B) + \beta_3 * ln(Costs_{it}) + \beta_4 * Temperature_t + \mu_i + \epsilon_{it}$$

The model includes two cartel coefficients, β_1 for Firm A and β_2 for Firm B. The coefficients on costs and temperature remain common across firms because the effect of these variables on prices is assumed to be the same for both. Firm fixed effects are retained to control for the persistent price level difference between the two firms.[105] Table 7 below reports the regression results across four specifications. Columns (I) and (II) show the results, if the regression is run for each firm separately. Column (III) pools both firms without controlling for heterogeneous cartel effects. Column (IV) pools both firms and allows for heterogeneous cartel effects using interaction terms.

104 Instead of including an interaction term for each firm as described above, an alternative way would be to include the (non-interacted) cartel dummy as well as the interaction term of the cartel dummy with a firm dummy for only one firm, for instance for Firm B. In this case, the coefficient of the (non-interacted) cartel dummy estimates the price overcharge for the firm for which no interaction term is included, i.e. the reference group, Firm A. The coefficient of the interaction term, however, estimates the difference between Firm B's cartel overcharge and the coefficient of the (non-interacted) cartel dummy. The cartel overcharge for Firm B in this case is given by the sum of both coefficients. Both approaches typically yield equivalent results. However, if the data are imprecise and standard errors are large, separate tests may suffer from low statistical power, so that multiple marginally non-significant results can arise even when a direct interaction-based specification would detect a significant effect. Such a scenario may occur when Firm B is exposed to a cartel effect while Firm A is not. In a specification that includes a non-interacted cartel dummy together with an interaction term for Firm B, both coefficients may appear insignificant. In contrast, a specification that directly models firm-specific cartel effects via separate interaction terms may correctly identify a significant effect for Firm B. The underlying reason is that splitting the effect across multiple parameters increases the burden of statistical inference, as significance must be established jointly across several estimated coefficients.

105 In this scenario, including both interaction terms in a model with firm fixed effects is equivalent to estimating the cartel effect separately for each firm, while using the pooled dataset for the estimation of the coefficients on control variables. If the effect of control variables on different firms is assumed to be heterogeneous as well, the estimation should be adapted accordingly, for instance, by using separate regression models for each firm or by adding additional interaction terms for control variables.

Table 7: Time-series regression results with and without interaction terms

Variables	(I)	(II)	(III)	(IV)
	Firm A	Firm B	Firm A & B	Firm A & B
Cartel period	0.093***	0.050***	0.071***	
	(0.003)	(0.003)	(0.003)	
Cartel period * Firm A				0.093***
				(0.003)
Cartel period * Firm B				0.050***
				(0.003)
Ln(Costs)	0.253***	0.253***	0.254***	0.253***
	(0.006)	(0.006)	(0.005)	(0.004)
Temperature	0.002***	0.002***	0.002***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	-0.502***	-0.327***	-0.495***	-0.504***
	(0.010)	(0.009)	(0.008)	(0.007)
Observations	156	156	312	312
Adjusted R-squared	0.965	0.956	0.976	0.982
Firm fixed effects	No	No	Yes	Yes

Note: *Standard errors in parentheses.* $^{***} p < 0.01$, $^{**} p < 0.05$, $^{*} p < 0.1$.
Source: *Own estimation.*

Columns (I) and (II) estimate the model separately for each firm, yielding cartel coefficients of 0.093 and 0.050, corresponding to estimated overcharges of approximately 9.7 percent and 5.1 percent respectively, holding all else constant. Both are close to the true effects. Column (III) pools both firms with firm fixed effects but uses a single common cartel dummy. The estimated coefficient of 0.071, approximately 7.4 percent, is an average of the two firm-specific effects and does not correctly describe the overcharge for either firm as it fundamentally mismatches the true economic effect of the cartel on prices of both firms. Column (IV) introduces the firm specific interaction terms. The resulting coefficients of 0.093 and 0.050 closely reproduce separately estimated effects while using the full pooled dataset, which yields higher statistical power as reflected in the higher adjusted R-squared.[106]

This example again illustrates the importance of the theory of harm. Whether the cartel effect is expected to be homogeneous or heterogeneous across firms or market segments is a question that cannot be answered by statistical testing alone. It requires an economic understanding of how the infringement operated and how competitive pricing would have differed across relevant units. A model that imposes homogeneity

[106] The interaction-term specification in column (IV) and the separately estimated models in columns (I) and (II) do not yield mathematically identical coefficients, because in the interaction specification the control variables are estimated jointly across both firms rather than separately by firm. The coefficients appear identical in the table only because they are rounded to three decimal places. In practice, where effect heterogeneity is suspected, running both separately estimated and interacted specifications and comparing the results is a useful robustness exercise (see section 3.3.1.4).

when the true effects are heterogeneous will produce estimates that are neither informative nor reliable for any particular claimant.[107]

3.3.1.3. Difference-in-differences

The difference-in-differences method is applied when data from a comparable market that was not affected by the infringement is available for both the infringement period and at least one comparison period. It combines the temporal variation used in the before-and-after approach with a cross-sectional comparison between an affected and an unaffected market. The cartel effect is identified from the difference between the price change over time in the cartel market and the corresponding price change over time in the comparator market.[108] Where the conditions for a reliable time-based comparison are not met, the difference-in-differences method may provide a valid alternative provided a suitable comparator market is available.[109] Where both a time-based comparison and a difference-in-differences analysis are in principle feasible, difference-in-differences is generally the preferred approach, as it is less reliant on the assumption that all relevant price determinants can be explicitly measured and included as control variables.[110]

The underlying logic of the difference-in-differences approach is most easily illustrated with a simple numerical example, as shown in Table 8. Suppose that the average price in the cartel during the infringement period is 40 cents and falls to 30 cents after the cartel ends, a difference over time of 10 cents. In the comparator market, prices move from 35 cents to 29 cents over the same period in time, a difference of 6 cents. If the parallel trend assumption holds, this 6-cent change in prices of the comparator market represents the price development that would also have occurred in the cartel market absent the infringement. The cartel effect is then estimated as the difference between the two time-differences, 10 cents minus 6 cents, yielding 4 cents. Equivalently, the

[107] Note that the question of homogeneous vs. heterogeneous effects does not only apply to the cartel effect. It could, for instance be the case, that the effect of temperature on demand and thus on prices is different for each firm. A regression model that assumes a homogeneous effect of temperature will not be able to correctly control for firm-specific price variation induced by changes in temperature and may thus yield biased results for the cartel coefficient. In this case, an interaction term of the firm indicator and temperature can be added to control for heterogeneous effects of temperature on prices.

[108] See Maier-Rigaud and Sudaric (2019).

[109] Conditions that undermine the reliability of a pure time-based comparison include cases where the pre- or post-infringement period is too short to obtain precise estimates of the competitive price level, where compositional changes in the underlying products, customers, or other relevant dimensions coincide with the cartel period, or where structural breaks in the data are correlated with the infringement period.

[110] In case where several different estimation approaches are feasible, it is generally advised to conduct multiple estimation approaches to test the robustness of the estimation. See section 3.3.1.4 for the importance of robustness checks.

cartel effect can be obtained as the difference between the cartel-comparator price gap in the two periods, 5 cents minus 1 cent, again yielding 4 cents.

Table 8: Stylised illustration of the difference-in-differences principle[111]

	Cartel period	Post-cartel period	*Difference over time*
Cartel market	40 cents	30 cents	*10 cents*
Comparator market	35 cents	29 cents	*6 cents*
Difference over markets	*5 cents*	*1 cent*	***4 cents***

Source: Own calculations.

This simple numerical example already reveals the advantage of the difference-in-differences approach relative to a pure time-based comparison. A naive comparison over time (without any control variables) would have attributed the entire 10 cents change to the infringement. By subtracting the 6 cents price change observed in the comparator market, the difference-in-differences approach controls for market-wide developments that affected both markets simultaneously, such as common cost trends or demand shocks, and thereby isolates the component of the price change that is due to the cartel market, without requiring control variables.

For this logic to yield valid results, two conditions must be satisfied. First, prices in the comparator market must be independent of the infringement ('independence assumption'). They must be set without reference to the pricing decisions of the cartelists, and the market must not have been affected by the cartel through any indirect channel.[112] Second, the 'parallel trend assumption' must hold. The assumption posits that in the absence of the cartel, prices in the cartelised market and in the comparator market are driven by similar dynamics over time. This does not require that prices in both markets are equal in levels. It requires only that pre-existing price level differences

111 In this example, the cartel period is compared with the post-cartel period. This is only an example, in a difference-in-differences model, also use the pre-cartel period or pre- and post-cartel period can be used to observe price changes over time.

112 A violation of the independence assumption may also arise through umbrella effects. If prices in the comparator market were elevated because firms there reacted to the cartel by raising their own prices, the comparator is itself contaminated. See section 3.4 on the quantification of umbrella effects.

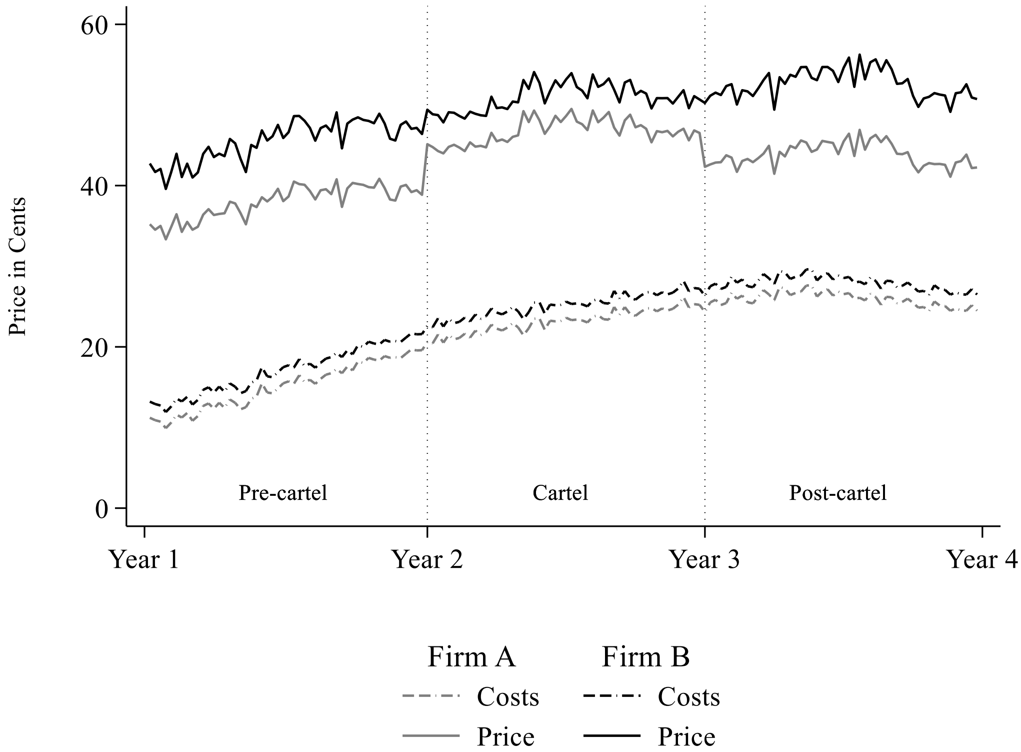
between the markets are time-invariant, so that the comparator market provides a valid guide to the counterfactual price trend in the cartelised market.[113]

To illustrate the difference-in-differences approach in the context of regression analysis, the bottled water case study introduced in section 3.3.1.1 is adapted accordingly. As before, two firms, Firm A and Firm B, are observed over three years. Unlike in the panel data application in section 3.3.1.2, however, the two firms are now assumed to operate in separate geographic markets and not to compete with each other. While Firm A sells in Market A and Firm B sells in Market B, prices in Market B are assumed to be set independently of pricing decisions in Market A. A cartel operated in Market A during year 2, raising prices by 10 percent above the competitive level. Firm B in Market B was not affected by the cartel and therefore serves as a comparator market for Market A with Firm A.[114] As before, Firm B has a somewhat higher cost level and charges prices at a persistently higher level. The effect of cost and temperature changes on prices is the same for both firms, satisfying the parallel trend assumption. Figure 12 shows the price and cost developments for both firms.

[113] Since counterfactual prices are unobservable by definition, the assumption cannot be tested directly. The plausibility of this assumption must be derived using market theory on price setting in both markets (see section 3.1.2). Additionally, empirical pre-trend tests in non-cartelised markets provide supporting evidence but do not constitute proof. See Angrist and Pischke (2009) for further details.

[114] In practice, finding a suitable comparator market is often the most demanding step in a difference-in-differences analysis. The requirement that the market must not have been affected by the infringement and must exhibit comparable price dynamics is frequently difficult to satisfy simultaneously. Markets that are structurally similar may face similar incentives to cartelise, while markets that are clearly unaffected may differ too much in their competitive dynamics to serve as a reliable counterfactual.

Figure 12: Weekly prices and costs for Firm A (cartel market) and Firm B (comparator market) in the bottled water case study



Source: Own illustration.

The figure shows that prices in both markets follow broadly similar trends throughout the observation period. During year 2, however, there is a visible divergence as prices for Firm A rise above their pre-cartel trajectory while prices of Firm B continue to follow the common pre-trend. After the cartel ends, prices of Firm A return to their pre-cartel level relative to Firm B. This pattern is consistent with a temporary cartel-induced price increase in Market A.

In a regression framework, the difference-in-differences approach requires three variables. The first is a time dummy variable indicating the cartel period, which takes the value of one for all observations in year 2 and zero otherwise. It captures general time-related price changes between periods that are common to both markets. The second is a dummy variable indicating the cartel market, which takes the value of one for every price observation of Firm A and zero for every observation of Firm B.[115] It

[115] In this example with only one firm per market, the cartel market dummy is equivalent to a firm fixed effect for Firm A. Where the dataset contains multiple price series per market, the variable captures the time-invariant average price difference between markets. If unit fixed effects (here firm fixed effects) are included in the regression, they already absorb this market-level-difference and the cartel market dummy becomes redundant and should be excluded to avoid multicollinearity.

captures the time-invariant price level difference between the two markets. The third variable is the interaction term of the two dummy variables. It takes the value of one for all observations of Firm A during the cartel period and zero otherwise. Its coefficient is the difference-in-differences estimator of the cartel effect and captures the additional price change in the cartel market relative to the control market over time. The regression model is:

$$ln(Price_{it}) = \beta_0 + \beta_1 * (Cartel\ period_t * Cartel\ market_i) + \beta_2 * Cartel\ period_t + \beta_3 * Cartel\ market_i + \epsilon_{it}$$

Table 9 below shows the regression results. The coefficient of the interaction term is 0.095, corresponding to an estimated overcharge of approximately 9.9 percent, which is very close to the true overcharge of 10 percent. The cartel period coefficient of 0.041 reflects the common upward pricing trend during year 2 that affected both markets simultaneously, driven by rising costs and seasonal demand patterns. The cartel market coefficient of -0.182 captures the time-invariant price level difference between the two markets. Prices of Firm A are on average approximately 17 percent lower than those of Firm B throughout the entire observation period.

