Hub-and-spoke cartels: Theory and evidence from the grocery industry – Online Appendix

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A Court documents

For the purpose of this paper, we base our understanding of the facts with respect to the alleged bread cartel case mostly on documents prepared by the Competition Bureau related to the investigation into allegations that Canada Bread Company, Limited; Weston Foods, Incorporated; Loblaw Companies Limited; Wal-Mart Canada Corporation; Sobeys Incorporated; Metro Incorporated; Giant Tiger Stores Limited and other persons known and unknown have engaged in conduct contrary to paragraphs 45(1)(b) and (c) of the Competition Act9as it existed form 2001-2010) and paragraph 45(1)(a) of the Act, as amended in 2010.

The Bureau filed a first application for (Information to Obtain - ITO) search warrants in this matter on October 24th 2017 with the Ontario Superior Court of Justice (East Region). With the initial ITO, the Bureau was seeking warrants to search the premises of the targets of the investigation. On October 26th and October 30th, the Bureau submitted revised ITOs in which it sought additional search warrants for premises. On October 31st 2017, Bureau officers began executing search warrants, at which point they discovered that additional warrants were required and so on the same day another ITO was filed for four additional search warrants. Finally, one additional site was identified and a companion ITO was filed on November 1st 2017. The analysis in this paper mostly uses the redacted November 1st 2017 ITO.

The ITOs explain that on August 11th 2017, the Commissioner commenced an inquiry to investigate allegations of price fixing. The inquiry was expanded on the 23rd of October 2017 to cover the time period form November 2001 to the time of the ITOs. Loblaw Companies Limited (LCL),

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George Weston Limited and Weston Foods (Canada) are, collectively, the Immunity Applicant. The targets of the investigation were Canada Bread, Walmart, Sobeys, Metro and Giant Tiger.

Paragraph 1.12.1 of the November 1st 2017 ITO alleges that Canada Bread and Weston Bakeries agreed to increase their respective wholesale prices for the sale of fresh commercial bread via direct communications between senior officers in their organizations. According to paragraph 1.12.2, the suppliers then met individually with their retail customers to inform them of the price increase and obtain acceptance of the agreed-upon price.

The ITOs explain that the investigation arose following the (i) application on March 3rd 2015 by LCL to the Bureau's immunity program (paragraph 4.1) and (ii) its reception of an email on January 4th 2016 from the Canadian Federation of Independent Grocers alleging collusion between Canada Bread and Weston Bakers with respect to a price increase for fresh commercial bread (paragraph 4.2).

On June 22nd 2023 it was announced that Grupo Bimbo pled guilty to Canada Bread's participation in the price fixing arrangement, and that it paid a $50 million fine.

This paper analyses the alleged cartel case strictly from an economic point of view. The investigation into, and prosecution of, firms involved in the alleged conspiracy is ongoing. The allegations have not been proven in a court of justice. However, for the purpose of this paper, we base our understanding of the facts mostly on the court documents, and take these facts as established.

A.1 Paragraphs from court documents

A.1.1 Cartel origins

4.24 On 20-21 December 2016, I conducted an interview of [redacted] During the interview, [redacted] informed me that, at some point [redacted] was approached by Person X, an employee of Canada Bread [redacted] believes that the approach may have occurred during an industry event called the where all the retailers and manufacturers/suppliers got together.

(a) Industry event

4.25 [redacted] recalled that during [redacted] conversation, Person X stated: "You know, this industry is crazy. In the business, increase prices every year. There's no reason the bakery business shouldn't do the same."

(b) Looking at other industries

4.26 [redacted] recounted that Person X showed [redacted] a PowerPoint presentation that Person X had prepared. Person X allegedly informed [redacted] that "have a document that taking out to the retail community to show them the power of pricing in bakery". [redacted] stated that "the basis of this presentation was that the profitability of the fresh bakery shelf at retail was underperforming, and then the wholesale side, the manufacturers, were underperforming as well from a price realization standpoint, and Person X did comparisons for retailers. Person X did comparisons to cereal and other grain-based products to show that bread was undervalued, but particularly undervalued when it came to the profitability performance of bread shelves."

(c) Looking at other industries

4.27 [redacted] recounted that [redacted] was informed, by Person X, of a plan whereby Person X was going to the retailers to get their buy-in for a price increase with the goal of orchestrating alignment through the retail community. [redacted] stated that "clearly when it left the meeting, Person X had a feeling and a sense that I was anxious and willing on behalf of Weston Bakeries to comply with an increase."

(d) Buy-in

A.1.2 Supplier activity

4.81 [redacted] described how price increases for fresh commercial bread were highly coordinated. [redacted] stated that, in general terms, the implementation of a price increase would be discussed at least 3-4 months in advance. I understand from [redacted] interview that the Retailers would engage in back-and-forth communications involving Canada Bread and Weston Bakeries where the Retailer would discuss specific dates and price points with respect to the increase.

4.82 [redacted] (R) described that these discussions would also touch upon other, competing, Retailers and what their prices would look like post-price increase. For example, when Canada Bread and Weston Bakeries approached [redacted] with a price increase, the Suppliers would be rather definitive in saying that they had spoken with competing Retailers (naming specific Retailers) and the Suppliers were fairly certain that the suggested retail prices would be reflected on store shelves, market-wide, post-price increase.

4.83 Similarly, [redacted] (R) stated that when [redacted] agreed to accept the price increase on behalf of [redacted] knew or expected that the Suppliers would communicate [redacted] (R)'s acceptance of the price increase to competing Retailers.

A.1.3 Retailer activity

4.94 According to [redacted] Canada Bread and Weston Bakeries each used the Retailers as conduits of information during the "socialization" process of a price increase.

4.95 [redacted] (R) recalled that during the first price increase in which [redacted] was involved, Weston Bakeries had approached [redacted] indicating that they wanted to take a price increase. [redacted] (R) then recalls being instructed by [redacted] to have pricing conversations with Canada Bread to determine whether Canada Bread was also interested in taking a price increase.

4.97 [redacted] (R) then recalls acting upon instructions from [redacted] and calling Rory Lesperance of Canada Bread [redacted]. As part of that conversation, [redacted] (R) stated that [redacted] would communicate Weston Bakeries' pricing intentions to Canada Bread along with the date of the proposed price increase.

4.80 Similarly, [redacted] (R) explained that important considerations in whether or not to accept a wholesale price increase from Weston Bakeries was whether Canada Bread was also increasing its price for the supply of bread to retailers and whether other retailers would increase their retail prices. [redacted] (R) stated that it was not possible for only one retailer to increase its retail price and the only way the price increase would happen is if there was a retail price increase among the other Retailers (*i.e.,* not including smaller retailers who were less likely to compete with the Retailers on price).

A.1.4 Cartel organization and impact

4.34 [redacted] described how this first increase was the point in time during which 7 cents at wholesale and 10 cents at retail became the pattern for increases. This pattern became colloquially known as "the 7/10 Convention".

4.35 I have reviewed a product price increase chart issued by Canada Bread. The price increase chart identifies that Canada Bread had announced a price increase (the date of the announcement is not specified) with an effective date of 3 November 2002. The chart features numerous product names with their corresponding UPCs (universal product codes) along with the former price per unit and a post-price increase price per unit. The chart specifies an increase of 7 cents per unit.

4.48 [redacted] stated that given the deviation from the 7/10 Convention, namely, that this price increase was – in fact – a "double", likely meant that the suppliers had coordinated this deviation from the norm to make sure that the price increase letters reflected the "double" rather than the usual "single".

4.53 I reviewed a price increase letter from Weston Bakeries in which Weston Bakeries announced its own price increase of "approximately 4%" on 10 January 2011 with an effective date of 27 March 2011.

4.62 Notably, Weston Bakeries did not announce a price increase on plain white bread (including Weston's Wonder and Gadoua brands) or private label bread. [redacted] informed me that Canada Bread responded by rescinding its price increase which, in turn, led to Weston Bakeries not implementing its price increase.

A.1.5 Evidence of difficulties in coordinating retailers

4.85 [redacted](S) stated that retail coordination was particularly difficult to manage in the discount end of the market, featuring retailers such as Walmart, Giant Tiger, LCL's No Frills banner, Sobeys' FreshCo banner and Metro's Food Basics banner.

4.88 [redacted], stated that Retailers expected the Suppliers to deal with market disturbances with respect to pricing. When discrepancies arose, the Retailers would inform the Suppliers and dictate to the Supplier that the Supplier needed to fix the problem or the price increase would be rejected.

4.91 [redacted](S) stated that the Retailers frequently complained to Weston Bakeries about prices, at their retail competitors, that they did not like. In reviewing an example of one such complaint memorialized in an email dated 24 April 2015, [redacted](S) explained that "[Ken Kunkel (Metro)] is essentially asking 'why the hell are they [Giant Tiger] at $1.88? The price increase just happened. Why would they go this cheap? You're upsetting the market. One crazy retail will cause other [Retailers] to [decrease their retail prices] and it'll get aggressive and therefore drive the overall retails down."

B Evidence of asymmetry and services provided

We focus our attention on the shopping platforms available for these retailers in mid-size cities in Ontario and Quebec.[1] We count the number of different bread products offered by all suppliers (including private label) and then determine the share of total offering represented by each of the two big suppliers (Canada Bread and Weston), by private labels, and by other producers.

