COMPETITIVE DYNAMICS OF ONLINE AND BRICK-AND-MORTAR RETAIL PRICES

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This article analyzes the competitive interplay of prices among retail channels: offline (brick-and-mortar) and online (such as retailers' websites and online marketplaces). Our empirical analysis draws from two data sources: a novel hand-collected price dataset, and a national aggregate scanner dataset. We find evidence of a close competitive relationship between the online and offline channels, and that prices in one channel are highly responsive to changes in the other channel's prices. Based on time series analyses, we find that online prices are more responsive to brick-and-mortar prices than the reverse, as well as evidence of asymmetric responses depending on which channel's price is higher. Our findings suggest that consumers online face almost identical pricing to consumers offline. Of relevance for competition and regulation, our findings suggest that competition among retail goods is vigorous, that these respond quickly to each other's prices and that, as a consequence, regulation affecting online commerce would be expected to affect prices in brick-and-mortar stores, and *vice versa.*

I. EXECUTIVE SUMMARY

This article summarizes a recent white paper by the authors analyzing the competitive interplay of prices amongst retail channels: offline (brick-and-mortar) and online (such as retailers' websites and online marketplaces).[2]

We find evidence of a close competitive relationship between the two channels, in which prices correspond tightly across channels. We find that prices in one channel are highly responsive to changes in the other channel's prices; in other words, when offline prices increase (or decrease), online prices tend to respond by also increasing (or decreasing). This means that consumers online face similar pricing trends to consumers offline, and the competition between different retailers and across channels is vigorous.

We specifically find that online prices are more responsive to brick-and-mortar prices than the reverse, which is consistent with the technological capacity for online prices to adjust more rapidly than brick-and-mortar price tags. Both brick-and-mortar and online prices react similarly when they are the lower price, and tend to adjust upwards. But their responses are clearly different when they are the higher price: brick-and-mortar prices will tend to stay high, while online prices will be pulled down to lower levels. This is consistent with intense price competition both within and across retail channels.

For the set of products analyzed at the national aggregate level, we also find that both channels experience increases and decreases in dollar sales at the same time and to the same degree. This is consistent with both channels being subject to the same market forces, highly responsive to each other, and are very frequently identical.

Of relevance for competition and regulation, our findings suggest that competition among retail goods is intense, that these respond quickly to each others' prices and that, as a consequence, regulation affecting online commerce is expected to affect prices in brick-and-mortar stores, and *vice versa.*

II. SUMMARY OF RELATED LITERATURE

Academic literature provides various perspectives on whether online and brick-and-mortar prices are similar. Several papers from the early 2000s conclude that consumers face lower prices online than brick-and-mortar due to lower consumer search costs and other informational effects facilitated in an online shopping environment.[3]

More recently, researchers find that prices are frequently identical at the online and brick-and-mortar stores of multi-channel retailers. For example, a 2016 paper by Alberto Cavallo makes use of hand-collected price data and finds that in the U.S., prices for the same goods at the same retailer are identical online and offline 69 percent of the time.[4] In this paper, we also present research based on a set of hand-collected price data and find that prices are identical an even greater percentage of the time (95 percent). The difference between our findings and Cavallo's is likely due to the difference in the set of goods analyzed in the two studies and likely increasing convergence over time, as Cavallo's paper uses data from years before our data sets.

Academic literature also provides varying conclusions regarding the behavior of price movements online and offline. Cavallo's research, cited above, suggests price changes do not typically occur simultaneously in online and brick-and-mortar locations of the same retailer, but does find that prices change with similar frequency and magnitude in both channels.[5] In contrast, other research suggests that online prices change

2 A working paper of the unabridged white paper can be found at https://www.brattle.com/insights-events/publications/competitive-dynamics-of-online-and-brick-and-mortar-retail-prices/. This research was funded by the Computer & Communications Industry Association (https://www.ccianet.org/).

3 See, for example, Brynjolfsson, Erik and Smith, Michael D., (2000), Frictionless Commerce? A Comparison of Internet and Conventional Retailers, Management Science, 46, issue 4, p. 563-585; Clay, Karen B. and Krishnan, Ramayya and Wolff, Eric D., (May 2001), Prices and Price Dispersion on the Web: Evidence from the Online Book Industry, NBER Working Paper No. w8271, Available at SSRN: https://ssrn.com/abstract=268880; Morton, F.S., Zettelmeyer, F. & Silva-Risso, J, (2003), Consumer Information and Discrimination: Does the Internet Affect the Pricing of New Cars to Women and Minorities?. Quantitative Marketing and Economics 1, 65–92. https://doi.org/10.1023/A:1023529910567; Jeffrey R. Brown and Austan Goolsbee, (2002), "Does the Internet Make Markets More Competitive? Evidence from the Life Insurance Industry," Journal of Political Economy, University of Chicago Press, vol. 110(3), pages 481-507; Sengupta, Anirban and Wiggins, Steven N., (November 2006), Airline Pricing, Price Dispersion and Ticket Characteristics on and Off the Internet. NET Institute Working Paper No. 06-07, Available at SSRN: https://ssrn.com/abstract=938609; Lieber & Syverson (2010) "Online vs. Offline Competition"

4 Cavallo, Alberto, and Roberto Rigobon. (2016), The Billion Prices Project: Using Online Prices for Measurement and Research. Journal of Economic Perspectives, 30 (2): 151-78.

