Testing for Price-Fixing Effects: A Difference-in-Difference Approach

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Abstract

Firms in an industry sometimes collude to "fix" prices, by raising or lowering price away from its competitive market level. Price fixing can harm competition and consumers, but may be hard to distinguish from other sources of price variation in the marketplace. For this reason, careful measurement and testing of price fixing overcharge effects can be important for determining guilt, liability, and damages in price fixing cases. The econometrics literature on price fixing effects focuses on two approaches: (a) time series regression models in which effects represented by dummy variables, (b) gaps between actual price and that forecasted from regression models in a pre-incident period. Both approaches face challenges when the relevant regression model is complex. An alternative, considered here, is to compare pre- and post-incident prices in the suspect industry to those in a comparable but non-suspect industry. When feasible, this "difference-in-difference" approach provides a simple alternative to existing methods, with a particular sort of resistance to model cherry-picking by unscrupulous economist experts.

Key words: antitrust, price-fixing, estimation, hypothesis testing, difference-in-difference method, regression model.

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1 Introduction

Firms in an industry sometimes collude to "fix" prices, by raising or lowering price away from its competitive market level.[2] Price fixing can harm competition and consumers, but may be hard to distinguish from other sources of price variation in the marketplace. For this reason, careful measurement and testing of price fixing effects can be important for determining guilt, liability, and damages in price fixing cases.

The econometrics literature on price fixing effects focuses[3] on two approaches:

1. Classical regression: Time series regression models of market price in which effects represented by dummy variables, estimated by ordinary least squares on pre-collusion and with-collusion periods.

2. Cross-validated regression: Gaps between actual price and that forecasted from regression models estimated on the pre-collusion period and evaluated by least squares on the with-collusion period.

The idea in approach #1 is to use a the econometrician's favorite tool, the regression model,[4] to specify and test the ceteris paribus effect of collusion on market price. To isolate the effect of collusion, the econometrician can include as additional regressors those variables that tend to shift supply and demand in a given market, including the price of substitute or complement goods, and production or input costs. Depending on the market there may be many such factors, not all of which are represented by existing data. For this reason, developing a useful model may be challenging. Also, a search among candidate regressors may produce a variety

[2]An early U.S. case of alleged price fixing is *United States v. E. C. Knight Company* in 1895, sometimes called the "Sugar Trust Case," see Gilbert (2018, Chapter 1) for discussion.

[3]See Rubindfeld and Steiner (1983), White, Marshall, and Kennedy (2006), Rubinfeld (2008), Bolotova (2009), McCrary and Rubinfeld (2014), and Deng (2019).

[4]See for example the textbook by Wooldridge (2010).

of test results for price-fixing. The possibility of “cherry picking” a model, to support a claim of price-fixing or no price fixing, presents a problem in cases where economist experts are unscrupulous.

To address the problem of cherry-picked models by unscrupulous economist experts, White, Marshall, and Kennedy (2006) propose the approach #2 listed above, whereby models are estimated on pre-collusion data and then used to forecast price in the with-collusion period. In econometric terms, this approach is a form of cross-validation, with a “training” sample being the pre-collusion data and the validation sample being the with-collusion data. Models that achieve a good fit on the training sample may not predict well on the validation sample. For this reason, attempts to cherry-pick a model on the training sample will have limited success in predicting the validation sample. It remains possible to cherry-pick a model by searching among those that predict reasonably well and also support the desired claim (price-fixing or no price-fixing). In other words, the unscrupulous economist expert may achieve their goal using either of the econometric approaches (1 or 2), and the cherry picking problem may persist if the economist has access to many regressors with which they can stock their models.

With cherry-picking associated with an abundance of candidate regressors, a possible way to reduce cherry-picking econometric bias is to somehow restrict the number of regressors. For markets generally, the forces of supply, demand, and government regulation provide many plausible variables that could serve as regressors, and the economic theorist may find that price-fixing regression models tend to contain too few regressors rather than too many.[5] If a reduction in cherry-picking bias is to be achieved via a restriction on regressors, this should be done in a way that somehow leverages additional information.

