Appendices

A Quadratic Utility and Linear Demand

Here we derive a linear demand system from an assumption of quasi-linear quadratic utility.[1]. Following the notation and proof in Amir et al. (2017) we have:

$$U(\boldsymbol{x}, y) = \boldsymbol{a}'\boldsymbol{x} - \frac{1}{2}\boldsymbol{x}'\boldsymbol{B}\boldsymbol{x} + y,$$

where $\boldsymbol{a}$ is a strictly positive vector of size n, $\boldsymbol{B}$ is a positive-definite $n \times n$ matrix, $\boldsymbol{x}$ is an n-vector representing quantities of goods, and y is the quantity of the numeraire good with price $p_y = 1$.

Being that matrix $\boldsymbol{B}$ is positive definite $\boldsymbol{B}^{-1}$ exists and is also positive definite. Then, imposing the standard budget restriction $\boldsymbol{p}'\boldsymbol{x} + y \leq m$ with exogenous price vector $\boldsymbol{p}$ and budget m; assuming interiority condition $\boldsymbol{B}^{-1}(\boldsymbol{a}-\boldsymbol{p}) > 0$ and feasibility condition $\boldsymbol{p}'\boldsymbol{B}^{-1}(\boldsymbol{a}-\boldsymbol{p}) \leq m$, we arrive at a system of linear demand functions:

$$\boldsymbol{q}(\boldsymbol{p}) = \boldsymbol{B}^{-1}(\boldsymbol{a} - \boldsymbol{p}). \tag{1}$$

Now, to match the market environment we model in our experiment, we impose restrictions on $\boldsymbol{a}$ and $\boldsymbol{B}$: we assume $a_i = a$, $b_{ii} = b$ and $b_{ij} = d \ \forall i, j \in [1, n], i \neq j$ for some strictly positive constants a, b, and d, with $b > d$ to ensure $\boldsymbol{B}$ is positive definite. These assumptions are equivalent to assuming that the utility derived from consumption of each good $\boldsymbol{x}$ is symmetric both in terms of own- and cross-product parameter values. Intuitively and as we will see, this leads to symmetric (linear) demand functions for each good $\boldsymbol{x}$.[2]

To explore this further and apply to our specific demand specification, we make the

[1] We thank an anonymous reviewer for comments that inspired the approach followed in this appendix

[2] As Amir et al. (2017) point out, our use of the term "linear demand function" is a slight abuse of terminology. More correctly we have an affine function whenever the implied result is positive and zero otherwise.

several definitions and impose the following additional restrictions on a, b, and d:

- Define parameters δ and $\gamma : \delta, \gamma \in \mathbb{R}_{++}$
- Define p_i as the ith element of price vector $\boldsymbol{p}$ and $p_{-i} \equiv \frac{1}{n-1} \sum_{j \neq i}^{n} p_j$ as the average of the other $n-1$ elements in the price vector
- Assume $n \in \mathbb{Z}, n \geq 2$
- Restrict $a = \delta n d$
- Restrict $b = d + \frac{n-1}{n\gamma}$
- For compactness of notation and clarity, define $\Delta \equiv \frac{n-1}{n\gamma} \cdot \frac{1}{d} \Rightarrow b = d(1 + \Delta)$

Next, we impose these restrictions on (1) in order to show that:

$$\lim_{d \to \infty} q_i(\boldsymbol{p}; d, n, \delta, \gamma) = \delta - \gamma(p_i - p_{-i})$$

Next, we must rationalize $\boldsymbol{B^{-1}}$. Noting that $b = d(1 + \Delta)$ we can rewrite $\boldsymbol{B}$ as $d \cdot \mathbb{B}$, where the diagonal elements of $\mathbb{B}$ are all $1 + \Delta$ and the off-diagonal elements are all 1. For example, to illustrate with $n = 4$:

$$\mathbb{B} = \begin{bmatrix} 1+\Delta & 1 & 1 & 1 \\ 1 & 1+\Delta & 1 & 1 \\ 1 & 1 & 1+\Delta & 1 \\ 1 & 1 & 1 & 1+\Delta \end{bmatrix}$$

