A comparison of multilateral price index methods: Scanner data and stockpiling during the COVID-19 pandemic

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Abstract

The COVID-19 pandemic caused significant short-term shifts in consumer behaviour around the world, including stockpiling of grocery items by consumers. This behaviour is captured in Australian supermarket scanner data, obtained for the production of the Australian Consumer Price Index (CPI).

Globally, National Statistical Offices (NSOs) are increasing their use of scanner data. Multilateral index methods are generally accepted as more suitable than bilateral methods for use with scanner data in the production of price indexes. Multilateral methods are theoretically well-equipped to account for extreme changes in expenditure shares and product substitution, and scanner data from the COVID-19 pandemic provides the opportunity to test this empirically.

In this paper, four multilateral methods are applied to Australian scanner data from 2020. This real-world scenario captures extreme consumer behaviours such as panic buying and stockpiling, as well as market responses such as temporary product range reduction and halting of typical discounting cycles, all of which are not easily simulated by synthetic data. The resulting indexes provide evidence of each method's robustness, a consideration for NSO's looking to adopt a multilateral method.

Overall, the alternative multilateral index methods react similarly to the unusual consumer behaviour, and differences are largely attributable to one product class which exhibited particularly extreme behaviours. This paper uses the decomposition methods in Webster and Tarnow-Mordi (2019) to measure product level contributions and explore how price and quantity changes for individual products affect the behaviour of each multilateral method.

Key words

Consumer Price Index, multilateral index methods, stockpiling, panic buying, COVID-19, scanner data, GEKS, consumer behaviour, transactions data

1. Introduction

As an increasing number of national statistical organisations (NSOs) gain access to scanner or transactions data, multilateral index methods such as the Gini, Eltetö, Köves and Szulc (GEKS), Geary-Khamis (GK) and Time product Dummy (TPD) have become the international standard for the creation of price indexes using these data sources. Although there is generally no consensus as to which of these methods is most appropriate for the measurement of price change, each method may behave differently under different scenarios. The Australian Bureau of Statistics (ABS) has used the GEKS-Tornqvist method with scanner data to measure price change of grocery products since late 2017.

The COVID-19 pandemic saw extreme stockpiling behaviours by consumers, whereby consumers bought very large quantities of products, particularly personal hygiene and household cleaning products, and non-perishable foods. Supermarket scanner data collected by the ABS exhibits this extreme shift in consumer behaviour during the early stages of the pandemic in Australia in March 2020.

Multilateral methods are theoretically well-equipped to account for changes in expenditure shares and product substitution (Ivancic et al. 2011). The consumer behaviour captured by scanner data provides the opportunity to test a range of multilateral index methods on an extreme real-world scenario. The characteristics of the dataset are discussed in more detail in Section 2. Using this data, we have performed a 'stress-test' of the GEKS-Tornqvist, Geary-Khamis, TPD and Quality Adjusted Unit Value TPD (QAUV-TPD) methods, analysing the different index method behaviours using the decomposition methods described in Webster and Tarnow-Mordi (2019). Details of the methods and parameters used are presented in Section 3.

The purpose of stress testing is to understand the extent of differences between the index methods in unusual circumstances, and how these differences can be explained by price changes and extreme changes in quantity for individual products. While there have been previous studies comparing the features of alternative multilateral methods (ABS, 2016; Chessa et al. 2017; Bialek and Beresewicz, 2020; ONS, 2020), these studies have typically analysed data representative of normal consumer behaviour. In the instances where multilateral methods have been stress tested, synthetic or simulated data was used (Diewert and Fox, 2018).

In Section 4, decomposition of the indexes into product-level contributions is used to identify product characteristics that lead to difference between the index methods, while in Section 5 we summarise our findings.

2. Data characteristics

The supermarket scanner datasets analysed are weekly aggregates from two national supermarket chains and contain the following information for a combined total of over 181,000 products: Stock keeping unit (SKU), product text description, date, total revenue, total quantity, category mapping (including expenditure class (EC) e.g., Fruit, and elementary aggregate (EA) e.g., Citrus) and location. Elementary aggregate is the lowest level of index calculation, and indexes are produced for individual retailers before being aggregated. Data is collected for the eight Australian state and territory capital cities and average prices are derived by dividing the total revenue by the total quantity sold. For the purposes of this work, the data has been aggregated on a monthly basis.

Typically, price change for fresh produce such as fruit and vegetables reflect growing seasons; meat price change reflects supply and global demand; and that for shelf-stable food products and non-food products reflect regular discounting cycles. There is a clear inverse relationship between price and quantity sold, whereby consumers purchase more of a product while discounted, and less while at normal price.

2.1 Impact of COVID-19 Pandemic on consumer behaviour

The arrival of COVID-19 in Australia in March 2020 disrupted life in Australia as it did across the globe. Mandated lockdowns combined with general uncertainty saw consumers abandon their usual purchasing behaviours, instead panic buying, and stockpiling. Price and brand became less important in determining product demand, as consumers looked to stock up on whatever was available. Within the data, product churn was observed to be at some of the highest levels during these times, between 6.0% and 8.8% across retailers, as some suppliers were unable to meet demands. No imputations were made for missing grocery products.

This extreme shift in consumer behaviour is clearly reflected in the supermarket scanner data. A sharp spike in expenditure can be seen in March 2020 across a wide range of products, in particular shelf-stable foods and personal hygiene items, but also fresh foods and other products. For some products, this spike in expenditure was followed by a dip as households consumed the products stockpiled. For other items, such as basic cooking ingredients, the increase in expenditure was sustained for a longer period as households substituted from eating out to cooking at home.

2.2 Resulting impact on consumer prices

Also seen in the scanner data is how prices and product ranges responded to this shift in consumer behaviour. Regular discounting cycles ceased for several weeks as supermarkets were unable to guarantee stock. Most products remained steady at their normal prices during this time, although some steadied at a higher price. Fresh produce prices increased, reflecting increased demand and transport disruptions. Buying limits (for example, 2 units per customer) were introduced for high-demand products. For some particularly high-demand products, such as toilet paper and tissues, product ranges were reduced, with limited brands and packet sizes available. This was partly due to shared manufacturing facilities across brands streamlining processes to meet demand.

