Parametric and Nonparametric Market Power Tests: An Empirical Investigation

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Abstract:

Parametric and nonparametric market power tests most commonly used to assess imperfectly competitive behavior are identified. Monte Carlo experiments are used to evaluate the accuracy of eight nonparametric market power tests. The results are compared to Raper, Love, and Shumway's (1997) findings concerning three parametric market power tests in the Bresnahan-Lau tradition. Both monopolistic and monopsonistic market power tests are implemented using data from ten known market structures. Only two of the nonparametric market power tests distinguish between market structures adequately. The parametric tests perform well, although functional form bias is not investigated in this study.

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INTRODUCTION

Three major approaches have developed within New Empirical Industrial Organization (NEIO) to measure market power exertion: parametric, nonstructural, and nonparametric market power tests. Parametric and nonparametric market power tests are discussed in this study. Both approaches develop from profit maximization assumptions. The parametric approach econometrically estimates market power by parameterizing the monopoly (monopsony) markup (markdown) term ((Appelbaum, 1979), (Bresnahan, 1982), (Lau, 1982)). Parametric tests yield testable hypotheses regarding market power exertion. However, these hypotheses depend on the functional form chosen for the underlying model.

The nonparametric approach to market power measurement is relatively new and developed in response to criticisms of the parametric approach ((Ashenfelter and Sullivan, 1987), (Lambert, 1994), (Love and Shumway, 1994), (Driscoll, et al., 1997)). Deterministic nonparametric tests are an exhaustive search for violations of the given hypothesis. In contrast to parametric tests, nonparametric tests do not require *ad hoc* specifications of functional form so the problem of testing joint hypotheses is avoided. They instead rely on raw data using algebraic techniques. Additionally, less data is required than for parametric tests because opposing supply or demand curves are not needed. However, deterministic nonparametric tests are not imbedded in a stochastic framework. This can result in the possible rejection of hypotheses that are only violated once because the magnitude of violations is not considered.

Various authors ((Sullivan, 1985), (Ashenfelter and Sullivan, 1987), (Hyde and Perloff, 1995)) argue the merits of each type of market power test, but to date no comprehensive comparison of the tests' performance has been conducted. For comparison of performance, it is necessary to apply the tests to data where the degree of market power exertion is known. This is accomplished via Monte Carlo experiments. Only Hyde and Perloff (1994, 1995) and Raper, Love, and Shumway (1997) use this technique to compare the accuracy of market power tests. Hyde and Perloff compare parametric and nonstructural market power tests, while Raper, Love, and Shumway assess the accuracy of traditional NEIO models (Bresnahan-Lau approach) under misspecification of market structure.

In this study we use the Monte Carlo data set developed by Raper, Love, and Shumway (1997) to implement selected nonparametric market power tests in estimating the degree of market power exertion using simulated data from ten different market structures, including perfect competition, monopoly, monopsony, Cournot and Stackelberg oligopoly and oligopsony, and three forms of cooperative bilateral monopoly. We then compare performance of these nonparametric tests with the performance of Bresnahan-Lau type parametric market power tests using our results and those of Raper, Love, and Shumway (1997). Only for Love and Shumway's (1994) test and its monopoly counterpart, we obtain results sufficiently close to the true value of market power exertion in the market to recommend it for use with real data.

NONPARAMETRIC TESTS

Eight deterministic nonparametric market power tests are investigated in this study. Ashenfelter and Sullivan (1985) were the first to develop and apply a nonparametric market power test. They construct a deterministic nonparametric test of the monopoly model based on revealed preference arguments and extend the test to assess the validity of some less extreme oligopoly models. We use Ashenfelter and Sullivan's approach to develop a similar test for monopsony market power exertion. The resulting test is the negative of the right-hand side term of their equation. We obtain results for both cases of the Ashenfelter and Sullivan test, but do not include data for the excise tax term as in the original test. See Appendix A for the empirical equations of all eight nonparametric market power tests used in this study.

Raper, Love, and Shumway (1996b) revise Ashenfelter and Sullivan's test to include input parameters and use Love and Shumway's (1994) method to account for structural shifts. We use the revisions for monopoly as well as for monopsony market power exertion.

Love and Shumway (1994) develop a nonparametric deterministic monopsony market power test incorporating the possibility of Hicks-neutral technical change. Raper, Love, and Shumway (1996b) adapt Love and Shumway's model to test for monopoly market power exertion. These two tests are also implemented.