Table B1: Brand shares by retailer (%)

	Canada Bread	**Weston**	**Private Label**	**Others**
		Loblaws		
City				
Trois-Rivières	4.3	37.0	26.1	32.6
Sherbrooke	0.9	31.0	27.3	40.8
London	4.6	43.3	17.1	35.0
Kingston	7.2	38.8	18.6	35.4
		Metro		
City				
Trois-Rivières	37.5	7.3	4.2	51.0
Sherbrooke	36.7	7.1	4.1	52.0
London	47.1	11.7	2.9	38.2
Kingston	51.5	7.4	2.9	38.2
		Sobey's (IGA)		
City				
Trois-Rivières	62.6	0	7.7	29.7
Sherbrooke	49.6	0	7.9	42.4

Constructed based on observations from the shopping platforms available for these retailers in mid-size cities in Ontario and Quebec

Weston is dominant at Loblaws, while Canada Bread is dominant at both Metro and Sobeys. In each case, there are at least five times as many products available belonging to the dominant supplier than the secondary supplier. Although Sobeys does not offer any Weston products through its IGA online shopping platform (Table B1), in its Ontario stores it stocks both Canada Bread and Weston products, with the former being much more prominent. It should be pointed out that Weston and Loblaws are vertically integrated, which explains why Weston is the main supplier for Loblaws. As mentioned, together they were the immunity applicants.

[1] Sobeys itself does not have an online shopping platform. We look instead at IGA, the Sobeys banner in Quebec, which does have an online shopping platform.

C Statistics Canada data

For the analysis in Section III we take monthly data from Statistics Canada's Consumer Price Index (monthly, not seasonally adjusted (Table: 18-10-0004-01, formerly CANSIM 326-0020). Statistics Canada breaks down its index into a number of different categories:

Food is the main category. *Food* is then broken up into *Food purchased from stores* and *Food purchased from restaurants*. Within the former there are a number of subcategories: (i) *Meat*, (ii) *Fish, seafood and other marine products*, (iii) *Dairy products and eggs*, (iv) *Fruit, fruit preparations and nuts*, (v) *Vegetables and vegetable preparations*, (vi) *Other food products and non-alcoholic beverages*, (vii) *Bakery and cereal products*.

Bakery and cereal products is further subdivided into: *Bakery products* and *Cereal products*. Finally, *Bakery products* are subdivided into: i. *Bread, rolls and buns* (our category of interest), ii. *Cookies and crackers*, and iii. *Other bakery products*.

To capture products that fit our criteria of being comparable to bread (i.e., some overlap in ingredients) but not mentioned as being collusive, we focus on the following five sub-categories, all from the *Bakery* and *Cereal* categories:

- *Other bakery products* from the *Bakery products* category
- *Cookies and crackers* from the *Bakery products* category
- *Breakfast cereal and other cereal products* rom the *Cereal products* category
- *Flour and flour-based mixes* from the *Cereal products* category
- *Pasta products* from the *Cereal products* category

The CDER-CPI Research store-level data set provides item-level prices for a sample of commodities of unchanged or equivalent quantity and quality used in the construction of the Canadian Consumer Price Index. Statistics Canada granted us access to these data for the five sub-categories listed above, plus bread.

For each of these product categories, we were provided with a certain number of items. For instance, for bread we have information on four different items:

- 118301 - White Bread
- 118302 – White Bread (another brand collected in the retail establishment)
- 118401 – Whole Wheat Bread
- 118402 – Whole Wheat Bread (another brand collected in the retail establishment)

At each store the interviewer is asked to select a distinct brand for item from those that meet the description of the representative product. The same brand need not be selected in different outlets by the same interviewer or a different interviewer in other outlets. Once a brand is selected the interviewer continues to price the same brand/product each month so long as it continues to be available, continues to be representative and the outlet continues to be in the Statistics Canada sample.

Table C2 presents summary statistics from the CDER-CPI Research dataset.

Table C2: CDER-CPI data set summary statistics

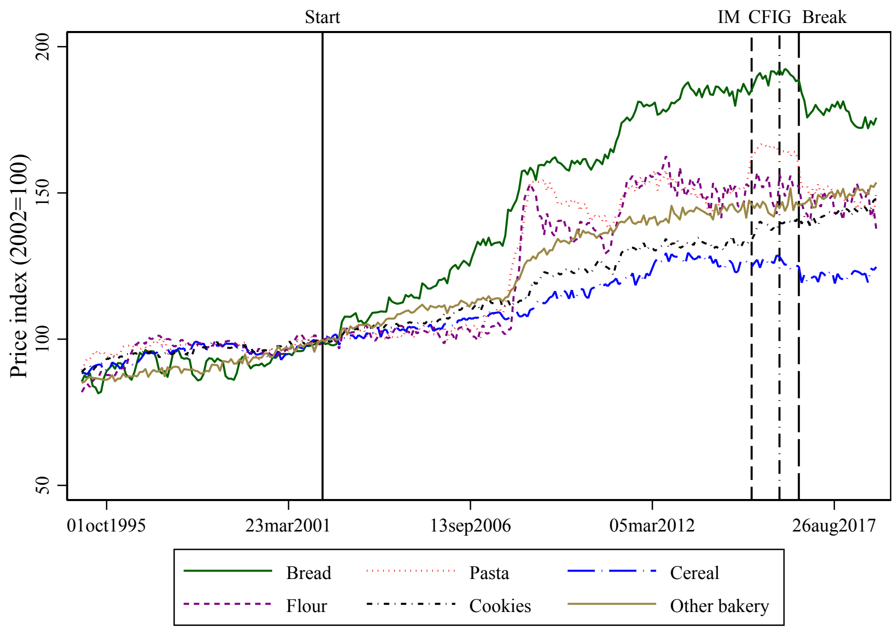
Categories	Years	Prices (CAD) Mean	Prices (CAD) Std-dev.	Nb. Outlets	Nb. Obs.
Bread, rolls and buns	2010	2.74	0.68	263	11,404
	2015	3.19	0.84	288	12,197
	2018	2.98	0.87	250	8,828
Breakfast cereal	2010	4.36	1.13	264	8,752
	2015	5.20	1.45	286	14,781
	2018	5.17	1.49	248	10,005
Cookies and crackers	2010	3.23	0.89	263	8,728
	2015	3.53	1.00	278	8,948
	2018	3.65	1.07	243	6,366
Flour and flour-based mixes	2010	4.74	1.16	257	5,684
	2015	5.06	1.37	280	5,979
	2018	4.96	1.34	244	4,241
Other bakery products	2010	3.61	1.06	263	5,774
	2015	4.04	1.21	281	5,898
	2018	4.43	1.38	246	4,079
Pasta products	2010	1.21	0.39	264	11,564
	2015	1.37	0.51	280	11,794
	2018	1.39	0.57	245	8,317

D Additional tables and figures

D.1 Cartel impact

Figure D1 reproduces Figure 1, but this time for the micro data categories (Other bakery, Pasta, Breakfast cereal, Flour, and Cookies).

Figure D1: National CPI: Bread vs other micro categories



Vertical lines: Solid: April 2002 (first coordinated price increase), Dash = March 2015 (immunity agreement), Dash-Dot = January 2016 (CFIG complaint), Long-Dash = August 2016 (end of coordination period)

D.2 Structural break test

Figure D2 zooms in on the bread price index (with 2002=100) between January 2014 and the December 2018. The vertical line shows that the best candidate break occurred in September 2016 (significant at 1%). The best candidate break is found by using a Quandt Likelihood Ratio test, which performs a modified Chow test, testing for breaks at all possible dates in the specified range. The hypothesis of a break at date t is tested using an F-statistic and then the largest of the resulting F-stats is selected to determine the best-candidate break.

Figure D2: Test for structural break in the bread price index

D.3 Pass-through regression

We estimate the following regression at the item (i), outlet (j) and month (t) level:

$$\Delta^p_{i,j,t} = \sum_{C \in \{\text{Bread}, \text{Other}\}} \alpha_{C,I} 1(j \in C, t \in T_I) + \beta_{C,I} X_m 1(j \in C, t \in T_I)$$
$$+\alpha_{\text{Bread},P} 1(j \in \text{Bread}, t \in T_P) + \beta_{\text{Bread},P} X_m 1(j \in \text{Bread}, t \in T_P) + \epsilon_{i,j,t}$$

where T_I refers to the coordinated price increase episodes, T_P refers to the placebo periods, and X_m are market-structure controls. We use three measures of concentration: (i) the HHI index across all establishments, (ii) the share of establishments controlled by the top 3 chains, and (iii) an indicator variable equal to one for markets with a single discount chain (i.e., since all markets have at least one discounters this captures markets least affected by discounters). The coefficient $\alpha_{C,I}$ measures the average price-change ratio in category C (bread or other) during price-increase episodes, while $\beta_{C,I}$ expresses the effect of the market structure variables X_m on price changes. $\alpha_{\text{Bread},P}$ and $\beta_{\text{Bread},P}$ are similarly defined for the placebo period (which only applies to bread).

Table D3 presents the estimates. We can see from column 1 that bread price-change ratios increased by almost exactly 1, confirming that, on average, stores perfectly coordinated on the proposed price increase. We can also see that average price-change ratios are much less than 1 for other categories and for bread during the placebo event. Columns 2 to 4 break this result down by retail market structure and suggest that the pass-through of wholesale price increases was greater in more concentrated retail markets. There is no market structure effect for other categories, or for the placebo period, except when using the single discount measure of concentration.