The present work compares pre-collusion and with-collusion prices in the suspected price-

[5]The Appendix to this paper includes a brief review of basic economic concepts relevant to testing for price fixing effects. See Blair and Kaserman (2009), Kaplow (2011), Gilbert (2018) and Gilbert (2020) for detailed discussions of price fixing law and economics.

fixing industry to those in a comparable but non-suspect industry. When feasible, this approach provides a simple alternative to classical and cross-validated regressions that focus only on the suspected industry. If an econometrician can find a comparable non-suspect industry then cross-industry comparisons of price changes (over time) may reasonably represent evidence of price-fixing, with greatly reduced need to add regressors to the model. The reduced regressor load affords fewer opportunities for cherry-picked econometric results. Of course, the unscrupulous economist can seek out opportunties to game any methodology, and for the difference-in-difference methodology the fraud may cherry-pick among comparable industries. If sufficiently many such industries exist, difference-in-differences may offer limited resistance to cherry-picking. The most promising applications may be where there are few comparable industries.

The difference-in-difference econometric methodology, applied to price fixing, is a straightforward combination of two empirical methods in price-fixing analysis: the "lookback" method, whereby price-fixing is assayed by comparing with-collusion and pre-collusion prices, and the "yardstick" method which compares with-collusion price in the suspect industry to that in a comparable non-suspect industry.[6] The difference-in-difference method could also be called a lookback+yarstick method of testing price fixing, and this may be a useful convention for pracitioners in antitrust law and economics.

There is some irony to proposing another method of testing for price-fixing, since a cherry-picking economist may respond by picking among an expanded set of methods, worsening the bias problem. Whatever is the list of reasonable methods, a possible convention is to require that evidence for (or against) price-setting should be comparable across the different methods. This consistency convention, which is compatible with the publishing standards of highly ranked peer-reviewed economics journals, provides further robustness to cherry-picking. It also can make it harder to establish a clear case for or against price-fixing, but

[6]See McCrary and Rubinfeld (2014).

an imposition that reduces the quantity of clear findings while increasing quality, a result that may sit well with law and economics scholars.[7]

The remainder of this work is organized as follows. Section 2 describes the difference-in-difference method of testing for price-fixing effects, Section 4.5 compares the method to classical and cross-validated within-industry regression. Section 4.6 concludes, and an Appendix contains a brief review of relevant antitrust economics principles.

2 Testing for Price-Fixing Using Lookbacks, Yardsticks, and Difference-in-Differences

To test for price-fixing, let Y_{1t} be the price in the suspect market in time period t, and let Y_{2t} be the price in a non-suspect market for a comparable good in period t. For example, if price-fixing is limited to a particular U.S. state, say California, a comparable market may be one (or more) markets regionally near California, such as those found in adjacent states. Alternatively, a comparable market may be for a substitute for the good whose market is suspect.[8]

Suppose that price-fixing collusion is suspected in market 1 during periods $t = 1, 2, ..., T$, for some number T. For example, these may be the $T = 24$ months January 2016 to December 2017. Suppose that price Y_{1t} is observed in the collusion period(s) $1, ..., T$ and also in previous periods $t = -(P+1), ..., 0$, with P the number of previous periods. For example,

[7] A consistency convention, like every other known stratagem devised to thwart cherry-picking, is imperfect. Requiring the econometrician to produce all data and computer code, used in a project, may also help, but can be hard to verify. See Christensen and Miguel (2018) for recent discussion.

[8] Each of these examples is subject to problems. First, California is much larger than surrounding states, and this may create challenges when using the surrounding states' markets as a "yardstick" for California's market. Second, if a perfect substitute's market is to serve as a yardstick, a problem arises since the availability of a perfect substitute would thwart any attempt at price-fixing, so a relevant substitute would have to be (sufficiently) imperfect to be consistent with price-fixing. Generally, the selection of any yardstick benefits from a structural economic understanding of the relevant markets.

these may be the 24 months preceding the collusion period, January 2014 to December 2015, in which case $S = 23$ and $t = -23, -22, ..., 0$.