The last two deterministic nonparametric market power tests utilized in this study use a very similar approach to Love and Shumway. However, instead of assuming positive as well as negative Hicks-neutral technical change, only nonregressive technical change is admitted. Assuming that future technologies are not available in current or past periods, the search for violations of the hypothesized behavior is restricted to the search over past periods. This assumption is reasonable when new technologies allow a firm to produce more output using the same amount of input or to use less inputs to produce the same amount of output compared to the time before the introduction of the new technology. This approach is the basis for Raper, Love, and Shumway's (1996a) statistical nonparametric test for monopsony market power exertion, but has not been used before for a deterministic nonparametric market power test. The two tests based on the following empirical equations are developed to measure monopoly

$$(1) \qquad \min_{mp^{ts}} \sum_{t=1}^{T} \sum_{s<t=1}^{T} c^{ts} mp^{ts}$$

subject to

$$(i) \qquad p_u^t(y_u^t - y_u^s) - mp^{ts}(y_u^t - y_u^s) - w_{u1}^t(z_{u1}^t - z_{u1}^s) - w_{u2}^t(z_{u2}^t - z_{u2}^s) \geq 0$$

$$\forall\ s < t \text{ except when } p_u^t - p_u^s \overset{S}{=} y_u^t - y_u^s \text{ and } mp^{ts} \geq 0$$

and monopsony market power exertion.

$$(2) \qquad \min_{ms^{ts}} \sum_{t=1}^{T} \sum_{s<t=1}^{T} c^{ts} ms^{ts}$$

subject to

$$(i) \qquad p_d^t(y_d^t - y_d^s) - v_d^t(x_d^t - x_d^s) - p_u^t(y_u^t - y_u^s) - ms^{ts}(y_u^t - y_u^s) \geq 0$$

$$\forall\ s < t \text{ except when } p_u^t - p_u^s \overset{S}{\neq} y_u^t - y_u^s \text{ and } ms^{ts} \geq 0,$$

where in the first equation p_u is the price of the upstream firm's potentially monopolistically exerted output, y_u, w_{u1} and w_{u2} are the prices of the upstream firm's inputs, z_{u1} and z_{u2}, c^{ts} is an arbitrarily chosen weight, *t* and *s* indicate time, and mp^{ts} is the monopoly market power parameter. In equation (2), p_d is the price of downstream firm's output, y_d, v_d is the price of the downstream firm's input x_d, ms^{ts} is the monopsony market power parameter, and p_u is the price of downstream firm's potentially monopsonistically exerted input y_u bought from the upstream firm.

We compare the results for the above eight nonparametric market power tests with Raper, Love, and Shumway's (1997) results of three parametric market power tests in the Bresnahan-Lau tradition (monopolistic, monopsonistic market power exertion, and FlexPower, a test developed by Raper, Love, and Shumway(1997)).

DATA AND IMPLEMENTATION

Raper, Love, and Shumway (1997) simulate data for ten different market structures: monopsony (MS), Stackelberg duopsony (SS), Cournot duopsony (CS), perfect competition (PC), Cournot duopoly (CP), Stackelberg duopoly (SP), monopoly (MP), and three forms of cooperative bilateral monopoly (buyer dominates (BMU), seller dominates (BML), and equal profit split (BM)) using a normalized quadratic functional form for the cost functions. The industry-level data are generated for 68 periods with exogenous variables held constant across alternative simulations. 1000 experiments are conducted for each market structure. More specific details regarding the simulation may be found in Raper, Love, and Shumway's paper.

We implement each of the previously discussed nonparametric market power tests for the ten market structures, using Raper, Love, and Shumway's (1997) data set. Ashenfelter and Sullivan's test as well as its modifications are calculated in SAS. The four other nonparametric market power tests require linear programming and are implemented using GAMS and the solver MINOS.

RESULTS

In this section we present the results of the nonparametric market power tests and compare them to the results of Raper, Love, and Shumway's study. Results are obtained for each of the ten market structures over 1000 simulations and for each market structure, the mean of the market power parameter is calculated.

Ashenfelter and Sullivan Type Market Power Tests

In Ashenfelter and Sullivan's monopoly market power test, comparisons of data more than two periods apart are excluded from the calculation of the market power parameter, identifying these

Table 1. Mean Value of Estimated Market Power Parameters (1000 Simulations) and Cumulative Cournot Numbers Equivalents (CNE) for Original Ashenfelter and Sullivan Monopoly Market Power Test.