Table D3: Regression of outlet price increases on market-structure controls

VARIABLES	(1)	(2)	(3)	(4)
1(Bread) x 1(Price increase)	0.987***	0.764***	0.621***	0.863***
	(0.0537)	(0.0620)	(0.0989)	(0.0377)
1(Bread) x 1(Placebo)	0.272***	0.317***	0.339***	0.183***
	(0.0381)	(0.0579)	(0.0809)	(0.0420)
1(Other cat.) x 1(Price increase)	0.397***	0.393***	0.404***	0.416***
	(0.0133)	(0.0187)	(0.0279)	(0.0215)
1(Bread) x 1(Price increase) x HHI		6.424***		
		(1.758)		
1(Bread) x 1(Placebo) x HHI		-1.352		
		(1.263)		
1(Other cat.) x 1(Price increase) x HHI		0.107		
		(0.241)		
1(Bread) x 1(Price increase) x Share top 3			1.829***	
			(0.485)	
1(Bread) x 1(Placebo) x Share top 3			-0.339	
			(0.365)	
1(Other cat.) x 1(Price increase) x Share top 3			-0.0325	
			(0.107)	
1(Bread) x 1(Price increase) x Single discount				0.240**
				(0.0938)
1(Bread) x 1(Placebo) x Single discount				0.171**
				(0.0672)
1(Other cat.) x 1(Price increase) x Single discount				-0.0351
				(0.0251)
Observations	19,222	19,079	19,079	19,222
R-squared	0.138	0.140	0.139	0.140

Robust standard-errors in parenthesis (cluster=city)

D.4 Collapse regression

We analyze the relationship between local market concentration and price decreases during the collapse for bread and for other products. We estimate:

$$\Delta \log p_{i,j,t} = \sum_{C \in \{\text{Bread,Other}\}} \alpha_C 1(j \in \text{C}) + \beta_C X_m 1(j \in \text{C}) + \epsilon_{i,j,t}$$

The results from Table D4 reveal the reverse patterns during the collapse period. Bread prices fell by 11% and the price decline was more pronounced in more concentrated markets. The estimated effects for other categories are all much smaller.

These findings highlight how local concentration and symmetry between retailers facilitated coordination and increased the pass-through of wholesale price increases. After the announcement of the beginning of the investigation, concentrated markets cut prices by the largest amount, consistent with the idea that markets with more competition from regional chains and discounters failed to coordinate on the collusive markups prior to the collapse.

Table D4: Regression of outlet price decreases on market-structure controls

VARIABLES	(1)	(2)	(3)	(4)
1(Bread)	-0.110***	-0.0570***	0.00731	-0.0875***
	(0.0125)	(0.0149)	(0.0334)	(0.0135)
1(Other cat.)	-0.000536	0.0133**	0.0265***	0.0144***
	(0.00571)	(0.00554)	(0.00932)	(0.00443)
1(Bread) x HHI		-1.505***		
		(0.245)		
1(Bread) x Share top 3			-0.577***	
			(0.146)	
1(Bread) x Single discount				-0.0432*
				(0.0225)
1(Other cat.) x HHI		-0.389***		
		(0.140)		
1(Other cat.) x Share top 3			-0.133**	
			(0.0582)	
1(Other cat.) x Single discount				-0.0282***
				(0.00951)
Observations	2,317	2,300	2,300	2,317
R-squared	0.080	0.091	0.093	0.088
Slope difference: Bread - Other		-1.116	-0.444	-0.0150
Standard-error		0.255	0.142	0.0208

Robust standard-errors in parenthesis (cluster=city)

D.5 Rank reversals

Table D5 presents the price quartile transition matrix and reveals that there is very little transitioning from one quartile to another. As a result, we can interpret the findings from Figure 6 as implying that there is a set of low-price (discount) stores that lower their prices around the time of the investigation, reversing all of the gains since 2015 and causing within-market dispersion to increase.

Table D5: Transition matrix

	Price quartile				
Price quartile	1	2	3	4	Total
1	82.46	16.27	1.2	0.07	100
2	9.7	77.05	13.09	0.16	100
3	1.4	13.3	75.25	10.05	100
4	0.23	0.9	6.88	92	100

E Vertical split of the incremental surplus from collusion

Here we investigate the relative bargaining power of the upstream and downstream firms (i.e., whether retail pass through is greater than wholesale pass through). This requires knowledge of the size of the input price changes that lead to some of the observed wholesale and retail price increases. Unfortunately, we do not have Statistics Canada data on industrial wheat prices (only CPI data) and about how much bread suppliers purchase for their products. To overcome this we take the following steps in an effort to construct the per loaf input price increase around observed coordinated price changes:

1. We use the fact that there are approximately 453 grams (16 ounces) of flour in a loaf of bread

2. We use information on wheat prices from Bloomberg to identify three cases of discrete price increases. For each of these we identify the month of the peak price and the month of the trough and then in each case take the average over this mont, the one preceding and the one following. We then take the difference between peak and trough averages to determine the discrete increase in the price of bread. Finally, we multiply this difference by 0.000453 to get the increase in the cost of a loaf of bread that can be attributed to the wheat price shock.

3. Results for the three chosen discrete jumps are as follows:

   -May 2007 to March 2008: $185.28/MT or $0.084/loaf of bread
   -June 2010 to February 2011: $140.38/MT or $0.064/loaf of bread
   -April 2012 to November 2012: $81.843/MT or $0.037/loaf of bread

4. We link each of these wheat increases with their respective wholesale and retail price increases:

   -Increase # 9, Oct. 2007: wholesale price increase of 14-16¢, presumed retail price increase of roughly 20¢.
   -Increase # 11, March 2011: wholesale price increase of 14¢, retail price increase of 20¢.
   -Increase # 13, Jan. 2013: wholesale price increase of 7¢, retail price increase of 10¢.

Taking these steps, we can determine roughly how large was the input price shock for wholesalers. Our findings suggest that 7-cent wholesale price changes can be associated with input price increases in the range of 3.5 or 4 cents, while double wholesale price increases of 14 or 16 cents are associated with input price increases of around 6.5 or 8.5 cents.

Our takeaway is that wholesalers more than passed through input price increases. From this we can also learn about the relative bargaining power of retailers and wholesalers, since we know retailer passthrough. Our findings suggest that in each case pass through is more than complete and tends to overshoot by about 3 or 4 cents. In other words, nominally, the retailers and wholesalers are sharing the pie by each marking up a further 3 to 4 cents on their respective cost increase.

F Model

F.1 Overview and model notation

The supply-chain model is an infinite horizon, discrete time model with two upstream suppliers and two downstream retailers. Suppliers are labelled $i = 1, 2$ and retailers $j = a, b$. Suppliers can sell to consumers only through retailers and each supplies its product to both retailers. These products are the only items that retailers sell. In the retail market, there is a measure $N = 1$ of consumers. Consumers view the products of the two suppliers as identical but view the retailers as differentiated, so that each consumer buys at most one of the products from only one of the two retailers. Each retailer sets a common price, p_j, for the two products and consumers observe prices prior to choosing a retailer from which to purchase. Consumer behavior is summarized by demand functions for retailers a and b given by:

$$Q_a(p_a, p_b)) = \frac{\exp((\delta - p_a)\alpha)}{1 + \exp((\delta - p_a)\alpha) + \exp((\delta - p_b)\alpha)}$$
$$Q_b(p_a, p_b)) = \frac{\exp((\delta - p_b)\alpha)}{1 + \exp((\delta - p_a)\alpha) + \exp((\delta - p_b)\alpha)}$$

respectively, with $\alpha, \delta > 0$. Suppliers 1 and 2 provide their products to retailer j at wholesale prices w_1^j, w_2^j respectively. These are the only variable costs retailer j incurs in selling.

The values of wholesale prices are determined at the start of each period, t, via a negotiation process in which the two suppliers simultaneously make wholesale price bids to each of the two retailers. This bidding process occurs sequentially prior to the retail price determination process. Having received the bids, each of the retailers simultaneously chooses one of the two suppliers to be its main supplier. The main supplier is promised a share of quantity sold – a shelf share – $s > .5$ and is paid its wholesale price bid for each unit supplied. In exchange for the greater shelf share, the main supplier provides services to the retailer that result in a fixed cost of $F > 0$. The other supplier becomes the secondary supplier and is paid its price bid. It obtains the remaining $1 - s$ share of quantity sold but incurs no fixed cost of supplying the retailer.

Which supplier is chosen as the main supplier by any retailer j is, in part, determined by the cost of switching main suppliers. At the beginning of the wholesale-price negotiation process in any period, one of the two suppliers is the incumbent main supplier from the previous period's bidding process. We assume that switching main suppliers is costly for the retailer as new arrangements must be put in place for the retail services provided. We model this cost as a fixed switching cost, Δ, incurred by the retailer should it switch main suppliers. We assume that Δ is a random variable whose value each period is realized only after the suppliers bids have been submitted and before the retailers make any switching decision. We assume that Δ is identically and independently distributed both across time and across retailers, has positive expected value and full support on the real line.[2]

The timing of moves is given in Figure 1. The state of the game, x, is given by the supply relationship – main or secondary – that supplier 1 had with retailers a and b in period $t - 1$. There are four possible states: $x = (M, M)$ denotes that supplier 1 was the main supplier to both retailers, $x = (M, S)$ denotes that supplier 1 was the main supplier to retailer a and the

[2]We allow for Δ to take on negative values with small probability to ensure that a retailer switches suppliers with a (small) positive probability even when wholesale prices are equal.

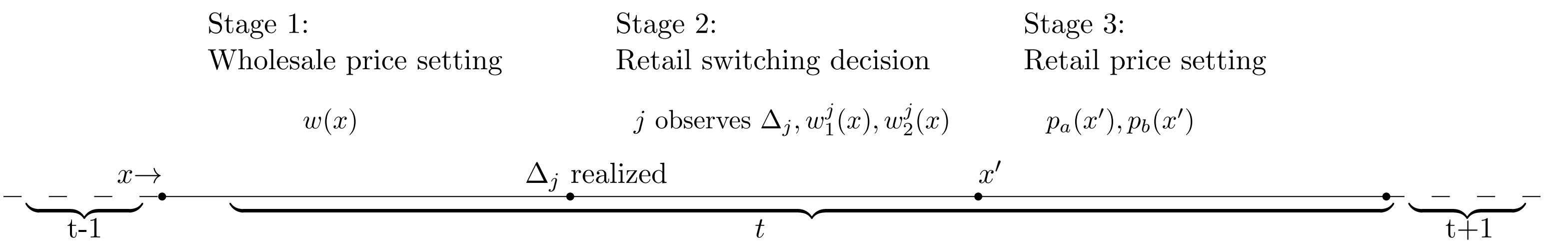


Figure F3: StageGame Timeline

secondary supplier to retailer b, $x = (S, M)$ denotes that supplier 1 was the main supplier to retailer b and the secondary supplier to retailer a, and $x = (S, S)$ denotes that supplier 1 was the secondary supplier to both retailers. Given x, suppliers simultaneously make wholesale price offers to retailers, $\{w_1^a(x), w_2^a(x), w_1^b(x), w_2^b(x)\}$. This collection is denoted by $w(x)$ in the timeline above. Retailer j observes the values of its two wholesale price offers but not the values of the wholesale price offers made to its retail competitor. Next, the values of the switching cost, Δ_j, are realized for each retailer. After having observed the realized value of their own switching costs (and their own wholesale price offers), the two retailers simultaneously decide either to retain or switch main suppliers. These switching decisions are then observed – the state transitions from x to x' – and the retailers simultaneously set retail prices. Each agent makes choices to maximize the present value of the stream of expected per-period profits, with retailers and suppliers having a common discount factor β, $0 \leq \beta \leq 1$.