This leads to a specification of $\boldsymbol{B}^{-1} = d^{-1} \cdot \mathbb{B}^{-1}$, with:

$$\mathbb{B}^{-1} = \frac{1}{\Delta(\Delta+n)} \begin{bmatrix} n-1+\Delta & -1 & -1 & -1 \\ -1 & n-1+\Delta & -1 & -1 \\ -1 & -1 & n-1+\Delta & -1 \\ -1 & -1 & -1 & n-1+\Delta \end{bmatrix}.$$

We then apply these restrictions to (1) and have:

$$\boldsymbol{q}(\boldsymbol{p}) = \boldsymbol{B}^{-1}(\boldsymbol{a} - \boldsymbol{p}) = \left(\frac{1}{d}\right) \mathbb{B}^{-1}(\boldsymbol{a} - \boldsymbol{p}).$$

Then, the demand for arbitrary good i can be represented as:

$$q_i(\boldsymbol{p}; d, n, \delta, \gamma) = \left(\frac{1}{d}\right) \cdot \frac{1}{\Delta(\Delta + n)} \left[(n - 1 + \Delta)(a - p_i) - (-1) \sum_{j \neq i}^{n} (a - p_j)\right]$$

$$= \frac{1}{d\Delta(\Delta + n)} \left[\Delta(a - p_i) + (n - 1)(a - p_i) + (n - 1)(a - p_{-i})\right]$$

$$= \frac{a - p_i}{d(\Delta + n)} - \frac{(n - 1)(p_i - p_{-i})}{d\Delta(\Delta + n)}$$

Substituting in $a = \delta n d$ and $\Delta = \frac{n-1}{n\gamma d}$, we have:

$$q_i(\boldsymbol{p}; d, n, \delta, \gamma) = \frac{\delta n d - p_i}{d\left(\frac{n-1}{n\gamma d} + n\right)} - \frac{(n - 1)(p_i - p_{-i})}{d\left(\frac{n-1}{n\gamma d}\right)\left(\frac{n-1}{n\gamma d} + n\right)}$$

(2) $$\Rightarrow q_i(\boldsymbol{p}; d, n, \delta, \gamma) = \frac{\delta - p_i/nd - \gamma(p_i - p_{-i})}{\left(\frac{n-1}{n^2\gamma d} + 1\right)}$$

Now, evaluating this expression as $d \to \infty$ we see that $\lim_{d\to\infty}\left(\frac{n-1}{n^2\gamma d} + 1\right) = 1$ and $\lim_{d\to\infty}(p_i/nd) = 0$, which implies:

(3) $$\Rightarrow \lim_{d\to\infty} q_i(\boldsymbol{p}; d, n, \delta, \gamma) = \delta - \gamma(p_i - p_{-i}), \qquad \text{QED.}$$

We thus see that our model of linear demand, with own- and cross-price parameters equal in magnitude, is consistent with an assumption of quadratic, quasi-linear utility, albeit a special case taken in the limit as parameters a, b and d tend towards infinity in the pathway described above.

B Experimental Material

B.1 Instructions

Good morning, and thank you for agreeing to participate in this economics experiment.

Earnings

As compensation, you will be paid a show-up fee of $5. In addition to the show-up fee, you will have the opportunity to earn additional money. We anticipate that this experiment will run around 90-100 minutes. The experiment consists of 5 rounds of 15 periods each, a total of 75 rounds. The computer will randomly select a number between 1 and 5, corresponding to one of the 5 rounds of the experiment. At the end of the experiment, your additional fee will be equal to the average payout during that particular round. You will then be paid the added total of the show-up fee plus the additional fee. You are free to leave at any time; if you do so you will still receive the $5 show-up fee, but if you leave before the experiment is complete you will not receive the additional fee. In all cases, your earnings will be paid individually and anonymously.