For market 2, which is not suspected of collusive price-fixing, suppose that price Y_{2t} is observed for $t = -(P+1), ..., T$, like Y_{1t}. Given price data Y_{1t}, Y_{2t}, some information is available for assessing price fixing in market 1. One simple approach, the lookback method, compares the sample average $\bar{y}_{1B}$ of Y_{1t}, on the with-collusion period "B", to the sample average $\bar{y}_{1A}$ on the pre-collusion period "A". A second simple approach, the yardstick method, compares market 1 suspect outcome $\bar{y}_{1B}$ to market 2 outcome $\bar{y}_{2B}$ in the same period.

Example 1: For a suspected collusion period January 2016 - December 2017, let average price in market 1 be \$2 per unit, and let average price in market 2 be \$1.70 per unit. For the pre-collusion period January 2014 - December 2015, let average prices be \$1.50 in market 1 and \$1.60 in market 2, respectively.

In Example 1, $\bar{y}_{1B} = 2$, $\bar{y}_{1A} = 1.5$, $\bar{y}_{2B} = 1.7$ and $\bar{y}_{2A} = 1.6$. The fact that $\bar{y}_{1B}$ is 50 cents higher than $\bar{y}_{1A}$ indicates elevated price in the suspected collusion period, relative to the previous period. Also, the fact that $\bar{y}_{1B}$ is 30 cents higher than $\bar{y}_{2B}$ indicates elevated price in the suspect market during the collusion period, relative to the non-suspect market. There may be non-collusion explanations for the differences price averages. An increase in market demand may raise price from the pre-collusion period A to the with-collusion period B, Regional failures in electric power generation may cause elevated costs and price in market 1 in period B, but not in market 2.

Consider now a combination of lookback and yardstick approaches, the difference-in-difference approach, that focuses on a statistic D defined as:

$$D = (\bar{y}_{1B} - \bar{y}_{1A}) - (\bar{y}_{2B} - \bar{y}_{2A}),$$

In Example 1, $D = (2-1.5)-(1.7-1.6) = 0.4$, and indicates that the average price increased 40 cents more in the suspect market than in the non-suspect market, in period B. If the only reasonable explanation for this 40 cent difference in differences is price-fixing, then D may supply evidence of collusion.

Random variation in price can create differences among sample averages of price in different periods and markets. For this reason, when testing for price-fixing via the difference-in-differences statistic D, it is useful to adjust for sampling variability. Let s_D the standard error of D, an estimate of the population standard deviation of the sample statistic D. Also, let $\mu_{1A}, \mu_{1B}, \mu_{2A}, \mu_{2B}$ be the population mean values for prices in market 1 (A and B periods) and market 2 (A and B), with the understanding that each observation within a particular market and period has the same population mean. The parameter of interest is $\delta = (\mu_{1B} - \mu_{1A}) - (\mu_{2B} - \mu_{2A})$, and the null hypothesis is $H_0 : \delta = 0$. To test H_0, the z statistic is $z = D/s_D$ which, under simplifying assumptions, has a probability distribution that is approximately standard normal under H_0 in large samples – when T and P are large.

Example 1, Continued: Suppose that price has the same population variance in each market and time period. Define sample deviations $e_{iBt} = y_{iBt} - \bar{y}_{iB}$ for market $i = 1, 2$ and each period t in B. Similarly, define $e_{iBt} = y_{iBt} - \bar{y}_{iB}$ for each market and each period t in A. The sum of squared deviations or errors is then $SSE = \sum_{iAt} e^2_{iAt} + \sum_{iBt} e^2_{iBt}$, which provides a "pooled" variance estimate $s^2_y = SSE/(2(P+T)-4)$. A suitable standard error s_D of the difference-in-difference statistic D takes the form: $s_D = s_y/\sqrt{2(P+T)}$. Let $s_y = \$1$. Then, from earlier assumptions, $P = T = 24$, so $s_D = 1/\sqrt{2(24+24)} = 0.103$ and, with $D = 0.4$, the price-fixing test statistic is $z = D/s_D = 0.4/0.103 = 3.88$.