Figure 1 presents an example of a spike in expenditure for a non-perishable food product which was typical during the peak stockpiling period. This spike is followed by below-average expenditure levels as consumers had purchased enough to last for some time. A key benefit of scanner data is availability of expenditure information which, when compiled using multilateral methods, can be used to weight price indexes to reflect expenditure in the current period.

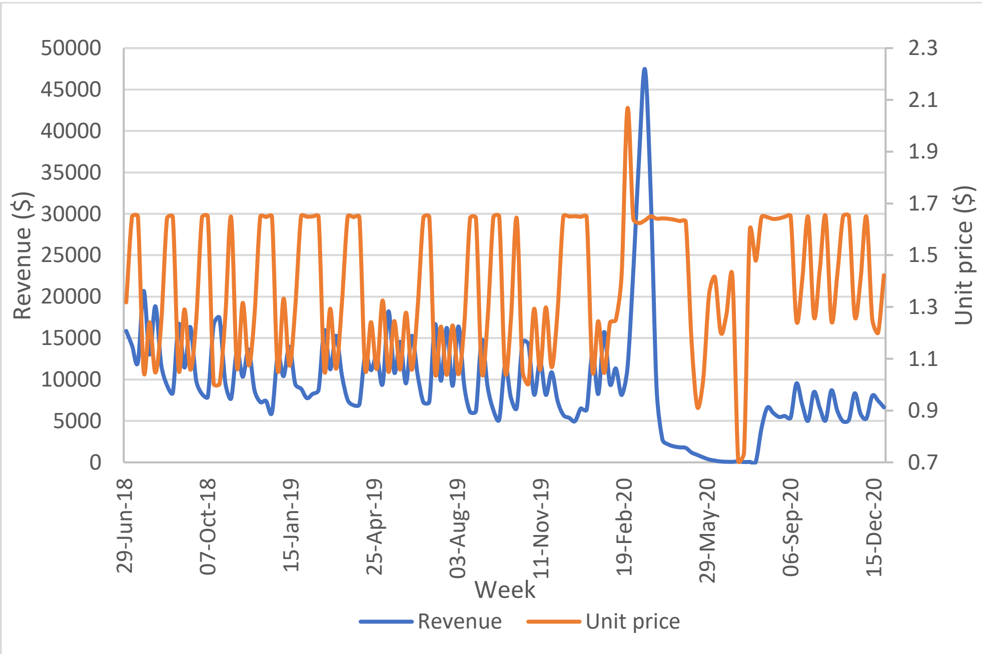


Figure 1. Price and expenditure of a single baked bean product during the COVID-19 pandemic

Figure 2 shows a typical change in price and expenditure for a toilet paper product during the same period. Expenditure remained elevated following the main spike. These two figures depict two of the common changes in price and revenue seen across a wide range of products during the pandemic.

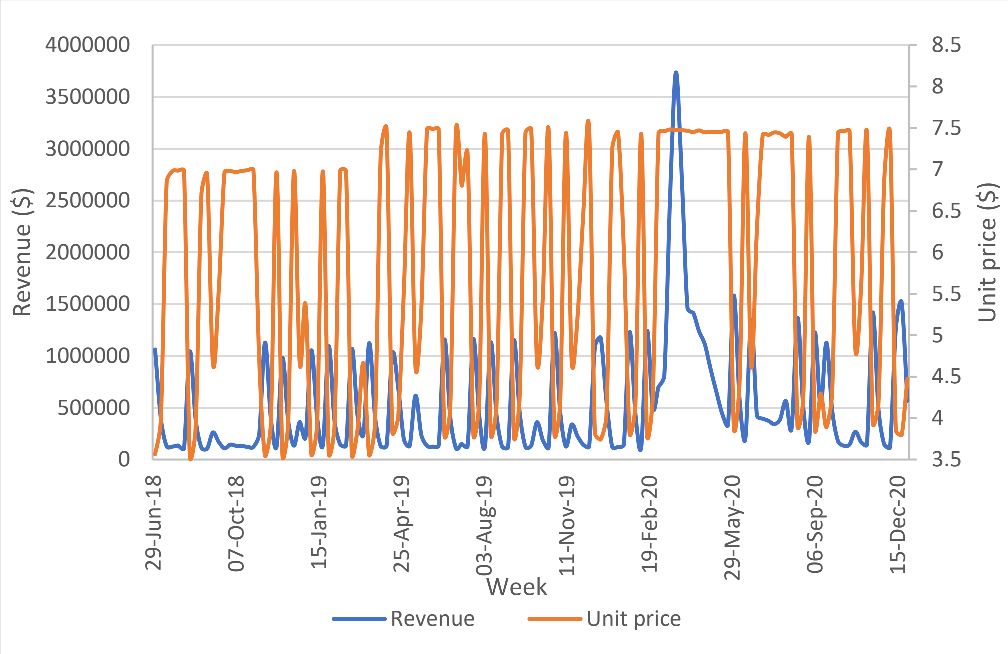


Figure 2. Price and expenditure of a single toilet paper product during the COVID-19 pandemic

3. Multilateral index methods

This paper compares the four multilateral methods which were previously evaluated by the ABS for use with supermarket scanner data (ABS, 2016). The four methods investigated were:

- Gini, Eltetö, Köves and Szulc (GEKS)-Tornqvist
- Weighted Time Product Dummy (TPD)
- Geary-Khamis (GK)
- Quality Adjusted Unit Value using TPD (QAUV TPD)

The previous testing of the different multilateral methods on supermarket transactions data by the ABS found little difference in the index series produced by each method, with the GEKS-Tornqvist being preferred for implementation primarily due to its interpretability being based on bilateral index number theory (ABS, 2017). Details of the four multilateral methods are outlined in Appendix 1.

3.1 Extension method

The four multilateral methods were applied to a 25-month window, starting in 2017, and the mean splice rolling window method detailed in Ivancic et al. 2011 and Diewert and Fox (2017) was used to extend the index series beyond the initial 25-month window. The mean splice rolling window method extends the index series using the geometric mean of the indexes produced from all possible choices of splice period, expressed as:

$$p^{t-1,t} = \prod_{s=t-T}^{t-1} \left(\frac{P_M^{s,t}(current)}{P_M^{s,t-1}(previous)} \right)^{\frac{1}{T}} \quad (3.1.1)$$

where the multilateral window length is $T+1$ periods, so the current and previous periods overlap between $t-T$, and $t-1$, and $P_M^{s,t}(z)$ denotes the aggregate price comparison between periods s and t derived from a multilateral window ending in period z. A 25-month window was determined at the time to be an appropriate window length, with Fox (2022) recently suggesting both this window length and extension method being the best performing of scenarios tested within that study.

