THE DISTRIBUTION AND MEASUREMENT OF INFLATION

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Abstract

Measured inflation records many shocks that are not representative of the persistent component of inflation. Several methods are used to construct measures of core inflation which abstract from these unrepresentative shocks; this paper focuses on trimmed means. Analysis of Australian CPI component price changes shows they are widely dispersed. Further, they are not normally distributed; there is a large proportion of extreme price changes (the distribution is fat-tailed) and the distribution is usually positively skewed. With an understanding of the behaviour of price changes, trimmed means are then developed. It is found that trimmed means provide a better measure of trend, or core, inflation when a large proportion of the distribution is removed. As a consequence of the distribution's systematic positive skew, slightly more than half of the trim should be taken from the left-hand tail to ensure that the trimmed mean records average inflation equal to that of the whole CPI.

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1. Introduction

Like several other central banks, the Reserve Bank of Australia has an explicit inflation target; specifically, the Bank's objective is to maintain average inflation over the medium term of between two and three per cent. Given the notorious long and variable lags of monetary policy, the central bank must set policy so that the expected outcome of inflation is consistent with the target. To do so, the central bank needs to discriminate between movements in inflation that alter the trend path of inflation, and movements that are transitory.

Measured inflation is subject to many shocks that are unrepresentative of the general trend in inflation induced by the interaction of aggregate demand and supply. In any given quarter, components of the CPI may be subject to transitory price movements, due simply to volatility or sharp exchange rate movements that are likely to be reversed over the longer horizon. Alternatively, there may be infrequent changes in the prices of CPI components that are either wholly or largely the result of changes in government policy. In either case, such movements in prices are not indicative of the persistent component of inflation. Typically, central banks examine some measure of core inflation that seeks to abstract from these influences. In Australia, the so-called 'Treasury underlying CPI' has been the core inflation series with the greatest prominence, although it is by no means the only measure of core inflation (RBA 1994).

This paper undertakes a detailed examination of the behaviour and distribution of Australian CPI component price changes, and uses this information to construct a preferred trimmed mean measure of core inflation. Most often, it is found that a 100 per cent trimmed mean is the preferred measure of core inflation. The 100 per cent trimmed mean focuses on the price change of *a single component in the distribution*, abstracting from the influence of extreme components in the distribution of price changes.

2. Behaviour of Price Changes

In this section, the distribution of price changes is examined. An understanding of the manner in which prices change can deliver an important insight into the inflation process and the behaviour of measures of inflation. Further, it can assist in determining the best method for measuring core inflation. The distribution of quarterly price changes is examined, rather than changes over a longer horizon, as monitoring inflation over a shorter horizon provides more timely information on turning points in the trend of aggregate inflation.[1]

2.1 The Data

Quarterly CPI expenditure class data – the finest level at which the Australian CPI is available – from September 1980 until March 1998 are used in this study. At this level of disaggregation there are approximately 100 components, although with the introduction of new CPI series, weights are updated and components are occasionally added to, or removed from, the CPI.[2] In this paper, two components, mortgage interest charges and consumer credit charges, are excluded from the analysis from December 1986. Interest rates represent the cost of intertemporal consumption smoothing, and so are not a current price of a good or service. It is, therefore, preferable to exclude them from a measure of goods and services price inflation (RBA 1997). Indeed, following the most recent review of the CPI, the Australian Bureau of Statistics (ABS) will remove interest charges from the 13th series of the CPI to be introduced from September 1998 (ABS 1997b). For the remainder of this paper, 'CPI' and 'total CPI' will refer to the CPI excluding interest charges.

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1 There are also pragmatic reasons for examining quarterly changes. Since the CPI is spliced using quarterly changes when the weighting regime changes, it is not possible to express the aggregate inflation rate as a weighted sum of the component inflation rates for horizons longer than one quarter. The derivation of the quarterly inflation rate as a weighted sum of the component inflation rates is shown in Appendix A.

2 Initially, there are 97 components, from March 1982 until September 1986 this increases to 102, and thereafter there are 107 components.