5 *Ibid.*

more frequently, but that price changes in brick-and-mortar stores are greater in magnitude.[6] Our research finds that, within the same retailer, medium-term price changes offline and online are typically identical in timing and magnitude, with frequent but short-term deviations in online prices.

III. DATA

We analyze two data sources, which together allow us to study various aspects of cross-channel and intra-channel price dynamics for a variety of goods.

- **Nation-wide aggregate price and volume point-of-sale data via NPD**.[7]
  - For each product, the data shows the weekly total dollar sales and total unit volume combined for all partner retailers nationwide. Thus, each week we observe the weighted average price of units sold, separately for the online and brick-and-mortar channels.
  - The data covers baby/child bed and bath products for 2018-2019.[8]
  - Point-of-sale data, also referred to as "scanner data," is a commonly-used type of data in economic studies of retail prices and competition. Scanner data captures all sales that occur at partner retailers. Scanner data allows the analysis of sales volume, which is not possible with pricing data collected purely by third party observers.

- **Novel dataset of hand-collected price observations from individual retail locations, via Premise**.[9]
  - The data contains both online and brick-and-mortar prices on each day from October 25, 2021 through December 2, 2021, for five grocery staples[10] from 18 retail locations in the Los Angeles metropolitan area.[11]
  - Together, these price observations comprise a month-long set of paired online-offline data observations perfectly controlling for retailer and geography. In total, the data has observations for 3,477 unique combinations of retail location, product, and date, of which 2,605 have price observations for both online and brick-and-mortar channels.

We acknowledge that our data covers a limited scope of products and time window, and in particular our hand-collected data is limited to specific retailers and geographical locations. Thus, further research using additional products, retailers, and cities would be desirable to address the generalization of our results to additional products. However, we also note that the research in our paper makes use of two datasets covering two different sets of products and geographies, both providing consistent evidence that online and offline retail channels are subject to the same market forces, behave very similarly to each other, and are highly responsive to each other. Therefore, our research is supportive of intense competition between these two channels.

6 Gorodnichenko, Yuriy, & Oleksandr Talavera, (2017), Price Setting in Online Markets: Basic Facts, International Comparisons, and Cross-Border Integration. American Economic Review, 107 (1): 249-82.

7 NPD obtains its data from a range of partner retailers including mass merchants, specialty retailers, and department stores; the exact list of partner retailers is not released publicly. The NPD data covers hundreds of thousands of retail locations. Retailer- or location-specific data was not available.

8 We selected the most recent two years of data pre-pandemic. Early 2020 saw major (though largely temporary) disruptions to many aspects of the retail process: supply-side issues like global supply chain disruptions, shipping delays, brick-and-mortar retail location closures; and demand-side changes such as lost income and changes in the types of goods consumers wish to buy. Given only two years of data, we would not be able to reliably separate "normal" competitive effects from reactions to these many sources of disruption.

9 The Premise data was collected based on an app through which contributors could gather prices in response to daily posted requests. For redundancy and quality control, multiple daily requests were posted per retail location, product, date, and channel. Contributors were required to submit a photograph (for brick-and-mortar) or screenshot (for online) as supporting evidence for their price observations. Based on these photos and screenshots, invalid prices were removed from the data (for example, if the submitter entered the price for the wrong product or wrong package size). Occasionally, valid price submissions were made for a given retail location, product, date, and channel (whether because no data contributor fulfilled the request on the app, or because the prices submitted were invalid).

10 Specifically: Barilla Spaghetti (1 lb package); Cheerios (one box, 8.9 oz); Gold Medal All-Purpose Flour (2 lb package); Jif Creamy Peanut Butter (16 oz jar); Land O' Lakes Salted Butter (1 lb, 4 sticks / 8 half sticks).

11 The 18 retail locations encompassed five different retailers: Albertsons, Food 4 Less, Target, Vons, and Walmart.

IV. ONLINE AND BRICK-AND-MORTAR PRICE LEVELS ARE CONSISTENT WITH BOTH CHANNELS BEING DRIVEN PRIMARILY BY COMMON COMPETITIVE FORCES AND ARE VERY FREQUENTLY IDENTICAL

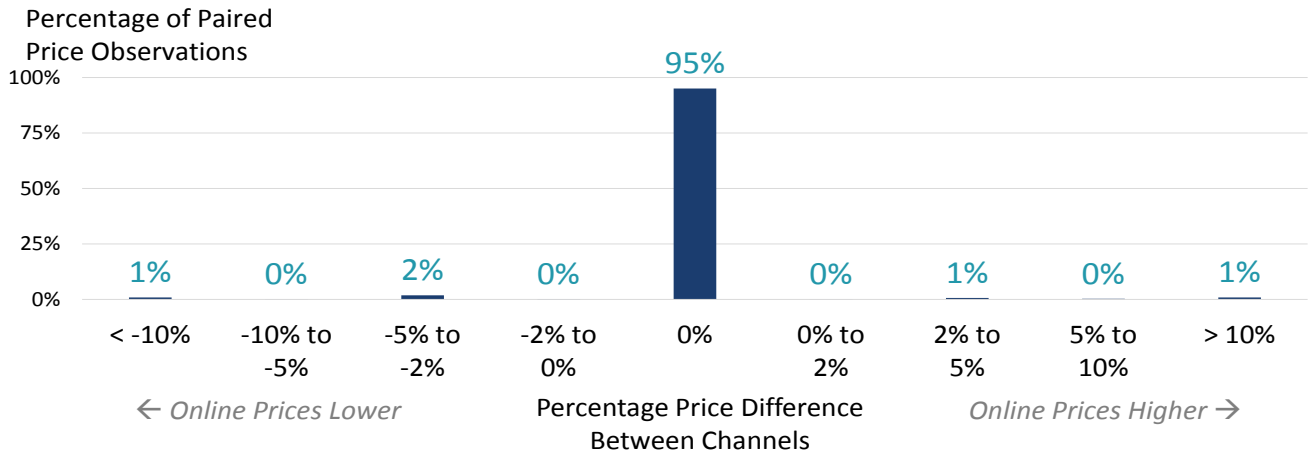
From both data sources, we find strong evidence that online and offline prices correspond closely to one another.