	PC	MP	CP	SP	MS	CS	SS	BM	BMU	BML
Mean β^{mp}	86174	86046	100794	86413	11450	40257	49310	147347	121872	103974
CNE ≤ 1	63.64	69.91	41.49	42.07	18.55	47.86	53.55	56.07	61.04	41.32
CNE ≤ 2	83.56	84.73	61.59	63.05	39.93	71.53	75.87	72.89	78.64	57.94
CNE ≤ 3	89.84	89.95	71.90	73.63	52.56	81.52	84.48	80.99	85.67	68.25
CNE ≤ 4	92.65	92.50	77.99	79.64	60.78	86.49	88.79	85.55	89.21	74.80
CNE ≤ 5	94.18	94.07	81.95	83.34	66.76	89.54	91.24	88.36	91.40	79.20
CNE ≤ 6	95.21	95.03	84.66	85.88	71.29	91.49	92.84	90.29	92.85	82.33
CNE ≤ 7	95.92	95.72	86.71	87.78	74.91	92.82	93.93	91.64	93.79	84.63
CNE ≤ 8	96.50	96.26	88.24	89.26	77.82	93.79	94.75	92.71	94.56	86.51
CNE ≤ 9	96.92	96.68	89.43	90.42	80.15	94.51	95.38	93.45	95.18	87.98
CNE ≤ 10000	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.00	100.00	87.98

comparisons as structural shifts (4290 in each simulation). Negative values of the market power parameter are considered to be violations of profit maximization and thus also excluded. Theoretically, the mean of the monopoly market power parameter (β^{mp}) should lie between zero and one, which is not the case for the calculated market power parameters for any of the ten market structures. Ashenfelter and Sullivan's Cournot Numbers Equivalent (CNE) is calculated as $1/\beta^{mp}$. CNE represents the least number of firms with Cournot behavior that the investigated industry could support. As seen in Table 1, for the monopoly market structure, 92.5 % of the CNE's are less or equal four. This indicates that 92.5 % of the data support the assumption that there are at the most four Cournot firms in the industry. The cumulative percentage of the data where the CNE is less than one, less than two, etc. should increase more rapidly with high levels of monopoly market power exertion. For data representing market structures where low or no market power exertion is expected, the size of the CNE should increase more slowly. This is not the case for Ashenfelter and Sullivan's monopoly test.

Ashenfelter and Sullivan's test modified to measure monopsony market power exertion performs similarly. The results reveal that only 56 % of the monopsony market structure data actually support a CNE of four firms. The largest support for a CNE of four firms is 90 % for the monopoly data. These two results should be switched to support the hypotheses behind the test. See Appendix B.1 for full results. Thus Ashenfelter and Sullivan's test represents an important step for nonparametric market power tests, but our study supports the call for potential improvements as

Table 2. Mean Value of Estimated Market Power Parameters (1000 Simulations) and Cumulative Cournot Numbers Equivalents (CNE) for Revised Ashenfelter and Sullivan Monopoly Market Power Test (Raper, Love, Shumway 1996b).

	PC	MP	CP	SP	MS	CS	SS	BM	BMU	BML
Mean β^{mp}	4.91	11.49[a]	5.13	4.20	1.49[b]	7.19	6.86	5.68	24.78	3.74
CNE ≤ 1	71.10	58.01	71.68	68.57	20.08	64.04	64.46	78.26	86.98	43.20
CNE ≤ 2	88.97	66.98	87.71	85.16	38.41	82.75	83.20	94.32	91.55	86.30
CNE ≤ 3	92.92	73.44	92.99	90.81	48.48	88.77	89.19	97.73	93.50	94.47
CNE ≤ 4	94.61	79.03	95.60	93.85	55.87	91.64	92.03	98.58	94.69	97.01
CNE ≤ 5	95.56	83.55	96.97	95.77	61.97	93.30	93.68	98.90	95.50	98.36
CNE ≤ 6	96.18	86.98	97.73	96.91	67.10	94.41	94.75	99.08	96.11	98.91
CNE ≤ 7	96.63	89.48	98.19	97.60	71.07	95.19	95.51	99.20	96.57	99.19
CNE ≤ 8	96.97	91.41	98.50	98.05	74.35	95.77	96.08	99.28	96.94	99.34
CNE ≤ 9	97.24	92.87	98.71	98.36	77.04	96.22	96.51	99.35	97.24	99.44
CNE ≤ 10000	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Mean Shifts	2243	3157	3029	2880	690	1729	1951	3051	3869	2966

Ashenfelter and Sullivan acknowledge in their paper. It is possible that inadequately accounted for information like measurement errors, technological change, or structural change might seriously bias the estimates. Also, the exclusion of all negative market power parameters from the calculation of the CNE's because they are assumed to be violations of profit maximization might be over-restrictive. Assuming a reasonable tolerance level for small violations may improve results.