3.2 Decomposition of multilateral index methods

Decomposition of a price index into contributions from individual products enables identification of the products with the greatest contributions to index change, and those which have the largest difference in contribution between alternative multilateral methods. By comparing the contributions of individual products to the aggregated indexes from different multilateral methods, we can identify the price and quantity change characteristics of the products which drive differences between the output indexes from the multilateral methods.

The GEKS-Tornqvist and TPD indexes are decomposed using the methods outlined in Sections 2 and 3 of Webster and Tarnow-Mordi (2019). These decompositions produce product contributions to the index movement between two time periods, and multiplying the movement contributions across all products produces the index movement between the two time periods. GK and QAUV TPD decompositions were not performed due to their similarity with the TPD series during the periods of interest.

4. Results

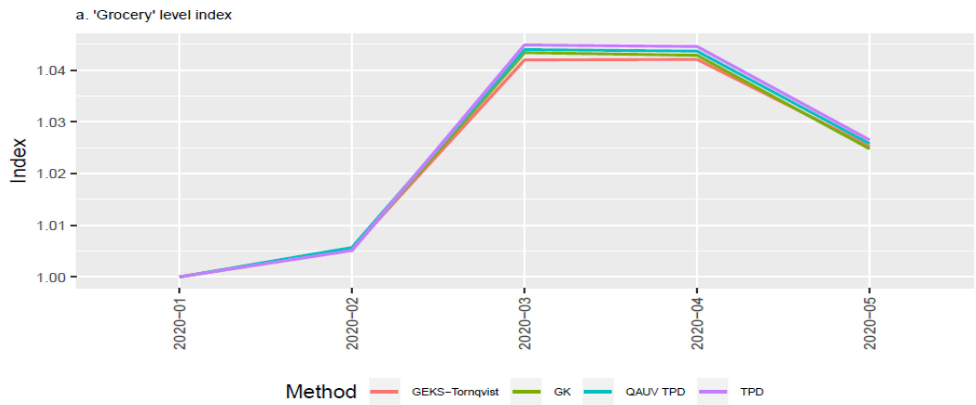
4.1 Grocery level indexes and their constituents

The first comparison of the multilateral methods is for a broad 'Grocery' level index which is representative of a similar aggregation of food products published as part of the Australian CPI (Figure 3).

At this aggregate level, index movements between February - March, and to a lesser extent March – April and April – May, were found to be quite similar for the TPD, GK and QAUV TPD methods, while the GEKS-Tornqvist index had a noticealby smaller positive movement when prices increased in March and a corresponding smaller negative movement when prices fell in May.

Breaking the Grocery level index down to finer levels (Figure 4 and Figure 5) revealed that most of the difference between the month-to-month movements of the GEKS-Tornqvist index and the other multilateral methods occurred in the Non-food group (1.47% for GEKS-Tornqvist and 1.70% for TPD), specifically the 'Non-durable household products' sub-group (2.57% for GEKS-Tornqvist and 3.23% for TPD).

Drilling down further into the 'Non-durable household products' sub-group, we observed that EAs corresponding to toilet paper products comprised the largest proportions of total expenditure across all capital cities and saw an increase between February and March 2020 while still having a higher than usual expenditure share in April (Table 1). This was observed to be the case across all capital cities but to limit the scope of this paper we focus on the results for Melbourne, which had one of the highest expenditure shares for toilet paper.



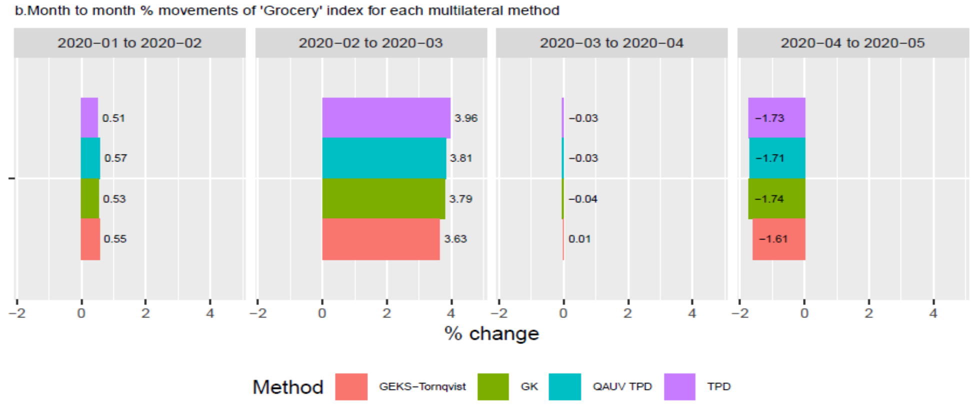
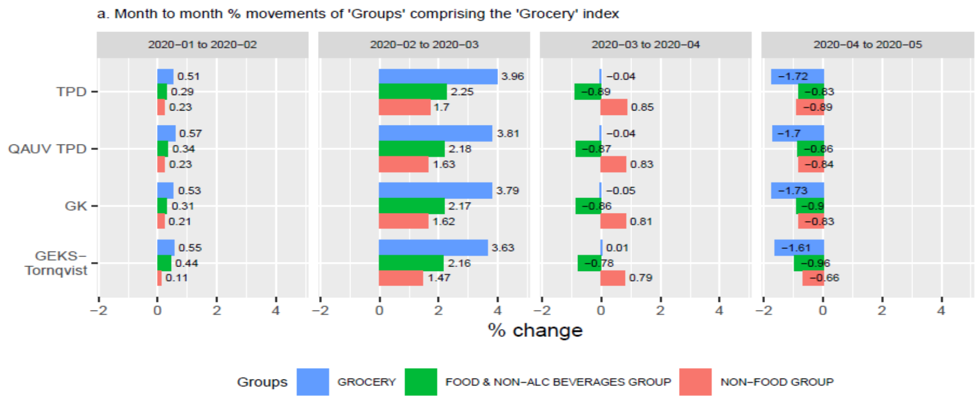


Figure 3.a shows the 'Grocery' level index for each of the four multilateral methods from Jan 2020 to May 2020. Figure 3.b shows the month-to-month index movements (%) for each of the four multilateral methods from Jan 2020 to May 2020.