Table 9: Simple difference-in-differences regression without further control variables

Variables	
Cartel period * Cartel market	0.095***
	(0.017)
Cartel market	-0.182***
	(0.010)
Cartel period	0.041***
	(0.012)
Constant	-0.715***
	(0.007)
Observations	312
Adjusted R-squared	0.602

Note: *Standard errors in parentheses.* *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: *Own estimation.*

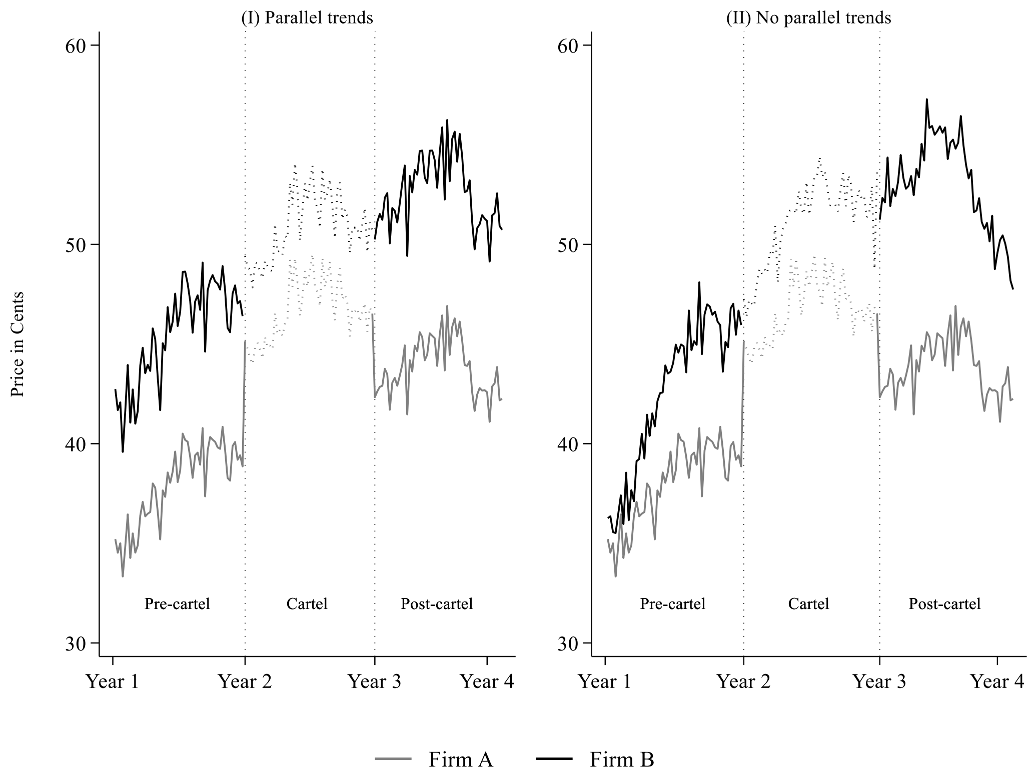
This result illustrates the key advantage of the difference-in-differences approach. The cartel effect is estimated correctly without including any control variables for costs and temperature. Because both markets are subject to the same cost and demand developments, these factors are differenced out through the comparator market. As long as the identifying assumptions hold, a difference-in-differences estimator does not require the analyst to specify and measure all relevant price determinants explicitly. For this reason, the difference-in-differences approach is often considered the gold standard among comparator-based methods for price overcharge estimation.

For this approach to yield valid results, the parallel trend assumption must hold. As it cannot be tested directly, its plausibility must therefore be assessed on two levels. At the theoretical level, economic theory must support the claim that the relevant price determinants operate in a comparable way across both markets, such that prices would have developed similarly absent the infringement. At empirical level, price developments in both markets during periods that are not affected by the cartel, that is before and after the infringement, can be examined to assess whether the two markets tracked each other closely.[116]

Figure 13 illustrates the assessment of pre- and post-cartel price trends using two stylised scenarios in the bottled water case study. Although such visualisation only has an indicative nature, Panel (I) shows a case in which the parallel trend assumption is plausible. Prices of Firm A and Firm B move closely together in pre- and post-cartel periods. During the cartel period, prices of Firm A diverge visibly from those of Firm B before converging again after the cartel ends. Panel (II) shows a case in which the assumption is not plausible in the raw data. Even in the pre-cartel period, prices of the two firms follow clearly different trajectories. Using Firm B as a comparator in this setting would yield a biased estimate, as the difference in price trends would be incorrectly attributed to the cartel.

[116] Testing for pre-trends is a standard robustness check in difference-in-differences applications. The most common implementation is to introduce interaction terms between the cartel market dummy and dummies for individual pre-cartel time periods and to test jointly whether their coefficients are statistically different from zero. The absence of significantly different pre-trends supports the plausibility of the parallel trend assumption but does not prove it holds for the cartel period itself. See Angrist and Pischke (2009) for further details.

Figure 13: Parallel price trends (I) and absence of parallel price trends (II) in pre- and post-cartel periods

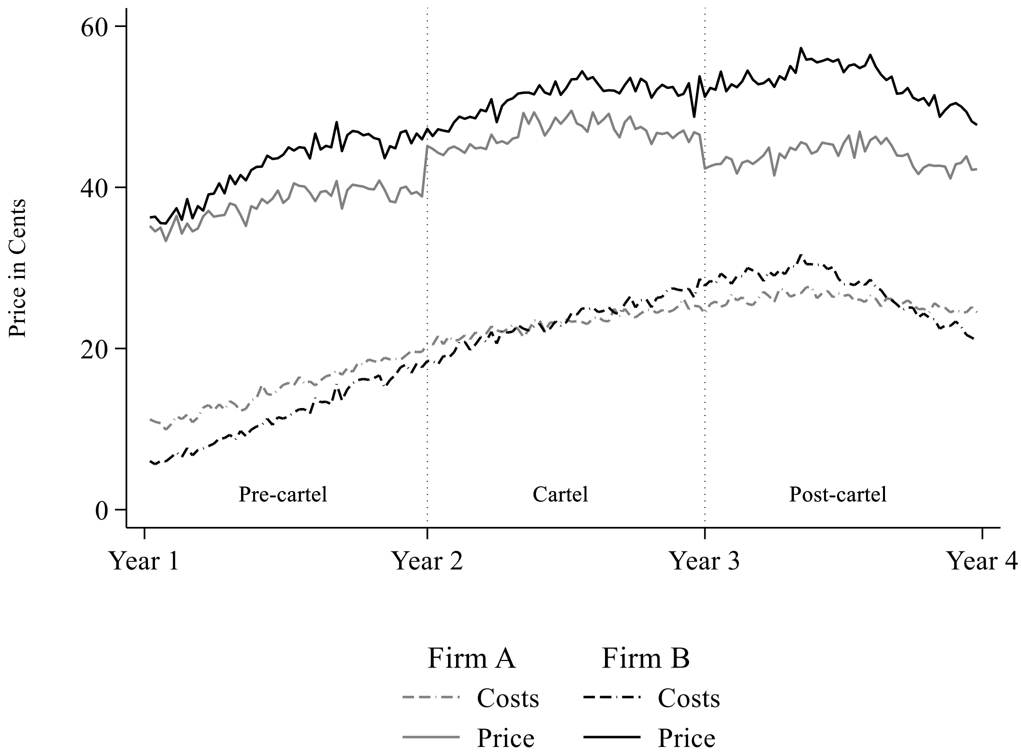


Source: Own illustration.

When the parallel trends assumption does not hold in the raw price data, it may still hold conditionally, that is, after controlling for observable variables that account for differences in price developments across markets. If economic theory identifies specific factors that caused the price development of the comparator market to diverge from that of the cartelised market, and if reliable data for those factors are available, including them as control variables in the difference-in-differences regression can restore the validity of the approach.

To illustrate this, the bottled water case study is modified so that the costs of Firm B follow a different trajectory than those of Firm A. Both firms continue to set prices in the same way and respond identically to cost and temperature changes. The infringement remains the same: Firm A raised prices by 10 percent in year 2. However, only because costs developed differently across the two firms, their prices no longer evolve in parallel even outside the cartel period. Figure 14 shows the price and cost developments in this modified scenario.

Figure 14: Weekly prices and costs for Firm A (cartel market) and Firm B (comparator market) in the bottled water case study with differing cost developments



Source: Own illustration.

The divergence in cost developments produces a visible difference in price trends between the two firms, most notably in the pre- and post-cartel periods. A simple visual inspection of the price series would lead one to conclude that the parallel trend assumption is violated, and that Firm B cannot serve as a valid comparator for Firm A. However, the underlying economic structure of both markets is identical. Prices react to changes in costs and temperature in the same way in both markets. The difference in price trends is entirely explained by the difference in cost developments. Once costs are controlled for, the remaining price dynamics are comparable across firms, and the conditional parallel trend assumption holds.[117]

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117 The conditional parallel trends assumption requires that, after controlling for the included explanatory variables, the remaining price dynamics in the cartel and comparator markets would have evolved in parallel absent the infringement. This is a weaker requirement than unconditional parallel trends and is more likely to hold in practice when the observable difference in market conditions can be fully captured by the control variables. In practice, this assumption would typically be assessed empirically, for example by analysing pre- and post-cartel trends via an event study controlling for different price determinants. A detailed discussion of such tests is beyond the scope of this paper. See Angrist and Pischke (2009) for further details.

Including costs as a control variable in the difference-in-differences regression addresses this problem directly. The augmented model is:

$$ln(Price_{it}) = \beta_0 + \beta_1 * (Cartel\ period_t * Cartel\ market_i) + \beta_2 * Cartel\ period_t + \beta_3 * Cartel\ market_i + \beta_4 * ln(Costs_{it}) + \epsilon_{it}$$

Table 10 reports the results for two specifications. Column (I) estimates the simple difference-in-differences without cost controls and Column (II) adds log-transformed costs as a control variable.

Table 10: Difference-in-differences regression without and with cost controls

Variables	(I)	(II)
	No controls	Costs control
Cartel period * Cartel market	0.060***	0.093***
	(0.023)	(0.006)
Cartel market	-0.153***	-0.182***
	(0.013)	(0.004)
Cartel period	0.076***	0.000
	(0.016)	(0.005)
Ln(Costs)		0.256***
		(0.004)
Constant	-0.745***	-0.298***
	(0.009)	(0.008)
Observations	312	312
Adjusted R-squared	0.444	0.957

Note: *Standard errors in parentheses.* $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.
Source: *Own estimation.*

Without cost controls, Column (I) reports a cartel coefficient of 0.060, corresponding to an estimated overcharge of approximately 6.2 percent. This is a substantial underestimate of the true overcharge of 10 percent, reflecting the fact that the differing cost developments introduce a spurious downward trend in the price difference between the two markets that is incorrectly attributed to the cartel effect. Column (II) controls for firm-specific costs. The estimated cartel coefficient rises to 0.093, corresponding to an estimated overcharge of approximately 9.7 percent, which closely matches the true cartel effect of 10 percent. By accounting for the divergent cost developments, the regression recovers the conditional parallel trends and yields an unbiased estimate.

This example demonstrates that the use of control variables is not restricted to the time-based comparison method but can also be brought to bear in a difference-in-differences approach. The gold standard properties of the difference-in-differences approach as described above apply unconditionally when the parallel trends assumption holds in the raw data, that is, when the observed price trends in the affected and the comparator market would have evolved in parallel absent the infringement, without any further adjustments. When the assumption does not hold in the raw data, for instance because the two markets are exposed to systematically different demand or cost developments, control variables can be introduced to restore the identifying assumption, in the same way and subject to the same criteria as in the time-based approach. The theory-guided selection of relevant and exogenous control variables remains essential.

Furthermore, all considerations regarding the functional form, fixed effects, and heterogeneous effects discussed in the context of time-based comparison in section 3.3.1.2 apply equally to the difference-in-differences approach.

One feature that is typically more relevant in the difference-in-differences setting, is the possibility of including time fixed effects. Time fixed effects are dummy variables for individual time periods, for instance weeks or years, that capture price changes common to all observed units in a given period, regardless of whether they are in the cartel or in the comparator market.[118] They control for aggregate external shocks such as sudden input price increases or economy-wide demand fluctuations, that affect both markets simultaneously and that are not captured by the included control variables.[119]

3.3.1.4. Further practical aspects

The preceding subsections outlined the most important econometric approaches to estimating price overcharges, illustrating each method with a case study based on simulated data featuring a particularly favourable data structure and straightforward modelling choices. In practice, empirical analyses rarely proceed without complications. Datasets are incomplete, control variables are imperfectly measured or not observed, the timing of the infringement is uncertain, and the observed price data may reflect changes in market composition rather than changes in underlying prices. This subsection briefly addresses the most important practical issues that arise when implementing the methods described above and discusses approaches to handle them.

---

[118] In principle, time fixed effects, can also be used in time-based comparison. A particular concern when using time fixed effects in a time-series context, however, is that they may absorb parts of the cartel effect if all observed price series are affected by the infringement. In a difference-in-differences setting, this risk is substantially reduced because the comparator market provides observations that are unaffected by the cartel throughout the observation period.

[119] In the present case study with only two price series, one per market, time fixed effects add little explanatory power because common shocks are already absorbed by the cartel period dummy. Their value increases substantially when the dataset contains many price series across multiple markets, since time fixed effects then control for aggregate developments that cannot be attributed to any single market.

In summary, it further illustrates the importance of robustness checks for empirical analyses.