Market Setup

In this experiment we will simulate markets, in which you and the other participants each play the role of the CEO of a company that produces and sells a single product in your particular market. You will be randomly grouped with X $(n-1)$ other companies (participants), and together the Y (n) of you will form this market. You will stay matched with the same participants in your market for the duration of the entire experiment. Each company is largely identical, faces the same identical costs to produce each unit, and has the same profit function. The only thing that differs between companies is the price they set for the product. Demand for your product will be simulated by the computer, according to a formula shown on the payoff sheet we have left at your workstation. The higher your price, the fewer units you will sell. The higher the average price of the other participants in your market, the more units you will sell.

During each period of the experiment, all Y (n) of you will be asked to set a price at which you will each sell the product. You will not know anything about the price the other participants set, until after you have set your own price. We will then ask you to guess the average price the other participants set during that same round. Finally, after all Y participants have set their own prices, we will show you the average price set by the other X participants, and calculate and show you your payoff for that particular round. You will be able to see the history of your prices, the average prices of the other participants, and your resulting payoff for each of the previous periods within each round, to help you make future pricing decisions.

How to Set Your Price and Predict Your Payout each Period

In the first round of 15 periods, you will face an input cost of $0.90 per unit produced. "Input cost" is shorthand for the total costs of raw materials, labor, etc., required to produce one unit of product. The payoff sheet at your workstation corresponds to this particular input cost. Based on what you guess the average of others' costs to be, shown along the columns, you can see how much you will earn for each potential price you would set, shown along the rows. For example, if the average price other participants set is $1.50, and you set your price at $2.00, your payoff would be $4.35. As another example, if the average other participants set is $2.90 and yours is $2.30, your payoff would be $17.01. Note that the maximum price you can set for your product is $3.00, because consumers in this market are not willing to pay more than $3.00 for the product. We only show prices that are multiples of $0.10, because otherwise the payoff sheet would be too large to print on a single piece of paper. The price you set can be anywhere between the input price and $3.00, in increments of $0.01. Finally, note that negative numbers are shown in the payoff sheet in parentheses, so for example ($1.00) means minus one dollar.

Changes in Input Cost

In each round, there will be a change to the input costs each company faces. Costs will increase or decrease by either $0.40 or $0.80. You will not know the size or direction of the change until it is announced at the beginning of each round. At that time, we will hand out a new payoff sheet that corresponds to the new input cost. Make sure you use only the payoff sheet that corresponds to the current input cost. Again, input costs will remain the same for all 15 periods of each round, but will change at the beginning of each new round.

Please raise your hand if you have a question, and one of us will come to you at your workstation. Please do not talk or discuss the experiment or anything else with your neighbors, until after the experiment is complete.

B.2 Comprehension Questions

Before we begin the experiment, please complete the following questions. Just write your answer on this sheet of paper. We will walk by each workstation and look at your answers, to ensure you understand. If you have questions please ask us when we come by, but DO NOT discuss or ask questions of your neighbors. If there is anything needing clarification, we will announce it to everyone in the group at the same time.

1) True/False: I will be rematched with different participants at the beginning of each round:

2) If I keep my price the same from one period to the next, but the average price others in my market set falls, my payout in that period will: (hint – look at the payout chart and see what happens as you go from right to left on any given row)

a. Rise

b. Fall

c. Stay the Same

d. May Rise or Fall, or Stay the Same

3) If the average price of others in my market stays the same between periods, but if I increase my price, my payout that period will: (hint – look at the payout chart, but this time see what happens as you go from top to bottom on any given column)

a. Rise

b. Fall

c. Stay the Same

d. May Rise or Fall, or Stay the Same

4) Use the Payoff Chart to answer the following questions:

a. If the average price others set in my market is $2.80, what is the price I could set that would maximize my own payout that period?

$

b. What would be the amount of that payout?