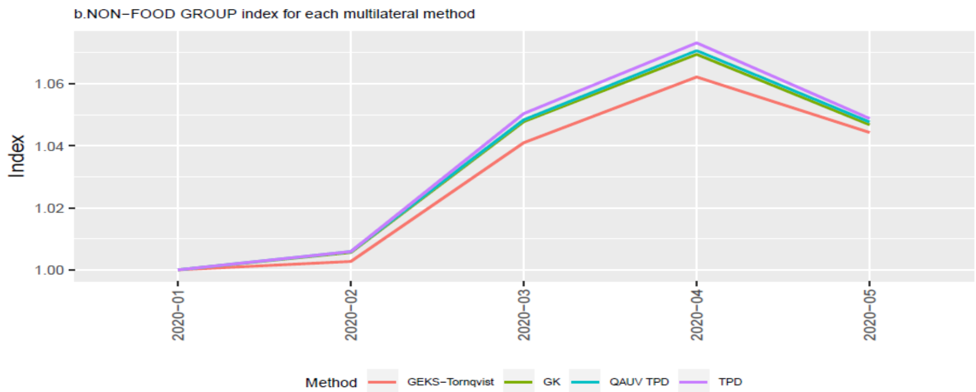


Figure 4.a shows the month-to-month index movements (%) of the 'Grocery' level index and the contributions of the two component groups for each of the multilateral index methods. Figure 4.b shows the Non-food group index series, where the largest differences between the methods was observed.

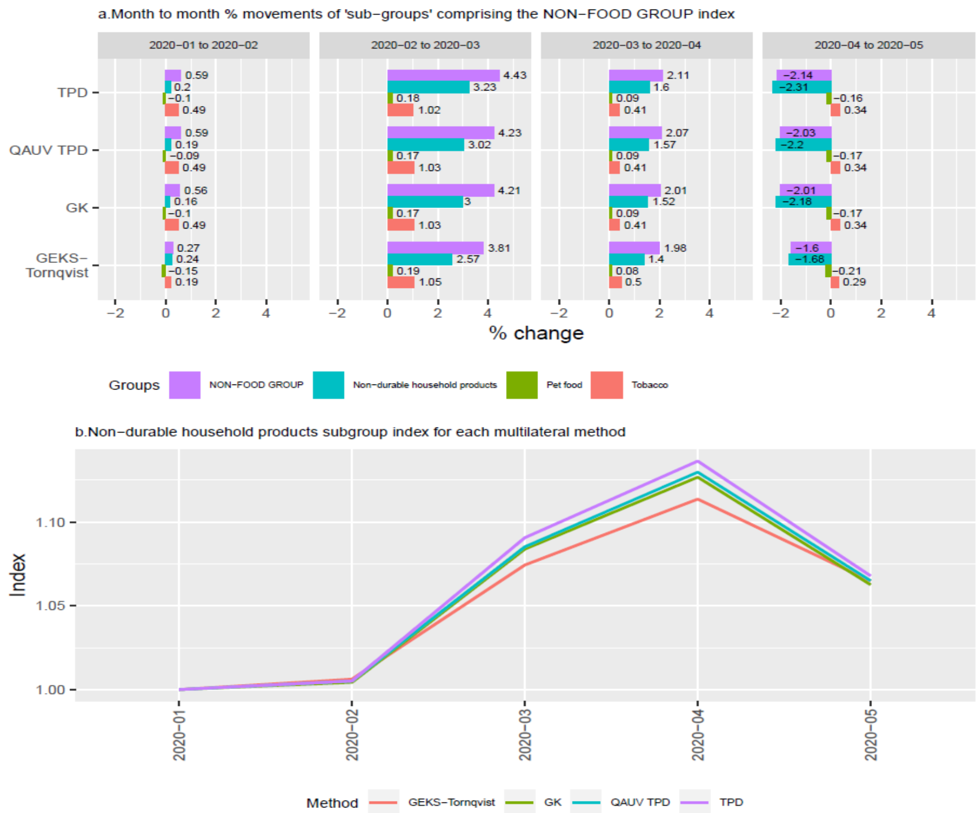


Figure 5.a shows the month-to-month index movements (%) of the Non-food group index and the sub-group contributions to the Non-food group movement for each of the multilateral index methods. Figure 5.b shows the non-durable household products index series, where the largest differences between methods was observed.

Table 1. The proportion of total expenditure on toilet paper products for their respective sub-group and the overall grocery expenditure for both Australia and the city of Melbourne (which had the highest total expenditure on toilet paper of all capital cities).

	Australia		Melbourne	
Month	**Toilet paper proportion of sub-group (%)**	**Toilet paper proportion of 'Grocery' (%)**	**Toilet paper proportion of sub-group (%)**	**Toilet paper proportion of 'Grocery' (%)**
01/2020	31.38	1.01	33.00	1.02
02/2020	30.39	1.06	32.32	1.06
03/2020	40.00	1.73	43.39	1.90
04/2020	34.45	1.23	34.63	1.17

Figure 6 shows the retailer-specific EA level indexes corresponding to toilet paper products for Melbourne, as well as the month-to-month percentage movements for the different multilateral methods. Large differences between the GEKS-Tornqvist method and other multilateral methods can be observed in the month-to-month movements between February and May. Importantly, the index levels are similar in May despite significant divergence over the previous two months.

Figure 6. shows the EA level indexes that correspond to toilet paper products for Melbourne where toilet paper expenditure was the highest and where lockdowns were most prominent. TOILET ROLLS and TOILET PAPER correspond to elementary aggregates from two different retail chains.