Based on the hand-collected paired grocery price data from Premise – which provide a micro-level view into pricing, explicitly controlling for retailer and geography – we see that online and brick-and-mortar prices are identical to each other the overwhelming majority of the time.

Deviations are the exception rather than the rule and tend to be brief, typically lasting no longer than a day before returning to the prior level. Given the information available to date, we find no evidence that retailers have the ability to set completely different price levels in different channels; on the contrary, online and offline prices appear to be tightly constrained by one another.

Figure 1 below provides a histogram of the percentage differences between online and offline prices. The figure shows that for 95 percent of paired price observations (i.e. corresponding to the same product, retailer, location, and date) online and brick-and-mortar prices are identical. For the remaining 5 percent of observations where online and offline prices differ, online prices are higher roughly half of the time. We find no evidence that online prices routinely over-price or under-price the brick-and-mortar channel. Instead, in the rare cases that prices deviate, online prices are very slightly more likely to be lower than higher.

Figure 1: Distribution of the Percentage Differences between Online and Brick-and-Mortar Prices for the same product, retailer, location, and date



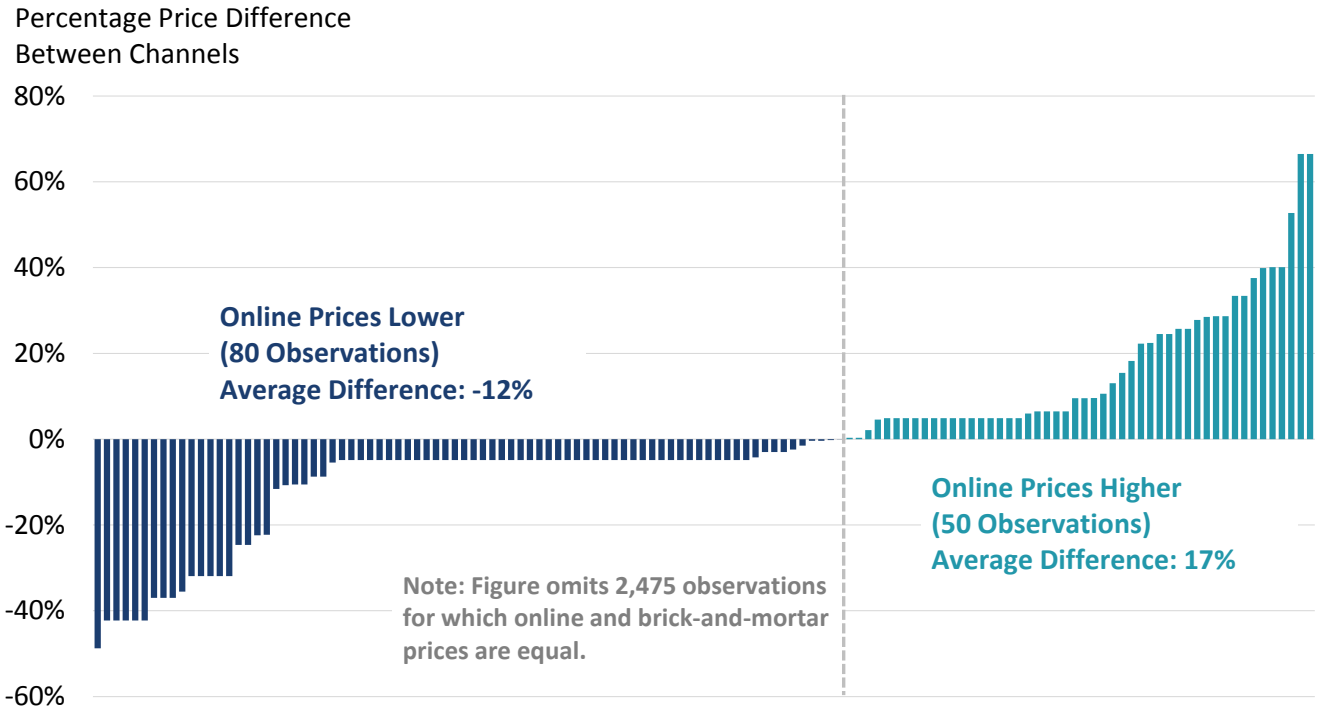
Source: Premise.

Percentage price difference between channels is calculated as ([Online Price] – [Brick-and-Mortar Price]) / (Average of Online and Brick-and-Mortar Prices).