In the non-collusive situation, we restrict both retailers and suppliers to using Markov strategies and define equilibrium as the symmetric Markov perfect equilibrium (SMPE) for the game. The value of s is determined by the retailer and is set such that the secondary supplier makes zero profits in period t. Suppliers' costs of production are identical and given by a constant unit cost, $c \geq 0$. We characterize the features of the SMPE below. Subsequently, we define the collusive arrangements of interest and define the incentive constraints for the collusive outcomes.

F.2 Non-Collusive Equilibrium

In what follows, we characterize the non-collusive equilibrium of the model. We begin by analyzing each of the stages of the period t game, beginning with the stage 3 retail pricing game.

Stage 3 game – retail pricing: At stage 3, retailers a and b have received wholesale price bids, w_1^a, w_2^a and w_1^b, w_2^b respectively, have realized switching costs Δ_a and Δ_b and made switching decisions resulting in a new state x'. The new state is observed by both retailers. The marginal cost for each retailer is determined by the values of the wholesale price offers that each receives and the shelf-share allocation as determined by the retailer's switching decision (captured by x'). For retailer a, then, marginal cost is given by

$$\bar{w}_a(\mathbf{w}|x', x) = \sigma_a(x')w_1^a(x) + (1 - \sigma_a(x'))w_2^b(x) \equiv \bar{w}_a,$$

where $\sigma_a(x')$ gives the shelf-share for supplier 1 under its supply contract with retailer a and given state x'. A similar expression gives retailer b's marginal cost. Given this, the gross profit for retailer a in period t is given by the expression

$$\pi_a(p_a, p_b) = (p_a - \bar{w}_a) Q_a(p_a, p_b).$$

A similar expression provides the gross profits for retailer b. As retailers set prices simultaneously to maximize profits, equilibrium prices, p_j^*, are defined by the following first-order conditions:

$$p_a^* = \bar{w}_a + \frac{1}{\alpha(1 - Q_a(p_a^*, p_b^*))} \tag{A1}$$

$$p_b^* = \bar{w}_b + \frac{1}{\alpha(1 - Q_b(p_a^*, p_b^*))}. \tag{A2}$$

The Nash equilibrium outcome variables for retailer j are denoted by the three following functions: $Q_j(\mathbf{w}|x', x)$, $p_j(\mathbf{w}|x', x)$, and $\pi_j(\mathbf{w}|x', x)$.

Given the logit demand specification in (1) and (2) above, one can show that the reaction functions defined by the above first-order conditions are upward-sloping and that there is a unique pricing equilibrium given some $\bar{w}_a, \bar{w}_b$. When the equilibrium values of $\bar{w}_a$ and $\bar{w}_b$ are equal, then $p_a^* = p_b^*$. If the equilibrium value of $\bar{w}_a$ is larger than that of $\bar{w}_b$, then both p_a^* and p_b^* increase relative to the case in which $\bar{w}_a = \bar{w}_b$ (the reaction functions are upward sloping) with $p_a^* > p_b^*$.

Stage 2 game – Contract choice: In the stage 2 game, retailers simultaneously decide whether or not to switch main suppliers and the value of the contracted shelf share s. In making these decisions retailer a, for instance, knows the values of its wholesale price bids, $w_1^a(x), w_2^a(x)$ and the realized value of its switching cost, Δ_a. Retailer a does not observe the wholesale price bids received by retailer b nor retailer b's realized value of switching cost. As a result, in making its switching decision, retailer a must form beliefs about the price offers retailer b has received, b's switching probability (recall that Δ is a random variable) and the future value of the game to retailer a under different switching choices. These beliefs must be consistent with retailer b receiving equilibrium wholesale price bids in each state x at date t, the value of b's switching cost being generated by a logistic distribution and future wholesale price bids being consistent with equilibrium.

Given these beliefs for retailer a, we can characterize a's decision problem as a dynamic discrete choice problem with Logit shocks. We let $\mathbf{w}(x) = [w_1^a(x), w_2^a(x), \tilde{w}_1^b(x), \tilde{w}_2^b(x)]$ and $\tilde{\mathbf{w}}(x') = [\tilde{w}_1^a(x'), \tilde{w}_2^a(x'), \tilde{w}_1^b(x'), \tilde{w}_2^b(x')]$ denote retailer a's observed and perceived wholesale price offers, respectively, using the superscript $\sim$ to indicate beliefs about future periods and rival retailer wholesale prices. Similarly, $\mathbf{w}$ and $\tilde{\mathbf{w}}$ are the collections of wholesale prices across states x. The optimal contract choice for retailer a is given by the following problem:

$$\begin{aligned} U_a(x, \mathbf{w}, \tilde{\mathbf{w}}) &= E_{\boldsymbol{\varepsilon}_a}\Bigg[\max\Big\{\sum_{x'} H(x'|x, \mathbf{w}, \tilde{\mathbf{w}}, \text{switch})\left(\pi_a(\mathbf{w}|x', x) - \bar{\Delta} + \varepsilon_{a,\text{switch}} + \beta U_a(x', \tilde{\mathbf{w}})\right), \\ &\qquad \sum_{x'} H(x'|x, \mathbf{w}, \tilde{\mathbf{w}}, \text{stay})\left(\pi_a(\mathbf{w}|x', x) + \varepsilon_{a,\text{stay}} + \beta U_a(x, \tilde{\mathbf{w}})\right)\Big\}\Bigg] \\ &= E_{\boldsymbol{\varepsilon}_a}\Big[\max\left\{u_{a,\text{switch}}(x, \mathbf{w}, \tilde{\mathbf{w}}) + \varepsilon_{a,\text{switch}}, u_{a,\text{stay}}(x, \mathbf{w}, \tilde{\mathbf{w}}) + \varepsilon_{a,\text{stay}}\right\}\Big], \end{aligned} \tag{A3}$$

where $\pi_a(\mathbf{w}|x', x)$ gives the maximized value of gross profits (from stage 3) for retailer a, $H(x'|\mathbf{w}, x, \text{switch})$ is the state transition matrix should retailer a decide to switch and $(\varepsilon_{a,\text{stay}}, \varepsilon_{a,\text{switch}})$ are logit shocks distributed $T1EV(0, \sigma_\Delta)$.[3] Note that $U_a(x, \tilde{\mathbf{w}})$ denotes the expected-value function of retailer a given common beliefs $\tilde{\mathbf{w}}$: $U_a(x, \tilde{\mathbf{w}}) \equiv U_a(x, \tilde{\mathbf{w}}, \tilde{\mathbf{w}})$.

From the above, and given any vectors $(\mathbf{w}, \tilde{\mathbf{w}})$, the probability that retailer a retains its existing main supplier is defined by a cut-off rule in which a keeps its main supplier if the realized switching cost is sufficiently large and switches otherwise. This means that we can define the Markov-perfect retention probability for retailer a as a fixed-point of the following best-response choice probability mapping:

$$\rho_a(x, \mathbf{w}, \tilde{\mathbf{w}}) = \frac{\exp(u_{a,\text{stay}}(x, \mathbf{w}, \tilde{\mathbf{w}})/\sigma_\Delta)}{\exp(u_{a,\text{switch}}(x, \mathbf{w}, \tilde{\mathbf{w}})/\sigma_\Delta) + \exp(u_{a,\text{stay}}(x, \mathbf{w}, \tilde{\mathbf{w}})/\sigma_\Delta)}. \tag{A4}$$

In addition, and omitting the dependence on wholesale prices and retailer identity, the controlled Markov process for the state variable is given by:

$$H(x'|x, \text{stay}) = \begin{pmatrix} \rho(M,M) & 1-\rho(M,M) & 0 & 0 \\ 1-\rho(M,S) & \rho(M,S) & 0 & 0 \\ 0 & 0 & \rho(S,M) & 1-\rho(S,M) \\ 0 & 0 & 1-\rho(S,S) & \rho(S,S) \end{pmatrix}$$

$$H(x'|x, \text{switch}) = \begin{pmatrix} 0 & 0 & \rho(M,M) & 1-\rho(M,M) \\ 0 & 0 & 1-\rho(M,S) & \rho(M,S) \\ \rho(S,M) & 1-\rho(S,M) & 0 & 0 \\ 1-\rho(S,S) & \rho(S,S) & 0 & 0 \end{pmatrix}.$$

Finally, given that the secondary supplier's only cost is a constant marginal cost, the (essentially) unique solution for shelf share under the contract is $s = 1 (1 - s = 0)$.[4]

Stage 1 game – wholesale pricing: In the first stage-game, suppliers simultaneously submit wholesale price bids w_i^j to maximize the expected discounted sum of profits in each state x, understanding subsequent equilibrium play of the game. Thus, the wholesale price choices for supplier 1, for instance, are given by the problem:

$$\begin{aligned} V_1(x, \mathbf{w}, \tilde{\mathbf{w}}) &= \max_{w_1^a, w_1^b} \sum_{x'} H(x'|x, \mathbf{w}, \tilde{\mathbf{w}}) \times \Big[\sigma_a(x') Q_a(\mathbf{w}|x', x)(w_1^a - c) \\ &\qquad + \sigma_b(x') Q_b(\mathbf{w}|x', x)(w_1^b - c) - F(x') + \beta V_1(x', \tilde{\mathbf{w}}, \tilde{\mathbf{w}})\Big] \\ &= \max_{w_1^a, w_1^b} \sum_{x'} H(x'|x, \mathbf{w}, \tilde{\mathbf{w}}) \times v_1(x'|x, \mathbf{w}, \tilde{\mathbf{w}}), \end{aligned} \tag{A5}$$

where $H(x'|x, \mathbf{w}, \tilde{\mathbf{w}})$ is the equilibrium transition probability matrix defined in the contract-choice stage game and $F(x')$ gives whatever fixed costs supplier 1 may incur in state x' (based on supplier 1's status as main or secondary supplier in x'). Supplier 2's value function is defined analogously.