4.2 Decomposing toilet paper EA into product level contributions

ABS (2017) found little difference in the empirical results between the multilateral methods while testing, but these series produced for early 2020 show that under extreme real-world conditions the methods can produce quite different results. The following discussion uses the decompositions of Webster and Tarnow-Mordi (2019) to explore the likely reason for the differing behaviours. By decomposing the EA-level indexes into individual product contributions, we can attribute the differences in the index behaviour to varying response of the index methods to unusual fluctuations of the price and quantity characteristics of individual products. A greater understanding of how changes in supply and consumer behaviour can affect the index will allow NSOs to make more informed decisions on the method they implement.

Note that in the below analysis, the same physical product sold in different chains is treated as two separate products. Products have been denoted ‘X’ and ‘Y’ to reflect the two different chains. The product number following the letter has no relationship between chains.

The product contributions from the decomposition are month-to-month, and multiplying the individual product contributions gives the overall index movement between those two months. For example, the product of all Jan – Feb product contributions will give the index movement between January and February. Products with a contribution >1 contribute positively to the index movement (index will increase) while products with contributions <1 contribute negatively to the index (index will decrease).

The effect of month-to-month price change on a product’s index contribution can be assessed independently, as changes in price of one product will not affect the contributions of other products. This, however, is not the case with expenditure shares of products within their EA, as changing the expenditure share of one product will impact the expenditure shares of other products and consequently their contributions to the index movement.

4.2.1 February 2020 – March 2020

Table 1 shows expenditure increased dramatically for toilet paper in early 2020, and in March, price discounts for toilet paper products ceased and in general had higher average prices than in previous months.

Table 2 shows the 10 products with the largest positive contributions to the GEKS and TPD indexes. This table also includes the five products with the greatest difference in contributions for the two methods, highlighted in bold. It is worth noting that the same physical products sold by different retailers are treated as different products since they each contribute to their respective retailer index.

All the largest contributors for each method had price increases between February and March (Price relative > 1), and expenditure share within retailer also increased in March for eight of these products. The product with the largest difference in contribution between the methods, X_3, however (1.0524 for TPD and 1.0174 for GEKS-Tornqvist), had only a modest increase in price (price relative = 1.03), but an enormous relative increase in expenditure share, 0.88% to 10.78% at a factor of 12.3. The other four products with the largest difference in contribution between the methods all had quite large increases in expenditure share between February and March (in addition to their price increase) and all had quite high total expenditure shares in March.

Table 2. Products with the largest positive contributions to the Melbourne toilet paper indexes. The GEKS-Tornqvist and TPD columns contain the product contributions to the index movement between the months of February and March 2020.

Product	Feb exp share (%)	Mar exp share (%)	Price relative	Exp share relative	GEKS-Tornqvist	TPD	Difference
X_1	**12.37**	**18.76**	**1.8430**	**1.5161**	**1.1016**	**1.1221**	**0.0205**
Y_1	**2.16**	**11.91**	**1.7504**	**5.5025**	**1.0291**	**1.0593**	**0.0302**
X_2	8.27	8.43	1.8418	1.0196	1.0526	1.0554	0.0028
X_3	**0.88**	**10.78**	**1.0373**	**12.3119**	**1.0174**	**1.0524**	**0.0351**
Y_2	**5.14**	**6.32**	**1.8027**	**1.2310**	**1.0320**	**1.0409**	**0.0089**
X_4	**0.70**	**5.68**	**1.6359**	**8.0718**	**1.0072**	**1.0189**	**0.0117**
Y_3	3.76	3.53	1.4280	0.9388	1.0160	1.0141	-0.0019
Y_4	2.95	5.72	1.2372	1.9381	1.0094	1.0126	0.0032
X_5	6.13	4.03	1.1298	0.6570	1.0063	1.0067	0.0003
X_6	1.28	1.67	1.5277	1.3034	1.0061	1.0063	0.0002

Table 3 shows the toilet paper products with price increases, but similar or decreasing expenditure shares. Products with considerable price increases but relatively small changes in expenditure shares (X_2, Y_3) had similar contributions for the two methods. Some interesting minor differences were observed for products which had a decrease in expenditure share. For instance, the GEKS-Tornqvist contribution is greater than that of TPD for product Y_3, a product which had a decrease in an already high expenditure share and a modest price increase. For product Y_6, the contribution to the TPD index is negative even though the price relative is > 1 which is due to the relative decrease in expenditure share. There are 4 products whose expenditure share relatives are <0.6 and in 3 of those cases the TPD contributions are lower than GEKS-Tornqvist contributions, the exception being Y_5 which has the largest price increase of those 4 products.

Table 3. Products whose prices increased between Feb and Mar but had either similar or decreasing expenditure shares.

Product	Feb exp share (%)	Mar exp share (%)	Price relative	Exp share relative	GEKS-Tornqvist	TPD	Difference
X_2	8.27	8.43	1.8418	1.0196	1.0526	1.0554	0.0028
Y_5	1.01	0.32	1.6693	0.3133	1.0013	1.0023	0.0009
X_6	1.28	1.67	1.5277	1.3034	1.0061	1.0063	0.0002
X_7	0.80	0.52	1.5151	0.6532	1.0021	1.0030	0.0009
Y_3	3.76	3.53	1.4280	0.9388	1.0160	1.0141	-0.0019
X_8	0.08	0.03	1.3230	0.3424	1.0000	1.0001	0.0001
X_9	0.77	0.42	1.2558	0.5399	1.0018	1.0013	-0.0004
Y_6	0.84	0.17	1.1602	0.2073	1.0004	0.9997	-0.0008
X_5	6.13	4.03	1.1298	0.6570	1.0063	1.0067	0.0003

Table 4 shows products which decreased in price between February and March. Of these products, all but one contributes negatively (< 1) to the index for the GEKS-Tornqvist method. For the TPD method there are two products that contribute positively to the index whereas those same products contribute negatively to the GEKS-Tornqvist. Those two products (X_10 and X_13) had considerable increases in their expenditure shares in March. This aligns with the statements made in Webster and Tarnow-Mordi (2019) that for this decomposition method there can be products whose prices decrease but contribute positively to the TPD index.

Table 4. Products with the largest price decreases between Feb and Mar.