The results for Raper, Love, and Shumway's revision of Ashenfelter and Sullivan's test measuring monopoly market power exertion are reported in Table 2. The mean of the monopoly market power parameter for each market structure decreased dramatically, except for the monopoly and monopsony data. After deleting two outliers (very high values for the market power parameter) in the monopoly data and one outlier in the monopsony data, the mean of the market power parameter decreases to reasonable values for both data sets. However, more than 90 % of the data support a CNE of four for all market structures except monopoly and monopsony. Results from oligopsony, perfect competition, or bilateral monopoly data should not bolster the assumption of monopoly market power with such strength.

The revised monopsony market power test produces somewhat more plausible results. For monopsony data, 96 % of the observations support a monopsonistic CNE of four firms. 87 % of Cournot duopsony market structure data supports a CNE of four, and 84 % of Stackelberg duopsony data support a CNE of four. However, for all other market structures, more than 76 % of the data support the assumption of a four firm Cournot equivalent in the market. This is still relatively higher than expected, given that the remaining structures are either perfectly competitive, monopolistic, or bilateral monopolistic rather than purely monopsonistic. Thus, the revision of the Ashenfelter and Sullivan monopoly market power test including input data and accounting differently for structural shifts does not substantially improve estimates of the degree of market power. See Appendix B.2 for full results.

Love and Shumway Type Market Power Tests

Using the original Love and Shumway monopsony market power test, the mean of the market power parameter (ms^{ts}) over 1000 simulations is significantly different from zero (p = 0.0001) for each market structure (Table 3). For full results see Appendix B.3. Theoretically, only the market power parameters for monopsony, Cournot duopsony, and Stackelberg duopsony market structures should be different from zero and close to their 'true' values. With simulated data, we have the luxury of knowing the true values of ms^{ts} for each structure and, thus, can test whether our estimates are statistically different from their true values. The null hypothesis of the monopsony market power parameter being equal to 2.06 is not rejected (p = 0.2775). However, the Cournot ms^{ts} is significantly different from its true value of 0.78 (p = 0.0001). The same is true of the Stackelberg duopsony ms^{ts}, where the true value is 0.46 (p = 0.0198). Thus, the monopsony market power test detects monopsony market power and in a magnitude which could be considered economically significant. However, the test also detects some monopsony market power when oligopolistic data are used. This implies that the test works well in identifying monopsony market power, but it is also very important to correctly specify the model in terms of market power direction.

The Love and Shumway test modified by Raper, Love, and Shumway (1996b) to test for monopoly market power does not perform quite as well (Table 4). For full results see Appendix B.4. Again, mean market power parameters for all market structures are significantly different from zero (p = 0.0001). For monopoly, Cournot duopoly, and Stackelberg duopoly data, which should be the only parameters significantly different from zero and close to their 'true' values, the market power

Table 3. Mean Value of Estimated Market Power Parameters (1000 Simulations) for Original Love and Shumway Monopsony Test

	Mean β^{ms}	Std. Error	Shifts
PC	0.1869	0.0196	2316
MP	0.1206	0.0036	1396
CP	0.1464	0.0035	1524
SP	0.2207	0.0092	1674
MS	2.0965	0.0617	3867
CS	0.5004	0.0284	2828
SS	0.4228	0.0180	2605
BM	0.0246	0.0009	1505
BMU	0.0065	0.0005	682
BML	0.0684	0.0013	1589

Table 4. Mean Value of Estimated Market Power Parameters (1000 Simulations) for Modified Love and Shumway Monopoly Test (R, L, S 1996b)

	Mean β^{mp}	Std. Error	Shifts
PC	0.0367	0.0013	2240
MP	0.2036	0.0089	3160
CP	0.7292	0.0339	3032
SP	0.7354	0.0323	2882
MS	1.5954	0.0510	689
CS	0.1412	0.0024	1728
SS	0.1043	0.0020	1951
BM	0.0228	0.0007	3051
BMU	0.0641	0.0014	3874
BML	0.0195	0.0007	2967

parameters are also significantly different from their true market power values of 1.0 (p = 0.001), 0.5 (p = 1.2007E-11), and 0.4046 (p = 0.0001), respectively. The values for Cournot duopoly and Stackelberg duopoly are relatively large, thus indicating market power exertion. However, the market power estimate for monopoly is relatively small as compared to the duopoly cases while the parameter for monopsony market power exertion is very large with 1.5954. Theoretically it should be near zero, while the monopoly market power parameter should be near 1.0. Monopsony, Cournot duopoly, and Stackelberg duopoly all have maximum market power values of a much greater magnitude than the other market structures.[1] Removing these outliers does not change the mean of