To carry out a z test of the no-collusion null hypothesis H_0 versus the alternative $H_1 : \theta \neq 0$, reject H_0 at significance level α if $|z| > z_{\alpha/2}$, with $z_{\alpha/2}$ the standard normal critical value for which there is probability α that a standard normal variable Z exceeds $\alpha/2$ in absolute terms. In Example 1, if the significance level is 5 percent then the z critical value is 1.96 and since the $|z| = 3.88 > 1.96$ the test rejects the null hypothesis in favor of the price-fixing alternative.

The difference-in-difference method, with its lookback and yardstick perspectives, is a very simple econometric method. One advantage of this simplicity is that the sense in which the test might actually shed light on price-fixing phenomena may be easy to determine, especially with some structural knowledge of the markets in question. The method can be more complicated when there are differences in variability across periods A and B and/or markets 1 and 2, as then the standard error s_D is more complicated than in Example 1, but this is a routine econometric exercise.[9] Another source of complexity is correlation among prices over time, but this also amounts to routine modification of s_D.[10]

For application to tests of price-fixing, the difference-in-difference method is clearly rele-

[9] For recent discussion, see Deng (2019).

[10] To say that heteroskedasticity and autocorrelation can be fully addressed by routine econometric methods would be an overstatement, but such methods are a starting point in addressing these issues.

vant as it builds in a natural way on lookback and yardstick methods which are well-known in price-fixing analysis. It would be perhaps surprising if a variant of the difference-in-difference method were not implicitly considered in some price-fixing cases, and the present work encourages such efforts by addressing this method explicitly.

3 Comparison to Regression Methods

The difference-in-difference method can be stated in terms of a regression model:

$$Y_{ijt} = \beta_0 + \beta_1 D_{i,jt} + \beta_2 D_{j,it} + \beta_3 D_{i,jt} D_{j,it} + \varepsilon_{ijt} \tag{1}$$

with $D_{i,jt}$ a dummy variable for observations (ijt) in market $i = 1, 2$, $D_{i,jt}$ a dummy variable for observations (ijt) in period $i = A, B$, ε_{ijt} a regression error term, β_0 an intercept parameter, and the remaining β terms slope parameters. The difference-in-difference parameter δ, in the regression model, coincides with the slope β_3 for the "interaction" term $D_{i,jt}D_{j,it}$.

If desired, one can carry out a difference-in-difference test by estimating the regression model (1) via ordinary least squares, and using a z or t statistic for the interaction effects slope β_3. This modelling approach is unnecessarily complicated in Example 1 discussed earlier, but may be useful in applications where prices Y_{ijt} are thought to be heteroskedastic or autocorrelated.

Whether or not the regression model (1) becomes useful when carrying out difference-in-difference tests for price-fixing, the model itself provides a point of comparison between the difference-in-difference approach other approaches that can be stated as regression tests. As discussed earlier, relevant regression models can contain a variety of regressors meant to track market demand and supply. The difference-in-difference approach provides a regression model with few regressors, and may provide a useful supplement to price-fixing tests based on larger models.

4 Conclusion

This paper points out the possible usefulness of combining lookback and yardstick approaches to price-fixing tests, via the "difference-in-difference" method. An example illustrates the point, and future work may usefully provide a more in-depth example in which the difference-in-difference method is applied alongside the familiar lookback regression approaches discussed in the Introduction, with some attention to the problem of cherry-picked regression models. The Appendix to this paper gives some additional economic background, and future work may further explore the strengths and weaknesses of the difference-in-difference price-fixing tests from the standpoint of economic theory.