Selection of control variables

As shown in the time-based comparison examples in section 3.3.1.2, failing to include relevant control variables leads to omitted variable bias. The cartel coefficient then captures not only the cartel effect but also the influence of the omitted price determinants that happen to be correlated with the cartel period.[120] In the case study, the relevant price determinants, costs and temperature, were known by construction. In practice, identifying the correct control variables is often one of the most contested aspects of the empirical analysis. While the fundamental criteria that guide the selection of control variables are described in section 3.3.1.1, some important aspects and caveats, that is data availability, endogeneity, and multicollinearity, are further discussed below.

Data for the ideal control variables are frequently unavailable. Hence, publicly available cost indices are often used as proxies for firm-specific production costs, demand indicators such as population density or regional income levels substitute for the underlying factors driving demand, and weather from the nearest available weather station proxies for local temperature. The use of proxies introduces measurement error[121], which can attenuate estimated coefficients and, if the measurement error is systematically related to the cartel period, may bias the cartel coefficient. Where several data sources are available for the same underlying concept, the choice among them should be guided by economic theory and supported by robustness checks using alternative data sources.[122]

More generally, systematic measurement error constitutes one potential source of endogeneity. Endogeneity arises when an explanatory variable is correlated with the error term of the regression. In this case, the coefficient on that variable cannot be given a causal interpretation and the estimates of all other coefficients, including the cartel coefficient, may be biased and inconsistent.

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120 In a difference-in-differences context, control variables are often less relevant because common price trends across markets are differenced out. They may, however, be needed to validate the conditional parallel trends assumption, as discussed in previous section 3.3.1.3.

121 In econometrics, measurement error means that the observed variable differs from the true variable. This discrepancy may arise from random noise, systematic bias or both. Thus, measurement error does not necessarily imply that a variable is 'measured incorrectly' in a colloquial sense, but rather that the observed measure is an imperfect realisation of the underlying true value.

122 See section 3.3.1.4 for the importance of robustness checks in empirical analyses.

One important source of endogeneity is simultaneity. Consider using the quantity of bottled water sold as a proxy for demand. In a simultaneous market equilibrium, prices and quantities are jointly determined, such that quantity is endogenous to the price equation. The two variables move together as part of the same economic mechanism and cannot be varied independently. Including quantity as a control variable in a price regression therefore raises a fundamental problem. The *ceteris paribus* condition requires that the coefficient on the cartel dummy can be interpreted as the price effect of the cartel holding all other included variables constant. Holding quantity constant while the cartel dummy changes implicitly asks what the price would be if the cartel became active while the quantity remained unchanged, which is generally not consistent with a competitive market equilibrium. A cartel-induced price increase would typically entail demand responses. Moreover, conditioning on quantity, when quantity is jointly determined with price, implies conditioning on an endogenous outcome. As a result, the regression may eclipse part of the cartel's effect on market outcomes, rather than isolating the total price effect of the cartel.

An endogeneity problem arises because price and quantity are jointly determined in equilibrium, implying that quantity is correlated with unobserved determinants of prices captured in the error term. This violates the exogeneity assumption required for unbiased estimates. A consistent approach is to use an exogenous proxy for demand, that is, a variable that shifts demand independently of price. In the bottled water case study, temperature serves this purpose, as it affects consumer demand but is not influenced by pricing decisions. If no exogenous proxy is available, instrumental variable estimation provides a solution.[123]

Apart from endogeneity as described above, multicollinearity constitutes a further potential problem when specifying the regression and selecting control variables as suggested by economic theory. Multicollinearity arises when two or more explanatory variables are highly correlated with each other. It does not cause bias in the estimated coefficients, provided the regressors are exogenous, but it inflates their standard errors, reducing statistical precision and making it difficult to separately identify the effects of (highly) correlated explanatory variables. In the extreme case of perfect

[123] Instrumental variables estimation addresses endogeneity by exploiting an instrument, i.e. a variable that is correlated with the endogenous variable but affects the dependent variable only through it, and not directly. In the bottled water case study, a variable measuring the availability of filling water, for instance, groundwater levels or precipitation amounts, could be used as an instrument for quantity since it affects the quantity of bottled water but is itself exogenous. The instrument is used to isolate exogenous variation in the endogenous variable, so that only this variation is used for estimation. Finding a valid instrument that satisfies both conditions in practice is often the main constraint, and a detailed treatment of instrumental variable estimation is beyond the scope of this paper. For further details, see Angrist and Pischke (2009).

multicollinearity, the regression cannot be estimated at all because the correlated variables themselves cannot be separately identified.

In the context of price overcharge estimation, a practically important case of multicollinearity arises when an included control variable itself is highly correlated with the infringement variable.[124] Suppose that production costs increased sharply at the exact moment a cartel began and declined again when it ended. In this case, the cartel dummy and the cost variable carry nearly identical information, and the regression cannot reliably distinguish the cartel's contribution to the price increase from the cost-driven contribution. The estimated cartel coefficient will be imprecise, with wide confidence intervals and low statistical significance, even if the true cartel effect is substantial. The presence and severity of multicollinearity can be assessed using the variance inflation factor.[125]

The typical remedies to multicollinearity are to increase the number of observations, for instance by extending the time series or adding further units to the dataset, or to switch to a difference-in-differences approach that uses a comparator market to provide an independent source of variation for the cost development. If neither is possible, the analysis may need to rely on indirect evidence and sensitivity analysis rather than a precisely estimated single coefficient.

Composition effects

In the bottled water case study examined above in sections 3.3.1.2 and 3.3.1.3, the price was given as a unit price for a single product for one or two firms. In practice, datasets may contain multiple products, customers and transaction types where the observed prices within the datasets reflect average prices across different units. Composition effects arise when an observed average price changes not because individual prices change but because the mix of observed units changes over time.

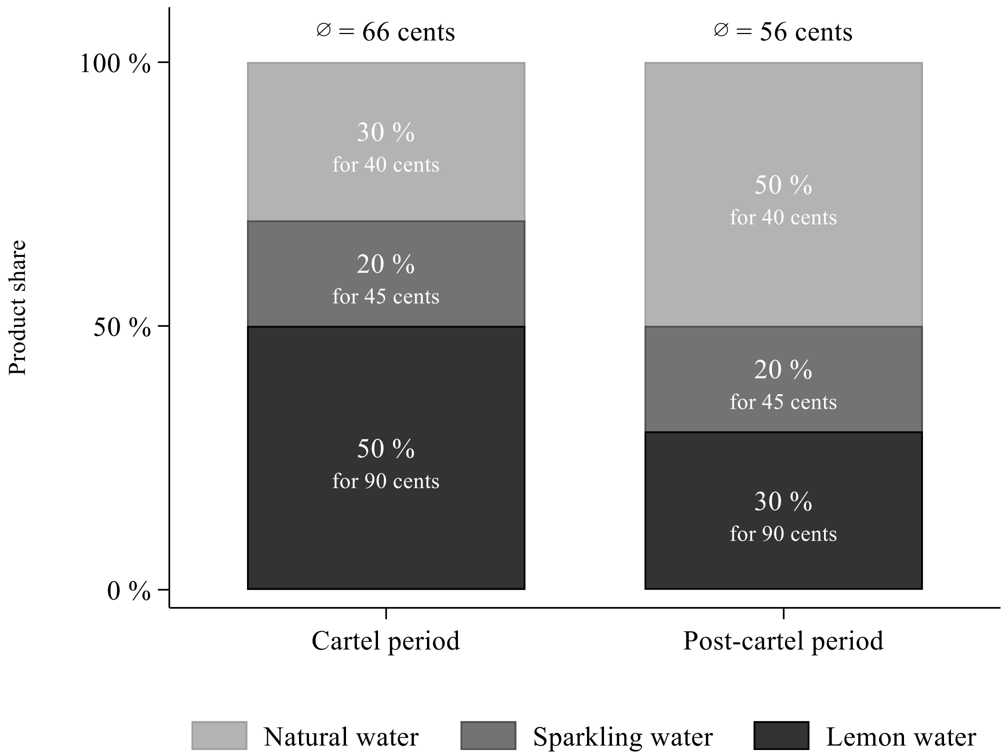
Consider, for instance, a modification of the bottled water case study, in which each firm not only sells one product, but three products: natural water, sparkling water and

[124] If multicollinearity exists only between control variables and does not extend to the cartel dummy, the estimation of the cartel coefficient is generally not affected. In this case, the individual contribution of each control variable to price variation cannot be precisely separated, but their joint contribution is correctly captured, which is sufficient to isolate the cartel effect. The problem described in the main text arises specifically when a control variable is itself highly correlated with the cartel dummy, in which case the multicollinearity directly impairs the precision of the cartel coefficient.

[125] The variance inflation factor (VIF) is the most widely used diagnostic for multicollinearity. It measures how much variance of an estimated coefficient is inflated due to correlation with other explanatory variables. A VIF above 10 is commonly taken as an indication of problematic multicollinearity, though this threshold is not a formal statistical rule (see Wooldridge, 2020).

lemon-flavoured water, with unit prices of 40 cents, 45 cents and 90 cents, respectively. These unit prices are assumed to be constant across all periods.[126] During the cartel period, the lemon-flavoured water accounts for 50 percent of all transactions, natural water for 30 percent and sparkling water for 20 percent. In the post-cartel period, the share of lemon-flavoured water falls to 30 percent while the share of natural water rises to 50 percent with sparkling water remaining at 20 percent. If only aggregated data on prices per firm are available, the weighted average price during the cartel period is 66 cents. In the post-cartel period, it falls to 56 cents. A naive comparison of mean prices across periods would suggest a cartel overcharge of 10 cents. In reality, no individual product price changed at all. The entire apparent price difference is an artefact of the shift in the product mix.[127] Figure 15 below illustrates that example.

Figure 15: Stylised illustration of composition effects with unchanged prices in a changing product mix



Source: Own illustration.

Composition effects can operate in either direction. If cheaper products become more prevalent during the cartel period, the average observed price will be lower than it

[126] For illustrative purposes, this assumption implies that the cartel was unable to impose a price increase.

[127] Although composition effects are illustrated here using a change in the product mix, the same problem can arise with other units of observations. If the composition of customers, transaction types, or geographic regions changes over time in a way that is correlated with the cartel period, similar biases can result.

would be with a stable product mix. This causes the regression to underestimate the true cartel effect. If more expensive products dominate during the cartel period, the average price will be artificially elevated, leading to an overestimate. In either case, attributing the change in average price to the cartel without accounting for compositional shifts produces a biased result.

The primary remedy is to work with disaggregated data at the unit level rather than with aggregated prices. If individual prices are available for each product separately, product fixed effects can be included in the regression to control for time-invariant price level differences across products.[128] This effectively compares each product with itself across periods, which removes the confounding influence of changes in the product mix. Where only aggregated data are available, it could be tried to only use data for which a constant composition is given. If this is not possible, it should at least be identified whether the composition changed around the cartel period and, if so, by how much. Controlling for product shares or category indicators is a partial remedy, though care must be taken that such variables are not themselves endogenous to the infringement.

Definition of the infringement period

The cartel dummy variable, for instance in a time-based comparison, identifies in which periods prices are expected to have been affected by the infringement. In the case study, the cartel period was given by construction. In practice, determining which periods to include in the cartel dummy can be a non-trivial modelling decision that has a direct effect on the estimated cartel coefficient.

The actual start date of a cartel is often uncertain. Competition authorities typically identify a period during which the infringement can be established on the basis of documentary evidence, but the economic effect of the cartel on prices may have begun earlier, for instance because firms started to coordinate their behaviour informally before the first documented agreement, or later, because price adjustments took time to be implemented.[129] If the cartel dummy starts too late, periods in which prices were already elevated are classified as part of the comparison period, which may understate

[128] Product-fixed effects control for time-invariant price level differences across products. They do not fully resolve composition effects when some products are observed only in certain periods, because within product comparison is then only possible for the subset of periods in which the product appears. If a product is sold exclusively during the cartel period and cannot be tracked into the comparison period, no within-product comparison is available and its price cannot contribute to the identification of the cartel effect.

[129] Statistical techniques, in particular structural-break tests and cartel-screening methods, can assist in identifying the start and end of the cartel period rather than relying solely on the dates established by the competition authority. See Harrington (2008) or Friederiszick and Maier-Rigaud (2007).

the overcharge. If it starts too early, periods without actual cartel influence are included in the treatment period, which may dilute the estimated effect.[130]

A related complication arises at the end of the cartel period, which is often referred to as the 'run-off' period. Post-cartel prices may not immediately reflect competitive conditions. Price can be downward rigid, particularly where long-term contracts lock in prices that were negotiated during the infringement period.[131] Cartelists may also retain informal coordination even after the formal agreement.[132] Whether such after effects are present in a given case is in the first instance a theoretical question that must be assessed on the basis of plausible economic mechanisms and case-specific evidence. If such after-effects are plausible, but not taken into account, the harm that occurs after the cartel period will be disregarded, and there is also a risk of underestimating the harm during the cartel period itself. The estimated overcharge will be downward biased in this case if the post-cartel period is part of the comparison group. As prices in the post-cartel period are due to after-effects still above the competitive levels, the counterfactual price is too high and thus the harm during the cartel period is underestimated. There are, however, methods available that avoid this problem. For example, when using a dummy variable for the cartel period, the cartel dummy gets a weight of one during the cartel period but is not immediately set to zero after this period but is instead only gradually reduced.[133] Another option would be to use separate dummy variables for the time periods after the cartel or a combination of both approaches. If after-effects arise because prices depend on their previous realisations, for instance through long-term contracts or menu costs, the speed of price adjustment can be estimated from price data within the cartel period itself. The reasoning is that the same adjustment mechanism delaying the return to competitive prices after the cartel ends also governs how prices responded to changes during the cartel, for instance to cost shocks. This lagged price adjustment is taken into account in a regression by letting the current price level depend to a greater or lesser extent on the past price level.[134]

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130 These considerations only affect the estimated overcharge, but of course there is also an effect if that overcharge is then applied to a larger or smaller volume of commerce.

131 See Inderst and Jakubovic (2012).

132 Some authors have also suggested that cartelists would have a strategic interest in maintaining high prices in order to ensure that the post-cartel period does not suggest a high mark-up that would be likely to be found if prices had substantially plummeted at the end of the cartel. See Harrington (2004).

133 See, e.g. Hüschelrath et al. (2012) for an application. The applied functional form of this reduction has to be assumed according to the facts of the individual case.