[1] Data available upon request.

the market power values significantly and does not change the 'switched' values of the monopoly and monopsony market structures. Hence, Raper, Love, and Shumway's monopoly market power test works to a certain extent; but again, the market structure specification of the model is very important as the test detects some market power when market power is instead being exerted from the opposite market.

Another modification of Love and Shumway's test is developed in this paper and restricts technical change to be nonregressive. As no technical change parameters are estimated, a problem similar to Ashenfelter and Sullivan's test is encountered since any measurement error or similar biases can only be detected by the market power parameter. The results for the nonregressive monopsony market power test point to such a problem, as all results are declared infeasible by the linear programming solver. Results for the nonregressive monopoly market power test were not obtained because the test created problems with the solver that could not be alleviated. The use of nonregressive technical change is reasonable; however, it does not work in a linear programming formulation.

Parametric Market Power Tests

Raper, Love, and Shumway (1997) report mean values and standard deviations of market power parameters over 1000 simulations for a Bresnahan-Lau type monopoly market power test, a monopsony market power test, and FlexPower, using the same data set as this study. The 'true' values for λ_{mp} for Bresnahan-Lau type parametric market power tests are 1.0 for monopoly, 0.5 for Cournot duopoly, and 0.4046 for Stackelberg duopoly. λ_{mp} should be equal to zero for all other market structure data. The 'true' values for λ_{ms} are 1.0 for monopsony, 0.5 for Cournot duopsony, and 0.3956 for Stackelberg duopsony. For all other market structures, λ_{ms} should be equal to zero.

Both the monopoly market power test and the monopsony market power test using the Bresnahan-Lau approach perform remarkably well. FlexPower combines the two uni-lateral market power tests into one test that does not assume *a priori* one side of the market to be perfectly competitive, but allows for either or both sides of the market to have some degree of market power. FlexPower gives results similar to the monopoly and monopsony tests when considering the significance of market power estimates. Additionally, FlexPower is able to distinguish between perfect competitive and bilateral monopoly data.

CONCLUSIONS

Knowledge of the degree of market power exertion is important in guiding antitrust and merger policies. With the help of Raper, Love, and Shumway's (1997) results, this study compares Bresnahan-Lau type parametric market power tests for monopoly market power exertion, monopsony market power exertion, and bilateral market power exertion (FlexPower) with the relatively new approach of deterministic nonparametric market power tests. Ashenfelter and Sullivan's test for monopoly market power and its counterpart for monopsony market power as well as revisions of the test proposed by Raper, Love, and Shumway (1996b) are implemented. Additionally, Love and Shumway's monopsony test, its monopoly counterpart, as well as selected revisions are implemented using Raper, Love, and Shumway's (1997) Monte Carlo data set that simulates data for ten different market structures.

Ashenfelter and Sullivan make a major contribution to the field by introducing the first nonparametric market power test. However, as they point out, their market power test might need modifications. This result is confirmed by this study. The results are not satisfactory for the original

Ashenfelter and Sullivan monopoly market power test, the analogous monopsony market power test, or Raper, Love, and Shumway's (1996b) revisions for monopoly and monopsony market power. This suggests that researchers should be hesitant about choosing Ashenfelter and Sullivan type tests to measure the degree of market power exertion in an industry.

Love and Shumway's monopsony market power test yields estimates close to the true value on the downstream firm's side. However, to some extent the test incorrectly attributes upstream market power to downstream firms. This implies that Love and Shumway's monopsony market power test can be implemented under the restriction that the model is specified for the 'right' direction. The monopoly market power test in Love and Shumway's tradition performs less accurately and should be implemented under the same restrictions. This indicates that if there is any potential for market power from the opposing side of the market, biased results may be obtained unless proper modifications are made. The revision of Love and Shumway's test to account for nonregressive technical change gives infeasible values for both the monopoly and the monopsony test.