Product	Feb exp share (%)	Mar exp share (%)	Price relative	Exp share relative	GEKS-Tornqvist	TPD	Difference
Y_7	0.37	0.95	0.8574	2.5751	0.9993	0.9996	0.0003
Y_8	0.50	0.85	0.8924	1.7022	0.9994	0.9998	0.0004
Y_9	0.79	3.25	0.9419	4.1076	0.9993	0.9996	0.0003
X_10	0.00	0.01	0.9482	27.0215	0.9979	1.0000	0.0021
X_11	1.89	0.38	0.9724	0.1992	0.9995	0.9996	0.0001
Y_10	0.00	0.01	0.9736	3.5895	0.9998	1.0000	0.0002
Y_11	1.31	0.36	0.9902	0.2742	0.9997	0.9997	-0.0001
X_12	0.10	0.04	0.9934	0.3843	1.0000	1.0000	0.0000
X_13	0.16	3.91	0.9955	23.8844	0.9995	1.0001	0.0006
X_14	12.51	8.54	0.9955	0.6825	0.9997	0.9996	-0.0002

Table 5 shows the other scenario highlighted in Webster and Tarnow-Mordi (2019) where a product has a negative contribution to the TPD index movement despite increasing in price. The negative contribution can be explained by considerable decreases in expenditure shares. The price increase is reflected in the GEKS-Tornqvist index, which has a contribution > 1 for these products.

Table 5. Products with price increases that contributed negatively to the TPD index.

Product	Feb exp share (%)	Mar exp share (%)	Price relative	Exp share relative	GEKS-Tornqvist	TPD	Difference
Y_6	0.84	0.17	1.1602	0.2073	1.0004	0.9997	-0.0007
Y_12	4.24	0.65	1.0382	0.1532	1.0023	0.9999	-0.0024

These results show that price change has the greatest impact on a product's contribution to the overall index, but also that large changes in product expenditure shares affect the two methods differently. The TPD method is more sensitive to expenditure share changes, and conversely the GEKS-Tornqvist more strongly reflects the price changes at the product level.

Correlation coefficients were analysed for the correlation between product contributions and (a) their price relatives, (b) expenditure share in the current month, (c) expenditure share in the previous month, and (d) relative change in expenditure share. It was found that the contribution to the index of a product correlates strongly with the price relative of the product between months (0.71 for GEKS-Tornqvist and 0.69 for TPD), while the product contributions for TPD correlate more strongly with expenditure shares in the current month than the GEKS-Tornqvist (0.62 to 0.58). The relationship between price relatives and contributions for each method in this instance differ to Figure 5 in Webster and Tarnow-Mordi (2019), where GEKS-Tornqvist contributions tended to be higher than TPD for products with higher price changes. It is suspected that this is due to the unusual changes in expenditure shares in this instance, which were not observed in the data analysed in Webster and Tarnow-Mordi (2019).

4.2.2 March 2020 – April 2020

Between March and April in 2020 the 'Non-food' Group and toilet paper indexes continued to rise (Figure 6), and a discrepancy between movements in the multilateral methods can still be observed in the 'Non-durable household products' index (Figure 5a.) with contributions of 1.60% and 1.40% for TPD and GEKS-Tornqvist respectively. The analysis of behaviour in this second month of the pandemic window highlights how the changes in price and expenditure between February and March have different effects on the contributions of products between March and April.

Table 6 shows the 12 products with the largest differences in March-to-April contributions between methods. Eight out of 10 positively contributing products are common between the methods, while there are two products that contribute positively to GEKS-Tornqvist but negatively to TPD. Of all the products that contribute positively to both indexes, all but one had considerable increases in expenditure shares, but several had price relatives slightly below 1.

Product X_3 contributes positively to both indexes even though the price relative equals 1, and the expenditure share decreases slightly. This product had a large contribution to both indexes between February and March and also had one of the largest expenditure share increases between those two months, so it appears that the product changes during February and March are having a slight carry-over effect on the contribution between March and April. There is a similar carry-over effect for product X_4, which also had considerable price and expenditure share increases between February and March. The GEKS-Tornqvist contribution for X_4 increased despite a price decrease and a considerable expenditure share increase between March and April.

It is worth highlighting the two products in Table 6 for which the expenditure share is almost zero in April (X_5 and Y_3) and have a price increase between March and April. The GEKS-Tornqvist product contributions are larger, reaffirming that the GEKS-Tornqvist index is less affected by extreme changes between months in expenditure shares and so is more reflective of pure price change in products.

Table 6. Products with the largest positive contributions to the Melbourne toilet paper indexes. The GEKS-Tornqvist and TPD columns contain the product contributions to the index movement between the months of March and April 2020.

Product	Mar exp share (%)	Apr exp share (%)	Price relative	Exp share relative	GEKS-Tornqvist	TPD	Difference
X_1	18.76	28.41	0.9989	1.5148	1.0443	1.0860	0.0418
X_2	8.43	14.19	1.0255	1.6843	1.0296	1.0576	0.0280

Y_1	11.91	21.43	1.0592	1.7998	1.0261	1.0316	0.0055
Y_2	6.32	10.48	1.0370	1.6572	1.0159	1.0285	0.0125
Y_12	0.65	4.05	1.6762	6.2329	1.0220	1.0257	0.0037
Y_4	5.72	10.39	0.9976	1.8171	1.0053	1.0085	0.0033
X_3	10.78	10.55	1.0001	0.9793	1.0036	1.0062	0.0026
X_15	0.65	2.73	0.9932	4.1829	1.0007	1.0039	0.0031
Y_5	0.32	1.15	0.9953	3.6101	1.0007	1.0035	0.0027
X_5	4.03	0.00	1.2742	0.0008	1.0046	0.9984	-0.0062
X_4	5.68	10.97	0.8543	1.9324	1.0018	0.9949	-0.0069
Y_3	3.53	0.00	1.2287	0.0013	0.9981	0.9865	-0.0116

Analysis of correlation coefficients shows that for both index methods the product contributions correlate similarly with changes in expenditure shares in the current (0.74 for GEKS-Tornqvist and 0.72 for TPD) and previous months (0.52 and 0.51), while GEKS-Tornqvist contributions correlate more with relative price change than TPD (0.30 to 0.16). Of the products with the largest expenditure shares (>10%), almost all are relatively unchanged in price between March and April yet contribute positively to each index. These products all had considerable price increases between February and March in addition to expenditure share increases, so we are effectively seeing a carry-over effect from these products which explains why price change is less correlated than in previous months.