Appendix: Review of Price-Fixing Economics

Economists study markets and how market supply and demand forces affect the price and quantity of goods sold in the marketplace. One simple model of markets is the perfect competition equilibrium model, in which there are many buyers and many sellers, each having an negligible effect on market equilibrium price. When real-world markets behave in ways similar to the perfect competition equilibrium model, economists generally interpret the result as socially desireable and efficient, except in special circumstances.[11]

According to Black's Law Dictionary (10th edition),[12] price-fixing is the "artificial setting or maintenance of prices at a certain level, contrary to the workings of the free market." While many agents might in principle be involved in the artificial setting of prices in a marketplace, price-fixing commonly refers to the setting of prices by producers or sellers in the market, multilaterally – with more than one seller involved.

Economists often interpret collusive behavior of firms in terms of profit-seeking. Sellers of a good or service typically want to earn a profit. With profit equal to revenue minus cost, profit is higher when revenue is higher, all else equal. If all units of a good sell at the same price, a firm's revenue equals price times quantity sold, and collusion among firms to influence price aims to increase profits. Collusion may involve an overcharge or artificial price increase, but could instead involve an undercharge – so as to drive a competing firm out of business, making way for future overcharges. Generally, price-fixing strategies are collusive efforts to increase profit, and the choice of strategy depends on market structure and dynamics.

The government has agencies whose job includes the detection and prosecution of price-fixing schemes. The U.S. Department of Justice ("DOJ") is empowered to investigate and

[11]The existence of externalities, or the failure of goods to be rival or excludable, can generate social inefficiencies in competitive market outcomes.

[12]Black's Law Dictionary is a reference work that has been in print for more than a century, and is often cited in court cases.

bring charges against firms for price-fixing. The U.S. Federal Trade Commission ("FTC")[13] also investigates price-fixing, and attorney generals of U.S. states may also join in price-fixing investigations and cases. Firms which may be affected by other firms' price-fixing can file lawsuits in state and federal courts. Cases that go to trial commonly appear in federal court.

Price fixing can harm competition and consumers, but may be hard to distinguish from other sources of price variation in the marketplace. For this reason, careful measurement and testing of price fixing effects can be important for determining guilt, liability, and damages in price fixing cases. Two basic methods of price comparison are the "lookback" and "yardstick" methods,[14] The lookback method compares market prices in the alleged collusion period to prices before that period, with the idea that collusion tends to alter price from its previous level. The yardstick method compares price in an allegedly collusion-affected market to a collusion-free market for a similar good, with the idea that collusion tends to drive a wedge between prices in the two markets.

specifically the difference in lookback time comparisons across a yardstick of two firms or industries. In econometric terms, this combination of time series and cross section data is a "difference in difference" approach to testing for collusion. Success of this approach depends on the extent and quality of data, and merits consideration of industry composition and dynamics. A variety of tests may be useful in this setting, discussed here and illustrated in some stylized examples.

4.1 U.S. Antitrust Law

The social efficiency of competitive markets, and the inefficiency of anti-competitive market outcomes, is key to the economic interpretation of U.S. antitrust legislation – including the Sherman Act of 1890 and the Clayton Act of 1914. The Sherman Act establishes that naked

[13]On its website, the FTC defines price fixing as "an agreement (written, verbal, or inferred from conduct) among competitors that raises, lowers, or stabilizes prices or competitive terms."

[14]See Blair and Kasserman (2009).

price fixing, by which some firms conspire to drive price way from its competitive market level, is necessarily or "per se" illegal.

The Sherman Anti-Trust Act, passed by the 51st U.S. Congress in 1890, contains as its Section 1 the following:

> Every contract, combination in the form of trust or other-wise, or conspiracy, in restraint of trade or commerce among the several States, or with foreign nations, is hereby declared illegal. Every person who shall make any such contract or engage in any such combination or conspiracy, shall be deemed guilty of a misdemeanor, and, on conviction thereof, shall be punished by a fine not exceeding five thousand dollars, or by imprisonment not exceeding one year, or by both said punishments, at the discretion of the court.