2.2 Defining the Distribution Moments

With many quarters of data, the moments of the distribution provide a useful summary of the distribution of component quarterly price changes. As shown in Appendix A, the aggregate quarterly inflation rate, p_t, can be expressed as a weighted sum of the n component quarterly inflation rates, p_{it}, where the time-varying weights, w_{it}, are an amalgam of the series weights, the index levels, and splicing factors:

$$p_t = \sum_{i=1}^{n} w_{it} p_{it} \tag{1}$$

These time-varying weights are used in calculating the moments, m_t^r, of the distribution of CPI component price changes. The first moment, where $r = 1$, the *mean* rate of inflation, is defined by Equation (1). The higher-order, r^th^ central moment is defined as:

$$m_t^r = \sum_{i=1}^{n} w_{it} (p_{it} - p_t)^r \tag{2}$$

The second central moment, $r = 2$, the variance, and its square root, the *standard deviation*, s, are measures of the dispersion of the distribution. The coefficients of *skewness* and *kurtosis* are scaled versions of the third and fourth moments:

$$S_t = \frac{m_t^3}{s^3} \tag{3}$$

$$K_t = \frac{m_t^4}{s^4} \tag{4}$$

These coefficients provide a summary of the shape of the distribution. For a symmetric distribution, the coefficient of skewness will be zero.[3] A positive

[3] Note, however, that skewness and asymmetry are not synonymous terms. Symmetry implies that the left and right sides of the distribution are mirror images, while the coefficient of skewness compares the density of the tails in distance relative with the mean. It is possible that

coefficient of skewness indicates the distribution is skewed to the right, that is, the right-hand tail is longer than the left-hand tail. Conversely, a negative coefficient indicates that the distribution is skewed to the left. The kurtosis coefficient indicates the extent to which the distribution has fat tails (leptokurtosis, $K_t > 3$) or thin tails (platykurtosis, $K_t < 3$) relative to a normal distribution, which has a kurtosis coefficient of 3 (mesokurtosis). For the remainder of this paper, the term moments will be used somewhat loosely to refer to the mean, standard deviation and coefficients of skewness and kurtosis.

2.3 The Moments of Inflation

Figure 1 plots the moments of the distribution of CPI component price changes in each quarter. The top panel shows the *mean* price change in each quarter. The decline in the inflation rate is clearly seen with the mean price change smaller over the 1990s than over the 1980s. The periodic volatility of the mean is also apparent with several episodes where the mean inflation rate is significantly different in adjacent quarters.

Several quarters of extreme mean price changes are worth noting. The large spike in inflation in December 1981 and the sharp fall in March 1984 were the result of movements in the cost of *Hospital and Medical Services*. Inflation picked up in late 1986 with the large depreciation in the exchange rate and the reversal of the oil price fall. Again in December 1990, at the time of the Gulf war, petrol prices caused a sharp rise in inflation, which was reversed in the subsequent quarter.

The large *standard deviation* demonstrates the significant dispersion of quarterly price changes. As shown in Appendix B, while some components are frequently in the tails, many components are occasionally in the tails.