134 This can be estimated by first considering a model for the profit-maximising price which is then combined with a model that describes the price adjustment process. This price adjustment model can be interpreted in a way that only some firms adjust their prices and all other firms keep their prices unchanged. For details see Gujarati (2002).

A further challenge in defining the infringement period is that the breakdown of a cartel sometimes triggers a period of unusually aggressive competition and price wars, during which prices fall substantially below their long-run competitive level and therefore provide an unreliable benchmark.[135] Using such periods as a comparison benchmark would cause the counterfactual price to be underestimated and the overcharge to be overstated. Where there is evidence that the immediate post-cartel period was distorted in this way, excluding it from the comparison period is one possible remedy, although the appropriate length of such an exclusion is case-specific and should be justified on the basis of the available evidence.

The decision which periods are affected by the cartel and which periods remain unaffected and thus serve as a valid comparator should be guided by economic theory and supported by robustness checks using alternative definitions of the cartel dummy. A further remedy may be to explicitly exclude periods that are suspected to affect the estimates from the regression. In many applications, for instance, both the pre-cartel and the post-cartel period are used jointly as the comparison baseline, which increases the number of observations available for estimating the competitive price level and generally improves precision. This approach implicitly assumes that both periods are representative for competitive conditions. If there are specific reasons to doubt this for one of the two periods, it may be preferable to restrict the baseline regression to the period that can more reliably be treated as a competitive scenario.

In some cases, the timing of the cartel's price effects differs across firms, products, or regions. Firms may have joined or left the cartel at different points in time, or the impact of the pricing agreement may have materialised with different lags across market segments. A single common cartel dummy that applies uniformly to all units may then fail to capture the structure of the treatment, and the estimated average effect may not accurately represent the overcharge for any individual unit. Where the theory of harm and the available evidence suggest heterogeneous timing, unit specific cartel dummies or interaction terms between the cartel dummy and unit identifiers can be used to allow the treatment period and intensity to vary across units, in the same way as the heterogeneous cartel effects discussed in section 3.3.1.2.

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135 This type of price war probably occurred after the breakdown of the German cement cartel, meaning that the prices of this phase were weighted down in the estimation of harm. See, e.g. Friederiszick and Röller (2010).

Weighting of observations

Weighting of observations becomes relevant when the price effects of the cartel are not uniform across transactions and these heterogeneities cannot, or should not, be fully resolved, for instance through interaction terms or sample splits.[136] Where effects are homogeneous or heterogeneous effects are fully accounted for, weighting does not affect the conclusions of the analysis. Where heterogeneity remains, however, the choice of weighting determines how individual observations contribute to the estimated average effect and therefore directly shapes what the resulting coefficient represents.

In a standard regression, every observation enters the estimation with equal weight. Where the dataset contains many observations that differ substantially in economic importance, equal weighting may not reflect the economic question of interest. If a bottled water producer has two price observations, each reflecting one transaction, a transaction of one million bottles of water to a large supermarket chain is economically more significant than a transaction of one hundred bottles of water to a small restaurant. Suppose further that the large supermarket chain was affected by a cartel overcharge of 5 percent, while the small restaurant was affected by an overcharge of 10 percent. An unweighted regression treats both observations equally and yields an average overcharge of 7.5 percent. Applying this estimate to the supermarket chain would substantially overstate the harm suffered by this customer, because the actual overcharge for this transaction was only 5 percent. A quantity-weighted regression, by contrast, would yield an overcharge close to 5 percent, reflecting the dominant economic weight of the large transaction.[137]

This can be addressed by assigning a weight to each observation before estimation. Common choices of weights are transaction quantity, revenue or market share. Quantity-weighted regressions effectively give each unit of the product equal weight across all transactions, which is appropriate when the question is the overcharge per unit sold. Revenue-weighted regressions give more weight to transactions that are

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[136] See section 3.3.1.2 for a further discussion of handling effect heterogeneities.

[137] The unweighted estimate would also substantially overstate the aggregate harm across both customers when applied to the total volume of commerce. The quantity-weighted estimate, by contrast, does understate the harm suffered by the smaller customer, but because the estimate more accurately reflects the overcharge of the economically more significant transactions, it approximates the aggregate harm across all customers well. The small individual deviations cancel out in proportion to the underlying transaction volumes. Quantity weighting is therefore not a perfect solution to heterogeneity in cartel effects, since individual customer-level harm is estimated less accurately, but a pragmatic way of accounting for heterogeneity where other solutions are not feasible.

larger in value, which could in turn distort the weight of cartelised transactions in the regression.

The choice of weights should be made on the basis of the economic question the analysis is designed to answer. Inappropriate weighting may overemphasise certain observations and produce results that are unrepresentative of the harm suffered by the relevant group of claimants. As with other modelling choices, the robustness of the results to alternative weighting schemes should therefore be assessed.

Importance of robustness checks

A price overcharge estimation requires many modelling choices. The specification of the regression model, the choice of comparators, the selection of control variables, and many others including the choice of different data sources. Each of these choices can influence the estimated cartel effect, sometimes substantially. Robustness checks assess whether the estimated effect remains stable when reasonable alternative choices are made. If the result is robust across a range of plausible specifications, confidence in the estimate increases. If the estimate changes materially with seemingly minor modifications, this signals sensitivity to modelling assumptions that must be addressed and explained.

Common robustness checks in price overcharge estimations include the following:

- Alternative control variables can be used, for instance substituting a different cost index or a different demand proxy, to test whether the result depends on the specific data source chosen.
- Regressions can be run separately for subgroups, such as individual firms or product categories, to examine whether the estimated cartel effect is homogeneous or driven by a particular subset of observations.
- Alternative time windows can be tested to assess whether the results are sensitive to the inclusion or exclusion of specific periods near the start or end of the cartel.
- Placebo tests use a fake cartel dummy defined for a product or period for which no infringement is known to have occurred. If the regression produces a statistically significant coefficient on this fake dummy, this suggests that the true cartel dummy of the model may have picked up a pattern unrelated to the cartel, which casts doubt on the reliability of the main estimate.
- Alternative functional forms can be tested to check whether the level-log distinction materially affects the result.
- Different weightings can be assessed to examine the sensitivity of results.

Not all robustness checks, however, are of equal quality, and not all alternative specifications are equally well motivated. The fact that a result can be made to change by varying the specification does not in itself invalidate the main estimate. On the contrary, one would expect of any open method that substantial modifications change results. Also smaller changes are unproblematic provided that the preferred specification is the one most strongly supported by economic theory and market evidence. Robustness analysis should be conducted transparently, covering a wide range of alternatives. The results of the robustness analyses should be compared. Where specifications produce materially different estimates, the reasons for this divergence should be explained and evaluated in terms of their underlying economic plausibility.[138]

3.3.2. Simulated comparator markets

3.3.2.1. Competitive behaviour and model selection

The market-based comparator methods introduced in section 3.3.1 require data of a comparison period or a comparison market that was unaffected by the infringement. Such data may be unavailable where a cartel lasted for a very long time, where the market changed structurally after the infringement, or where plausible comparison markets were themselves influenced by the cartel, for instance through umbrella effects.[139] In these circumstances, the counterfactual price can be generated based on a structural economic model setting out how the affected market would have operated in the absence of the infringement.[140]

The approach is structural in the sense that it models demand, supply, and competitive interaction directly. Its persuasiveness depends on the evidence used to specify and calibrate those elements. Relevant data may include prices, quantities, costs, capacity, product characteristics, customer substitution patterns, and internal documents describing how prices were set. The simulation approach is therefore best understood as a model-based comparator: an artificial market outcome that is disciplined by economic theory and market evidence.

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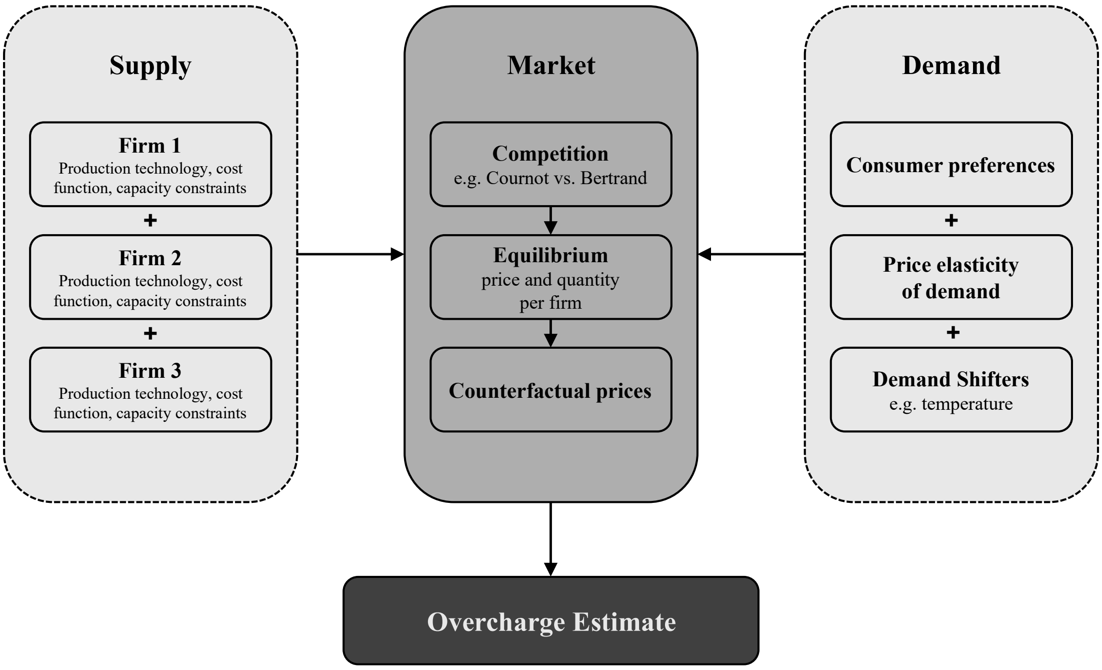
138 The challenge of selecting among multiple robustness checks is sometimes addressed by pre-registering the main specification before seeing the results, which reduces the risk of specification searching and p-hacking. In the litigation context, pre-registration is not always feasible, but transparency regarding the range of specifications considered and principled justification of the preferred specification are important for the credibility of the analysis.

139 See section 2.2.1.2.

140 See Maier-Rigaud and Heller (2021).

Applying the simulation approach requires three main components to be specified explicitly. A demand function or system is needed to describe how the quantity demanded by customers responds to changes in price and to other relevant market conditions. Supply factors of the firms in the market must be determined, for instance, marginal costs or capacity constraints. Furthermore, an assumption about how firms would have competed in the absence of the cartel must be made. Together, these three components allow one to compute the equilibrium price that would have prevailed in the absence of the infringement, which serves as the counterfactual price against which the observed cartel price is compared. Figure 16 below illustrates this structure for the bottled water case study introduced in section 3.3.1.

Figure 16: Components of a simulation model in the bottled water case study



Source: Own illustration based on Maier-Rigaud and Heller (2021).

The sequence of the analysis, however, matters. As discussed in section 3.1.2, market theory identifies the variables that guide any empirical exercise. In the context of a simulation model, market theory is particularly important. A market with quantity competition, for instance, requires a market demand curve and information on marginal costs and capacity to be modelled. In the case of price competition with differentiated products, own-price and cross-price responses for each relevant product are required. A capacity-constrained price model requires information on the size and use of capacity. The market theory of competition therefore determines the underlying economic model as well as the required demand and firm-side inputs, which are discussed in sections 3.3.2.2 and 3.3.2.3.

The importance of the model choice can be illustrated by comparing two classical benchmark models of oligopoly competition. In a homogeneous-product Bertrand model, firms choose prices. If products are identical, marginal costs are equal, and each firm can serve all demand at the market price, any price above marginal costs can be undercut by a rival. The standard Bertrand model therefore predicts a counterfactual price equal to marginal costs.[141] A Cournot model, in contrast, starts from a different competitive mechanism. Firms choose quantities or capacity and take the output of rivals as given. The equilibrium price is generally above marginal costs even without collusion, because each firm recognises that expanding output depresses the market price on the units it already sells. The equilibrium price under Cournot competition therefore depends on the market demand, marginal costs, and the number of active firms.[142] These two benchmark models can give very different counterfactual prices for the same underlying market data, which illustrates how strongly the choice of competition model can drive the numerical result.

Many markets, however, require moving beyond homogeneous-product models. If products are differentiated by brand, quality, size, location, contract terms, or service level, a price increase by one firm does not cause all customers to switch to the lowest-priced rival. Some customers remain loyal, some switch to close substitutes, some switch to more distant substitutes, and some leave the product market altogether. In such markets, a model of price competition with differentiated products is often more appropriate.[143] The empirical focus then shifts to a demand system that describes the pattern of substitution among products. A linear demand system relates the demand for each product to its own price, the prices of rival products, and other demand shifters. It is transparent and can be useful where the number of products is limited, although the number of parameters rises quickly. A multinomial logit model starts from customer choice among products and an outside option and can often be estimated from market share and product characteristic data, although the simplest version imposes restrictions on substitution patterns that may be implausible where some products are especially close substitutes.[144] Nested logit and random coefficient logit models relax some of these restrictions at the cost of richer data requirements and additional modelling choices.[145]

141 See Tirole (1988).
142 See Tirole (1988).
143 See Davis and Garcés (2010) for a general overview.
144 See Werden and Froeb (1994).
145 See Nevo (2000).

Other market settings may call for further models. Bertrand-Edgeworth models address how price competition changes when firms face binding capacity constraints. Auction models may be more appropriate for procurement markets or bid-rigging cases, where the relevant competitive interaction takes place tender by tender. Bargaining models may be needed where prices are negotiated bilaterally with large customers rather than posted publicly. Model selection should identify the strategic variable through which competition would have operated absent the infringement, whether prices, quantities, capacities, bids, product characteristics, or contract terms.

The following practical questions are useful when selecting the market theory for a simulation model:

- Do firms primarily compete by setting prices, quantities, capacities, bids, or contract terms?
- Are products homogeneous, or do brand, quality, location, and service create material differentiation?
- Could a firm that undercuts its rivals actually serve the additional demand, or would capacity and distribution constraints become binding?
- Are prices posted uniformly, negotiated customer by customer, or determined in tenders?
- Is the relevant counterfactual short-run competition with existing assets, or a longer-run scenario in which entry, capacity expansion, or product repositioning could also occur?