$

B.3 Payoff Table and Experimental Interface

PAYOFF TABLE - FOR USE ONLY WHEN INPUT COSTS = $ 0.90

Demand for your product = 8.50 - 7.275 * (Your Price - Average of Others' Prices)
Your Payoff = (Your Price - Input Cost) * Demand - $1.00

Others' Average Price ====>

		$ 1.30	$ 1.40	$ 1.50	$ 1.60	$ 1.70	$ 1.80	$ 1.90	$ 2.00	$ 2.10	$ 2.20	$ 2.30	$ 2.40	$ 2.50	$ 2.60	$ 2.70	$ 2.80	$ 2.90	$ 3.00
Your	$1.30	2.40	2.69	2.98	3.27	3.56	3.86	4.15	4.44	4.73	5.02	5.31	5.60	5.89	6.18	6.47	6.77	7.06	7.35
Price	$1.40	2.89	3.25	3.61	3.98	4.34	4.71	5.07	5.43	5.80	6.16	6.52	6.89	7.25	7.62	7.98	8.34	8.71	9.07
||	$1.50	3.23	3.66	4.10	4.54	4.97	5.41	5.85	6.28	6.72	7.16	7.59	8.03	8.47	8.90	9.34	9.77	10.21	10.65
||	$1.60	3.42	3.93	4.44	4.95	5.46	5.97	6.48	6.99	7.50	8.01	8.51	9.02	9.53	10.04	10.55	11.06	11.57	12.08
||	$1.70	3.47	4.05	4.64	5.22	5.80	6.38	6.96	7.55	8.13	8.71	9.29	9.87	10.46	11.04	11.62	12.20	12.78	13.37
||	$1.80	3.38	4.03	4.69	5.34	6.00	6.65	7.30	7.96	8.61	9.27	9.92	10.58	11.23	11.89	12.54	13.20	13.85	14.51
V	$1.90	3.14	3.86	4.59	5.32	6.05	6.77	7.50	8.23	8.96	9.68	10.41	11.14	11.87	12.59	13.32	14.05	14.78	15.50
	$2.00	2.75	3.55	4.35	5.15	5.95	6.75	7.55	8.35	9.15	9.95	10.75	11.55	12.35	13.15	13.95	14.75	15.55	16.35
	$2.10	2.22	3.09	3.96	4.84	5.71	6.58	7.45	8.33	9.20	10.07	10.95	11.82	12.69	13.57	14.44	15.31	16.18	17.06
	$2.20	1.54	2.48	3.43	4.38	5.32	6.27	7.21	8.16	9.10	10.05	11.00	11.94	12.89	13.83	14.78	15.72	16.67	17.62
	$2.30	0.72	1.73	2.75	3.77	4.79	5.81	6.83	7.84	8.86	9.88	10.90	11.92	12.94	13.96	14.97	15.99	17.01	18.03
	$2.40	(0.25)	0.84	1.93	3.02	4.11	5.20	6.29	7.39	8.48	9.57	10.66	11.75	12.84	13.93	15.02	16.12	17.21	18.30
	$2.50	(1.00)	(0.20)	0.96	2.12	3.29	4.45	5.62	6.78	7.94	9.11	10.27	11.44	12.60	13.76	14.93	16.09	17.26	18.42
	$2.60	(1.00)	(1.00)	(0.15)	1.08	2.32	3.56	4.79	6.03	7.27	8.50	9.74	10.98	12.21	13.45	14.69	15.92	17.16	18.40
	$2.70	(1.00)	(1.00)	(1.00)	(0.10)	1.21	2.51	3.82	5.13	6.44	7.75	9.06	10.37	11.68	12.99	14.30	15.61	16.92	18.23
	$2.80	(1.00)	(1.00)	(1.00)	(1.00)	(0.05)	1.33	2.71	4.09	5.47	6.86	8.24	9.62	11.00	12.39	13.77	15.15	16.53	17.91
	$2.90	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(0.00)	1.45	2.91	4.36	5.82	7.27	8.73	10.18	11.64	13.09	14.55	16.00	17.46
	$3.00	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	0.04	1.57	3.10	4.63	6.16	7.68	9.21	10.74	12.27	13.79	15.32	16.85

Note: numbers in parentheses () indicate negative numbers. For example, (1.00) means -1

Figure 1: Example payoff matrix/table. Provided to subjects when marginal cost is equal to $0.90.