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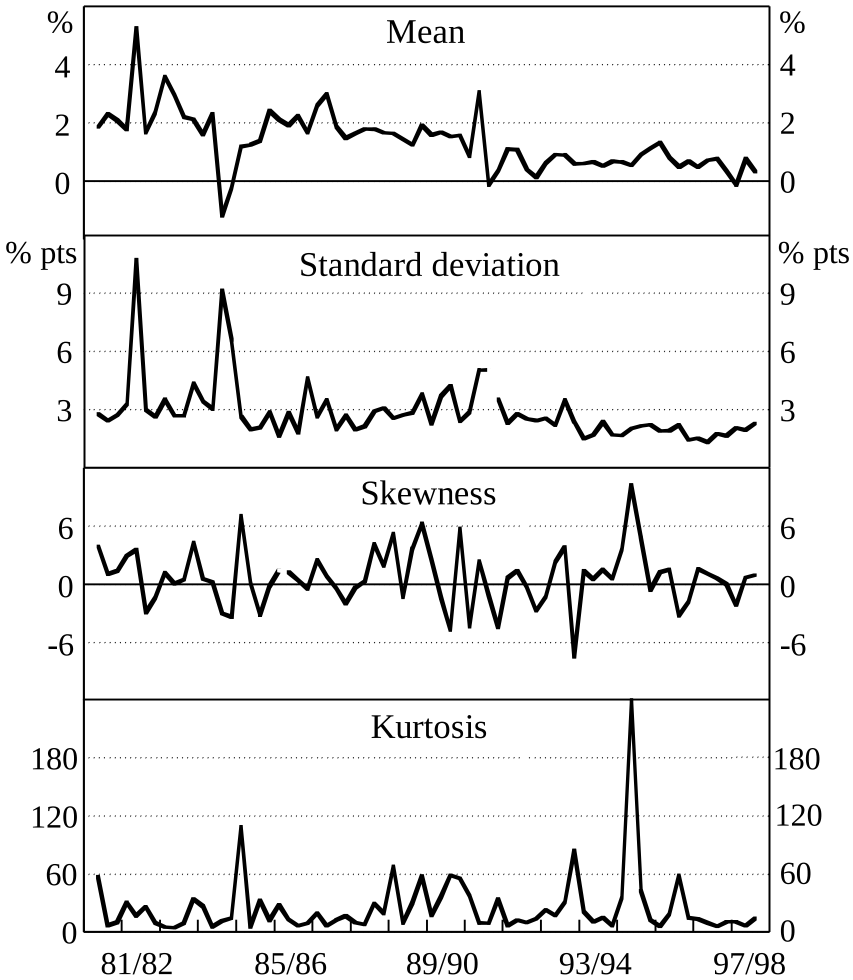
a distribution may be asymmetric and yet have a zero coefficient of skewness. However, a distribution with a non-zero coefficient of skewness must be asymmetric.