We next focus on the 5 percent of paired price observations for which online and brick-and-mortar prices differ. While these represent a minority of price observations, this allows us to more clearly zoom in on the magnitude of price differences when they are present.

Figure 2 below shows the data for 130 paired price observations for which online and brick-and-mortar prices differ. Each bar in the figure corresponds to a single retail location, product, and date. The height of the bar indicates the percentage difference between online and brick-and-mortar prices, and the bars are sorted from smallest to largest. The dark blue (negative) bars correspond to the 80 observations for which online prices are lower, showing an average difference of 12 percent between the channels. The teal (positive) bars correspond to the 50 observations for which online prices are higher, showing an average difference of 17 percent between the channels.

Figure 2: Percentage Price Difference Between Channels, isolating retail location, products, and dates for which online and brick-and-mortar prices differ



Source: Premise.

Percentage price difference between channels is calculated as ([Online Price] – [Brick-and-Mortar Price]) / (Average of Online and Brick-and-Mortar Prices).

The chart above shows that for the rare instances in which prices differ between channels, we find that online prices are more frequently lower. We further find that the average price discrepancy between channels is larger when online prices are higher as compared to when they are lower.

As another way of looking at this data, we separately examine each of the 18 retail locations, for each of the five products. We test whether online and offline prices are always identical on all days covered by our data, or whether there is ever a difference between online and offline prices. In the instances in which we see a difference, we characterize which channel's prices deviate away from the typical price level[12] prevailing for that product at that retail location.

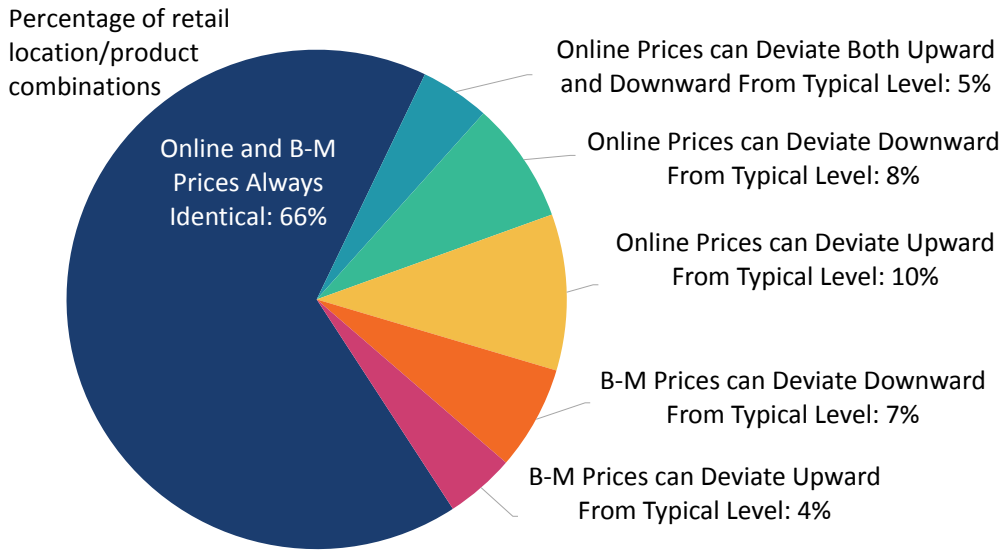
Figure 3 below summarizes our results. We find that for all products, the majority of retail locations always see the same price online and offline during the period of observation. That is, during the period of study, consumers visiting the retail location in-person would see the same prices for the five products as customers shopping on that retailer's website.

The remainder of retail locations have at least one day during the period of study for which prices online and offline can differ. For these, we observe no consistent pattern suggesting one channel's ability to deviate permanently from the other: both channels can deviate from the typical price level, sometimes upwards, sometimes downwards. These deviations are not persistent, and prices tend to come together again quickly.

Finally, to contextualize these findings, recall from Figure 1 above that even when prices between the online and offline channels differ, the magnitude of the difference is quite small.

12 We define the "typical price level" as the mode price during a rolling five-day period centered on the day in question.

Figure 3: Percentage of Products and Retail Locations For Which Online and Offline Prices are Always Identical, or Exhibit Differences, for the period 10/25/21 – 12/2/21



Source: Premise

The national aggregate data from NPD provides additional evidence of persistent similarity in prices between the online and brick-and-mortar channels. Because of the national aggregate nature of the NPD data, we expect to find some degree of difference between prices online and offline.[13] Despite this limitation of the data, we still see a close correspondence between prices online and brick-and-mortar in the NPD data. Typically, online and offline prices fall within +/-5 percent of each other.

V. ANALYSIS OF PRICE MOVEMENTS INDICATES NEITHER CHANNEL HAS THE ABILITY TO RAISE AND SUSTAIN HIGHER PRICES THAN THE OTHER CHANNEL IN THE LONGER TERM

Based on the hand-collected pricing data, we analyze the price movements we observe in both channels, demonstrating that although prices between both channels remain tightly inter-locked, the overall pricing pattern is far from static.
We observe the following patterns in price movements within the hand-collected grocery pricing data:

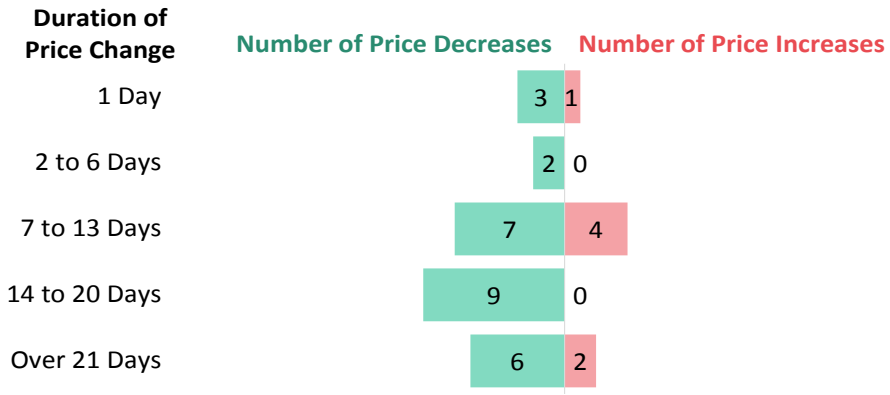
- **Promotional sales and discounts typically begin and end on the same day in both channels for a given retail location**. We find no evidence of persistent or widespread differences in the timing of price changes online and offline. This suggests that a given retailer decides what price to use for a particular product and geographical location, and simultaneously implements this price across channels.
- **Online prices rarely deviate away from brick-and-mortar prices, and when they do, deviations are both upwards and downwards**. This is consistent with the fact that changing prices in a brick-and-mortar store involves a relatively more costly physical effort, whereas online prices can be updated more quickly and easily.
- **Different customers shopping at the same retailer online can see different prices on the same day**. This is consistent with the practice of "A/B testing" whereby a retailer's online channel performs an experiment to test the effect of a price change and help achieve the profit-maximizing price.[14] A subset of customers is shown an alternate price, and quantities purchased can then be compared against the customers who are shown the original price. This pattern of price movement is consistent with very short-term information gathering which helps retailers rapidly respond to changes in demand. The price quickly shifts back to its baseline level, consistent with the online channel being competitively constrained by brick-and-mortar prices.

13 Because the NPD data aggregates together all sales at all partner retailers, we are unable to distinguish price variation by channel from any other reasons prices might differ (e.g. regional variation across different geographical locations, different pricing by different retailers, location-specific promotional pricing). As a simplified example to illustrate this point, suppose we are studying the price of rubber duckies. Suppose also that during the first week of July, only one rubber ducky is sold nationwide, at a boutique in Manhattan. In the second week of July, again only one rubber ducky is sold, this time at a discount retailer in Ohio. Based on the information reflected in our data, it would look like the price of rubber duckies fell substantially week-over-week, even if the prices at each of the two retailers remained constant.

14 For a discussion of A/B testing, see, e.g. Gallo, Amy. "A Refresher on A/B Testing." Harvard Business Review (June 28, 2017). Available at https://hbr.org/2017/06/a-refresher-on-ab-testing.

Figure 4 below summarizes the number and duration of brick-and-mortar price changes. Overall, we observe 34 price change events in the brick-and-mortar data, between October 25 and December 2, 2021. The majority of these (79 percent) are price decreases. Very few price changes last less than a week (only 6 total), due to the costly nature of posting new prices in brick-and-mortar stores. Most price changes last one or two weeks. We also see some examples of effectively permanent changes: 6 price decreases, and 2 price increases, lasting over 21 days.

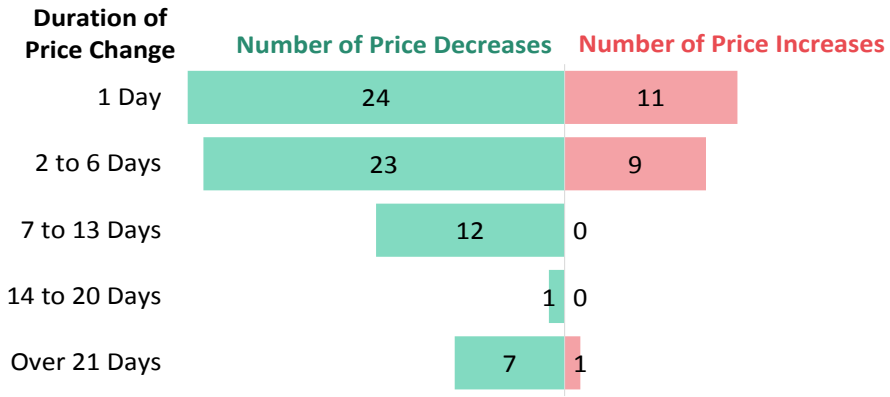
Figure 4: number and duration of brick-and-mortar price changes



Source: Premise

Figure 5 below presents a similar analysis of online price changes. We observe more price changes online (88 total); however, prices still end up the same as the brick-and-mortar price 95 percent of the time (per Figure 1 above). Online price changes frequently last only a single day, consistent with the low cost of adjusting the prices that customers see online. The majority of price changes are decreases (76 percent). We see do see some longer-term changes in online prices: 7 price decreases and 1 price increase, which largely align with the same price changes occurring in the brick-and-mortar channel.