All three parametric market power tests perform very well in Raper, Love, and Shumway's (1997) study. FlexPower incorporates the monopoly and monopsony market power tests into one test and performs equally well as the uni-lateral monopoly and monopsony market power tests, suggesting that FlexPower should be implemented when choosing to perform a parametric market power test. However, as Hyde and Perloff (1994) point out, parametric market power tests can be seriously biased when the functional form is misspecified.

Thus, the question remains as to which test to employ for investigation of market power. Our results suggest that parametric tests are less subject to misspecification bias with respect to direction of market power and give more accurate estimates of market power but are sensitive to functional form misspecification. Though nonparametric tests do not perform as accurately as parametric tests in this study, it should be noted again that the approach is relatively new. The advantages presented, such as relatively small data needs and no functional form bias, are perhaps sufficient for this approach to merit further development.

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APPENDIX A. EMPIRICAL EQUATIONS FOR NONPARAMETRIC MARKET POWER TESTS

Method	Equation	Lerner Index Equivalent
Original Ashenfelter & Sullivan Monopoly	$\beta^{mp} \leq \dfrac{-p_u^t(y_u^t - y_u^s)}{(p_u^t - p_u^s)\, y_u^s} \quad \forall t \neq s, \text{ where } \lvert t - s \rvert \leq 2$	β^{mp}
Modified Ashenfelter & Sullivan Monopsony Noelke & Raper	$\beta^{ms} \leq \dfrac{p_u^t(y_u^t - y_u^s)}{(p_u^t - p_u^s)\, y_u^s} \quad \forall t \neq s, \text{ where } \lvert t - s \rvert \leq 2$	β^{ms}
Revised Ashenfelter & Sullivan Monopoly Raper, Love & Shumway (1996b)	$\beta^{mp} \leq \dfrac{-p_u^t(y_u^t - y_u^s) + w_{u1}^t(z_{u1}^t - z_{u1}^s) + w_{u2}^t(z_{u2}^t - z_{u2}^s)}{(p_u^t - p_u^s)\, y_u^s},$ $\forall\ s \neq t$ except when $y_u^t - y_u^s \overset{s}{=} p_u^t - p_u^s$	β^{mp}
Revised Ashenfelter & Sullivan Monopsony Raper, Love & Shumway (1996b)	$\beta^{ms} \leq \dfrac{p_d^t(y_d^t - y_d^s) - v_d^t(x_d^t - x_d^s) - p_u^t(y_u^t - y_u^s)}{(p_u^t - p_u^s)\, y_u^s},$ $\forall\ s \neq t$ except when $y_u^t - y_u^s \overset{s}{\neq} p_u^t - p_u^s$	β^{ms}

Original Love & Shumway Monopsony	$\min_{A^{t^+}, A^{t^-}, ms^{ts}} \sum_{t=1}^{T} (b^{t^+} A^{t^+} + b^{t^-} A^{t^-} + \sum_{s \neq t=1}^{T} c^{ts} ms^{ts})$ subject to (i) $p_d^t(y_d^t - A^{t^+} + A^{t^-} - y_d^s + A^{s^+} - A^{s^-}) - v_d^t(x_d^t - x_d^s) - p_u^t(y_u^t - y_u^s) - ms^{ts}(y_u^t - y_u^s) \geq 0$ $\forall s \neq t$ except when $y_u^t - y_u^s \overset{S}{\neq} p_u^t - p_u^s$, (ii) $A^{t^+} \geq 0, \forall t$, (iii) $A^{t^-} \geq 0, \forall t$, (iv) $ms^{ts} \geq 0, \forall s \neq t$	$\beta^{ms} = \frac{ms^{ts}}{p_u^t}$
Modified Love & Shumway Monopoly Raper, Love & Shumway (1996b)	$\min_{A^{t^+}, A^{t^-}, mp^{ts}} \sum_{t=1}^{T} (b^{t^+} A^{t^+} + b^{t^-} A^{t^-} + \sum_{s \neq t=1}^{T} c^{ts} mp^{ts})$ subject to (i) $p_u^t(y_u^t - A^{t^+} + A^{t^-} - y_u^s + A^{s^+} - A^{s^-}) - mp^{ts}(y_u^t - y_u^s) - w_{u1}^t(z_{u1}^t - z_{u1}^s) - w_{u2}^t(z_{u2}^t - z_{u2}^s) \geq 0$ $\forall s \neq t$ except when $p_u^t - p_u^s \overset{S}{=} y_u^t - y_u^s$, (ii) $A^{t^+} \geq 0, \forall t$, (iii) $A^{t^-} \geq 0, \forall t$, (iv) $mp^{ts} \geq 0, \forall s \neq t$	$\beta^{mp} = \frac{mp^{ts}}{p_u^t}$