Figure 1: The Moments of Inflation

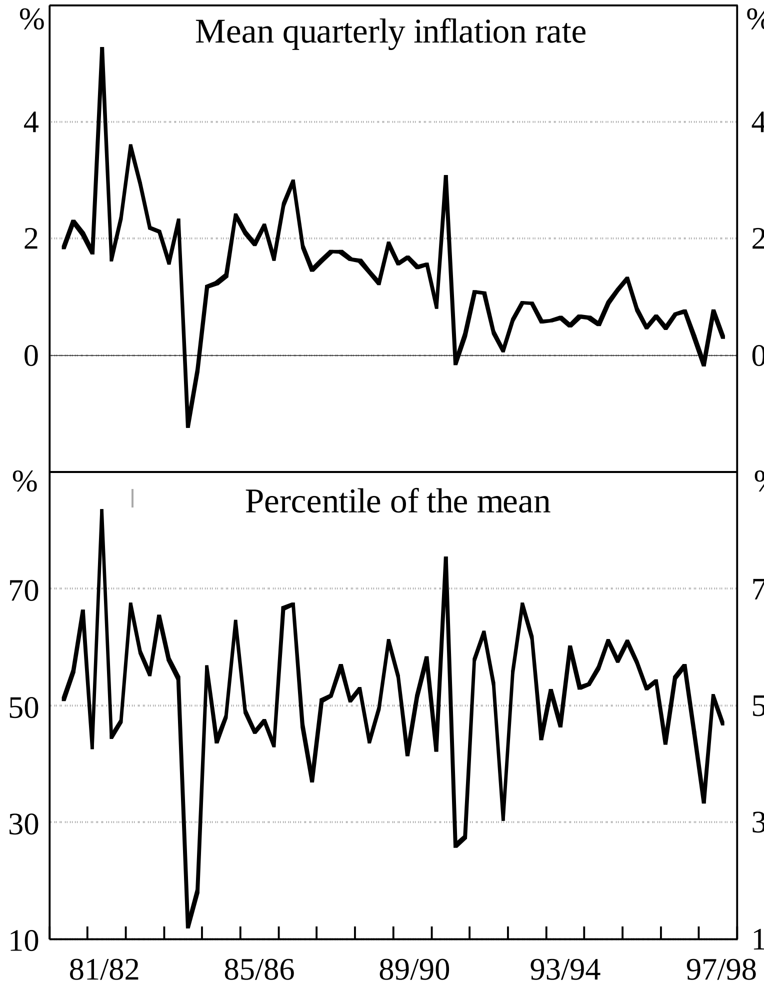


The plot of the coefficient of *skewness* in the third panel illustrates that in most quarters the distribution of price changes is skewed. The distribution is more often positively skewed than negatively skewed.[4] On average, the coefficient of skewness is 0.7, indicating that, typically, the right-hand tail of the distribution is longer than the left-hand tail. The coefficient of skewness is not the only measure of the distribution's asymmetry. An alternative simple diagnostic is to compare the mean and median of the distribution. If the distribution is symmetric, then the mean and median will be equal. However, Figure 2 demonstrates that the mean inflation rate usually has a percentile ranking greater than 50, indicating that the mean inflation rate is greater than the median inflation rate (so observations in the right-hand side of the distribution are, on average, further from the median than those in the

4 In 45 quarters the distribution is positively skewed, while it is negatively skewed in only 25.

left-hand side).[5] The percentile ranking of the mean also demonstrates that when the mean inflation rate moves sharply between quarters, it is typically some distance from the central portion of the distribution.

Figure 2: The Percentile of the Mean



The *kurtosis* coefficient, as shown in Figure 1, is often very large. Indeed, it is greater than 3 in every quarter, indicating the distribution of quarterly price changes is always leptokurtotic (that is, more fat-tailed than a normal distribution). This indicates that in a typical quarter, a large proportion of the CPI basket experiences price changes significantly different from the mean inflation rate. Using the skewness and kurtosis coefficients, the normality of the distribution can be tested statistically. Not surprisingly, the null hypothesis, that the quarterly CPI component

5 On average, the mean is at the 52nd percentile of the distribution.

price changes have a normal distribution, can be comprehensively rejected in all but one quarter out of 70.[6]

The high import penetration of the Australian economy possibly contributes to the significant dispersion of price changes. A large appreciation or depreciation of the exchange rate will result in significant changes in the prices of imported goods, often placing largely imported CPI components in one of the tails of the distribution. This will skew the distribution, increasing its measured dispersion and the proportion of components in the tails. Over the sample period, the distribution of quarterly exchange rate changes is negatively skewed, suggesting asymmetric exchange rate shocks could be responsible for the positive skew of the distribution of price changes.[7] However, episodes of exchange rate depreciations, in particular the mid 1980s, do not coincide with increased positive skew of CPI component price changes.

An alternative explanation lies in the behaviour of the prices of non-market components, such as *Government Dwelling Rents* or *Education*. The prices of these components change infrequently, because of different pricing policy to the market sector, and possibly, as Roger (1995) suggests, because the non-market sector contains fewer price setters.

Table 1 demonstrates that the coefficient of skewness falls when the components whose prices are set, or heavily influenced by, government policy, are excluded.[8]

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6 The normality of a distribution can be tested using the test statistic $N\left[\frac{1}{6}S_t^2+\frac{1}{24}\left(K_t-3\right)^2\right]$, which has a chi-squared distribution with two degrees of freedom under the null hypothesis, where N is the sample size. In December 1982 the null hypothesis of normality can not be rejected at the 17 per cent level of significance. In all other quarters, the null hypothesis can be rejected at a significance level of, at most, 0.2 per cent.

7 Recall that an exchange rate fall leads to a rise in the price of imports. The coefficient of skewness of quarterly percentage changes of the import-weighted exchange rate index from December 1980 to March 1998 is -0.9. For the trade-weighted exchange rate index the coefficient is -0.7.