4.2.3 April 2020 – May 2020

Between April and May the price index for toilet paper decreased significantly for all methods, and while there was little difference between the index levels in May across multilateral methods, the movements across multilateral methods are notably different. Between April and May there were considerable changes in expenditure shares of some products, with many decreasing and a couple of others increasing considerably, largely explained by changes in supply conditions. Some new products were also introduced that accounted for reasonable proportions of expenditure.

There were only 5 products (from a total of more than 60 products) across both retailers that contributed positively to each of the GEKS-Tornqvist and TPD indexes, all of which had almost no change in price and except for one product which had less than 2% expenditure share.

Table 7 shows products with the largest negative contributions to both indexes. The most interesting observation in Table 7 is that product X_1 had almost no change in price between April and May but had a large decrease in expenditure share, which while it has a negative impact on the index for both methods, it is more pronounced in the TPD method. Almost all products in Table 7 have had both price decreases and considerable decreases in expenditure shares.

Each retailer had a single product with a very large expenditure share increase in May. Table 8 shows that for these products there was almost no price change, and their May expenditure shares were very large. The average price of product Y_14 has not changed over a two-year period, while X_14 has not changed in price since its inception in January 2019. Product Y_14 did not contribute to the index movements for either method despite the changes in expenditure share, while Product X_14 contributed slightly negatively to the TPD index. These behaviours in contributions differ greatly to what can be seen in Table 7 where products with very little change in price but large decreases in expenditure (X_1, Y_4, Y_12) contribute negatively to the index.

Table 7. Products with the largest negative contributions to the Melbourne toilet paper indexes. The GEKS-Tornqvist and TPD columns contain the product contributions to the index movement between the months of April and May 2020.

Product	Apr exp share (%)	May exp share (%)	Price relative	Exp share relative	GEKS-Tornqvist	TPD	Difference
X_1	28.41	11.38	0.9982	0.4004	0.9428	0.8941	-0.0486
Y_1	21.43	8.26	0.6894	0.3854	0.9549	0.9203	-0.0345
X_3	10.55	4.07	0.9929	0.3856	0.9882	0.9642	-0.0240
X_2	14.19	8.32	0.7968	0.5858	0.9588	0.9352	-0.0235
Y_2	10.48	5.00	0.8105	0.4773	0.9723	0.9549	-0.0173
X_4	10.97	3.41	0.6094	0.3110	0.9867	0.9752	-0.0115
Y_4	10.39	0.97	0.9999	0.0934	0.9901	0.9829	-0.0072
Y_12	4.05	2.71	1.0025	0.6683	0.9957	0.9912	-0.0045
Y_13	5.27	1.57	0.7305	0.2976	0.9992	0.9962	-0.0029
Y_5	1.15	0.35	0.9451	0.3050	0.9992	0.9965	-0.0027
X_15	2.73	2.37	0.9423	0.8663	0.9993	0.9971	-0.0022
Y_6	0.70	0.05	0.9920	0.0708	0.9992	0.9983	-0.0008
X_10	0.00	0.00	0.8333	1.4736	0.9944	0.9999	0.0056

Table 8. Products with the largest expenditure shares for each retailer.

Product	Apr exp share (%)	May exp share (%)	Price relative	Exp share relative	GEKS-Tornqvist	TPD	Difference
Y_14	25.27	47.12	0.9998	1.8647	0.9999	0.9999	0.0000
X_14	1.38	24.86	1.0008	17.9853	0.9998	0.9995	-0.0003

5. Summary/Discussion

Overall, the alternative multilateral index methods react similarly to the unusual consumer behaviour, and differences are largely attributable to one product class which exhibited particularly extreme behaviours. The most noticeable differences between the methods were for indexes for toilet paper, the commodity which had particularly extreme changes in quantity and a suspension to the usual discounts. The greatest disruption to prices and quantities were between February and March, the pair of months when the greatest differences between GEKS-Tornqvist and other multilateral methods can be observed. The toilet paper indexes diverged further between March and April; however, the index levels were much more similar in May as the decreases between April and May were less pronounced for the GEKS-Tornqvist compared with the others.

The GEKS-Tornqvist method was observed to behave more conservatively and arguably more favourably in this extreme scenario because it was less influenced by the extreme changes to expenditure shares of individual products. Some further insights from the decomposition tool can be summarised as:

- Price changes between months were found to have the greatest effect on index contribution and had a strong correlation with contribution for both multilateral methods, while TPD contributions were more correlated with expenditure share in the current month and expenditure share changes than GEKS-Tornqvist.
- The effect of changes in expenditure share on the TPD index can also be observed between April and May where negative contributions to the TPD index are greater when there is also a considerable decrease in expenditure share. It is important to note however, that when prices

and quantities are largely restored in May, the index level differences between the GEKS-T and TPD indexes which emerged in March and April are largely 'undone'.

- Products that contributed positively to both indexes but were found to contribute more to TPD than GEKS-Tornqvist in most cases had large increases in expenditure shares (e.g., price relative = 1.750, exp share = 11.91%, exp share relative = 5.5025, GEKS = 1.0291, TPD = 1.0593). The largest difference in contributions between methods was observed for a product that only had a modest price increase, but a considerable expenditure share increase - X_3: price relative = 1.037, exp share previous = 0.88%, exp share current = 10.78%, GEKS = 1.0174, TPD = 1.0525, difference = 0.0351.
- Between February and April all products with price increases and expenditure shares > 0 had a neutral or positive contribution to the GEKS-Tornqvist index, however there were several products which had price increases between months but contributed negatively to the TPD index. These products were observed to have considerable decreases in expenditure share (e.g., price relative = 1.160, exp share relative = 0.2073, GEKS = 1.0004, TPD = 0.9997). Webster and Tarnow-Mordi (2019) mentioned that this behaviour with their decomposition is not uncommon for the TPD index but is both less common and pronounced for the GEKS-Tornqvist method.
- Products with price decreases tended to have a neutral or negative contribution to each index, however there were some products with price decreases that contributed positively to the TPD index but negatively to GEKS-Tornqvist; all these products had increases in expenditure shares.