[3] This specification is equivalent to one in which there is a single random switching cost that follows a logit distribution such that the switching cost may be negative. We adopt this specification to avoid corner solutions and to facilitate the analysis of suppplier collusion on a single price.

[4] The exception is the case in which the secondary supplier's price bid is c. As will be seen, this bid cannot be an equilibrium bid if $s < 1$. Note also that, should the secondary supplier have a positive fixed cost of servicing the retailer, then the equilibrium contract would have $s < 1$.

The Nash equilibrium $\mathbf{w}^*$ in state x is defined by the following first-order condition for supplier 1 negotiating with retailer a (other bids are defined analogously):

$$\sum_{x'} \Bigg[\underbrace{\frac{\partial H(x'|x,\mathbf{w}^*)}{\partial w_1^a} v_1(x'|x,\mathbf{w}^*)}_{\text{Competition for shelf-share}} + \underbrace{H(x'|x,\mathbf{w}^*)\sigma_a(x')Q_a(\mathbf{w}^*|x',x)}_{\text{Direct price effect}}$$

$$+ \underbrace{H(x'|x,\mathbf{w}^*)\left[\sigma_a(x')\frac{\partial Q_a(\mathbf{w}^*|x',x)}{\partial w_1^a}(w_1^a - c) + \sigma_b(x')\frac{\partial Q_b(\mathbf{w}^*|x',x)}{\partial w_1^a}(w_1^b - c)\right]}_{\text{Competition for consumers}} \Bigg] = 0. \quad \text{(A6)}$$

The first component above gives the impact of a change in supplier 1's offer to retailer a on the probability that a retains/switches main suppliers. This decision affects supplier 1's assessment of the state transition probabilities given by H:

$$\frac{\partial H(x'|x,\mathbf{w}^*)}{\partial w_1^a} = H(x'|x,\mathbf{w}^*,\text{stay})\frac{\partial \rho_a(x,\mathbf{w}^*)}{\partial w_1^a} - H(x'|x,\mathbf{w}^*,\text{switch})\frac{\partial \rho_a(x,\mathbf{w}^*)}{\partial w_1^a}.$$

where $\rho_a(x,\mathbf{w}^*) = \rho_a(x,\mathbf{w}^*,\mathbf{w}^*)$ is equilibrium retention probability.

The marginal effect of w_1^a on $\rho(x,\mathbf{w}^*)$ can be thought of as a one-time change in the wholesale price of retailer a. Since this is not a permanent change, it only affects $\rho(x,\mathbf{w}^*)$ by changing the period profit of retailer a, holding fixed the continuation value. Further, since this wholesale price deviation is not observed by retailer b, the change in profit is strictly coming from a change in the price of retailer a (holding retailer b's price fixed p^{*b}). More specifically, the marginal effect of w_1^a on $\rho(x,\mathbf{w}^*)$ is given by:

$$\begin{aligned}
\frac{\partial \rho_a(x,\mathbf{w}^*)}{\partial w_1^a} &= \frac{\rho_a(x,\mathbf{w}^*)(1-\rho_a(x,\mathbf{w}^*))}{\sigma_\Delta}\left[\sum_{x'} H(x'|x,\text{stay},\mathbf{w}^*)\frac{d\pi_a(\mathbf{w}^*|x',x)}{dw_1^a}\right] \\
&\quad - \frac{\rho_a(x,\mathbf{w}^*)(1-\rho_a(x,\mathbf{w}^*))}{\sigma_\Delta}\left[\sum_{x'} H(x'|x,\text{switch},\mathbf{w}^*)\frac{d\pi_a(\mathbf{w}^*|x',x)}{dw_1^a}\right],
\end{aligned}$$

where

$$\frac{d\pi_a(\mathbf{w}^*|x',x)}{dw_1^a} = \underbrace{\frac{\partial \pi_a}{\partial p_a}\Big|_{p_a=p^*}}_{=0}\frac{dp^*}{dw_{1a}} - \sigma_a(x')Q_a(\mathbf{w}^*|x',x) = -\sigma_a(x')Q_a(\mathbf{w}^*|x',x).$$

The third component, the *competition for consumers* effect, arises from a change in retailer a's price following a change in w_1^a. The essence of this effect is that, should supplier 1, say, lower its wholesale price offer to retailer a, this lowers a's costs and so allows a to lower price. This price reduction shifts consumers from retailer b to retailer a, affecting supplier 1's sales revenues from both locations. The net impact on supplier 1 depends on 1's status – main or secondary supplier – at each location. In the case in which 1 turns out to be the main supplier to retailer a and the secondary supplier to retailer b, this shift in purchases to retailer a represents a net benefit to supplier 1. In other cases, it can be either a wash (as saywhen 1 is the main supplier to both retailers) or be a net loss (when 1 is the secondary supplier to retailer a and the main supplier to retailer b. The effect of this quantity shifting for any state x' is given by:

$$
\begin{aligned}
\frac{\partial Q_a(\mathbf{w}^*|x',x)}{\partial w_1^a} &= \frac{\partial D_a(p_a,p_b^*)}{\partial p_a}\Big|_{p_a=p_a^*}\frac{dp^*}{d\bar{w}_a}\sigma_a(x') \\
&= -\alpha Q_a(\mathbf{w}^*|x',x)(1-Q_a(\mathbf{w}^*|x',x))\frac{dp^*}{d\bar{w}_a}\sigma_a(x') \\
\frac{\partial Q_b(\mathbf{w}^*|x',x)}{\partial w_1^a} &= \frac{\partial D_b(p_a,p_b^*)}{\partial p_a}\Big|_{p_a=p_a^*}\frac{dp^*}{d\bar{w}_a}\sigma_a(x') \\
&= \alpha Q_a(\mathbf{w}^*|x',x)Q_b(\mathbf{w}^*|x',x)\frac{dp^*}{d\bar{w}_a}\sigma_a(x').
\end{aligned}
$$

Our analysis focuses on symmetric Markov-perfect equilibrium (MPE). Imposing symmetry leads to wholesale prices for the main and secondary suppliers in states with high (H - states (M,M)/(S,S)) or low (L - states (M,S)/(S,M)) upstream concentration: $w_M^*(H)$, $w_S^*(H)$, $w_M^*(L)$ and $w_S^*(L)$. Similarly, the equilibrium cutoff strategies of retailers a and b are such that $\rho_a^*(\omega)=\rho_b^*(\omega)=\rho^*(\omega)$ for $\omega=H,L$, and retailers are more likely to switch suppliers when upstream concentration is high: $\rho^*(L)<\rho^*(H)$. Retail prices are similarly defined for each initial and next-period states. A MPE is a collection of strategies, $\{w_M^*(\omega),w_S^*(\omega),\rho^*(\omega),p^*((M,M),\omega),\dots,p^*((S,S),\omega)\}_{\omega=H,L}$, that solves retailers' and suppliers' first-order conditions (equations A6 and A1), and retailers' optimal retention probability (equation A4).

Given the above characterization of the stage game equilibria, one can show, using standard conditions for Markov games, that a Markov Perfect equilibrium exists (although it need not be unique). In particular, since Δ has full support and the Bertrand-Nash profit function is unique and monotonically decreasing in $\bar{w}$, there exists a pure-strategy equilibrium for the contracting subgame (see Doraszelski and Satterthwaite (2010)). As the equilibrium retention probability is decreasing in wholesale price offers, suppliers face downward-sloping demand and the wholesale pricing game is described by upward sloping best-response functions. The existence of an equilibrium follows standard conditions for Bertrand games with differentiation.

We solve for the non-collusive Markov-Perfect equilibrium by iterating on the following nested-fixed point algorithm:

1. Initial values: $w_M^0(H),w_S^0(H),w_M^0(L),w_S^0(L),\rho^0(L),\rho^0(H)$ as well as the retail prices $p_a^0(x',x)$.

2. Given wholesale prices, solve equilibrium retail prices and retailer profits (separately for each (x',x)).

3. Given retail prices and profits, solve for the equilibrium retention probabilities by iterating on equation A4.

4. Evaluate new wholesale price by inverting equation A6: w^*

5. Update wholesale price using a weighted average of w^* and w^{k-1}:

$$w^k=\lambda w^*+(1-\lambda)w^{k-1}$$

6. Stop if $||w^k-w^{k-1}||<\epsilon$ for all states. Otherwise repeat steps (2-6).

We set $\lambda = 0.25$ and $\epsilon = 10^{-12}$.

For our analysis of collusion, two features of the equilibrium prove important. One is that, because $s = 1$, there is considerable asymmetry between the profits earned by the secondary supplier relative to the main supplier. This fact, combined with positive expected switching costs, means that the secondary supplier has an incentive to compete more vigorously in price than does the main supplier. As our subsequent calibration demonstrates, this incentive tends to create a price gap between the wholesale bid of the main supplier and that of the secondary supplier. This price gap proves an important challenge should retailers try to collude on retail price. We turn to these matters next.