When the answers to these questions are uncertain, sensitivity analysis is preferable to false precision. Presenting results under more than one plausible competition model allows a court to assess how strongly the estimation results depend on the assumed form of competition and to evaluate which assumptions are best supported by market evidence. A homogeneous Bertrand model may serve as a useful lower benchmark in some cases, while a Cournot model may better reflect capacity constrained competition in others. Each simulated result should be grounded in an explicit and defensible view of the counterfactual market.

Applying these considerations to the bottled water case study, the homogeneous Bertrand benchmark requires assumptions that are too demanding for the stylised facts of the market. Bottling capacity can be expected to be fixed in the short run, distribution capacity cannot be expanded instantly, and a producer that slightly undercuts rivals is unlikely to be able to serve the entire market immediately. These features weaken the undercutting mechanism that drives the strict Bertrand result, which relies on the assumption that any firm can absorb the full market demand after a small price-cut. Cournot competition seems more appropriate in this setting, as it explicitly accommodates capacity constraints and the resulting limits on each firm's ability to expand output in response to rivals' pricing decisions. Although Cournot competition is usually linked to the setting of quantities, it can also be used to describe price-setting markets under certain conditions.[146] More complex models such as differentiated Bertrand or Bertrand-Edgeworth would in principle provide an even richer description of competition in the bottled water market, but their application requires a full demand system and additional data that go beyond the scope of this illustration.[147]

The Cournot model is therefore assumed to be the preferred counterfactual for the bottled water case study, with homogeneous Bertrand benchmark retained as a sensitivity to illustrate the effect of a more extreme assumption. Calibrating the Cournot model requires an estimate of the demand function and an observation of the marginal costs of the firms. These are derived in sections 3.3.2.2 and 3.3.2.3 respectively, before the model is assembled and the counterfactual prices are computed in section 3.3.2.4.

3.3.2.2. Demand estimation

Once the market theory is specified, the demand estimation problem becomes more precise. The relevant demand object depends on the chosen competition model. In a homogeneous Cournot model, this is a market demand curve or inverse demand curve. In a differentiated-products Bertrand model, it is a demand system with own-price and cross-price effects. In an auction model, demand may enter through participation rates, reserve prices or buyer substitution. In all cases, the demand information determines how strongly customers reduce their purchases when prices rise, and therefore influences the margins that firms can realise even under effective competition.

In the bottled water case study, the product is treated as sufficiently homogeneous for the Cournot simulation. Demand can therefore be represented by a simple relationship between weekly quantity sold, the producer price, and all relevant demand shifters. In

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146 Kreps and Scheinkman (1983) show formally that a two-stage game in which firms first commit to capacity and then compete in prices yields the Cournot outcome as the unique equilibrium. The intuition is that capacity decisions made in advance constrain each firm's ability to absorb rivals' customers after a price cut, which reintroduces the quantity-setting logic of Cournot competition into a price-setting environment. For the bottled water market, bottling infrastructure represents precisely such a capacity commitment: it is installed in advance, fixed in the short run, and cannot be rapidly scaled up in response to competitive price moves. The Cournot model can therefore be used to describe competition in this market even though firms were assumed to set prices rather than quantities directly.

147 On Bertrand-Edgeworth competition with capacity constraints, see e.g. Tirole (1988).

the case study, the only demand shifter is temperature, as established in section 3.3.1. The demand function is assumed to take the following linear form.[148]

$$Quantity_t = \alpha - \beta * Price_t + \gamma * Temperature_t + \epsilon_t$$

The coefficient β measures the reduction in quantity sold for each one-unit increase in price, holding temperature constant. The coefficient γ captures the effect of temperature on demand. Estimating this equation via a regression model requires care as price and quantity are not independent, which introduces endogeneity in the model.[149] If there is an unobserved increase in demand in a particular period, firms may raise prices and sell more units at the same time. A simple regression may then confuse a shift of the demand curve with a movement along it. The standard remedy is instrumental variable estimation, in which a variable that shifts price through the supply side, but does not directly affect the quantity demanded is used to isolate the relevant exogenous variation in price.[150] In practice, demand estimation is among the most econometrically challenging and most frequently contested steps of a simulation analysis.

For the purposes of this illustration, the demand parameters are taken as given rather than derived from a live estimation. The analysis draws on 52 weekly observations from the cartel period only, as it is assumed that no comparison period or market is available and the simulation must therefore be based on the data from the affected period.[151] The postulated demand function for the bottled water case study is:

$$Quantity_t = 7{,}000{,}000 - 62{,}500 * Price_t + 50{,}000 * Temperature_t$$

At an average cartel-period price of 52 cents and an average temperature of 10 degrees Celsius, this function implies a weekly quantity of approximately 4,250,000 bottles demanded. The implied price elasticity at these averages is approximately -0.76, indicating a moderately inelastic demand, which is plausible for a consumer staple such as bottled water.[152]

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148 In this stylised example, it is assumed that demand is linear in prices and temperature. In practice, however, depending on the case at hand, other assumptions about functional forms might be more plausible.

149 See section 3.3.1.4.

150 A thorough description and discussion of instrumental variable estimation approaches is beyond the scope of this paper. For further details, see Angrist and Pischke (2009).

151 Relying only on data of the cartel period may, however, cause further difficulties in demand estimation. Cartel prices may vary little, may follow agreed rules, or may change precisely when demand conditions change. The key question concerns the source of price variation in the dataset. A short dataset with a strong independent cost shock may be more useful than a longer dataset in which prices are nearly fixed by cartel discipline.

152 The price elasticity of demand η at any point on this function is given by $\eta = -\beta * \frac{Price}{Quantity}$.

If the market were treated as differentiated, the simple demand curve used in the main illustration would have to be replaced by a richer demand system. A linear demand system would require data on prices and quantities of each relevant product and would estimate how the price of each product affects demand for all others. A logit model would require market shares, product characteristics, prices, and an outside option such as not purchasing bottled water or switching to tap water or other beverages. Qualitative evidence becomes particularly valuable at this point. Internal pricing documents, customer switching evidence, tender records, and market research can all help assess whether the estimated substitution patterns are plausible. If the model predicts little substitution between two products that customers and firms consistently describe as close alternatives, the demand specification requires reconsideration.

3.3.2.3. Firm characteristics and cost structure

On the firm side, relevant inputs include marginal costs, capacity constraints, utilisation rates, product ownership, product technology, and distribution bottlenecks. As with the demand inputs, the market theory determines which of these are needed. In a homogeneous Cournot or capacity-constrained price model, the per-unit marginal costs of each active firm and information on the capacity available to each is required. In a differentiated-products model, costs are needed at the product level and information on which firms own which products becomes relevant, because a multi-product firm internalises substitution among its own brands when setting prices.

Comparator regressions and simulation models use cost information in fundamentally different ways. In the market-based comparator methods described in section 3.3.1, costs often enter as a control variable tracking cost movements over time. In a simulation model, the equilibrium price under effective competition is a function of costs. The relevant object is the marginal cost of supplying an additional unit, not an index of cost variation.

In practice, per-unit marginal costs are typically reconstructed from a combination of sources. Firm-level accounting data, such as costs of goods sold or variable production costs, provide a starting point. Such data may, however, include allocations of overhead or standard costs that do not measure marginal costs. Where the production process is well understood, engineering or production data can be used to establish the quantities of each input required per unit of output, which, combined with observed input prices yields a constructed cost series. In the bottled water case study, the relevant cost components may include spring water sourcing fees, bottling and packaging equipment, energy for the filling process, and perhaps distribution to customers. Each component must be converted to a per-bottle figure before aggregation. Fixed overhead costs, brand expenditure, and plant depreciation do not automatically form part of the short-run marginal costs.

One important caveat applies where cost data are drawn from the infringement period. A cartel may affect the cost structure of participating firms via two mechanisms. First, firms operating under cartel protection face reduced competitive pressure to minimise costs, which may lead to X-inefficiency and elevated cost levels relative to a competitive counterfactual.[153] Second, if the cartel suppresses output below the competitive level, firms may incur higher per-unit costs due to the loss of scale economies. Where either effect is plausible, cartel-period data should be used with caution as a proxy for counterfactual marginal costs.

A further difficulty arises where cost data are not directly observed and must instead be inferred from prices. In merger simulation, marginal costs are sometimes recovered from observed prices and an assumed competitive pricing model. In a cartel harm case, this technique is risky because the observed prices are the allegedly collusive prices. Recovering marginal costs by assuming that cartel prices were generated by competitive first-order conditions may partly build the infringement into the counterfactual. Direct cost evidence, for instance from accounting, procurement, production, and engineering records is therefore especially valuable.

Moreover, capacity information is equally important where the counterfactual is Cournot or capacity-constrained price competition. In this case it is required to know how much each firm could produce, whether capacity was fully utilised, and how quickly additional capacity could have been added.

In the bottled water case study, the per-bottle production costs are observed directly as a weekly time series and have been used as a control variable throughout section 3.3.1. These costs, averaging 23 cents during the cartel period, are used directly as the marginal cost input in the formula derived in the following section. In this stylised setting, it is assumed that these costs do not include per-bottle shares of overhead or other fixed costs. Moreover, it is assumed that the cartel did not affect costs, and no further transformation is required. In practice, the reconstruction of a reliable per-unit marginal cost series from raw accounting and production records is typically a more complex step of a full simulation analysis.

153 X-inefficiency describes a situation in which firms, due to reduced competitive pressure, do not produce at the lowest possible cost. See Leibenstein (1966).

3.3.2.4. Model calibration and validation

After the market theory has been selected and the demand and firm-side inputs have been determined, the simulation model computes the counterfactual equilibrium. For a linear demand function with n symmetric firms, the Cournot equilibrium price in the bottled water case study is given by the following formula.

$$Price_t^{\text{Cournot}} = \frac{((\alpha + \gamma * Temperature_t) \,/\, \beta) + n * Costs_t}{n + 1}$$

The formula is derived from the standard Cournot first-order condition and is applicable to any linear demand specification that includes a demand shifter.[154] It requires only the estimated demand parameters and the observed marginal costs. The Cournot price is a weighted average of the demand side intercept, which represents the price at which demand falls to zero, and the supply-side cost floor. As the number of firms increases, the Cournot price converges towards marginal costs. As the number of firms declines to one, the Cournot price approaches the monopoly price. Applied to the bottled water case study with $n = 3$ firms and using the results from section 3.3.2.2, the formula becomes:

$$Price_t^{\text{Cournot}} = \frac{((7{,}000{,}000 + 50{,}000 * Temperature_t) \,/\, 62{,}500) + 3 * Costs_t}{4}$$

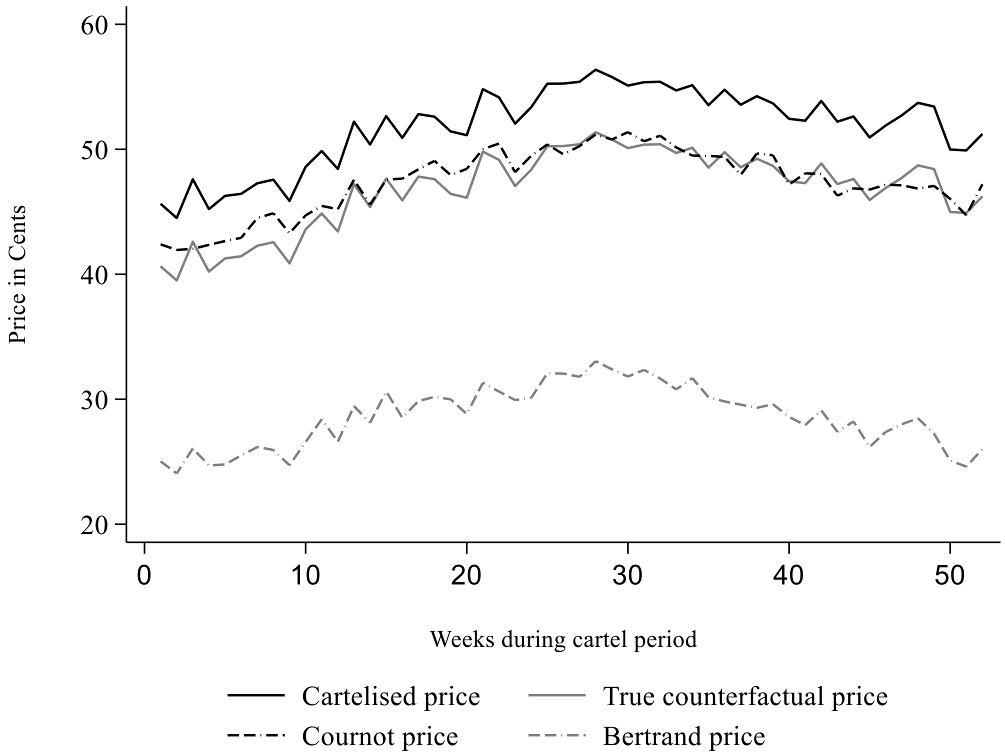
This yields a weekly time series of counterfactual Cournot prices that vary with both observed costs and temperature, mirroring the same market forces that drive variation in the observed cartel price. For the homogeneous Bertrand benchmark, the counterfactual price is simply the observed marginal costs:

$$Price_t^{\text{Bertrand}} = Costs_t$$

Figure 17 below shows the observed cartel price given an underlying 5 cents price overcharge, the true counterfactual price from the data-generating process, the simulated Cournot price, and the simulated Bertrand price for all 52 weeks of the cartel period.

[154] Without a demand shifter, the general formula simplifies to $P_t^{\text{Cournot}} = \frac{(\alpha/\beta) + n * Costs_t}{n+1}$.

Figure 17: Cartelised prices, true counterfactual and simulated counterfactual prices during cartel period in the bottled water case study



Source: Own illustration.

The simulated Cournot price tracks the true counterfactual closely throughout the cartel period, confirming that the Cournot model is well suited in this stylised example. Both series vary from week to week as costs and temperature change, capturing the dynamic character of the competitive counterfactual. The simulated Bertrand price, by contrast, lies well below the true counterfactual throughout because it treats marginal costs as the competitive price and thereby assumes away the capacity constraints that matter in the bottled water market.

The per-unit overcharge in each week t is the difference between the observed cartel price and the simulated counterfactual price. The Cournot simulation yields an average overcharge of approximately 4.4 cents per bottle, which is close to the true overcharge of 5.0 cents per bottle. The Bertrand simulation yields an average overcharge of approximately 28 cents per bottle, roughly six times the true value. The result illustrates that an incorrect modelling assumption can lead to a substantial deviation from the true overcharge.

