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Wenqing Li, James F. Nieberding,

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ABSTRACT

In regressions using a semi-logarithmic functional form that include a dummy variable, Kennedy (1981) showed that instead of interpreting the dummy coefficient directly, one needs to "correct" it to estimate the percentage effect of the dummy variable on the dependent variable. In the context of an antitrust application, we show that when using a dummy variable to estimate the overcharge as a percentage of the actual price, one should not apply the correction proposed by Kennedy because doing so will lead to an overcharge estimate with a larger bias.

Keywords: Dummy variable; overcharge; antitrust; bias; reduced-form; collusion; price-fixing

JEL classifications: C22; K21; L4

INTRODUCTION

Antitrust agencies in the USA and other countries have investigated a number of high profile global price-fixing cases in recent years. These schemes have included products and services such as thin film transistor-liquid crystal display

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(LCD) panels, cathode ray tubes, Dynamic random-access memory (DRAMS), vitamins, chemicals, automobile parts, air transportation, ready-mix concrete, and optical disk drives, to name just a few.[1] An important economic issue in these types of cases is to estimate the increase in price of the affected items that can be attributed to the collusive behavior. Economists sometimes use a reduced-form price equation with a dummy variable indicating the collusion period to estimate overcharges resulting from the price-fixing.[2] Because economists frequently use the logarithm of prices and other continuous variables in the regression analysis, there is semi-logarithmic relationship between the logarithm of prices and the collusion dummy variable.

Suppose the coefficient of the collusion dummy variable is α_d in a reduced-form semi-logarithmic price equation. Halvorsen and Palmquist (1980) pointed out that in this functional form the percentage effect of the dummy variable on the dependent variable is $\exp(\hat{\alpha}_d) - 1$, and not merely the coefficient itself. Kennedy (1981) further showed that if $\hat{\alpha}_d$ represents the estimate of α_d, instead of using $\exp(\hat{\alpha}_d) - 1$, one should make a further correction and use $\exp(\widehat{\alpha}_d - \frac{1}{2}\widehat{V}(\widehat{\alpha}_d)) - 1$ to estimate the percentage effect of the dummy variable on the dependent variable (e.g., prices), where $\widehat{V}(\widehat{\alpha}_d)$ is the estimated variance of $\widehat{\alpha}_d$. We call this correction the "Kennedy correction." According to Kennedy, $\exp(\widehat{\alpha}_d - \frac{1}{2}\widehat{V}(\widehat{\alpha}_d)) - 1$ has smaller bias than $\exp(\hat{\alpha}_d) - 1$ because $\exp(\hat{\alpha}_d) - 1$ has a log normal distribution. However, as this chapter illustrates, if one uses a dummy variable coefficient to estimate percentage overcharges as a percentage of the actual price (as opposed to the but-for price), the Kennedy correction is inappropriate because using it will lead to overcharge estimates with a larger bias than if the correction were not used.[3]

THE INTERPRETATION OF THE COLLUSION DUMMY VARIABLE IN OVERCHARGE ESTIMATION

Suppose the reduced-form price equation used to estimate an overcharge is

$$\ln(P_t^a) = \alpha + \alpha_d D_t + \beta_1 \ln(x_{1t}) + \beta_2 \ln(x_{2t}) + \ldots + \beta_k \ln(x_{kt}) + \varepsilon_t \quad (1)$$

where P_t^a is the actual price; D_t is a dummy variable equal to 1 in the collusion period and 0 otherwise; $x_{1t}, x_{2t}, \ldots x_{kt}$ are demand and supply factors that affect the price; and ε_t is the error term which has an *i.i.d.* normal distribution, $N(0, \sigma^2)$.