Price-fixing, as a contract or conspiracy to restrain trade, falls under the heading of the Sherman Act's Section 1. Some states have their own antitrust acts, such as: 740 ILCS 10/Illinois Antitrust Act.

Since the Sherman Act's passage in 1890, many price-fixing cases have been tried in courts. One such case reviewed by the U.S. Supreme Court is: U.S. v. Socony-Vaccum Oil Co. 310 U.S. 150, 225-26 n. 59, 60 S.Ct. 811, 845 n. 59 (1940).[15] The Court's written opinion on this case includes the following:

> "Price-fixing agreements may or may not be aimed at complete elimination of price competition. The group making these agreements may or may not have the power to control the market. But the fact the the group cannot control the market prices does not necessarily mean that the agreement as to prices has no utility to the members of the combination. The effectiveness of price-fixing agreements is dependent on many factors, such as competitive tactics, position in the industry,

[15] See the last section of these notes for some additional oft-cited cases.

> the formula underlying price policies. Whatever economic justification particular price-fixing agreements may be thought to have, the law does not permit an inquiry into their reasonableness. They are all banned because of their actual or potential threat to the central nervous system of the economy."

From an economic standpoint, this Supreme Court opinion and Section 1 of the Sherman Act are noteworthy in the scope of behavior they address. Even if colluding firms can't inflate price across a whole market, they may still act to boost their own profits by restraining trade.

Firms in the same market can act to coordinate pricing decisions, leading to horizontal price fixing. Also possible is coordination of pricing decisions across vertically integrated markets, but since the U.S. Supreme Court decision on State Oil Co. vs. Khan in year 1997, vertical price fixing is no longer viewed a *per se* violation of the Sherman Act.

4.2 Price-fixing in a Simple Market Model

Consider a market for a good, with each unit of the good selling at the same price, and with many buyers – each paying the same price. Let $D(Q)$ be the market demand curve, such that buyers will buy an amount Q of the good when faced with a price $D(Q)$. Suppose that the law of demand holds, in which case $D(Q)$ is a downward-sloping curve. Also, suppose that firms each supply the good with a constant marginal cost MC associated with each unit produced.

The competitive equilibrium price P_c, in this market, is such that price equals marginal cost: $P_c = MC$, and the competitive equilibrium quantity Q_m is such that $P_m = D(Q_m)$. In other words, the competitive equilibrium outcome is at the crossing point of MC and demand curves, as in Figure 1 below.

If firms collude, they may act to fix price at a level different from competitive price P_c.

If they all agree to charge the same price, the fixed price that maximizes their collective price is the "monopoly" price P_m at which their collective marginal revenue $MR(Q)$ equals marginal cost MC. With $MR(Q) = d/dQ(PQ) = d/dQ(D(Q)Q) = D'(Q) + D(Q)$, the law of demand implies that $D'(Q) < 0$, in which case $P_m > P_c$. Also, the quantity Q_M sold under collusion is less than the quantity Q_c sold in perfect competition, as in Figure 1.