The deviation of the Cournot estimate from the true value reflects the fact that the demand parameters postulated for this illustration are not identical to the exact parameters of the data-generating process. In practice, parameter estimates derived from observed data will always carry some degree of estimation uncertainty, and the resulting simulation will deviate from the true counterfactual by a corresponding amount.

More fundamentally, the assumptions underlying a simulation model must not be chosen in a way that predetermines the result. A simulation model that is set up such that a positive overcharge is the only possible outcome does not constitute evidence of harm since it merely reflects the assumptions built into the model. The simulation method is therefore open-ended by design such that it does not mechanically produce any particular result and can in principle yield a zero or negative overcharge if the data and model indicate so.[155]

Validation should use all available evidence. The estimated demand elasticity should be plausible in the light of customer behaviour and market documents. The implied margins should be compatible with cost evidence. The simulated quantities should be feasible given capacity. Where limited pre- or post-cartel data exists, even if insufficient for a full market-based comparator analysis, they may still provide useful validation checks on the model's predictions.

Robustness analysis is particularly important because models require several modelling choices. It should therefore be tested how results change when alternative demand specifications, cost measures, capacity assumptions, or competition models are used. The exercise should show which assumptions drive the result and whether the preferred estimate remains stable across economically reasonable variations. Where data permit, simulation-based estimates should also be compared with market-based estimates from section 3.3.1. Convergence between the two approaches can increase confidence in both. Divergence calls for explanation by returning to the market theory, the theory of harm, and the underlying evidence.[156] The most credible estimate is the one produced by the method whose underlying assumptions best match the characteristics of the market under investigation.

155 This point is, for instance, illustrated by Maier-Rigaud and Heller (2021), who argue that simulation approaches that model both the competitive counterfactual and the cartel price separately using distinct economic models will necessarily imply a positive overcharge, since the model used for the cartel period will by construction produce a higher price than the model used for the competitive counterfactual. They refer to this as the 'Two Model approach' and contrast it with the approach taken in this section, in which only the competitive counterfactual is simulated structurally and the cartel price is taken directly from observed data.

156 See section 3.1.

3.4. Quantification of umbrella effects

Umbrella effects arise when non-cartelised competitors raise their own prices in response to the shifted demand away from the cartelists due to the elevated cartel price. Because the cartel increases the general price level in the affected market, rival firms that do not participate in the cartel, and may not even be aware of its existence, can profitably set prices above the competitive level without losing customers to cartelists. The resulting price increase by non-cartelists harms their purchasers even if the firms are not part of the cartel.[157]

Two distinct groups of non-cartelists may optimally set higher prices in response to umbrella effects. The first comprises firms operating in the same market that produce identical or closely substitutable products. These firms benefit from the price umbrella opened by the cartelists and will typically raise their prices alongside the cartel. The second group comprises firms outside the formally defined relevant market whose products would not ordinarily be regarded as substitutes for the cartelised product but become substitutes at the elevated cartel price, diverting demand towards them and enabling them to raise prices as well.

Since umbrella effects describe optimal price responses of firms outside the cartel to cartel-induced price increases, their quantification follows the same conceptual logic as the estimation of price overcharges in section 3.3. The counterfactual question is identical: What price would the non-cartelist have charged in the absence of the cartel? Accordingly, the dependent variable in the empirical analysis is the price charged by the non-cartelised competitor rather than the cartel price, and the cartel dummy continues to identify prices set in affected markets in the time period in which they are affected.[158] The estimated coefficient on the umbrella dummy, that is the cartel dummy equivalent for non-cartelists, then captures the extent to which the non-cartelist's price was elevated during the cartel period relative to the competitive counterfactual.

All three main approaches from section 3.3 translate directly to the umbrella context. A time-based comparison uses the pre- and/or post-cartel prices of the non-cartelist as the comparator and estimates the umbrella dummy coefficient in the same way as the cartel dummy described in section 3.3.1.2. A difference-in-differences analysis compares the price change of the non-cartelist in the affected market over time with the

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[157] The economic foundations of this mechanism, as well as the conditions under which umbrella effects are likely to be significant were already touched upon in section 2.2.1 and is discussed in great detail in Inderst et al. (2014).

[158] This period usually corresponds to the infringement period. Besides the general caveats in defining the affected periods describes in section 3.3.1.4, the affected periods with respect to umbrella effects may, however, show a certain lag depending on the market and pricing characteristics.

corresponding price change in a suitable unaffected comparator market, yielding a difference-in-differences estimator of the umbrella effect.[159] All methodological considerations discussed in section 3.3.1 apply without modification: the choice and specification of control variables, the selection of functional form, the use of unit and time-fixed effects, the treatment of heterogeneous effects, and the full range of considerations set out in section 3.3.1.4 are equally relevant. Where data on non-cartelist's prices are limited, structural models may serve as alternatives, following the logic described in section 3.3.2.

While the methodology already described applies in full, two aspects warrant particular attention when estimating umbrella effects. First, the identification of affected non-cartelists. In a standard cartel overcharge analysis, the identity of the cartelists is determined by the competition authority's finding and is not itself a subject of econometric inference. When estimating umbrella effects, the question of which non-cartelists were affected by the cartel's pricing umbrella must be answered before any regression is run. This is especially demanding for firms whose products only become substitutes at elevated cartel prices and for whom umbrella exposure is less obvious. The definition of the affected group must rest on economic theory of how the cartel's price increase would have diverted demand towards the non-cartelists in question, derived from market theory and substitutability.[160]

The second aspect of particular relevance for the quantification of umbrella effects is the contamination of comparator markets. The risk that a comparator market is itself affected by the infringement is a general concern in any difference-in-differences analysis.[161] In the umbrella context, a non-cartelist on a market related to the cartelised market is a plausible umbrella candidate precisely because it operates in a market that is sufficiently close to the cartel to have received pricing impulses from it. When searching for a comparator for this non-cartelist, one is therefore looking for a market that is structurally similar to a market that is, by assumption, located near the cartel's sphere of influence. The set of naturally similar comparator markets is thus more likely to include markets that were themselves exposed to umbrella pricing than would typically be the case when searching for a comparator for the cartelist in a standard

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159 The identifying challenges discussed in section 3.3.1.3 apply in full. The parallel trend assumption must be assessed both theoretically and empirically.

160 If a large number of potential non-cartelists were tested for a statistically significant price increase during the cartel period and only those yielding significant results were included in the damages claim, the estimated effect would be systematically biased upward. By chance alone, some firms will show elevated prices during the cartel period regardless of any causal umbrella effect. This error is known as *ex-post* selection bias.

161 See section 3.3.1.3.

overcharge analysis. This does not mean that a valid comparator cannot be found, but it does mean that the independence of the comparator from the infringement requires more careful scrutiny.

Besides the empirical approaches already discussed in section 3.3, a complementary and more exploratory approach is to analyse the degree of price co-movement between cartelists and non-cartelists directly. A price co-movement regression takes the following form:

$$Price_t^{\text{Non-cartelist}} = \beta_0 + \beta_1 * Price_t^{\text{Cartel}} + \epsilon_t$$

The dependent variable is the price of the non-cartelist and the main explanatory variable is the concurrent price of the cartel.[162] A positive and statistically significant coefficient β_1 can indicate that non-cartelists potentially adjusted prices in response to cartel pricing behaviour. A price co-movement regression of this form, however, does not necessarily identify a causal effect of the cartel price on the non-cartelist price in the econometric sense. Both prices may co-move simply because they respond to common demand or supply factors omitted in the regression. A statistically significant and positive coefficient is necessary but not sufficient to indicate an umbrella effect, as it may instead reflect common market trends. The regression is best treated as a descriptive exercise that motivates further analysis rather than a standalone basis for inference on umbrella effects.

3.5. Quantification of pass-on effects

Pass-on occurs when a purchaser that faces a cartel-induced price overcharge on the upstream market partially or fully transfers that higher cost to its own customers in the form of higher downstream prices.[163] The extent to which this occurs determines how cartel harm is distributed across levels of the supply chain and is therefore of central importance both for the establishment of damages claims by indirect purchasers and for the quantification of damages payable by the defendants. The economic foundations of pass-on, including its role in the distribution of harm across different groups of economic actors, are discussed in section 2.2.1. As a general economic concept, pass-on describes how firms optimally adjust their prices in response to changes in input costs, irrespective of the source of those changes. The existence of an upstream price

[162] Logarithmic prices can be used instead of level prices if a proportional relationship is more plausible, in which case β_1 is interpreted as a price elasticity.

[163] See, e.g. Maier-Rigaud et al. (2019a) or van Dijk and Verboven (2009) and for pass-on in the context of regulated industries, Maier-Rigaud et al. (2019b).

overcharge is therefore not a prerequisite for the methodological analysis of pass-on as such. In the context of antitrust harm, however, pass-on becomes relevant only where an upstream overcharge can be established, as it is only such an overcharge that can be transmitted downstream.

The pass-on rate, or pass-through rate, measures the proportion of a given upstream cost increase that is reflected in downstream prices. Its magnitude depends on the nature of the upstream price increase[164], the structure of the downstream market and the nature of competition.[165] Conditions that favour higher pass-on rates include a high share of the cartelised input in total variable costs, low price elasticity of downstream demand, broad coverage of downstream competitors affected by the cost increase, and the presence of cost-plus pricing contracts[166]. The pass-on rate is reduced when the cartelised input is a fixed rather than a variable cost, when downstream customers are bound to fixed-price long-term contracts, or when downstream market power allows firms to insulate their margins from upstream cost changes. As with the quantification of direct price overcharges, any empirical analysis of passed-on harm must be embedded in a coherent market theory both on upstream and downstream markets as well as in a theory of harm that rationalises an upstream price overcharge and its passing on.

Several ways of proceeding are available for quantifying the pass-on rate. First, the downstream price overcharge can be estimated directly, using the same comparator-based methodology as for the upstream overcharge in section 3.3, and derives the pass-on rate implicitly from the ratio of the two estimated overcharges. Furthermore, the pass-on rate can be estimated directly by regressing downstream prices on upstream prices.[167]

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164 If the upstream price increase affects variable costs of production of the downstream purchaser, the price increase is usually more likely to be passed on. If the upstream price increase, however, affects fixed costs of downstream purchaser, the price increase is less likely to be passed-on.

165 In competitive downstream markets where firms price at marginal cost, a market-wide increase in variable input costs tends to be passed on at a relatively high rate because competitive pressure implying already low margins prevents firms from absorbing cost increases through further lowering margins. Downstream market power, by contrast, generally reduces the pass-on rate, as firms with pricing power can adjust mark-ups and absorb part of the cost increase rather than fully transferring it.

166 Cost-plus pricing contracts are arrangements in which prices are determined by adding a fixed or proportional margin to observed costs, rather than being set directly in response to market conditions.

167 The two approaches are conceptually equivalent in the sense that both estimate the same underlying economic quantity. They may nonetheless yield different numerical results depending on the data used, its quality, the specification of control variables, and the functional form adopted. Running both approaches and comparing their results is therefore a useful robustness check. Consistent estimates across two methods provide stronger support for the identified pass-on rate than either approach alone.

3.5.1. Comparator-based estimation of downstream overcharges

The first approach applies the methodologies of section 3.3 directly to downstream prices. A price overcharge regression is estimated with the downstream price, that is the price set by direct purchaser of the cartel in transactions with its customers, as dependent variable and a cartel dummy identifying the infringement period as the key explanatory variable. Appropriate control variables for the downstream market are included to isolate the cartel's contribution to the downstream price increase from other factors, following the same principles as in the upstream regression. Time-based comparison, the difference-in-differences method, and structural models are all applicable, with the choice among them governed by data availability and the structure of the downstream market. All methodological considerations discussed in sections 3.3.1.2 to 3.3.1.4 apply without further modification to the downstream overcharge regression.

The estimated coefficient on the cartel dummy measures the average downstream price increase attributable to the cartel. This estimated downstream overcharge can be used to directly quantify harm to indirect purchasers. To derive an estimate of the pass-Fion rate, the estimated downstream overcharge is then compared to the upstream overcharge that is estimated. If, for example, the upstream overcharge in the bottled water case study is 10 cents and the downstream regression yields a cartel-induced price increase of 5 cents, the implicit pass-on rate is 50 percent.

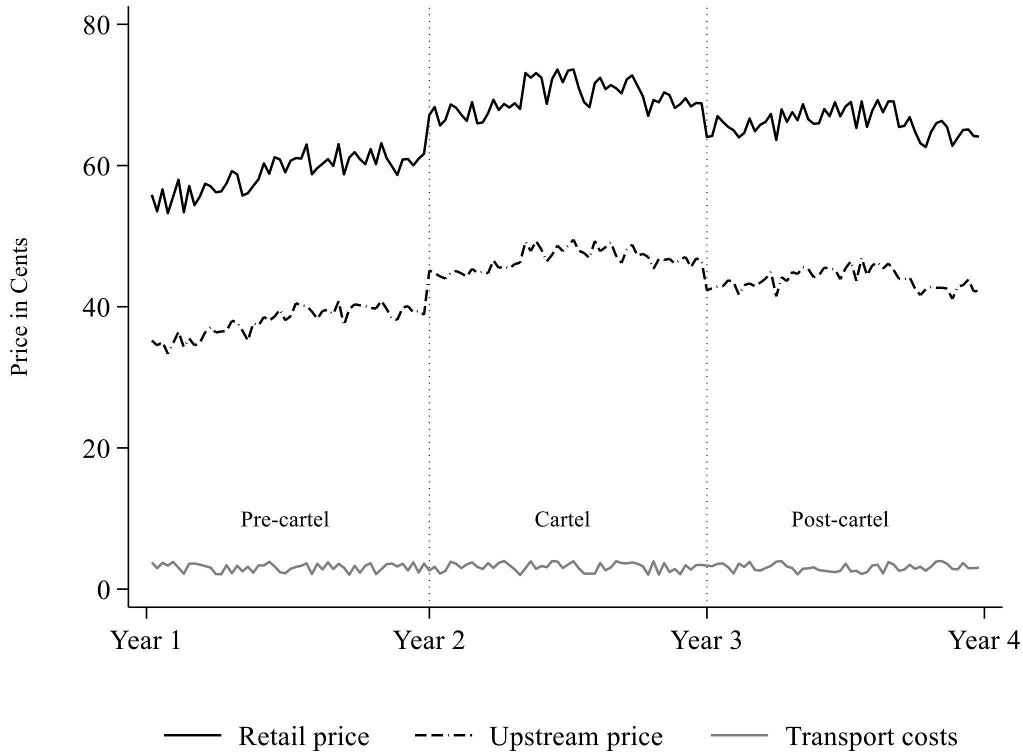
The comparator-based approach has the advantage that it is methodologically transparent and directly comparable to the upstream overcharge estimation. Its main limitation is that it requires the identification of a valid comparator for the downstream market, which may be difficult if the downstream market is itself broadly affected by the cartel's upstream price increase. In markets where cartelised input is used widely by downstream competitors, finding an unaffected comparator requires careful justification.