8 The classification of components whose prices are set or largely determined by Government policy is that of Department of Treasury (1995). The components excluded are: *Government Owned Dwelling Rents; Local Government Rates and Charges; Household Fuel and Light; Postal and Telephone Services; Automotive Fuel; Urban Transport Fares; Tobacco and Alcohol; Health Services; Pharmaceuticals; and, Education and Childcare.*

Non-market prices therefore clearly contribute to the skewness of price changes. Table 1 also presents evidence that there is a seasonal element to non-market prices. Seasonal adjustment reduces the coefficient of skewness more in the total basket than in the market basket, implying that skewness in non-market components contributes disproportionately to the skewness of price changes.[9]

Non-market components cannot, however, account for all of the skewness of price changes, since even the market basket exhibits substantial skewness. Seasonal adjustment of this basket has very little effect on skewness, suggesting that the remaining skewness does not derive from seasonal price changes.[10]

Table 1: Moments of Inflation

	Mean	Standard deviation	Skewness	Kurtosis
	September 1980 to March 1998			
Original:				
All components	1.35	2.87	0.69	24.97
Excluding policy components[(a)]	1.23	2.45	0.49	31.36
Seasonally adjusted:[(b)]				
All components	1.35	2.47	0.32	22.27
Excluding policy components[(a)]	1.23	2.06	0.41	29.32
	September 1990 to March 1998			
Original:				
All components	0.70	2.34	0.35	26.65
Excluding policy components[(a)]	0.52	2.06	0.20	37.66

Notes: (a) The CPI excluding policy components is the total CPI less those components excluded from the Treasury underlying CPI basket because their prices are heavily affected by changes in government policy, see footnote 8.

(b) In the seasonally adjusted sample all components are individually seasonally adjusted using the full sample period.

9 All seasonal adjustment was conducted using EZ-X11.

10 Laflèche (1997) notes that some components in the Canadian CPI are priced at set intervals but not each period and so by definition their price changes will be ‘seasonal’. However, with the exception of seasonal clothing, which is a small portion of the total basket, all components of the Australian CPI are priced each quarter. Indeed, work conducted by the Australian Bureau of Statistics suggests that the seasonal pattern in the CPI is weak (Zarb 1991).

Given that the distribution's skew cannot solely be attributed to infrequent but systematic price adjustment, there is obviously a more fundamental cause. Two models that deliver a skewed distribution of price changes are proposed by Ball and Mankiw (1995) and Balke and Wynne (1996). In Ball and Mankiw's model, menu costs generate a positive relationship between the rate of inflation and the skewness of the distribution of price changes. De Abreu Lourenco and Gruen (1995) extend this model to show that the inflationary impetus of the dispersion of shocks depends on the level of inflation expectations. Balke and Wynne generate a skewed distribution of price changes that is positively related to the mean inflation rate, using a different framework. They use a dynamic equilibrium model with flexible prices, and show that if there is an asymmetric input-output relationship between sectors, the mean and skew of the distribution will be positively related. It is beyond the scope of this paper to investigate the fundamental cause of the skewness in the distribution of Australian consumer prices. Rather, its existence, and the extent to which it is caused by seasonality or is a sectoral phenomenon, is noted for the impact it has on the construction of a statistical measure of core inflation.

2.4 Correlations of the Moments

The correlations of the moments in Table 2 demonstrate that the dispersion of price changes is positively related to the mean rate of inflation. The finding that price changes are more dispersed at higher rates of inflation is consistent with a wide body of literature, which has been surveyed thoroughly by Golob (1993). There is little accord within this literature on the cause or nature of this relationship. Fischer (1981) lists a range of models that support a relationship between the rate of inflation and relative price variability. As Golob (1993) notes, the empirical evidence has supported models premised on sticky prices, menu costs, limited information and supply shocks. The differing models also have a range of implications for the causality between inflation and the dispersion of price changes and the economic costs of relative price variability. The mean rate of inflation is also found to be positively correlated with the skew of the distribution of price changes, a result that is consistent with the models by Ball and Mankiw, and Balke and Wynne discussed above.

Table 2: Correlations of Moments[(a)]

	Mean	Standard deviation	Skew	Kurtosis
Mean		0.30	0.25	-0.09
Standard deviation	0.24		-0.12	-0.04
Skew	0.27	-0.07		0.38
Kurtosis	-0.12	-0.05	0.41	

Notes: (a) The correlations in the lower triangle are for the moments of the full CPI basket from September 1980 to March 1998 while those in the upper triangle are from September 1990 to March 1998.