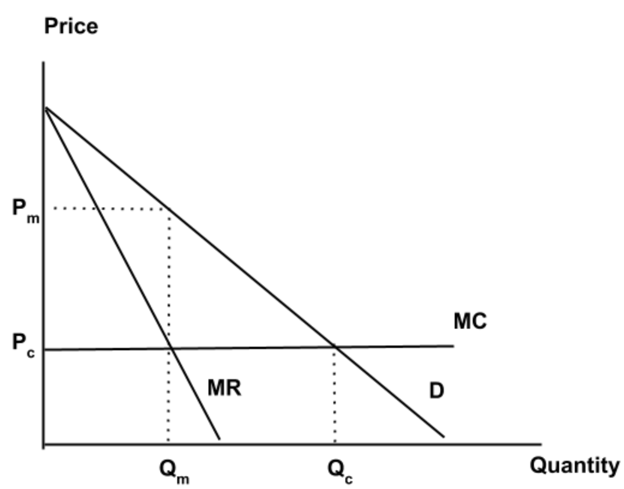

Figure 1: Market Outcomes With and Without Price-Fixing

4.3 Price Overcharge in a Simple Market Model

In a market with perfect competition, each firm charges the same price, and there is no harm if one firm sets their price equal to another firm's price. A price overcharge is collusive if it entails some agreement among firms, and is anticompetitive if it somehow restrains trade. In the simple model described earlier, the price overcharge by colluding firms equals the difference between monopoly price P_m and perfectly competitive price P_c, multiplied by quantity sold:

$$\text{overcharge} = (P_m - P_c)Q_m.$$

To calculate this overcharge, it's enough to know: (a) the market demand curve, and (b) the marginal cost of production. A benefit of working with a simple model is that it helps to connect overcharges to buyer and seller behavior in a clear way. A limitation of simple models is that they may miss important types of behavior, and may otherwise be difficult to apply.

4.4 Overcharge in a dynamic market model

The simple market model, described earlier, describes a market outcome taking place at a single point in time. For a market that exists over a period of time, buyer and seller behavior can change, as can seller costs. Entry and exit, by sellers and buyers, can occur, as can changes in market characteristics such as sales tax rates, subsidies, and tariffs.

Central to measuring overcharge is the possibility that market demand shifts over time. In a perfectly competitive marketplace, an increase in demand over time can increase market price, as in Figure 2 shown below.

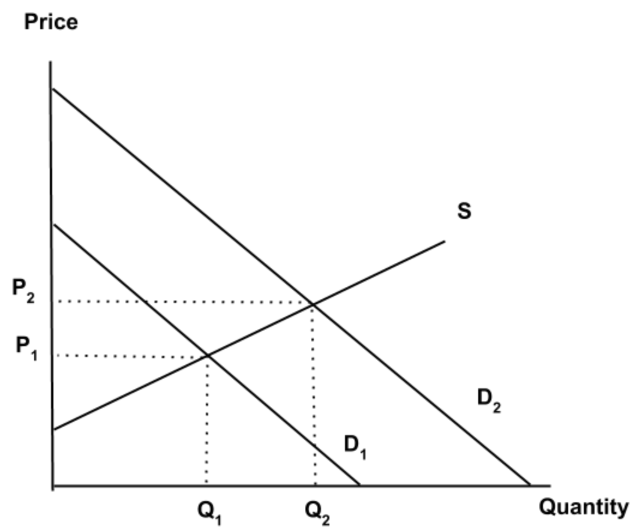

Figure 2: Dynamic Market Outcomes With a Demand Shift

In Figure 2, an increase in demand causes the competitive equilibrium price to rise from P_1 to P_2. If such a price increase were to take place during a time of suspected price-fixing, the price hike $P_2 - P_1$ might be mistaken for a collusive price overcharge.

The rise in competitive equilibrium price from P_1 to P_2 relies on an upward-sloping industry supply curve. The supply curve may be upward sloping if each firm faces increasing marginal costs of production. This is a different situation than the one assumed in the simple market model discussed earlier, wherein marginal cost was constant for all units produced. With constant marginal cost, the supply curve S becomes horizontal and there are no effects of demand change on price: an increase in demand raises quantity traded but not price.

The situations depicted in Figures 1 and 2 illustrate the importance of having some specific of understanding supply and demand in an industry, when trying to measure an overcharge associated with price-fixing. Ideally, industry data permit the identification of the demand curve and firm costs at each date, from which overcharge can be measured at each date. In reality, data limitations may constrain the economist's ability to measure overcharges.