3.5.2. Direct estimation of pass-on rates

The second approach estimates the pass-on rate directly by regressing downstream prices on upstream prices. The estimated coefficient of the upstream price measures how much the downstream price changes in response to a given change in the upstream price, which is the pass-on rate.[168] Extending the bottled water case study from section 3.3, suppose that food retailers purchase bottled water from the cartelised producers and sell it to end customers. In addition to the upstream price, retailers face transport costs for logistics, which vary over time and represent a downstream-specific cost driver. As before, it is assumed that the producers of bottled water engaged in a cartel during year 2 and agreed to raise upstream prices by 10 percent, while a certain pass-on seems plausible given the economic theory. Figure 18 illustrates the development of downstream retail prices, upstream prices, and transport costs over the total observation period.

[168] This approach is methodologically similar to the price co-movement regression proposed for the estimation of umbrella effects in section 3.4, where the price of the non-cartelist is regressed on the price of the cartelist. In the umbrella context, that regression was characterised as indicative rather than causal, because the co-movement of prices may reflect common demand or cost factors rather than a genuine causal transmission from the cartel price to the outsider price. In the pass-on context, the identification of a causal effect is on stronger footing for two reasons. First, there is a direct structural transmission channel: the upstream price enters the cost function of the direct purchaser, creating a mechanical link between upstream and downstream prices that does not depend on strategic price-following behaviour. Second, the direction of causation is economically well-defined and supported by the contractual relationship between the cartelist and the direct purchaser. These conditions are not generally present in the umbrella setting, where the non-cartelist has no direct input cost exposure to the cartel price.

Figure 18: Retail prices, upstream prices, and transport costs in the bottled water case study



Source: Own illustration.

The figure shows that retail prices broadly tracked upstream prices throughout the observation period. Both increased at the start of the cartel period in year 2 and declined after its end. Transport costs remained roughly stable throughout, providing a clean exogenous cost control for the downstream regression. To estimate the pass-on rate directly, the following log-log regression model is used:

$$ln\left(Price_t^{Retail}\right) = \beta_0 + \beta_1 * ln\left(Price_t^{Upstream}\right) + \beta_2 * Transport\ Costs_t + \epsilon_t$$

The dependent variable is the logarithmic retail price. The logarithmic upstream price is the main explanatory variable. The log-log specification means that β_1 directly measures the percentage change in retail price associated with a one-percent change in the upstream price, which is the pass-on rate. Transport costs are included in levels as the downstream-specific cost control. Transport costs are exogenous by construction in this example because they reflect logistic costs specific to the retailer and do not affect upstream production costs. Temperature, which was included as a demand control in the upstream regression, is deliberately excluded from this specification because it drives demand at both the upstream and the downstream level simultaneously and would introduce endogeneity if included alongside the upstream price as a regressor.[169] Table 11 reports the regression result.

Table 11: Pass-on rate regression for the bottled water case study

Variables	Pass-on
Ln(Upstream price)	0.797***
	(0.009)
Transport costs	1.591***
	(0.149)
Constant	0.194***
	(0.008)
Observations	156
Adjusted R-squared	0.982

Note: *Standard errors in parentheses.* *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: *Own estimation.*

The coefficient on the upstream price is 0.797. A one-percent increase in the upstream producer price for bottled water is thus associated, on average and holding transport costs constant, with a 0.80 percent increase in the retail price for bottled water. The estimated pass-on rate is therefore approximately 80 percent. The model explains 98.2 percent of the variation in retail prices over the observation period, as indicated by the adjusted R-squared, suggesting a good model fit and that only a very limited share of price variation is driven by factors not captured in the specification.

The estimated pass-on rate can be used directly to calculate the harm to indirect purchasers. The passed-on harm is obtained by multiplying the upstream overcharge by the pass-on rate. If the upstream price overcharge is 10 percent and the pass-on rate is 80 percent, then approximately 8 of the 10 percentage points of the upstream overcharge were passed on to retail customers. To translate this into an absolute harm amount, the passed-on harm percentage of 8.0 percent is applied to the counterfactual upstream price and multiplied by the number of units purchased by the indirect purchaser during the infringement period.[170]

[169] Temperature is omitted in this illustrative example since its effect on prices is already captured by the upstream price variable itself, which is the key explanatory variable. Adding temperature as a separate control would therefore create a redundant and potentially endogenous explanatory variable (see section 3.3.1.4; see also Cinelli et al., 2024). In practice, the appropriate set of downstream-specific controls must be identified based on market theory and the structure of the downstream market, following the principles set out in sections 3.3.1.1 and 3.3.1.4.

[170] For example, if the counterfactual upstream price is 40 cents per bottle and the indirect purchaser bought one million bottles during the infringement period, the total passed-on harm amounts to $0.080 * 40 \text{ cents} * 1{,}000{,}000 = €32{,}000$.

In the case study above, the upstream price enters the downstream regression as an exogenous variable by construction of the data-generating process in this stylised example. In practice, the upstream price is frequently endogenous in a pass-on regression.[171] The same demand or supply shocks that drive upstream prices may independently affect downstream prices, creating a correlation of the upstream price and the error term of the downstream regression. If unaddressed, this violates the exogeneity assumption and biases the estimated pass-on rate. Addressing endogeneity in a pass-on regression typically requires an instrumental variable approach. A valid instrumental variable must be correlated with the upstream price but affect downstream prices only through it and not directly.[172] Finding such an instrument is often the main practical constraint, and the identification and validity of proposed instruments must be assessed carefully in each case.[173]

As with all empirical analyses in this paper, the pass-on rate estimated under either approach should be guided by expectations from economic theory and cross-checked against the results from the alternative approach and subjected to the robustness checks described in section 3.3.1.4. Consistent estimates across methods and specifications provide stronger support for the identified pass-on rate and reduce the risk that results are driven by a specific modelling choice.

3.6. Quantification of harm caused by exclusionary conduct

3.6.1. Constructing the counterfactual scenario

To estimate harm resulting from exclusionary conduct, the same basic conceptual framework as in cartel or exploitive conduct cases applies. The actual situation with the infringement has to be compared to the hypothetical counterfactual situation in the absence of the abuse. The total harm is then determined by the difference in wealth of economic actors in both scenarios. A practical application, however, is often associated with considerable difficulties.

To calculate the harm caused by an exclusionary abuse, the situation that would have occurred in the market absent the exclusionary conduct has to be assessed, in order to determine the profits competitors would have been able to obtain and the prices

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171 See section 3.3.1.4 for a discussion on the problem of endogeneity in regression analyses.

172 In the case of bottled water production such an instrument could be specific input costs of the upstream producer that do not directly influence downstream purchasers, for instance costs for spring water licenses.

173 A thorough description and discussion of instrumental variable estimation approach is beyond the scope of this paper. For further details, see Angrist and Pischke (2009).

purchasers would have had to pay in the counterfactual scenario. Unlike cartel cases, where the counterfactual typically requires identifying a hypothetical competitive price, constructing the counterfactual in exclusionary conduct cases requires modelling an alternative market development. This encompasses assumptions about market structure, the distribution of market shares and the strategic interaction among competitors. The key elements of a competitor's profit function, that is sales volumes, costs, and prices, may all be simultaneously distorted by the abusive conduct, as the dominant firm attracts demand that it would not have obtained under competitive conditions.[174]

In terms of comparator-based methods, the primary candidate generally is the time-based estimation, that is a consideration of the market prior to the initiation of the exclusionary strategy. As exclusionary abuse typically unfolds over time and in different phases, a comparison with a unique moment in time provides only an incomplete picture of the effects. Normally, the question of how the market would have developed absent the anti-competitive conduct has to be answered. This is particularly relevant in markets with network effects.[175] In such cases, a dominant firm may prevent a competitor from winning a critical mass of consumers, so that considering the market situation prior to the abuse may not itself provide a sufficiently meaningful counterfactual scenario as excluded competitors would have earned substantial profits in the absence of the abuse in the meantime.

In general, there will also be no comparable geographic or product market that is similar to the market at hand. In order to guarantee a minimum degree of comparability, the market would need to exhibit a similar market concentration, comparable cost structures as well as similar demand conditions, something that will be rather rare. Therefore, many of the empirical methods discussed in the context of cartels cannot be applied because the necessary data are not available.

A further conceptual problem arises in establishing what is meant by 'in the absence of the exclusionary abuse'. This is unclear as there may be a multitude of possible scenarios that a dominant firm could have followed in order to ensure compliance with competition law, and these scenarios would likely have led to very different market outcomes. For instance, in the case of exclusionary abuse aimed at the exclusion of a

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[174] See Buccirossi (2010) or Ormosi et al. (2026).

[175] Network effects occur when the value of a product or service to a user increases with the number of other users. In markets characterised by such effects, a competitor prevented from reaching a critical scale faces a compounding structural disadvantage, as a smaller user base translates directly into a less attractive product and further loss of users. A well-known example are social networks, where the utility of membership increases with the number of other members on the platform.

competitor by means of retroactive rebates, several possibilities ranging from a linear price to a two-part tariff or an incremental quantity discount could be appropriate counterfactual pricing schemes, all entailing potentially different market outcomes. In principle, the counterfactual scenario would have to be characterised by an oligopolistic equilibrium in which the dominant firm maximises profits under the constraint of complying with competition law. In some cases, it may be possible to develop such a counterfactual scenario, for instance, in the case of tying, the relevant question is what profits competitors of the dominant firm would have made absent the tying, that is, if the products had also been sold independently. In other cases of exclusionary conduct, such as entry barriers, the construction of an economically well-founded counterfactual is likely to be difficult. A simulation-based approach may offer a solution in these cases, by modelling the possible development of the market absent the abusive behaviour.

For these reasons, estimating harm in exclusionary abuse cases often has to rely on a more or less rough estimation of competitors' lost profits and the harm accrued to purchasers, rather than on a precise comparison between the observed outcome and a fully developed hypothetical counterfactual. When using such an estimate, the conditions of the relevant market should be considered such as the size and geographic extent of the market, the importance of entry barriers, the type of products traded (homogeneous or differentiated, intermediate or final goods), the degree of market development and the degree of innovation.

To address these difficulties and fully utilise all available information, it is appropriate to consider several realistic counterfactual scenarios that are compatible with the underlying characteristics of the market in question. Different scenarios could be generated by utilising different approaches from the toolkit of comparator-based methods. They could also be generated by varying some of the crucial determinants of the outcome in a simulation model. Building on this counterfactual framework, the following subsections discuss the quantification of harm from the perspective of the principal categories of affected actors, namely competitors, direct and indirect purchasers, and suppliers.

3.6.2. Harm to competitors

As set out in sections 2.1.2.2 and 2.2.2.2, the bulk of harm from exclusionary abuse is typically borne by the excluded or marginalised competitors, making them the primary victims of exclusionary abuse. The relevant target variable for quantifying their harm, thus, is not the price paid in a transaction, but typically the profit that the competitor would have earned in the absence of the abuse. The empirical methods developed in sections 3.3 to 3.5 for the estimation of price overcharges, pass-on and umbrella effects are therefore only of limited direct use, and the quantification of competitor harm requires a separate methodological approach centred on the developments of revenues, costs, and profits.

For competitors, the profits obtained during the different phases need to be compared with the profits that would have been obtained in the counterfactual scenario. As an exclusionary abuse can target the revenue or costs of competitors, it may be useful to estimate changes in profits of the competitors by a separate analysis of the development of revenues and costs. Such an approach could facilitate the distinction between changes in profit that are not due to the abusive conduct and those that are. Generally speaking, when sales fall, the firm typically adjusts its production accordingly, so that variable costs decrease as well. The change in profit therefore corresponds to the difference between the change in revenues and change in costs.

Where the claim is brought by a potential competitor that was prevented from entering the market, for instance because of predatory pricing, the quantification of lost profits requires further assumptions. In particular, it is important to consider the technology a potential competitor would have used upon entry, that is, whether it would have developed a superior, inferior or identical technology. Without additional information or evidence that the company would have produced more efficiently, it may be useful to assume that such a competitor would have entered the market using the same technology, exhibiting a similar efficiency as the dominant firm. This assumption provides a tractable starting point for estimating the counterfactual cost base and, together with assumptions about counterfactual market shares and prices, the counterfactual profit of the potential entrant.

A similar type of abusive behaviour to predatory prices are retroactive discounts which imply a reduced price for all units previously bought if a given target quantity is exceeded. In many cases, this leads to a very low or even negative marginal price that gives rise to a suction effect, that is, customers have a strong incentive to buy the necessary units to reach the target, and it becomes very difficult for competitors to compete with these low or even negative prices. Therefore, retroactive discount schemes may cause the exclusion of competitors, their marginalisation or prevention of market entry. Thus, their effects could be similar to those of predatory prices. However, there are some aspects of retroactive discount schemes that distinguish them from predatory prices. First, retroactive discount schemes may also exhibit some pro-competitive effect, such as giving retailers the right incentives to provide an efficient level of sales. Secondly, if retroactive discount schemes are used as a barrier to expansion, these pricing schemes might be used for a long time and there are no different phases as in the case of predatory prices. Thirdly, it is difficult to assess the economically correct counterfactual scenario, which may be a uniform price, a two-part tariff or discount compatible with competition law. In addition, it has to be pointed out that the prices under a retroactive discount scheme need not be lower than undiscounted prices despite the term 'discount', as the discount is calculated relative to a price that may itself be set above the competitive level. As it is problematic to determine the counterfactual scenario in case of retroactive discount schemes, the quantification of potential harm proves particularly difficult. The most important aspect, as in most other cases of exclusionary abuse, is the determination of the counterfactual scenario.