Let P_t^{bf} represents the price but-for the cartel's collusive activities. Since α_d measures the impact of the collusive behavior, we have

$$\ln(P_t^{\mathrm{bf}}) = \ln(P_t^a) - \alpha_d \quad (2)$$

From Eq. (2), it can be shown that the overcharge as a percentage of the but-for price is

$$\frac{P_t^a - P_t^{\mathrm{bf}}}{P_t^{\mathrm{bf}}} = \exp(\alpha_d) - 1 \tag{3}$$

Eq. (3) is the result derived by Halvorsen and Palmquist.[4] From Eq. (2), the overcharge as a percentage of the actual price can be derived as

$$\frac{P_t^a - P_t^{\mathrm{bf}}}{P_t^a} = 1 - \frac{1}{\exp(\alpha_d)} \tag{4}$$

Since the but-for price is not observable, an overcharge measured as a percentage of it arguably cannot be used to accurately calculate total dollar overcharges in real applications. Instead, one can calculate the overcharge as a percentage of the actual price and apply this percentage overcharge to actual purchases to compute the total monetary overcharge. By way of example, assume that the cartel price is \$125, the but-for price is \$100, and buyers purchased 1 million units of the affected product during the conspiracy. The overcharge percentage would be 20 percent using Eq. (4) (i.e., \$25 is 20 percent of \$125), and the total dollar overcharge would be \$25 million (i.e., \$25 × 1 million, or 20 percent × \$125 million). However, if one were to use Eq. (3) as the overcharge percentage, the overcharge percentage would be 25 percent, and the monetary overcharge would be \$31.25 million if applied to actual purchases of \$125 million, an amount that exceeds the \$25 per-unit overcharge multiplied by 1 million units sold. Therefore, an overcharge as a percentage of the actual price is appropriate to compute the total overcharge (in dollars) when multiplying the percentage overcharge by buyers' actual purchases.[5]

THE KENNEDY CORRECTION

Let $\hat{\alpha}_d$ represents the ordinary least squares (OLS) estimate of α_d from Eq. (1). Because $\exp(\hat{\alpha}_d)$ has a log normal distribution, Kennedy pointed out that one should estimate Eq. (3) using $\exp(\hat{\alpha}_d - \frac{1}{2}\hat{V}(\hat{\alpha}_d)) - 1$ instead of $\exp(\hat{\alpha}_d) - 1$, where $\widehat{V}(\widehat{\alpha}_d)$ is the estimated variance of $\hat{\alpha}_d$. However, as demonstrated below, to estimate Eq. (4), one should use $1 - \frac{1}{\exp(\hat{\alpha}_d)}$ without the Kennedy correction because applying it will increase the bias of the overcharge estimate.

Let X denotes the matrix of the independent variables in Eq. (1) and define B_1 as the absolute value of the bias without the Kennedy correction when using Eq. (4) to calculate an overcharge percentage. We have

$$B_1 = \left| E_X\left(1 - \frac{1}{\exp(\widehat{\alpha}_d)}\right) - \left(1 - \frac{1}{\exp(\alpha_d)}\right) \right| = \left| \frac{1}{\exp(\alpha_d)} - E_X\left(\frac{1}{\exp(\widehat{\alpha}_d)}\right) \right| \tag{5}$$

where E_X represents the expectations operator conditional on X. Jensen's inequality in the context of probability theory implies that $E_X\left(\frac{1}{\exp(\widehat{\alpha}_d)}\right) > \frac{1}{\exp(\alpha_d)}$,[6] therefore,

$$B_1 = E_X\left(\frac{1}{\exp(\widehat{\alpha}_d)}\right) - \frac{1}{\exp(\alpha_d)} \tag{6}$$

Define B_2 as the absolute value of the bias with the Kennedy correction. We have

$$\begin{aligned} B_2 &= \left| E_X\left(1 - \frac{1}{\exp\left(\widehat{\alpha}_d - \frac{1}{2}\widehat{V}(\widehat{\alpha}_d)\right)}\right) - \left(1 - \frac{1}{\exp(\alpha_d)}\right) \right| \\ &= \left| \frac{1}{\exp(\alpha_d)} - E_X\left(\frac{1}{\exp\left(\widehat{\alpha}_d - \frac{1}{2}\widehat{V}(\widehat{\alpha}_d)\right)}\right) \right| = \left| \frac{1}{\exp(\alpha_d)} - E_X\left(\frac{\exp\left(\frac{1}{2}\widehat{V}(\widehat{\alpha}_d)\right)}{\exp(\widehat{\alpha}_d)}\right) \right| \end{aligned} \tag{7}$$