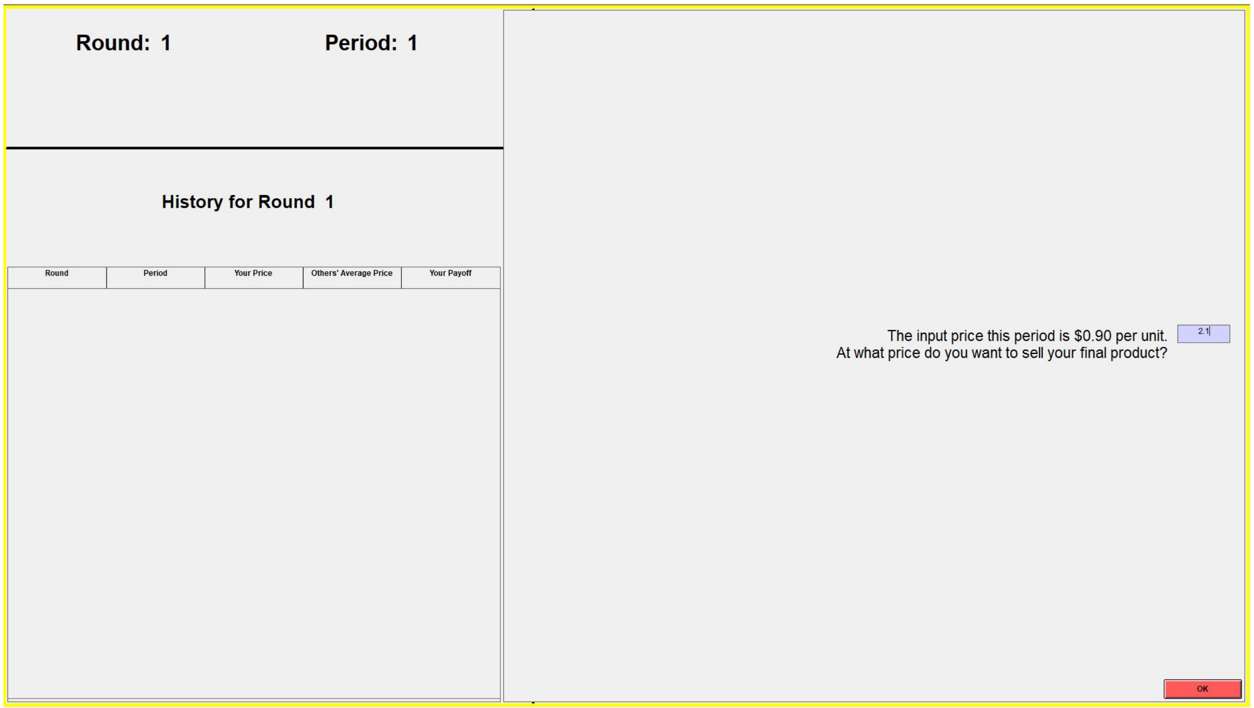

Figure 2: An example for price setting screen.