F.3 Collusive Equilibria

The question we explore in this section is why agents might opt for a collusive arrangement involving both retailers and suppliers rather than some simpler supplier-only or retailer-only collusive arrangement. One can imagine that suppliers might want to support retailer collusion if the suppliers are able to extract some of the collusive profits via increased wholesale prices. Less obvious is the reason retailers might want to participate in a collusive arrangement that raises their own wholesale prices.

To explore this specific question, and because the evidence we have involves only collusion on price, we focus specifically on price collusion equilibria (and not on equilibria involving collusion on the main supplier switching decision). We focus on three scenarios. The first is independent supplier collusion. In this case suppliers choose a common wholesale price bid, w^c, regardless of whether the suppler is the main or secondary supplier; retailers play the non-collusive equilibrium strategies given this common wholesale price bid. The second is independent retailer collusion. In this scenario retailers are assumed to choose a common retail price, p^c, but to set shelf-share in a non-collusive fashion; suppliers choose wholesale price bids using the non-collusive equilibrium strategies given retailer shelf-share choice and the collusive retail price p^c.[5] The final scenario is joint collusion, in which retailers and suppliers jointly decide on a common value for the wholesale price, w^c, a common value for the retail price, p^c, and a common shelf share, s^c. Note that unlike independent retailer collusion, under joint collusion shelf share can be part of the collusive arrangement because suppliers act as a perfect monitor should retailers deviate.

For simplicity, in each of the collusive scenarios, we restrict the colluding parties to using stationary, symmetric strategies and assume deviations from the collusive arrangement are punished by reversion to the non-collusive equilibrium strategies in the following period. For independent supplier collusion, supplier strategies can be conditioned on all past wholesale price bids. Deviation by either supplier from the common collusive price, w^c, at time t results in reversion at $t+1$ to the non-collusive equilibrium. For independent retailer collusion, the stage 3 retailer pricing strategies can be conditioned on all past retail price outcomes. The stage 2 contracting strategies continue to be the stage 2 non-collusive equilibrium strategies given wholesale price bids and the collusive retail pricing strategies. Deviation by either retailer from the common collusive price, p^c, at time t results in reversion at $t+1$ to the non-collusive equilibrium. Under joint collusion, both supplier and retailer pricing strategies can be conditioned on all past wholesale prices, retail prices and shelf-share outcomes (the switching decision continues to be made using the non-collusive strategy given

[5] Under an alternative specification in which the retailers set s strategically as part of the MPE, it is a dominant strategy for them to set $s = 1$.

w^c, p^c, s^c). For each form of collusion, equilibrium is defined as the perfect Bayesian equilibrium given the strategy restrictions specified above.

In what follows, we look at both independent supplier collusion and independent retailer collusion and examine the incentives for the colluding parties to deviate in each case. Finally, we consider joint collusion and examine how it can be used to resolve the challenges to collusion under the independent collusive scenarios.

F.3.1 Independent supplier collusion

Under independent supplier collusion, the punishment should either supplier deviate from the collusive wholesale price, w^c, is reversion next period to the non-collusive equilibrium. The value of this punishment, given any state x' is given by $V_1(x, \mathbf{w}^*)$ defined in equation A5 above. The value of colluding on w^c in any state x is given by $V_1(x, \mathbf{w}^c)$, where $\mathbf{w^c}$ has $w_i^j = w^c$ for all i, j. The reason is that, under independent supplier collusion, retailers are playing the non-collusive strategies in stage games 2 and 3. The optimal deviation for supplier 1 with retailer a is defined as follows:

$$
\begin{aligned}
V_1^d(x, w^d, \mathbf{w}^c) \;&=\; \max_{w^d} \sum_{x'} H(x'|x, \mathbf{w}, \mathbf{w}^c) \times \Big[\sigma_a(x')Q_a(\mathbf{w}|x', x)(w^d - c) \\
&\qquad + \sigma_b(x')Q_b(\mathbf{w}|x', x)(w^c - c) - F(x') + \beta V_1(x', \mathbf{w}^*)\Big], \qquad \text{(A7)}
\end{aligned}
$$

where $\mathbf{w} = [w^d, w^c, w^c, w^c]$. The first-order condition for the optimal deviation is analogous to equation A6 above. Supplier collusion is supportable as an equilibrium if, for all states x, $V_1(x, \mathbf{w^c}) \geq V_1^d(x, w^d, \mathbf{w}^c)$.

The challenge for supplier collusion, as our calibration study shows, is the asymmetry in shelf share allocations between main and secondary suppliers. Indeed, in the state $x' = (S, S)$ supplier 1 earns zero period t profits even-though it is colluding. Further, since the collusive price is state independent, there is a significant probability that supplier 1 will remain in the (S, S) state in future periods. This means that, once a supplier enters the (S, S) state it can expect to earn very little from collusion: $V(x = (S, S), \mathbf{w^c})$ is small. This makes deviating from the collusive agreement attractive to supplier 1 and so, without a very high discount factor, it will be difficult to support the collusive outcome.

F.3.2 Independent retailer collusion

Given it is difficult to support independent supplier collusion, how does this impact independent retailer collusion? Similar to the case of independent supplier collusion, the value of colluding for retailer a is given by the value function $U_a^c(x, p^c, \mathbf{w}^{rc})$ given in the stage two contracting game. The difference is that, instead of retail price being determined non-collusively in the stage 3 game, retail price is now set at p^c for all states x. The other difference is that the equilibrium wholesale prices, $\mathbf{w}^{rc} \neq \mathbf{w}^*$, are now determined by the suppliers in the stage 1 game, taking account of the fact that the retailers are now colluding on retail price in the stage 3 game (and any impact that this collusion has on on the stage 2 switching decision). This changes the tradeoff facing suppliers since the pass-through rate of wholesale prices is now zero, which soften wholesale price competition (i.e.

competition for consumers is zero):

$$\sum_{x'}\Bigg[\underbrace{\frac{\partial H(x'|x,\mathbf{w}^{rc})}{\partial w_1^a}v_1(x,\mathbf{w}^{rc})}_{\text{Competition for shelf-share}}+\underbrace{H(x'|x,\mathbf{w}^{rc})\sigma_a(x')Q_a(\mathbf{w}^{rc}|x',x)}_{\text{Direct price effect}}$$
$$+\underbrace{H(x'|x,\mathbf{w}^{rc})\left[\sigma_a(x')\frac{\partial Q_a(\mathbf{w}^{rc}|x',x)}{\partial w_1^a}(w_1^a-c)+\sigma_b(x')\frac{\partial Q_b(\mathbf{w}^{rc}|x',x)}{\partial w_1^a}(w_1^b-c)\right]}_{\text{Competition for consumers=0}}\Bigg] = 0 \quad \text{(A8)}$$

where $H(x'|x,\mathbf{w}^{rc}) = H(x'|x,\mathbf{w}^{rc},\mathbf{w}^{rc})$ is transition probability evaluated at the equilibrium wholesale price $\mathbf{w}^{rc}$.

In essence, then, the value of retail collusion is determined just as in the non-collusive equilibrium except with the stage 3 game outcome determined by the collusive pricing scheme.

As before, the value of the punishment path for any state x is just $U_a(x,\mathbf{w}^*)$. The value of the best deviation given any state x is determined in a two part process. First, retailer a determines the best price deviation in stage 3 given state x'; then retailer a determines the best switching decision in stage 2 (the transition from x to x') given the values of w_i^a and the deviation in stage 3. To support retailer collusion, it must be that, for all states x, the value of colluding for each retailer is at least as large as the value of the optimal deviation (followed by the non-collusive equilibrium).

The challenge for independent retailer collusion, as our calibration shows, is that the suppliers adjust wholesale prices in the face of the retailer collusion in an attempt to extract some of the collusive profits from the retailers. This can happen in two ways. One is that the main supplier, recognizing the switching costs, raises its price bid (relative to the non-collusive one) to extract retailer profits. The secondary supplier, realizing the added profitability of being main suppier, raises its price bid by less (so as to increase the switching probability). The result is that the non-cooperating suppliers expand the gap between wholesale price bids, especially in the (S,S) state. This means that, when one retailer switches main suppliers and the other does not, there is a greater cost asymmetry between retailers. This asymmetry enhances the gains to the lower cost retailer when deviating from the collusive price and so makes retailer collusion more difficult. In essence, the simple act of suppliers best-responding to the collusive prices of retailers can act as a disruptive force to retailer collusion.

A second way is that a supplier actively works to disrupt retailer collusion by lowering wholesale prices. In this case, supplier 1, say, sets a wholesale price bid to retailer a sufficiently low as to actively induce retailer a to break the collusive pricing agreement. This outcome can occur if the suppliers are unable to extract much of the collusive profit from higher wholesale prices and when the elasticity of demand across retailers is large. In this case, the benefit to suppliers from on-going retailer collusion is low (relative to the non-collusive outcome) and they seek to extract profits by inducing a one-shot retailer deviation that garners significant sales increases and so profit increases for the supplier.

F.3.3 Joint collusion

What the above analysis suggests (and our calibration shows) is that the suppliers can indeed benefit from retailer collusion; however, when the suppliers don't participate in the collusion, they're attempt to extract profits can serve to disrupt the arrangement. Joint collusion serves as a means of transferring profits to the suppliers directly in a way that maintains the collusive arrangement.

For the joint collusion case, the incentive constraints for retailers and suppliers are defined similarly to the above two cases. The retention probabilities are obtained by solving the non-collusive probabilities, $\rho^{joint}(x)$, assuming fixed retail and wholesale prices. Relative to the retailer-only collusion in which the wholesale price bids of main and secondary suppliers differ, with common wholesale price bids under joint collusion, the retention probability is high (much as in the case of supplier only collusion). On the retail price side, the main difference (relative to retailer only collusion) is that retailers optimally deviate from the arrangement assuming that marginal costs for both retailers is $\bar{w} = w^c$.