Let e_t denotes the regression residual in Eq. (1) and $S^2 = \frac{e'e}{n-k-2}$ is the estimate of σ^2. Then we have

$$\frac{1}{2}\widehat{V}(\widehat{\alpha}_d) = \frac{1}{2}S^2(X'X)^{-1}_{DD} \tag{8}$$

where $(X'X)^{-1}_{DD}$ is the diagonal element of the matrix $(X'X)^{-1}$ that corresponds to $\hat{\alpha}_d$. Since S^2 is independent of $\hat{\alpha}_d$ we have

$$B_2 = \left| \frac{1}{\exp(\alpha_d)} - E_X\left(\exp\left(\frac{1}{2}\widehat{V}(\widehat{\alpha}_d)\right)\right) E_X\left(\frac{1}{\exp(\widehat{\alpha}_d)}\right) \right| \tag{9}$$

Because $S^2 > 0$ and $(X'X)^{-1}_{DD} > 0$, $\frac{1}{2}\widehat{V}(\widehat{\alpha}_d) > 0$, and hence, $E_X\left(\exp(\frac{1}{2}\widehat{V}(\widehat{\alpha}_d)\right) > 1$. Invoking Jensen's inequality as above, we have

$$B_2 = E_X\left(\exp\left(\frac{1}{2}\widehat{V}(\widehat{\alpha}_d)\right)\right)E_X\left(\frac{1}{\exp(\widehat{\alpha}_d)}\right) - \frac{1}{\exp(\alpha_d)} \tag{10}$$

Taking the difference between Eq. (10) and Eq. (6), we have

$$B_2 - B_1 = \left(E_X\left(\exp\left(\frac{1}{2}\widehat{V}(\widehat{\alpha}_d)\right)\right) - 1\right)E_X\left(\frac{1}{\exp(\widehat{\alpha}_d)}\right) > 0 \tag{11}$$

If we define B_1^U as the absolute value of the unconditional bias without the Kennedy correction and B_2^U as the absolute value of the unconditional bias with the Kennedy correction, it can be shown that

$$B_2^U - B_1^U = E\left(\left(E_X\left(\exp\left(\frac{1}{2}\widehat{V}(\widehat{\alpha}_d)\right)\right) - 1\right)E_X\left(\frac{1}{\exp(\widehat{\alpha}_d)}\right)\right) > 0 \tag{12}$$

since Eq. (11) holds for any X. Therefore, applying the Kennedy correction when Eq. (4) is used to estimate an overcharge percentage increases the bias compared to when the Kennedy correction is not used.

Applying the Kennedy correction to Eq. (3) – where the but-for price is used to estimate an overcharge percentage – results in less bias than if Eq. (3) were used directly.[7] This can be seen as follows. As above, define B_1 as the absolute value of the bias without the Kennedy correction given the matrix X of independent variables in Eq. (1)

$$B_1 = \left|E_X(\exp(\widehat{\alpha}_d) - 1) - (\exp(\alpha_d) - 1)\right| = \left|E_X(\exp(\widehat{\alpha}_d)) - \exp(\alpha_d)\right| \tag{13}$$

Jensen's inequality indicates that $B_1 > 0$. Define B_2 as the absolute value of the bias with the Kennedy correction

$$\begin{aligned} B_2 &= \left|E_X\left(\exp\left(\widehat{\alpha}_d - \frac{1}{2}\widehat{V}(\widehat{\alpha}_d)\right) - 1\right) - (\exp(\alpha_d) - 1)\right| \\ &= \left|E_X\left(\exp\left(\widehat{\alpha}_d - \frac{1}{2}\widehat{V}(\widehat{\alpha}_d)\right)\right)\right| - \exp(\alpha_d) \end{aligned} \tag{14}$$