Nonregressive Technical Change Monopsony Noelke & Raper	$\min_{ms^{ts}} \sum_{t=1}^{T} \sum_{s<t=1}^{T} c^{ts} ms^{ts}$ subject to (i) $p_d^t(y_d^t - y_d^s) - v_d^t(x_d^t - x_d^s) - p_u^t(y_u^t - y_u^s) - ms^{ts}(y_u^t - y_u^s) \geq 0$ $\forall\ s < t$ except when $p_u^t - p_u^s \overset{s}{\neq} y_u^t - y_u^s$, (ii) $ms^{ts} \geq 0$	$\beta^{ms} = \frac{ms^{ts}}{p_u^t}$
Nonregressive Technical Change Monopoly Noelke & Raper	$\min_{mp^{ts}} \sum_{t=1}^{T} \sum_{s<t=1}^{T} c^{ts} mp^{ts}$ subject to (i) $p_u^t(y_u^t - y_u^s) - mp^{ts}(y_u^t - y_u^s) - w_{u1}^t(z_{u1}^t - z_{u1}^s) - w_{u2}^t(z_{u2}^t - z_{u2}^s) \geq 0$ $\forall\ s < t$ except when $p_u^t - p_u^s \overset{s}{=} y_u^t - y_u^s$, (ii) $mp^{ts} \geq 0$	$\beta^{mp} = \frac{mp^{ts}}{p_u^t}$

APPENDIX B. RESULTS

B.1. Mean Value of Estimated Market Power Parameters (1000 Simulations) and Cumulative Cournot Numbers Equivalents (CNE) for Modified Ashenfelter and Sullivan Monopsony Market Power Test (Noelke and Raper)

	PC	MP	CP	SP	MS	CS	SS	BM	BMU	BML
Mean β^{ms}	211500	122459	47111	37931	31020	200558	109746	135182	166545	70672
Mean CNE	5.83	4.18	4.82	4.91	41.13	9.98	8.34	5.88	5.80	8.42
CNE ≤ 1	58.22	66.49	32.34	32.02	26.00	46.85	50.13	56.84	55.69	45.75
CNE ≤ 2	74.21	81.21	67.92	69.70	40.46	64.22	67.59	73.37	74.07	65.55
CNE ≤ 3	81.47	87.05	81.48	82.94	49.90	73.32	76.23	81.29	81.93	74.67
CNE ≤ 4	85.49	90.14	87.01	88.23	56.35	78.72	81.36	85.74	86.21	80.25
CNE ≤ 5	88.17	92.05	89.91	90.91	61.24	82.33	84.63	88.52	88.79	84.02
CNE ≤ 6	89.95	93.30	91.76	92.62	65.08	84.91	86.91	90.38	90.58	86.63
CNE ≤ 7	91.32	94.29	92.99	93.73	68.15	86.89	88.57	91.70	91.90	88.49
CNE ≤ 8	92.35	94.99	93.92	94.57	70.70	88.42	89.94	92.67	92.89	89.87
CNE ≤ 9	93.15	95.51	94.62	95.21	72.90	89.63	90.92	93.47	93.66	90.96
CNE ≤ 10000	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
# Neg β^{ms}	188	156	83	84	199	184	184	128	153	106
# Pos β^{ms}	78	110	183	182	67	82	82	138	113	160

B.2. Mean Value of Estimated Market Power Parameters (1000 Simulations) and Cumulative Cournot Numbers Equivalents (CNE) for Revised Ashenfelter and Sullivan Monopsony Market Power Test (Raper, Love, and Shumway, 1996b)