If a subset of components experienced extreme price changes, both the standard deviation and kurtosis coefficient would rise, so these moments would be positively correlated. No positive correlation, however, is found. Indeed, the standard deviation and kurtosis of the distribution are slightly negatively correlated. A significant negative correlation would suggest that increases in the standard deviation are associated with increased dispersion of the central core of the distribution rather than of outlying observations in the tails. In addition, the skew and kurtosis are positively related, implying that the fat-tails of the distribution are often not symmetric.

The nature of CPI component price changes will determine the behaviour of the CPI and any measure of core inflation which is based on the CPI components. Having examined the distribution of price changes, summarised by the moments and their correlations, Section 3 describes various methods for measuring core inflation and investigates the range of trimmed mean measures of core inflation.

3. Measuring Core Inflation

In a closed economy, core inflation is typically regarded as being the persistent component of inflation, the rate of change of prices that is caused by the interaction of aggregate demand and supply (Blinder 1982; RBA 1994). In an open economy, like Australia, sustained movements in the exchange rate will also affect the persistent component of inflation. However, measured inflation can differ markedly from such a definition of core inflation. The published series may reflect shocks to the supply of particular goods or services and, over short horizons, it may exhibit a seasonal pattern. Statistically, like other time series, inflation can be decomposed into trend, irregular and seasonal components. The trend component equates to the economic concept of core inflation. However, several methods exist for defining and removing irregular and seasonal components, and so constructing measures of core inflation.

3.1 Methods for Measuring Core Inflation

To be widely accepted, and to be useful for economic policy purposes, a measure of core inflation should be easily understood, available on a timely basis, not subject to revisions, and capable of being easily verified (ABS 1997a; Roger 1997). Broadly, three methods are used to construct measures of core inflation: certain components can be regularly excluded; there can be case-by-case specific adjustment of prices; or, some statistical criterion can be used.

Exclusion-based measures of core inflation permanently remove specified components from the CPI basket because their price movements over a short horizon are perceived to be unrepresentative of market-induced inflation trends. Typically, their prices are: seasonal; volatile, so movements are often quickly reversed; or largely determined by government policy. The Treasury underlying CPI used in Australia, and the CPI excluding food and energy in the US, are both exclusion-based measures of core inflation. Such measures are timely and transparent. They are also relatively intuitive and easily understood, although these advantages decline if a large proportion of the basket is excluded. Exclusion-based core inflation measures do have significant limitations. Information is discarded with the price changes of the components that are excluded. Further, it is necessary to make an *ex ante* judgment on which components to exclude. If the excluded components have a different trend rate or cyclical pattern of inflation, an exclusion-based core series may be somewhat unrepresentative of general price movements. Finally, an exclusion-based approach does not control for shocks to components retained in the basket.

Specific-adjustment methods of calculating core inflation are conceptually preferable to other methods, because by definition, they measure only those price movements attributable to the balance of supply and demand. In each period, the estimated impact on each component of changes in taxes and subsidies, seasonality and volatility are removed, with the residual price changes for all components combined to produce the core inflation series. While such a series defines the concept of core inflation well, it requires a large amount of information, and judgment, to decompose the price movements for each component into core and non-core changes. As such, it is less timely and cannot be easily verified, so is unlikely to be widely understood or accepted.

Statistical measures (or limited-influence estimators) of core inflation remove, or reduce the weight of, those components with extreme price changes, based on the premise that extreme price changes are not indicative of the persistent component of inflation. The most common class of these measures is the trimmed mean. These measures remove a proportion of each tail of the distribution, and take the weighted average price change of the central core of the distribution. They are timely and highly transparent, with no judgment required for their construction once the size of the trim is specified (although they may be more difficult to communicate to a broad audience than exclusion based core measures). Trimmed means have been calculated for many countries.[11]

The best known trimmed mean is the 100 per cent trim centred at the midpoint of the distribution. This is, of course, the median: the price change of the central component of the distribution. In principle, however, a 100 per cent trimmed mean can be 'centred' anywhere in the distribution. (For example, the 100 per cent trim centred at the 52nd percentile measures the price change of the component ranked at the 52nd percentile in the distribution.) To anticipate the results, it is found that a 100 per cent off-centre trimmed mean is often the 'optimal' measure of core inflation.