Taking the difference between Eq. (14) and Eq. (13), we have

$$\begin{aligned} B_2 - B_1 &= E_X\left(\exp\left(\widehat{\alpha}_d - \frac{1}{2}\widehat{V}(\widehat{\alpha}_d)\right)\right) - E_X(\exp(\widehat{\alpha}_d)) \\ &= E_X\left(\frac{\exp(\widehat{\alpha}_d)}{\exp\left(\frac{1}{2}\widehat{V}(\widehat{\alpha}_d)\right)}\right) - E_X(\exp(\widehat{\alpha}_d)) < 0 \end{aligned} \tag{15}$$

This holds as long as $\exp\left(\frac{1}{2}\widehat{V}(\widehat{\alpha}_d)\right) > 1$, or $\widehat{V}(\widehat{\alpha}_d) > 0$.

EMPIRICAL IMPLICATIONS

This section illustrates that use of the Kennedy correction in the context discussed above. Suppose Eq. (1) takes the form of Eq. (16) where Dum_t equals 1 during the cartel period (and 0 otherwise), and price is a reduced-form function of a supply-side factor (S_t), a demand-side factor (D_t), and the quantity of imports of a competing product (M_t).

$$\ln\hat{P}_t^a = \underset{}{2.489} + \underset{(0.0536)}{0.145}\ln S_t + \underset{(0.0468)}{0.134}\ln D_t - \underset{(0.0253)}{0.103}\ln M_t + \underset{(0.1225)}{0.2295} Dum_t \tag{16}$$

Regression Eq. (16) reports the estimates of this illustrative model with the corresponding OLS standard errors in parentheses.[8] The coefficient and t-statistic on Dum_t indicates that prices were elevated during the cartel period relative to the benchmark period. In particular, the percentage overcharge during the cartel period using Eq. (3) with the but-for price as the denominator equals 24.86 percent and 25.80 percent, respectively, with and without the Kennedy correction.[9] The percentage overcharge estimated using Eq. (4) with the actual price as the denominator equals 19.91 percent and 20.51 percent, respectively, with and without the Kennedy correction. Even though the difference with and without Kennedy correction with the actual price as the denominator is only 0.6 percent, when the volume of affected commerce is large, this can lead to relatively large differences in estimated overcharges. For example, if the affected commerce is $5 billion, a 0.6 percent decrease in overcharge due to the incorrect application of Kennedy correction will cause overcharges to be lower by $30 million.

In general, if the estimated coefficient on the cartel dummy variable is relatively small so that the dummy coefficient can only be statistically significant with a small standard error, then the estimated overcharges with and without the Kennedy correction will be similar no matter whether the but-for price or the actual price is used as the denominator in the calculation. On the other hand, if the estimated coefficient on the cartel dummy variable is relatively large and, hence, the dummy coefficient can still be statistically significant even with a relatively large standard error, applying the Kennedy correction can result in non-negligible differences in the estimated overcharges.

For example, Kamita (2010) examined the impact on airfares of the temporary antitrust immunity agreement between two Hawaiian airlines that began on December 1, 2002, and continued through October 1, 2003. When using heavily traveled routes as the control group, the author estimated the immunity period dummy coefficient to be 0.827 with a standard error of 0.153 in a semi-log regression.[10] Using the but-for price as the denominator, the author calculated the percentage change in price to be 129 percent without the Kennedy correction.[11] Given that the standard error of the estimate is relatively large, the overcharge estimates with and without the Kennedy correction are dissimilar. If one uses the actual price as the denominator, the immunity period dummy coefficient implies a percentage change in price of 56.3 percent without the Kennedy correction and a percentage change in price of 55.7 percent with the Kennedy correction. In other words, applying the Kennedy correction incorrectly will lead to 0.51 percent decrease in price change, which is similar to the illustrative example discussed above.