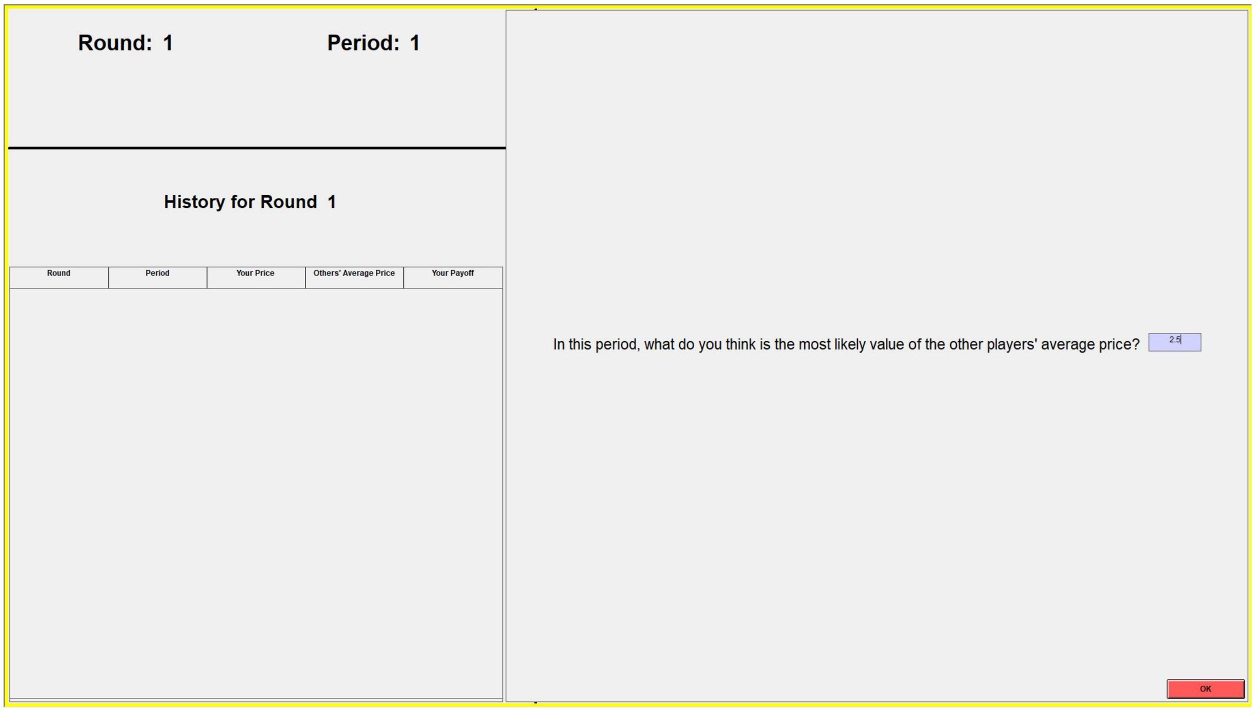

Figure 3: An example for guess decision screen.