For a market that functions during periods $t = 1, 2, ..., T$, let P_t be the price in the market at time t. As earlier, assume that a single homogeneous good is traded in the market, with each good selling at the same price.

To test for an overcharge, an economist can use an econometric model of price. One such model is a multiple linear regression model of price on a "dummy" variable D_t, which equals 1 at dates with the alleged collusion period and equals 0 at all other date, and on some "control" variables X_t that are distinct from X_t but may also affect price. The classic multiple regression model takes the form:

$$P_t = \alpha + \beta D_t + \gamma' X_t + \varepsilon_t,$$

for $t = 1, ..., T$, with intercept parameter α, slope coefficient D_t for the overcharge effect, a $K \times 1$ vector X_t of controls, a $K \times 1$ vector γ of slope coefficients for control, and a random error ε_t which is normal with population mean 0 and some population variance σ_ε^2. Also, in the classical model the errors ε_t are independent and identically distributed (i.i.d.) over times $t = 1, ..., T$.

The classical regression model is commonly estimated by ordinary least squares (OLS), producing an OLS estimate $\hat{\beta}$ of overcharge per-unit. OLS also provides a formula for the standard error of $\hat{\beta}$, and a t statistic – the ratio of slope estimate and its standard error. In the absence of overcharge, the t statistic has a known probability distribution in the classical regression model. Using this t distribution under the null hypothesis of no overcharge, a

t test for overcharge rejects the null if the t statistic's value exceeds the relevant critical value.[16]

Additional information may be available on markets that lie beyond the alleged price-fixing conduct. This data may be included in a "panel data" model of market price:

$$P_{it} = \alpha_i + \beta D_{it} + \gamma' X_{it} + \varepsilon_{it},$$

with P_{it} the price at time t in market i, for $i = 1, 2, ..., N$ markets, and with α_i a market-specific individual "effect". Suppose that $i = 1$ is the single market in which price-fixing is alleged, in the panel setting, D_{it} equals 1 if $i = 1$ and t falls in the alleged price fixing period, and equals 0 otherwise.

As in the single-market regression model, the panel data regression model provides a per-unit overcharge estimate $\hat{\beta}$ via OLS, as well as tests for an overcharge.

4.5 Interpreting Tests for Overcharge

A t test for an overcharge provides some information on the relative plausibility of the "no overcharge" and "overcharge" hypotheses. Also, the statistic $\hat{\beta}$ estimates the per-unit overcharge. To estimate the total amount of overcharge, multiply the per-unit overcharge estimate by the market quantity Q.

It is important to put econometric testing evidence in additional perspective. One point to consider is that estimated overcharge effects may contribute only trivially to the actual variation in price over time and across markets. When running regressions, statistics like adjusted R square and root mean squared error shed some light on the ability of the model to explain actual price variation. The same statistics, obtained from a model in which the

[16] The critical value depends on the sample size, the test significance level, and whether the null hypothesis is tested against a one-sided or two-sided alternative.

collusion dummy variable is excluded, may provide insight into the explanatory power of the collusion variable.

Another important point is that some institutional and behavioral analysis may be needed to pick good controls X for inclusion in the model. Such analysis may sometimes suggest controls that are unavailable, making it difficult to put together a useful model. Strategies that attempt to leverage good controls include **difference in difference** and **regression discontinuity** designs. The seminar that goes along with these discussion notes presents some research on these strategies.

4.6 Overcharge Evidence in Relation to Guilt, Liability, and Damages

An econometric test that rejects "no overcharge" in favor of "overcharge", at a commonly-used significance level such as 5 percent, may be an input to establishing guilt, liability, and damages in price-fixing cases. An important point is that a price-fixing overcharge runs afoul of U.S. antitrust law only if there is a demonstrable agreement or contract to collude or conspire.

If firms are found to guilty or liable for price-fixing, they may face "treble damages" that include 3 times the amount of estimated overcharges. For this reason, overcharge estimates can play a major role in price-fixing cases.

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