Huschelrath, Muller, and Veith (2013) use publicly available price index data from the German cement industry to estimate an overcharge due to the "hard-core" cartel in the German cement market announced by the German Federal Cartel Office in the summer 2002. These authors report (in Table 2) the results of estimating a reduced-form (semi-log) price equation, and find that the coefficient on the cartel dummy equals 0.188 with a standard error of 0.020. They state, "It is revealed that the price difference between the cartel period and the non-cartel period (that is, the price overcharge) is $\exp(0.188) - 1 = 20.7$ percent."[12] These authors use Eq. (3) to determine the overcharge percentage with the but-for price as the denominator. However, given the preciseness with which their cartel dummy is estimated, the overcharge percentage would be essentially identical to 20.7 percent if the Kennedy correction were used.[13] Similarly, whether one applies the Kennedy correction or not, the overcharge percentage with actual price as the denominator would be essentially identical as well.[14]

CONCLUSION

This chapter shows that when an overcharge rate is estimated as a percentage of the actual price as in Eq. (4), one should use $1 - \frac{1}{\exp(\hat{\alpha}_d)}$ without the Kennedy correction because applying the Kennedy correction will increase the bias of the overcharge estimate. In practice, if the estimated coefficient on the cartel dummy variable is relatively small so that the dummy coefficient can only be statistically significant with a small standard error, then the estimated overcharges with and without the Kennedy correction will be similar. However, if the estimated coefficient on the cartel dummy variable is relatively large and, hence, the dummy coefficient can still be statistically significant even with a relatively large standard error, applying the Kennedy correction can result in non-negligible differences in the estimated overcharges.

NOTES

1. See, for example, U.S. Department of Justice (2009a, 2009b, 2017).

2. For example, see Nieberding (2006); McCrary and Rubinfeld (2014). As noted in Rubinfeld (2008, p. 724), "The most common statistical method employed in antitrust litigation involves the estimation of 'reduced-form' price equations."

3. Dr. Li has seen economists apply the Kennedy correction in estimating overcharge as a percentage of the actual price in confidential expert reports submitted to the courts.

4. This result of interpreting dummy variables in semi-logarithmic regression models (also known as "log-linear" or "log-lin" models) can readily be found in the relevant literature. See, for example, Gordon (2015, p. 372).

5. See Komninos et al. (2009, p. 14). In practice, the unit monetary overcharge

> usually reflects the difference between the price actually charged and the price that would have prevailed in the absence of the alleged anticompetitive conduct (i.e., the "but-for" price under the "counterfactual"), … [and] [t]he estimated overcharge is then multiplied by the relevant quantity [purchased] to determine damage. (see ABA, 2010, pp. 197, 199, 202)

See also Brander and Ross (2006, p. 338) who state, "damage is most commonly presumed to equal the overcharge multiplied by the quantity sold." When using an overcharge percentage based on the but-for price, this "standard approach" to damages is no longer applicable, as one needs to incorporate elasticity considerations regarding the (higher) but-for quantity buyers would have purchased at the (lower) but-for price. Reliably estimating the relevant demand curve (and the associated deadweight loss) in a price-fixing case would, in general, complicate the analysis and substantially add to the data requirements.

6. According to Jensen's inequality, if $f(x)$ is convex, $E(f(x)) \geq f(E(x))$. See Goldberger (1991, p. 32).

7. See Giles (1982, p. 78).

8. This example follows Nieberding (2006).

9. In this illustrative example, the estimated variance of the coefficient for Dum_t is 0.01500625.

10. Kamita (2010, pp. 252–253).

11. Kamita (2010, p. 255).

12. Huschelrath et al. (2013, p. 110).

13. Applying the Kennedy correction under Eq. (3) generates an overcharge percentage of 20.659 percent (i.e., exp(0.188 − (0.5*0.0004)) − 1). This is essentially the same as the one without the Kennedy correction (20.683 percent) which has been rounded to 20.7 percent by these authors.

14. If Eq. (4) were used to estimate the overcharge percentage with the actual price as the denominator, it would equal 17.139 percent which is virtually identical to 17.122 percent which (inappropriately) incorporates the Kennedy correction.

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