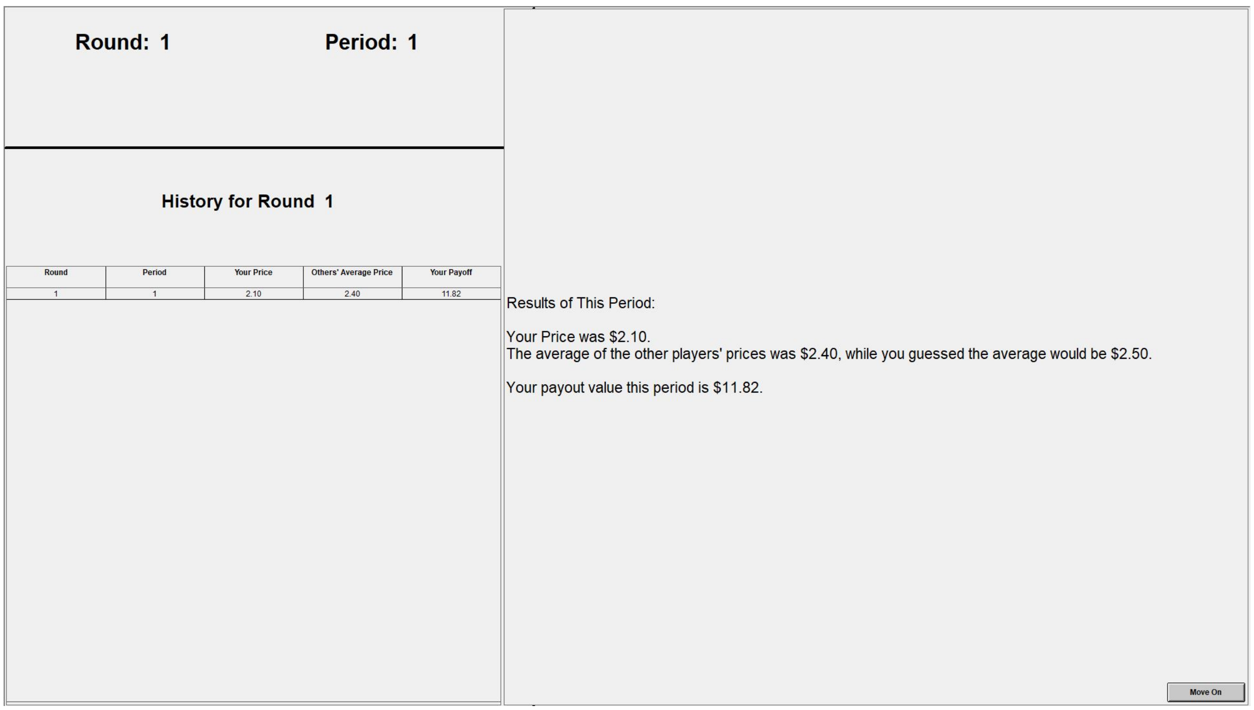

Figure 4: An example for feedback screen.

C Additional Analysis

C.1 Regression Results of Asymmetry

The regression estimates used in Figure 2 of the main text are reported on Table 1 under column (1). The remaining columns introduce control variables in a step-wise manner. In all models, the dependent variable is the change in output price (i.e., $\Delta p_{i,t} = p_{i,t} - p_{i,t-1}$). The robust standard errors that are clustered at market level are reported in parentheses, below estimates.

C.2 Pass-through Rates for $\tau = 14$

Table 2 reports the pass-through rates when $\tau = 14$ for different aggregation levels of data.

C.3 Non-parametric Test on Excess Market Power

Table 3 reports average of excess market power broken out by round and by group size. The rows 7 and 8 report the p-values resulting from Wilcoxon signed-rank test on the average of excess market power for small and large shocks, respectively. The null hypothesis is that the average of excess market power during rounds 2 and 5 (or 3 and 4) are equal.