On the supplier side, the key difference with supplier-only collusion is that when supplier 1 deviates by lowering w_1^a, say, retailer a correctly anticipates that the next period equilibrium will revert to the non-collusive equilibrium and therefore will immediately deviate from the collusive price also. In other words, because the game is played sequentially, a supplier deviation also triggers a retail deviation. As with supplier-only collusion, this changes the retention probability of supplier 1, and retailer a responds by choosing the optimal deviation price assuming that the other retailer continues to charge p^c.

In the case in which $s^c = 1$, joint collusion lessens the incentives for retailers to deviate (relative to independent retailer collusion). The reason is that joint collusion results in a common value of wholesale price bid, w^c. This lessens the gains from one-shot pice deviation for a retailer because there is no asymmetry in retailer costs. Because retailer collusion reduces quantity sold, relative to the supplier only collusion case, suppliers incentive to deviate form w^c increases relative to that case. This is because the return to colluding falls while the gains from a one-shot deviation increase. To induce supplier participation, retailers need to transfer some of the collusive profits to suppliers. This can be done either by lowering s or by raising the common value of w. The former is a particular benefit of joint collusion not available under independent collusion: the participation of both suppliers and retailers in the collusive arrangement allows for monitoring of shelf share choices not available under independent collusion.

F.4 Model Calibration

We assume that consumers view retailers a and b as horizontally differentiated, and parametrize demand using a multinomial Logit specification with outside option price p_o and differentiation parameter α:

$$Q(p_i, p_{-i}) = \frac{\exp\left(\alpha(p_o - p_i)\right)}{1 + \sum_{k=a,b} \exp\left(\alpha(p_o - p_k)\right)}.$$

The cost to a retailer of switching main suppliers is given by a Logistic probability distribution:

$$\rho(\Delta) = \frac{1}{1 + \exp\left(-(\Delta - \bar{\Delta})/\sigma_\Delta\right)}.$$

The location parameter ($\bar{\Delta}$) measures the market power of the main supplier, while σ_Δ is the amount of private information that retailers have at the contract negotiation stage. A large σ_Δ implies that retailers have more bargaining leverage. The spread parameter also determines the incentive of the secondary supplier to offer a large discount to the retailer. If $\sigma_\Delta \to 0$, the suppliers are differentiated by a fixed amount $\bar{\Delta}$, and the secondary supplier earns zero profit. As σ_Δ increases, price competition is softened, and upstream markups increase.

The model is defined by the following parameters, listed in Table F6a: the shelf-share allocation (s), the discount factor (β), the fixed cost of managing the shelves (F), the outside option price

p_0, the marginal wholesale cost c, the demand slope α, and the two parameters determining the retention probability $(\bar{\Delta}, \sigma_\Delta)$. We fix the first four, and select the remaining parameters by matching moments obtained from our reduced-form analysis of the life-cycle of the cartel, as well as grocery industry summary statistics. In addition, we need to select the level of prices under the collusion (i.e., p^c and w^c).

We calibrate the model to match seven moments, listed in Tables F6b and F6b. We use results from our analysis of price changes (relative to the food price index) to set the non-collusive price to \$1.50 (pre-2001 average), the collusive price to \$2.50 (3.36% annual inflation over fifteen years), and the post-collusion price level to \$1.95 (-8% annual inflation for three years). Although we do not observe wholesale prices, we assume that 50% of the observed retail price increase was due to an increase in the wholesale cost. Conditional on c, this assumption determines the level of w^c. This is motivated by the fact that pass-through following three large shocks to the industrial price of wheat appear to have been split 50-50 between retailers and wholesalers during the collusive period.[6]

To use the model for the predicting the post-collusion price level, we assume that the price decrease following the collapse is entirely due to retailer deviation, consistent with our empirical results showing the collapse led to an increase in within-market price dispersion and the fact that changing suppliers involves large costs for retailers (such that upstream conduct was likely unchanged during the collapse period). This assumption allows us to identify the elasticity of substitution between retailers (α).

To identify the size of the switching cost, we target an average retention rate of 85% during the non-collusive period. This slightly smaller than the average frequency (90%) with which the identity of the dominant brand at US grocery chains changes from year to year.[7] We also restrict the switching probability during to the collusive period to be near zero.[8] Because we use a Logistic distribution distribution for the switching cost parameter, the model predicts a positive switching probability even when wholesale prices are the same. By choosing a target retention rate of 85% instead of 90%, we insure that the estimated σ_Δ is large enough to facilitate the solution of the game. As get σ_Δ gets close to zero the retention probabilities converge to zero or one, and a pure-strategy equilibrium is no longer guarantee to exists.

The last two moments correspond to the average non-collusive markups, used to identify the suppliers' marginal cost and switching cost spread. The retail markup during the non-collusive period is from the Dominick's data-set (KiltsCenter, 2018), which provides an average retail markup for the cookies product category over the period 1989 to 1994 of approximately 25%.[9] We do not have access to similar statistics on wholesale markups. Since suppliers in the model incur a fixed-cost, we target upstream markups of 25%. Since we fix F, this assumption helps identify the switching cost distribution parameters.

The remaining parameters are set to fixed values. We assume in our calibration that retailers set $s = 1$ in the non-collusive equilibrium, and $s = 0.9$ during the joint-collusion period. Increasing s towards one is optimal for retailers to generate more competition between suppliers, and lower marginal costs. As we will see below, lowering s during the collusion phase makes the joint collusion agreement more stable. We set the discount factor to 0.8, which roughly corresponds to the critical

[6] See the discussion in Online Appendix E.

[7] See Clark, Houde and Zhu (2022) for analysis of brand dominance asymmetry across grocery chains in the US.

[8] Since Δ can be negative, retailers switch with positive probability even when suppliers set uniform prices.

[9] The Dominick's data does not cover the bread category.

discount factor under independent collusion. The fixed-cost parameter does not play an important role in our model simulations, and none of the moments provide a clear source of identification. We choose a relatively small value ($F = 0.05$) for our numerical analysis. Finally, we consider two alternative values for the outside option price (p_o). Specification (1) assumes that the outside option price is high than the collusive price ($p_o = 3$), while Specification (2) sets p_0 to \$2.5 $= p^c$. We use these alternative parameterizations to analyze the role of competition from retailers outside of the cartel. When the outside option is priced low, collusion leads to a reduction in aggregate demand for suppliers. In contrast, in the last two specifications the different collusion arrangements only affect the split of surplus between retailers and suppliers.

Table F6: Model calibration parameters and predictions

(a) Parameter estimates

	Spec. 1	Spec. 2
Retailer differentiation (α)	6.1	6.1
Outside option (p_o)	3	2.5
Marginal cost (c)	0.714	0.72
Switching cost - location ($\bar{\Delta}$)	0.66	0.633
Switching cost - spread (σ_Δ)	0.192	0.185
Shelf management cost (F)	0.05	0.05
Shelf space (s)	1	1
Fraction of loyal consumers (L)	0	0
Discount factor (β)	0.8	0.8

(b) Calibration moments (specification 1)

	Model predictions	Targets
Price - MPE	1.51	1.5
Price - Collapse	1.95	1.95
Price - Collusion	2.49	2.5
Retention prob. - MPE	0.866	0.85
Retention prob. - Collusion	0.969	0.99
Retail markup - MPE	0.252	0.25
Wholesale markup - MPE	0.249	0.25

(c) Calibration moments (specification 2)

	Model predictions	Targets
Price - MPE	1.51	1.5
Price - Collapse	1.95	1.95
Price - Collusion	2.49	2.5
Retention prob. - MPE	0.868	0.85
Retention prob. - Collusion	0.969	0.99
Retail markup - MPE	0.249	0.25
Wholesale markup - MPE	0.25	0.25

The shelf-share allocation for the main supplier is $s = 1$ in the non-collusive and independent collusion examples, and $s = 0.9$ in the joint collusion case.

The parameters are chosen to minimize the sum of the square of the difference between predicted and target moments. For each value of the candidate parameters, we solve the game under three conduct assumptions: (i) non-collusive equilibrium (MPE), (ii) joint collusion with non-collusive contract choice (Joint), and (iii) supplier-only collusion with non-collusive retail pricing and contract choice (SC). Moments are computed by calculating the long-run average of each variable.

We use a nested-fixed point algorithm to solve the non-collusive equilibrium. For each candidate value of the wholesale price, we solve the Bertrand-Nash equilibrium (under MPE and SC) and Markov-perfect contract retention thresholds. The outer-loop iterates over the first-order condition of suppliers. To calculate the critical discount factor for the collusion cases, we perform a grid search over β, repeatedly solving the optimal deviation suppliers and retailers (when computing the supplier's problem), and the optimal deviation of the retailer (when computing the retailer's problem).

Tables F6b and F6c summarize the fit of the model. Since we use more moments than parameters, the calibrated moments are not matched perfectly. Because of the logistic assumption, the predicted retention probability under supplier collusion is at most 97%, compared to our target of 99%. Otherwise, the model matches very accurately the other moments. Note also that changing the value of p_o does not affect the other calibrated parameters significantly.

Our main results and related discussion are presented in the text, with additional results presented in the next section.