Figure 5: number and duration of online price changes



Source: Premise

The patterns above are consistent with the relative costs associated with adjusting prices in each channel. Because online retailers can adjust prices at virtually zero cost, it may be worth adjusting prices only briefly, if this maximizes revenue. This is consistent with the short-term information-gathering price research, or A/B testing, that we discussed above. A price increase would lead to a higher revenue per item, but lower volume sold, and a price decrease would lead to a lower revenue per item, but higher volume sold; both scenarios could lead to higher total revenues depending on consumer demand. If the price change turns out not to have increased revenue, the online retailer can simply move prices back to the previous level. However, because brick-and-mortar retailers have a higher cost associated with posting new prices, a brief price change may not be worth the cost of adjusting prices (and adjusting them back if the price adjustment was detrimental to revenue). Moreover, it is not possible to establish a randomized experimental treatment and control group in a brick-and-mortar setting, as all customers see prices posted on the shelf.

In addition, brick-and-mortar retailers benefit more than online retailers from the "loss-leader" effect whereby lower prices on one product (such as the staple groceries studied in this sample) attract customers to the store, where customers purchase additional goods while under one roof. For example, a customer could come into the store because of a sale on spaghetti, and then also buy spaghetti sauce while they are there, and other groceries as well. In this hypothetical example, the spaghetti would be the "loss leader." The grocery store can benefit from loss leaders because many goods are sold under one roof, and it is costly for customers to compare prices across brick-and-mortar retailers and visit multiple retail locations.

The "loss leader" effect can occur in online retail but may be less pronounced because it is easy for the consumer to shop at multiple stores online. For example, a customer visiting Retailer A's website because of a sale on spaghetti might also find it convenient to purchase other items (such as spaghetti sauce) on Retailer A's website. However, the shopper may also quickly research sauce prices across different stores online and choose to purchase sauce more cheaply from Retailer B's website. Thus the "loss leader" effect may be less pronounced online.

For medium-term price changes lasting over one week, the vast majority (95 percent) of online price movements occur in the downwards direction. In other words, we see no evidence that online retailers have the ability to raise and sustain higher prices in the longer term.

All of the foregoing analyses show that within the Premise data, pricing patterns are consistent with retailers engaging in active pricing research online and finding they are competitively constrained. Even when retailers experiment with raising prices online, the price does not remain higher than brick-and-mortar prices for long, which is consistent with competitive pressure bringing it back to a baseline level. The pricing patterns are generally strong evidence of intense price competition in retail, especially within the consumer packaged goods ("CPG") market that the Premise data draws from.

VI. DOLLAR VOLUME OF BRICKANDMORTAR VERSUS ONLINE SALES ARE CONSISTENT WITH BOTH CHANNELS BEING SUBJECT TO THE SAME MARKET FORCES

The NPD data allows us to observe the proportion of sales occurring online versus brick-and-mortar. We see that in each week, roughly the same dollar volume is transacted online as in brick-and-mortar stores, for the subset of products available in the data. Moreover, this is true both during periods of high dollar sales and periods of low dollar sales. This suggests that the two channels are subject to the same market forces.

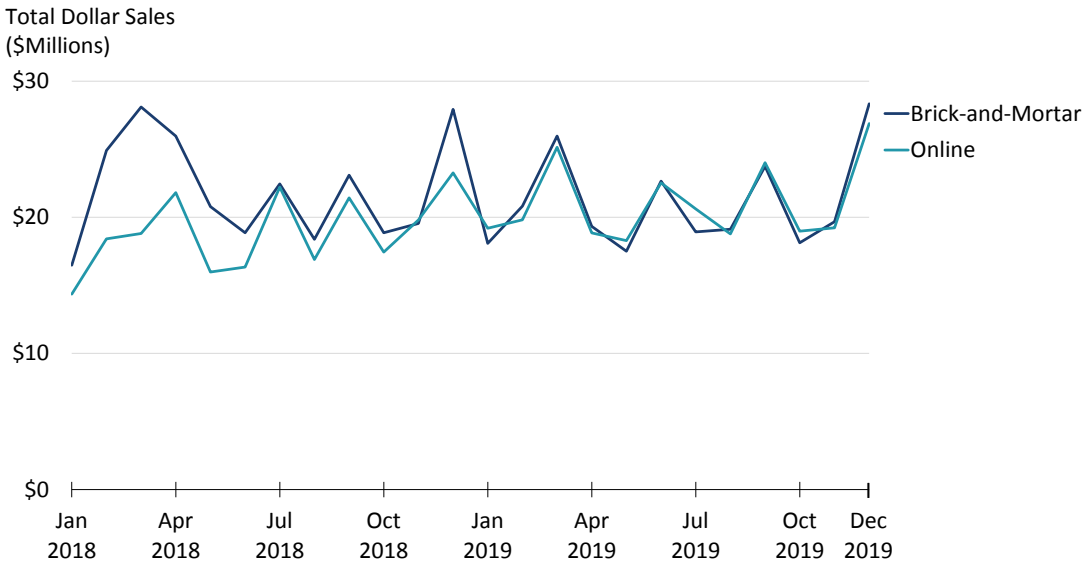
We note that because our national aggregate data is limited to a certain set of products, our findings regarding the proportional market share of e-commerce are not representative of all retail for all products.[15]

Figure 6 plots the total dollar sales in each channel. Some seasonal trends are evident, with both channels seeing a spike in sales approximately every three months (April, July, September, and December of 2018, and March, June, September, and December of 2019).[16] The synchronization of sales volumes between channels is consistent with both channels being subject to the same market conditions. In other words, the same drivers of supply and demand that drive dollar sales appear to affect both online and offline sales similarly. Though not unexpected, the strength of the result is evident.