	PC	MP	CP	SP	MS	CS	SS	BM	BMU	BML
Mean β^{ms}	4.94	5.60	2.28	2.23	16.21	10.01	7.98	3.00	4.40	2.60
Mean CNE	16.70	15.37	15.42	13.87	2.61	12.32	8.97	10.59	55.45	31.34
CNE ≤ 1	46.69	49.76	37.11	39.33	83.85	62.66	57.54	47.26	41.32	40.01
CNE ≤ 2	62.96	64.91	62.70	65.11	91.60	76.76	72.61	68.30	50.40	61.75
CNE ≤ 3	71.14	72.32	73.08	74.88	94.26	82.93	79.80	77.39	58.94	71.34
CNE ≤ 4	76.12	77.16	78.45	80.02	95.62	86.49	83.93	82.18	65.11	76.42
CNE ≤ 5	79.61	80.31	82.01	83.24	96.43	88.85	86.64	85.25	69.84	79.54
CNE ≤ 6	82.14	82.78	84.47	85.51	97.01	90.48	88.53	87.35	73.40	81.71
CNE ≤ 7	84.20	84.71	86.28	87.18	97.42	91.72	89.99	88.77	76.12	83.45
CNE ≤ 8	85.69	86.16	87.71	88.57	97.74	92.68	91.13	89.86	78.35	84.82
CNE ≤ 9	86.99	87.40	88.88	89.66	97.99	93.44	92.03	90.72	80.25	85.98
CNE ≤ 10000	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	100.00
Mean Shifts	2308	1395	1524	1674	3845	2822	2600	1504	680	1588
# Neg β^{ms}	2183	3076	2807	2658	257	1548	1797	2989	3842	2855
# Pos β^{ms}	60	84	224	224	432	181	154	63	32	112

B.3. Mean Value of Estimated Market Power Parameters (1000 Simulations) for Original Love and Shumway Monopsony Market Power Test.

	PC	MP	CP	SP	MS	CS	SS	BM	BMU	BML
Mean β^{ms}	0.1869 0.0196[a]	0.1206 0.0036	0.1464 0.0035	0.2207 0.0092	2.0965 0.0617	0.5004 0.0284	0.4228 0.0181	0.0246 0.0009	0.0065 0.0005	0.0684 0.0015
St. Dev.	0.6197	0.1140	0.1117	0.2904	1.9524	0.8980	0.5706	0.0293	0.0169	0.0395
p-value					0.2775[b]	0.0000[c]	0.0198[d]			
Min β^{ms}	0.0466	0.0425	0.0756	0.0917	-2.6982	0.1599	0.1309	0.0138	0.0011	0.0523
Max β^{ms}	18.29	2.40	1.88	5.22	24.98	25.13	7.59	0.62	0.45	0.87
Mean Pos. Tech. Change	2.55	2.12	4.24	4.58	1.56	3.93	3.99	2.86	3.30	2.46
Mean Neg. Tech. Change	3.12	2.63	3.09	2.98	0.92	2.34	2.59	3.02	4.42	2.12
Mean Shifts	2316	1396	1524	1674	3867	2828	2605	1505	682	1589

Model status equals for all simulations 'globally optimal.'

[a] Standard errors of mean market power parameters (St.Dev/$\sqrt{N}$).

[b] Null hypothesis is that mean market power parameter is equal to 2.06, the true value.

[c] Null hypothesis is that mean market power parameter is equal to 0.78, the true value.

[d] Null hypothesis is that mean market power parameter is equal to 0.46, the true value.

B.4. Mean Value of Estimated Market Power Parameters (1000 Simulations) for Modified Love and Shumway Monopoly Market Power Test (Raper, Love, and Shumway 1996b).

	PC	MP	CP	SP	MS	CS	SS	BM	BMU	BML
Mean β^{mp}	0.0367 0.0013[a]	0.2036 0.0089	0.7292 0.0339	0.7354 0.0323	1.5954 0.0510	0.1412 0.0024	0.1043 0.0020	0.0228 0.0007	0.0641 0.0014	0.0195 0.0007
St. Dev.	0.0404	0.2805	1.0727	1.0225	1.6141	0.0751	0.0635	0.0208	0.0445	0.02
p-value		0.0000[b]	0.0000[c]	0.0000[d]						
Min β^{mp}	0.0145	0.0423	0.1243	0.1301	-35.5356	0.0603	0.0450	0.0024	0.0105	0.00
Max β^{mp}	1.24	5.25	16.57	14.60	29.35	1.85	1.37	0.23	0.72	0.26
Mean Pos. Tech. Change	2.36	1.20	1.31	1.65	2.02	1.67	1.64	1.65	0.95	1.71
Mean Neg. Tech. Change	1.12	0.35	0.64	0.63	1.91	1.82	1.98	0.91	0.63	0.93
Mean Shifts	2240	3160	3032	2882	689	1728	1951	3051	3874	2967

Model status equals for all simulations 'globally optimal.'

[a] Standard errors of mean market power parameters (St.Dev/$\sqrt{N}$).

[b] Null hypothesis is that market power parameter is equal to 1.00, the true value.

[c] Null hypothesis is that market power parameter is equal to 0.50, the true value.

[d] Null hypothesis is that market power parameter is equal to 0.4046, the true value.