F.4.1 Additional numerical results

Table F7: Markov-perfect equilibrium values, prices and retention probabilities (specification 1)

(a) Non-collusive equilibrium

States	$V_1(x)$	$U(x)$	$w_1(x)$	$\Pr(\Delta > \rho_a(x))$	$p_a(x,1)$	$p_a(x,2)$	$p_a(x,3)$	$p_a(x,4)$
M,M (1)	1.34	1.45	1.4	0.825	1.73	1.61	1.4	0.983
M,S (2)	0.75	1.44	1.16	0.893	1.38	1.48	0.967	1.23
S,M (3)	0.75	1.44	0.639	0.893	1.23	0.967	1.48	1.38
S,S (4)	0.381	1.45	0.655	0.825	0.983	1.4	1.61	1.73

(b) Retail collusion equilibrium

States	$V_1(x)$	$U(x)$	$w_1(x)$	$\Pr(\Delta > \rho_a(x))$	$p_a(x,1)$	$p_a(x,2)$	$p_a(x,3)$	$p_a(x,4)$
M,M (1)	1.62	3.18	1.54	0.735	2.49	2.49	2.49	2.49
M,S (2)	1.16	3.18	1.54	0.735	2.49	2.49	2.49	2.49
S,M (3)	1.16	3.18	0.593	0.735	2.49	2.49	2.49	2.49
S,S (4)	0.695	3.18	0.593	0.735	2.49	2.49	2.49	2.49

(c) Supplier collusion equilibrium

States	$V_1(x)$	$U(x)$	$w_1(x)$	$\Pr(\Delta > \rho_a(x))$	$p_a(x,1)$	$p_a(x,2)$	$p_a(x,3)$	$p_a(x,4)$
M,M (1)	3.53	1.4	1.62	0.969	1.95	1.95	1.95	1.95
M,S (2)	2.02	1.4	1.62	0.969	1.95	1.95	1.95	1.95
S,M (3)	2.02	1.4	1.62	0.969	1.95	1.95	1.95	1.95
S,S (4)	0.507	1.4	1.62	0.969	1.95	1.95	1.95	1.95

(d) Joint collusion equilibrium

States	$V_1(x)$	$U(x)$	$w_1(x)$	$\Pr(\Delta > \rho_a(x))$	$p_a(x,1)$	$p_a(x,2)$	$p_a(x,3)$	$p_a(x,4)$
M,M (1)	3.11	2.72	1.62	0.969	2.49	2.49	2.49	2.49
M,S (2)	1.97	2.72	1.62	0.969	2.49	2.49	2.49	2.49
S,M (3)	1.97	2.72	1.62	0.969	2.49	2.49	2.49	2.49
S,S (4)	0.828	2.72	1.62	0.969	2.49	2.49	2.49	2.49

Each equilibrium is computed assuming that retailers select suppliers non-collusively. The parameters used correspond to Specification 1 ($p_0 = 3$). The discount factor is equal to 0.8. The shelf-share allocation for the main supplier is $s = 1$ in the non-collusive and independent collusion examples, and $s = 0.9$ in the joint collusion case.

Table F8: Markov-perfect equilibrium values, prices and retention probabilities (specification 2)

(a) Non-collusive equilibrium

States	$V_1(x)$	$U(x)$	$w_1(x)$	$\Pr(\Delta > \rho_a(x))$	$p_a(x,1)$	$p_a(x,2)$	$p_a(x,3)$	$p_a(x,4)$
M,M (1)	1.29	1.42	1.38	0.822	1.71	1.6	1.39	0.984
M,S (2)	0.753	1.41	1.17	0.897	1.4	1.49	1.01	1.25
S,M (3)	0.753	1.41	0.678	0.897	1.25	1.01	1.49	1.4
S,S (4)	0.38	1.42	0.656	0.822	0.984	1.39	1.6	1.71

(b) Retail collusion equilibrium

States	$V_1(x)$	$U(x)$	$w_1(x)$	$\Pr(\Delta > \rho_a(x))$	$p_a(x,1)$	$p_a(x,2)$	$p_a(x,3)$	$p_a(x,4)$
M,M (1)	1.56	1.86	1.88	0.735	2.49	2.49	2.49	2.49
M,S (2)	1.11	1.86	1.88	0.735	2.49	2.49	2.49	2.49
S,M (3)	1.11	1.86	0.559	0.735	2.49	2.49	2.49	2.49
S,S (4)	0.668	1.86	0.559	0.735	2.49	2.49	2.49	2.49

(c) Supplier collusion equilibrium

States	$V_1(x)$	$U(x)$	$w_1(x)$	$\Pr(\Delta > \rho_a(x))$	$p_a(x,1)$	$p_a(x,2)$	$p_a(x,3)$	$p_a(x,4)$
M,M (1)	3.45	1.36	1.63	0.969	1.95	1.95	1.95	1.95
M,S (2)	1.98	1.36	1.63	0.969	1.95	1.95	1.95	1.95
S,M (3)	1.98	1.36	1.63	0.969	1.95	1.95	1.95	1.95
S,S (4)	0.497	1.36	1.63	0.969	1.95	1.95	1.95	1.95

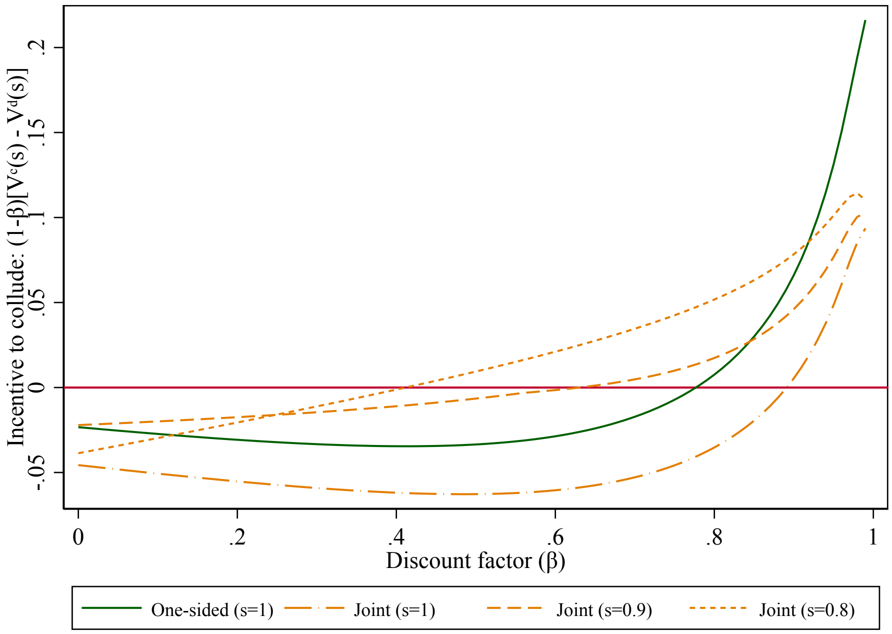
(d) Joint collusion equilibrium

States	$V_1(x)$	$U(x)$	$w_1(x)$	$\Pr(\Delta > \rho_a(x))$	$p_a(x,1)$	$p_a(x,2)$	$p_a(x,3)$	$p_a(x,4)$
M,M (1)	2.01	2.03	1.63	0.969	2.49	2.49	2.49	2.49
M,S (2)	1.28	2.03	1.63	0.969	2.49	2.49	2.49	2.49
S,M (3)	1.28	2.03	1.63	0.969	2.49	2.49	2.49	2.49
S,S (4)	0.551	2.03	1.63	0.969	2.49	2.49	2.49	2.49

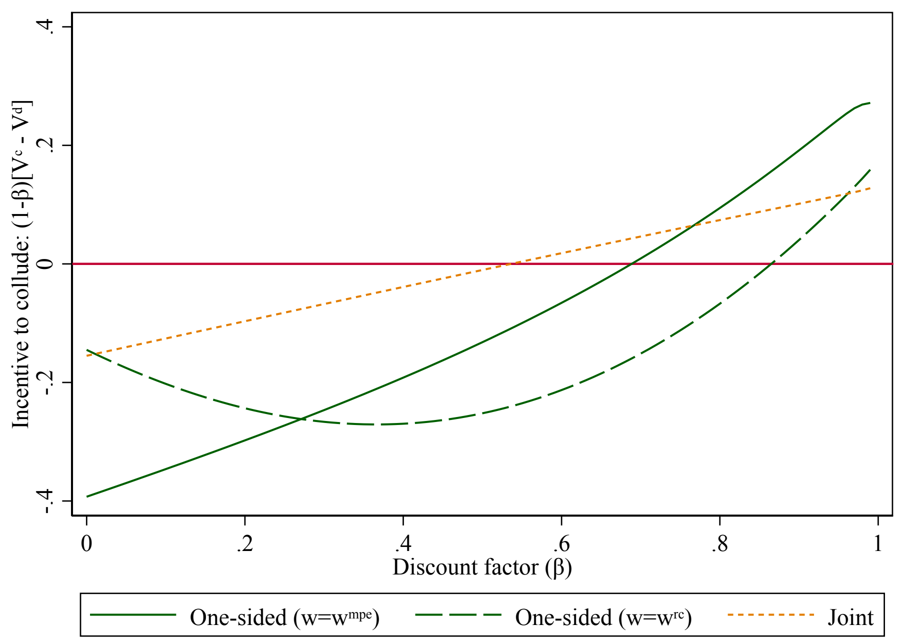
Each equilibrium is computed assuming that retailers select suppliers non-collusively. The parameters used correspond to Specification 2 ($p_0 = 2.5$). The discount factor is equal to 0.8. The shelf-share allocation for the main supplier is $s = 1$ in the non-collusive and independent collusion examples, and $s = 0.9$ in the joint collusion case.

Figure F4: Vertical externalities and the incentive of each side to collude independently (Specification 2)

(a) Suppliers: Shelf-share allocation



(b) Retailers: Upstream competition



Incentive constraints calculated using parameter estimates from spec. 1: $p_o = 2.5$ and higher Δ. Figure F4a plots the gain from collusion for suppliers for three values of s, and Figure F4b the gain from collusion for retailers when suppliers post prices valid in MPE (w^{mpe}), and when suppliers optimally respond to retail collusion (w^c).

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