Table 1: Estimation of asymmetry

	(1)	(2)	(3)	(4)	(5)
Δmc_t	0.497***	0.487***	0.227**	0.224**	0.769***
	(0.050)	(0.051)	(0.066)	(0.066)	(0.070)
Δmc_{t-1}	-0.540***	-0.520***	-0.169	-0.165	-1.265***
	(0.076)	(0.076)	(0.088)	(0.088)	(0.125)
Δmc_{t-2}	0.566***	0.527***	0.362***	0.352**	1.257***
	(0.099)	(0.099)	(0.104)	(0.104)	(0.134)
Δmc_{t-3}	-0.295***	-0.265***	-0.172*	-0.164*	-0.582***
	(0.063)	(0.063)	(0.065)	(0.064)	(0.077)
Δmc_{t-4}	0.063***	0.053**	0.030	0.028	0.102***
	(0.016)	(0.016)	(0.016)	(0.016)	(0.018)
$k = 0$ (c_t)	0.412***	0.432***	0.583***	0.043	0.478***
	(0.106)	(0.109)	(0.140)	(0.144)	(0.118)
$k = 1$ (c_{t-1})	0.152	0.113	-0.026	-0.036	0.004
	(0.098)	(0.100)	(0.124)	(0.123)	(0.118)
$k = 2$ (c_{t-2})	-0.230	-0.152	-0.134	-0.113	-0.084
	(0.122)	(0.125)	(0.141)	(0.140)	(0.140)
$k = 3$ (c_{t-3})	0.161*	0.102	0.082	0.067	0.067
	(0.077)	(0.078)	(0.082)	(0.081)	(0.087)
$k = 4$ (c_{t-4})	-0.051*	-0.031	-0.024	-0.018	-0.008
	(0.021)	(0.021)	(0.020)	(0.020)	(0.022)
$N = 3$		-0.007***	-0.005***	-0.005	-0.010***
		(0.002)	(0.001)	(0.003)	(0.003)
$N = 4$		-0.007***	-0.005***	-0.008***	-0.009***
		(0.001)	(0.001)	(0.002)	(0.002)
$N = 6$		-0.009***	-0.007***	-0.012***	-0.013***
		(0.002)	(0.001)	(0.002)	(0.003)
$N = 10$		-0.008***	-0.006***	-0.007**	-0.011***
		(0.002)	(0.001)	(0.002)	(0.003)
$\Delta p_{-i,t-1}$			0.287***	0.287***	0.347***
			(0.022)	(0.021)	(0.024)
Three-way interaction terms with immediate asymmetry					
$(N = 3) \times c_t$				0.492*	
				(0.192)	
$(N = 4) \times c_t$				0.680***	
				(0.142)	
$(N = 6) \times c_t$				0.828***	
				(0.154)	
$(N = 10) \times c_t$				0.561***	
				(0.143)	
AR(4) included?	No	No	No	No	Yes
N	17130	17130	17130	17130	17130
adj. R^2	0.132	0.133	0.165	0.178	0.301
F-statistic	92.240	70.604	160.112	136.818	135.597

Table 2: Asymmetry in the pass-through rates after 14 periods

	All	$N > 2$	$N = 2$	$N = 3$	$N = 4$	$N = 6$	$N = 10$
Small shocks							
β_{14}^{-}	0.881	0.957	0.483	1.004	1.002	1.088	0.749
	(0.0543)	(0.0518)	(0.192)	(0.145)	(0.0764)	(0.114)	(0.0816)
β_{14}^{+}	0.599	0.729	-0.0806	0.783	0.815	0.479	0.836
	(0.0518)	(0.0432)	(0.197)	(0.0809)	(0.0818)	(0.110)	(0.0564)
p-value	0.000	0.001	0.108	0.145	0.066	0.000	0.475
Large shocks							
β_{14}^{-}	0.821	0.902	0.398	0.811	0.961	0.878	0.936
	(0.0251)	(0.0205)	(0.0849)	(0.0598)	(0.0393)	(0.0417)	(0.0205)
β_{14}^{+}	0.802	0.866	0.465	0.637	0.978	1.002	0.796
	(0.0297)	(0.0270)	(0.105)	(0.0765)	(0.0450)	(0.0430)	(0.0399)
p-value	0.064	0.042	0.955	0.021	0.331	0.156	0.000
Observations	245	209	36	39	52	48	70

The averages of pass-through rates by differing group sizes are reported. Below averages, standard errors are reported in parentheses. p-values correspond to the result of the Wilcoxon signed-rank test on the equality of pass-through rates for small or large shocks (i.e. $H_0 : \beta_{14}^{+} = \beta_{14}^{-}$).

Table 3: Non-parametric test on excess market power

Rounds	All Markets	$N > 2$	$N = 2$	$N = 3$	$N = 4$	$N = 6$	$N = 10$
1	0.025	0.021	0.051	0.019	0.020	0.029	0.017
2	0.043	0.037	0.077	0.034	0.033	0.046	0.034
3	0.011	0.008	0.029	-0.012	0.019	0.019	0.004
4	0.048	0.042	0.083	0.038	0.044	0.052	0.038
5	0.030	0.025	0.061	0.026	0.029	0.027	0.020
All Rounds	0.032	0.027	0.060	0.021	0.029	0.034	0.023
Small η (2vs5)	0.000	0.000	0.499	0.115	0.109	0.000	0.000
Large η (3vs4)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Observations	245	209	36	39	52	48	70