As discussed in section 3.1, when quantifying harm all relevant factors have to be controlled for that are not linked to the infringing behaviour. An important factor in this context could be the business model used by the firm, which may differ in situations with and without abusive conduct. In principle, the econometric methods allow for an estimation of the impact of these factors on costs, revenues and profits. Depending on the case at hand, however, this may be difficult. For a most precise estimation of the harm, it is, however, of central importance to identify all these factors and to control for them in an econometric analysis. Otherwise, it is possible that changes in profits will be attributed to the abusive conduct even though they were, at least in part, caused by other factors.

3.6.3. Harm to purchasers

While the bulk of harm in exclusionary conduct cases is typically borne by competitors, purchasers of the dominant firm are typically affected as secondary victims, as set out in sections 2.1.2.2 and 2.2.2.2. The exclusionary practice first reduces competitive pressure by foreclosing rivals, and the harm to purchasers materialises through the prices, quantities, quality and choice that prevail once the abuse has successfully reduced or eliminated competition. Once the dominant firm exploits the resulting reduction in competition, direct purchasers and (potentially) indirect purchasers pay higher prices and may also suffer from reduced choice, since in markets with differentiated products, the elimination of competitors reduces product variety and thereby reduces consumer welfare. Quantifying the harm from reduced choice is, however, difficult.

As far as price effects are concerned, the conceptual framework and the empirical methods presented in sections 3.3 to 3.5 remain largely applicable. The relevant target variable is the price paid by the (direct or indirect) purchaser, and the counterfactual outcome is the price that would have prevailed absent the exclusionary conduct. Time-based comparison, difference-in-differences approaches, simulation-based methods and other comparator-based methods can in principle be used in the same way as in cartel or exploitive abuse cases. Where relevant, pass-on effects between direct and indirect purchasers can be analysed along the lines set out in section 3.5.

Two caveats, however, are specific to the exclusionary context. First, the phased structure of exclusionary abuse complicates the choice of a reference period. During phase one, the phase of exclusion of rivals, purchasers may not have been harmed at all or may even have benefited from lower prices, for instance, under a predatory pricing or margin squeeze strategy. The harm typically materialises only in phase two, the exploitation phase that begins once the competitors have been excluded or marginalised, and the dominant firm exploits the resulting market power. A naive time-based comparison that treats the pre-infringement period as the counterfactual may therefore misstate harm if it ignores the dynamics across phases. The total impact on purchasers should reflect the net effect across phases. Where the abuse takes a form that raises rivals' costs, refusal to deal or other input-foreclosure strategies, prices may already increase in phase one, and the temporal pattern of harm differs accordingly.

Second, all difficulties constructing a credible counterfactual in exclusionary abuse cases, as set out in section 3.6.1, apply equally to purchaser claims. The price that would have prevailed absent the abuse depends on the assumed structure of the counterfactual market, and in particular on whether and to what extent competitors would have remained active. In practice, suitable comparator markets are often unavailable, and the pre-infringement market may not provide a sufficiently informative reference. Purchaser damages claims in exclusionary conduct cases therefore tend to inherit the conceptual problems of the counterfactual analysis from the competitor side, even where the methodological toolkit applied to the price variable is essentially the same as in cartel cases.

3.6.4. Harm to suppliers

Suppliers of foreclosed or marginalised competitors are a further category of potential claimants in exclusionary conduct cases. The harm they suffer arises through two channels. First, the reduced sales of the excluded competitors potentially translate into a reduced demand for their inputs, so that the supplier sells lower volumes than it would have done in the absence of the abuse. The harm takes the form of lost profits on these forgone sales. Second, where the exclusionary conduct weakens the buyer side of the supplier's market, the dominant firm may obtain a stronger bargaining position vis-à-vis its own remaining suppliers, which can translate into lower input prices and therefore reduced supplier margins on the volumes that are still sold.[176]

Methodologically, the quantification of supplier harm closely follows the approach used for competitor claims, since lost profit is again the relevant target variable. The factual development of revenues and costs of the affected supplier is compared with a counterfactual development in which the foreclosed or marginalised competitor would have remained an active buyer. The conceptual problems of the counterfactual analysis set out in section 3.6.1 therefore largely carry over to supplier claims, with the additional difficulty that the supplier counterfactual is conditional on the counterfactual market position of the foreclosed competitor. Where harm arises through increased buyer power of the dominant firm, the analysis instead focuses on the counterfactual input price that would have prevailed in a market with unimpaired downstream competition.

3.7. Further aspects of harm quantification

3.7.1. Apportionment of harm in cartel cases

Typically, once the harm caused by a cartel has been quantified, the question arises of how this harm should be allocated between the different members of the cartel. While it is possible that a single member of the cartel pays the entire damages awarded in a first step, as a result of the individual cartel members' liability under the principle of joint and several liability, those damages must be allocated among the cartelists in a second step. Once the damages award is known, the cartel-internal allocation determines what firms are most affected. While often neglected, this is particularly relevant as the naive approach that would simply determine the allocation on the basis of the sales volume of the individual cartel member over time lacks a solid economic foundation. The Directive stipulates that this allocation is a question of national law, which should respect 'the principles of effectiveness and equivalence'.[177] While this leaves the question open what the appropriate apportionment or sharing rule should be, the Directive further specifies in the context of leniency that an immunity recipient should 'be relieved in principle from joint and several liability for the entire harm and (...) any contribution it must make vis-à-vis co-infringers [should] not exceed the

[176] See Ormosi et al. (2026).
[177] Recital 37.

amount of harm caused to its own direct and indirect purchasers'.[178] The Directive further stipulates that 'the contribution of the immunity recipient should not exceed its relative responsibility for the harm caused by the cartel'.[179] This means that, while immunity applicants are exempted from joint and several liability, they are nevertheless liable, in principle, for the portion of the harm for which they are responsible. While suggesting that this responsibility is to be measured in terms of 'harm caused to its own direct and indirect purchasers', this is incorrect from an economic point of view.

Traditionally, criteria that are employed to apportion the harm are the market shares of cartel members, their respective turnover during the cartel period and also their respective role in the cartel. All these criteria do not, however, directly address the relevant question of what the individual 'contribution' of each cartel member to the overall harm was, that is, the harm that an individual cartel member is responsible for. In this context, approaches from the theory of cooperative games, in particular axiomatic bargaining theory could be applied to deal with this important problem. One of the major research questions in axiomatic bargaining theory revolves around team production and the question of how gains resulting from a joint project should be divided. This theory also addresses the question of common cost allocation on different products and the apportionment of a jointly caused harm.[180]

Many of these models are axiomatic, that is, they state several properties that such a division has to satisfy. Examples of such solution concepts are Shapley value, the Kalai-Smorodinsky solution or the nucleolus of a game.[181] For problems of division of a jointly generated gain, and also of a jointly caused harm, in particular the Shapley value has been successfully applied to many different problems. The idea of this solution concept is based on the marginal contribution of a player to a coalition, that is, in the context considered here, the additional harm that a firm causes if it joins a (partial) cartel. As a measure for harm, the decrease in total welfare, the decrease in consumer welfare (the sum of price and quantity effect) or the price effect of a cartel could be applied. For each firm, all marginal contributions are considered, that is, the additional harm caused by this firm if it were to join all possible partial cartels. These marginal contributions are added up and divided by the number of partial cartels to yield the average marginal contribution. Thus, the Shapley value is a concept that effectively formalises the idea

178 Recital 38.

179 Ibid.

180 For a survey on cooperative game theory see Peleg and Sudhölter (2007) or Chakravarty et al. (2015). On joint cost distribution see, e.g. Young (1994). On the division of a jointly caused harm see Dehez and Ferey (2013).

181 See Shapley (1953), Schmeidler (1969) and Kalai and Smorodinsky (1975).

that each member's share of the harm caused by a cartel should reflect the contribution that this member has made to the overall harm.

The Shapley value has been applied to models of cartels in markets with homogeneous goods and quantity competition, and in markets with differentiated products and price competition.[182] It could be demonstrated that in both cases an apportionment of the overall harm caused by the cartel is different from the usual rule typically used to apportion the harm such as an attribution of responsibility based on the volumes sold. For example, in a Cournot-model, the market shares in times without the cartel are a better approximation of the Shapley value than the volume sold or the market shares during the cartel.

For analysts tasked with quantifying harm in a specific case, the apportionment question has two practical implications. First, the choice of apportionment rule should be made transparent and economically justified, rather than defaulting to the conventional but unfounded use of cartel-period sales volumes or market shares. Second, where data and market structure permit, an approach based on marginal contributions, such as the Shapley value applied to a parameterised model of the relevant market, provides an economically meaningful benchmark against which the implication of simpler rules can be assessed. The level of detail required will depend on the legal and procedural context, in particular on whether apportionment is contested between cartel members or determined by the court based on national law.

3.7.2. Compounding and discounting harm

The following section discusses the economic rationale for applying interest and compounding interest payments on harm suffered. More detailed accounts of how interest is calculated and what different interest regimes in Europe are can be found in Maier-Rigaud et al. (2016).[183]

Harm caused by a competition law infringement occurs at a different point in time than the payment of compensation to the injured party. To put the harmed party in the position it would have been absent the infringement, the monetary value of the harm must be expressed at a common point in time, usually the time of compensation. This

[182] See Schwalbe (2013), Maier-Rigaud and Schwalbe (2017), and Napel and Oldehaver (2015) for applications to different market structures.

[183] Maier-Rigaud et al. (2016) also contains a comparison with the US regime. See also Maier-Rigaud (2017).

requires adjusting historical harm figures forward and, where harm extends into the future, expected future harm backward, using an appropriate rate of interest.[184]

The economically appropriate rate of interest depends on whether the harm is known with certainty or remains uncertain at the time of calculation. Where the harm figure is certain, for instance an overcharge that has already been paid, the risk-free rate of interest is appropriate. Where the harm figure is uncertain, for instance, lost profits that depend on how the firm would have performed absent the infringement, a risk-adjusted rate that reflects risk borne by the harmed party should be used. This is typically the cost of capital of the harmed firm.[185]

Building on these two principles, two perspectives can be distinguished when lost profits are at stake. The *ex ante* approach takes the perspective of the time of the infringement, when harm was still uncertain. The *ex post* approach takes the perspective of the time of compensation, when harm has materialised and is known.

Consider, for example, the case of a firm that has been forced to exit a market due to an infringement at a single point in time. Lost profits, however, accrue from that point until compensation is paid. Under the *ex ante* approach, the harm corresponds to the expected lost profit at the time of the infringement. Since these expected profits were uncertain at that point, they must be discounted to the time of the infringement using a risk-adjusted rate of interest, such as the costs of capital of the harmed party.[186] The resulting amount is then carried forward to the time of compensation using the risk-free rate, since the figure is no longer subject to any uncertainty.

Under the *ex post* approach, however, only the harm that actually materialised is considered. The realised harm of each period is carried forward to the time of compensation using a risk-free rate. In the case of an on-going infringement, as, for example, in the case of a price cartel, the differences between the two approaches disappear, since the harm accrues continuously and can be observed period by period.

An *ex post* assessment needs to account for after-effects, such as ongoing harm from a cartel or abuse that extends beyond the infringement period into the future. Since such

[184] The basic idea is that a euro received today is not equivalent to a euro received in the past or in the future. A lost euro in the past represents not only the original amount, but also foregone returns it could have generated, and a euro expected in the future is worth less today because of the time value of money. The rate of interest is the tool by which these adjustments are made.

[185] Both approaches aim to put the harmed party in a position it would have been absent the infringement. They differ, however, in how the uncertainty surrounding lost profits at the time of the infringement is handled.

[186] The cost of capital reflects the return that investors would have required to bear the risk associated with the firm's profits. Using this rate ensures that the harmed party is compensated not only for the expected lost profit but also for having borne the underlying risk.

future harm is uncertain at the time of compensation, it should be treated using the *ex ante* logic and discounted to present value using the cost of capital of the harmed firm.[187]

[187] Note, however, that eventual remedies imposed by the competition authority may mitigate or fully reverse these after-effects.

4. Conclusion

The quantification of harm remains one of the most demanding tasks in applied competition economics. At its core, it requires the construction of a credible counterfactual, a hypothetical market outcome that by definition never occurred and cannot be observed directly. As this paper has sought to demonstrate, that task cannot be reduced to a mechanical application of econometric methods. The methods are only as reliable as the theoretical foundations on which they rest. Market theory determines which price determinants must be controlled for, which comparators are valid, and at what level of aggregation the data should be analysed. The theory of harm identifies how the conduct unfolded and where effects should be expected, over what period, and why the estimated effect can be interpreted as harm caused by the specific infringement. Without both, even technically sophisticated econometric analysis risks generating estimates that are statistically precise, but economically uninterpretable.

Against this background, the paper has developed the major approaches to harm quantification in a unified framework, using a consistent illustrative example to make visible how methodological choices and underlying assumptions shape the resulting estimates. The same counterfactual logic extends to further harm channels, including umbrella effects and pass-on, where specific estimation challenges arise but the conceptual framework remains the same. Harm in exclusionary conduct cases remains more complex. The phased structure of harm, the need to construct counterfactuals that account for competitive dynamics over time, and the interaction with regulatory remedies all make quantification substantially more difficult than in cartel or exploitive abuse cases, and further methodological development in this area remains necessary.

Several challenges cut across all infringement types. Harm cannot in general be estimated with precision, as point estimates imply a degree of certainty that is rarely warranted given the inherent unobservability of the counterfactual and the sensitivity of results to modelling assumptions. Expressing harm as an interval, with upper and lower bounds that naturally emerge from variation in estimation methods, comparators, or key assumptions, is therefore preferable to relying on a single figure. Sensitivity analysis and methodological pluralism strengthen robustness and make underlying uncertainty transparent. Finally, while damages litigation has historically focused on price overcharges to direct purchasers, a complete assessment of harm requires considering quantity effects, upstream and downstream propagation, and the full circle of potentially affected economic actors set out in section 2.

The field continues to evolve. Growing data availability, advances in causal econometrics, and an expanding body of case experience are progressively raising both the methodological standards and the practical expectations in damages proceedings. The framework developed in this paper, grounded in economic theory, illustrated through a consistent practical example, and applied across a range of infringement types and harm channels, is intended to provide a foundation that is both analytically rigorous and practically useful for navigating this landscape.

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