15 See, e.g. St. Louis Fed data which shows overall e-commerce represented approximately 10 percent of all retail activity during the same time period of 2018-2019. https://fred.stlouisfed.org/series/ECOMPCTSA.

16 As a robustness check (not pictured), we also performed this analysis within each product category. The spikes in sales occur in the majority of product categories. A notable exception was the Bath Toys product category which saw pronounced spikes only in December of 2018 and 2019, coinciding with holiday shopping.

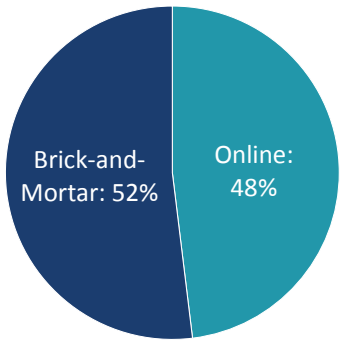
Figure 6: Dollar sales by channel, showing periods of higher and lower sales



Source: NPD

Figure 7 shows the percentage of sales occurring in each channel, as a fraction of the total dollar sales from both channels combined during January 2018 through December 2019. As the pie chart shows, roughly half of sales occur in each channel. Within the set of products studied, neither channel dominates the other.[17]

Figure 7: Percentage of Dollar Sales Occurring online versus brick-and-mortar, January 2018 – December 2019



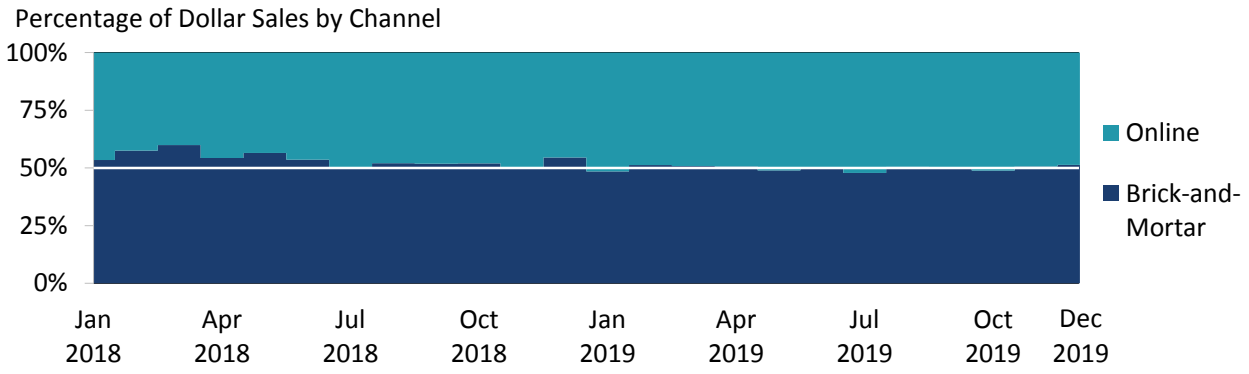
Source: NPD

Figure 8 breaks the pie chart out by month, showing the percentage of total dollar volume each month occurring within each channel. A white horizontal line marks the 50 percent level. The graph shows that the split in volume between channels is stable over time. [18] This is consistent with the idea that online and offline channels are subject to the same market forces, since both channels experience periods of high and low sales volume at the same time and to the same degree.

17 The different product categories saw different proportions of sales conducted online. Bath Toys and Potty Training see the least amount of online sales (~30 percent). Changing Pads has the greatest proportion of online sales (~60 percent).

18 All product categories show a similar stability in the percentage of sales occurring online, with very little month-over-month variation.

Figure 8: Fraction of Dollar Sales Occurring in Each Channel is persistent over time



Source: NPD

VII. CROSS-CHANNEL PRICING DYNAMICS ARE CONSISTENT WITH A DYNAMICALLY COMPETITIVE MARKET

In our final set of analyses, we apply a selection of time-series methodologies to study price dynamics over time in the national aggregate data.

We study the evolution of prices over time by using past price levels to explain the current price levels. For each channel, we simultaneously study both the "own-channel" dynamics (using past online prices to explain current online prices, and past brick-and-mortar prices to explain current brick-and-mortar prices), and the "cross-channel" dynamics (using past online prices to explain current brick-and-mortar prices, and vice versa). This allows us to examine how online prices react to an increase in brick-and-mortar prices and vice versa.

Our key findings are as follows:

- We find that when explaining the variation in brick-and-mortar prices, past values of brick-and-mortar prices have virtually identical explanatory power as past values of online prices. The same is true for explaining online prices. This is consistent with a highly responsive and competitive market between the two channels.
- We further find that online prices move towards brick-and-mortar prices, whether the latter are higher or lower than the former. The data suggests that online retailers are subject to constant competitive pressures and generally respond to competition by matching the lowest price on offer within or across channels.
- The data suggests that online retailers are subject to constant competitive pressures and generally respond to competition by matching the lowest price on offer within or across channels.

To compensate for the noisy nature of the aggregate national data, we apply a time series filter that smooths the data to remove some of the noisiest week-to-week movements. In each of our results, we apply two degrees of smoothing: less filtering which keeps "trend and cycle" movements, and a stronger degree of filtering which keeps "trend" movements only.