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Appendix 1. Multilateral method formulas

A1.1 GEKS-Tornqvist

The GEKS-Tornqvist method takes the geometric mean of the ratios of all bilateral Tornqvist indexes between a number of time periods. The Tornqvist bilateral index can be expressed as:

$$P_T^{0,t} = \prod_{i=0}^{n} \left(\frac{p_i^t}{p_i^0}\right)^{\frac{s_i^t + s_i^0}{2}} \tag{A1.1.1}$$

where,

$P_T^{0,t}$ = Tornqvist index between periods 0 and t

p_i^t = price of item i in period t

p_i^0 = price of item i in period 0

$\frac{s_i^t + s_i^0}{2}$ = average expenditure share of item i across periods 0 and t

n = number of matched items between periods 0 and t

The GEKS-Tornqvist is calculated as the geometric mean of the ratios of all matched-model Tornqvist bilateral indexes ($p^{l,0}\ and\ p^{l,t}$) where each period is taken in turn as the base (de Haan 2015), and can be expressed as:

$$P_{GEKS}^{0,t} = \prod_{l=0}^{T} \left(\frac{p^{l,t}}{p^{l,0}}\right)^{\frac{1}{T+1}} = \prod_{l=0}^{T} \left(p^{0,l} * p^{l,t}\right)^{\frac{1}{T+1}} \tag{A1.1.2}$$

where,

$P_{GEKS}^{0,t}$ = GEKS index between periods 0 and t

$p^{l,t}$ = Tornqvist index between periods l and t

$p^{l,0}$ = Tornqvist index between periods l and 0

T = number of periods in the window

A1.2 TPD

The TPD method uses a regression approach, similar to hedonic based methods previously used in the Australian CPI (ABS 2016), that uses the statistical relationship between prices, products and time to estimate price change over time. The method is an adaptation of the Country Product Dummy (CPD) method used for spatial comparisons by Aizcorbe et al. 2003. The TPD model is estimated for a specified window length by modelling the log of price against time and product binary indicators and can be expressed as:

$$\ln(p_i^t) = a^0 + \sum_{t=1}^{T} \delta^t D_i^t + \sum_{i=1}^{N-1} \gamma_i D_i + \varepsilon_i^t \qquad \text{(A1.2.1)}$$

where,

$\ln(p_i^t)$ = log of price for item i in period t

a^0 = intercept term

δ^t = time parameter corresponding to period t

D_i^t = time dummy variable, equal to 1 if the price observation p_t^t pertains to period t

γ_i = product parameter corresponding to product i

D_i = product dummy variable, equal to 1 if the price observation p_i^t pertains to item i

ε_i^t = error term

The time effect δ^t reflects the overall price level in period t relative to a reference period 0 and the price index can be directly estimated from this as follows:

$$P_{TPD}^{0,t} = \frac{\hat{p}_i^t}{\hat{p}_i^0} = \exp(\delta^t) \qquad \text{(A1.2.2)}$$

where,

$P_{TPD}^{0,t}$ = price movement between periods 0 and t

$\hat{p}_i^0$ = predicted price of product i from period 0

$\hat{p}_i^t$ = predicted price of product i from period t

To produce a weighted price index a weighted least squares version of Equation A1.2.1 is fitted such that the following sum is minimised:

$$S = \sum_U s_i^t (e_i^t)^2 \qquad \text{(A1.2.3)}$$

where,

S = weighted sum of squared residuals

U = set of all price observations in the window

s_i^t = expenditure share of product i relative to other products sold in period t

e_i^t = residual error term of price observation p_i^t

A1.3 QUAV TPD

The QUAV TPD method appeals to the notions of homogeneity and unit values by expressing the quantity of products into common units by standardising it with respect to some base item and then calculating a unit value across all products. The QUAV TPD price index can be calculated as:

$$p^{0,t} = \frac{V^{0,t}}{Q_{QAUV}^{0,t}} \qquad \text{(A1.3.1)}$$

where,

$p^{0,t}$ = unit value index between periods 0 and t

$V^{0,t}$ = value index between 0 and t

$Q_{QAUV}^{0,t}$ = quantity index between periods 0 and t

The quantity index $Q^{0,t}$ is standardised with respect to some base item and is expressed as:

$$Q_{QAUV}^{0,t} = \frac{\sum_{i \in U^t} v_{i/b} q_i^t}{\sum_{i \in U^0} v_{i/b} q_i^0} \qquad \text{(A1.3.2)}$$

where,

$Q_{QAUV}^{0,t}$ standardised quantity index

$v_{i/b}$ = adjustment factor comparing item i to base item b
q_i^t = quantity of item i in period t
q_i^0 = quantity of item i in period 0
U^t = sample of products from period t
U^0 = sample of products from period 0

The adjustment factor comparing item i to base item b is calculated as:

$$v_{i/b} = \frac{\hat{p}_i^t}{\hat{p}_b^t} = \frac{\exp(\hat{\gamma}_i)}{\exp(\hat{\gamma}_b)} \quad \text{(A1.3.3)}$$

where,
$\hat{\gamma}_i$ = product parameter from Equation A1.2.1 corresponding to product i
$\hat{\gamma}_b$ = product parameter from Equation A1.2.1 corresponding to product b

A1.4 GK

The GK method is similar to the QUAV TPD in that it also appeals to the notions of homogeneity and unit values by expressing the quantity of products into common units and then calculating a unit value across all products (see Equations A1.3.1 and A1.3.2). Where they differ is in how the adjustment factor is estimated, with the GK method using an iterative approach (detailed in Chessa (2016)) to produce the quantity weighted average of deflated prices, which can be expressed as:

$$v_{i/b} = \sum_{z \in T} \varphi_{i,z} \frac{p_{i,z}}{p_{GK}^z} \quad \text{(A1.4.1)}$$

where,
$v_{i/b}$ = weighted average of deflated prices of product i
$\varphi_{i,z}$ = quantity share of product i in period $z \in T$
$p_{i,z}$ = price of product i in period $z \in T$
p_{GK}^z = price index in period $z \in T$

The quantity share of product i in period $z \in T$ is calculated as:

$$\varphi_{i,z} = \frac{q_{i,z}}{\sum_{s \in T} q_{i,s}} \quad \text{(A1.4.2)}$$

where,
$q_{i,z}$ = quantity of product i in period z
$\sum_{s \in T} q_{i,s}$ = total quantity of product i over all time periods $s \in T$