Detailed specifications of these analyses, including the time series filter, are presented in the Technical Appendix of the unabridged white paper.[19]

A. Own-Channel and Cross-Channel Explanatory Strength

In our first analysis, we measure to what extent price movements in one channel can be attributed to price movements in the other channel. In other words, we are asking: when prices online vary over time, is this likely due to market forces specific to the online channel, or to market forces that affect both the online and offline channels? Similarly, when brick-and-mortar prices vary from one week to the next, is this likely due to market forces specific to the brick-and-mortar channel, or is it based on market forces affecting both channels? We find that the answer is "both," which is consistent with a very responsive and competitive market that includes both channels.

19 Available at https://www.brattle.com/insights-events/publications/competitive-dynamics-of-online-and-brick-and-mortar-retail-prices/.

In technical terms, this analysis measures the explanatory power of own-channel and cross-channel effects to explain observed price variation.[20] We conduct this analysis for each variation of the filter, and for three time windows (one week prior, 4 weeks prior, and 12 weeks prior).

We find that cross-channel and own-channel prices each explain roughly half of the variation in prices, for both brick-and-mortar and online prices. This holds true even when looking at the trend-and-cycle filter (which allows for more high-frequency noise). Both series are highly responsive to each other, and they are almost equally responsive to cross-channel price movements as they are to own-channel movements. Specifically, when a brick-and-mortar price goes up this week, there is about a 53 percent chance that it is moving in response to a price increase last week from brick-and-mortar, and 47 percent chance that it was due to a price increase for online last week. This is consistent with a very responsive and competitive market that includes both channels.

The pattern is consistent with strong competition both within and across channels. Prices not only respond to variation in prices within the same channel, but also in variation in the other channel. We observe that prices are slightly more responsive to their own price variation than to price variation coming from the other channel.

B. Analysis of Asymmetric Responses

Our second time series analysis quantifies the size and direction of price responses to movements in the same and other channel. In this analysis, we explore the magnitude of own-channel and cross-channel price responses, depending on whether this channel's prices are higher or lower than the other channel's prices. In other words, we look to analyze potential asymmetric responses. Again, the results are consistent with a very competitive setting across channels.

While we do find statistically significant evidence of asymmetry of responses between channels depending which channel's prices are higher or lower, the dollar magnitude of the asymmetry present in the effect size is small. For practical purposes, the behavior of both channels is effectively identical.

Again, we conduct this analysis for each variation of the filter, and for three time windows (one week prior, 4 weeks prior, and 12 weeks prior).

Our "explanatory power" analysis above finds that current prices are about as likely to vary due to past own channel price variation as cross channel price variation. This means that, at any moment in time, price for one channel already reflects price movements from both channels about equally. Therefore, if we want to guess what brick-and-mortar prices will be this week, the best predictor is brick-and-mortar prices from last week, because last week's prices already summarize both channels' prices.[21]

At intervals of two to three months, we find an increased responsiveness to the other channel's prices, for both online and brick-and-mortar. This result holds for both the trend-only filter (which captures low-frequency patterns) and the trend-and-cycle filter (which captures both low-frequency patterns and high-frequency patterns).

We find the following patterns in brick-and-mortar prices:

- When the price level for brick-and-mortar is higher than the online price level, brick-and-mortar prices do ***not*** tend to adjust to meet the lower online prices.
- However, when brick-and-mortar prices are lower than online prices, brick-and-mortar prices ***do*** tend to adjust upward to meet higher online prices.

We find the following patterns in online prices:

- When online are higher than brick-and-mortar prices, online prices tend to be pulled down towards the lower brick-and-mortar prices.
- When online prices are lower than brick-and-mortar prices, online prices tend to be pulled up towards the higher brick-and-mortar prices.
- In summary, both brick-and-mortar and online prices react similarly when they are the lower price, and tend to adjust upwards. But their responses are clearly different when they are the higher price: brick-and-mortar prices will tend to stay high, while online prices will be pulled down to lower levels.

20 Specifically, we are performing a variance decomposition analysis for a set of regression equations; the Technical Appendix provides our model specification and results.

21 While this is always true for both types of filters and at the various time windows, the effect is are stronger at shorter time windows and for the cycle-and-trend filter.

As a general statement, the story that emerges is that online prices move towards brick-and-mortar prices, whether the latter are higher or lower than the former. But while brick-and-mortar prices increase towards online prices when online prices are higher, they will not decrease to the same extent if online prices are lower. This pattern suggests that online retailers are subject to constant competitive pressures and generally respond to competition by matching the lowest price on offer within or across channels. All of our findings are consistent with evidence of competition between online and offline channels.

VIII. CONCLUSION

In this paper, we demonstrate evidence of a dynamic competitive relationship between online and brick-and-mortar channels for retail goods. We find that online prices competitively constrain brick-and-mortar prices, and vice versa. This has implications in policy and regulatory settings, as many regulations targeting one retail channel will likely affect pricing in the other retail channel as well due to intense competition between online and offline retail.

We find that online prices are subject to frequent changes that appear to be related to short-term information gathering and price research. Nonetheless, we find online prices closely adhering to brick-and-mortar prices in the longer term. Thus, we find no evidence that one channel has the ability to systematically raise and sustain higher prices in comparison to the other channel.

Our analyses show several patterns consistent with intense competition between online and offline retail, with both channels responding to the same market forces. This suggests that in the context of antitrust, analyses involving dynamic competition and substitutability for retail goods should incorporate information from both online and brick-and-mortar retail sales.

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