It may seem odd that an 'optimal' measure of core inflation could be derived by focusing solely on the price change of one component of the distribution. However, it should be remembered that the rest of the distribution is not simply ignored in the calculation of a 100 per cent trimmed mean. Instead, all price changes are ranked

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11 Several papers that outline the construction of trimmed means for various countries are Bryan, Cecchetti and Wiggins (1997), Bryan and Cecchetti (1994), Laflèche (1997), RBA (1994), Roger (1995) and Shiratsuka (1997).

from the lowest to the highest, and the price change of the component at the chosen percentile of the distribution is recorded.

3.2 Distributions and Statistical Measures of Inflation

Section 2 demonstrated that the cross-section of price changes frequently contained outlying observations, in one or both of the tails of the distribution. Such extreme price changes greatly affect the mean rate of inflation. Furthermore, they are typically unrepresentative of the trend rate of inflation.

The components that Department of Treasury (1995) classify as having volatile or seasonal prices, or prices that are heavily influenced by government policy, are excluded from the Treasury underlying measure of inflation. These components are among those most often found in the tails of the distribution although they are not always in the tails (as Appendix B shows). Also, items retained in exclusion-based core inflation measures are occasionally in the tails of the distribution. If extreme price changes are unrepresentative of the persistent component of inflation, an exclusion-based measure of core inflation will often include unrepresentative price changes but exclude valuable information. Trimmed means, in contrast, may be a better measure of core inflation because they remove extreme price changes regardless of the nature of the component that experiences that price change.[12]

As noted, the mean inflation rate is heavily influenced by how far in the tails is an extreme price change. In contrast, for trimmed mean measures of inflation, the ranking of extreme price changes is relevant, not their distance from other price changes; for the remaining central core of components, their distance from other price changes, and not just their ranking, is important in determining the trimmed mean rate. However, for the median measure of inflation, all component price changes are treated equally; only the ranking of each component price change is relevant in determining the value of the median.

[12] Bryan, Cecchetti and Wiggins (1997) argue in favour of trimmed means on the grounds that CPI component price changes are random draws from a population that is not normally distributed. Hence, as an estimator of the economy wide inflation rate (the population mean), trimmed means will be more efficient – that is, have smaller variance – than the sample mean. However, the components of the CPI are fixed and priced throughout the quarter, and so are not usually regarded as being random draws.

3.3 Constructing a Statistical Measure of Core Inflation

Statistical measures of core inflation can be calculated using component price changes over any horizon. In this paper, they are all based on quarterly changes – the shortest horizon possible with Australian CPI data – as such series should provide more timely information on turning points in inflation. In addition, because the components excluded change each quarter, components that are subject to a large price shock need only be excluded for one period rather than several. This section outlines how the preferred trimmed mean might be chosen.

As discussed above, the high leptokurtosis of the distribution of price changes implies that there are many observations in the extremities of the tails which have a disproportionate influence on the mean. Indeed, as the degree of excess kurtosis increases – implying there are more price changes that are unrepresentative of the core rate – it may be desirable to remove a larger proportion of the tails of the distribution in calculating a trimmed mean measure of inflation. Particular attention must be given to the skew of the distribution when constructing a trimmed mean measure of inflation. If the distribution is, on average, positively skewed, observations in the right-hand tail will typically be further from the mean than the observations in the left-hand tail. Hence, if the trim is symmetric – that is the same proportion is removed from both tails – the trimmed mean will systematically record lower inflation than the sample mean. Conversely, for a negatively skewed distribution, a symmetric trimmed mean will record higher inflation than the sample mean.

Given the systematic positive skew of the distribution of CPI component price changes, there is likely to be a bias in the average inflation rate of a symmetric trimmed mean. This bias can be eliminated by removing a larger proportion of the trim from the tail opposite to the direction of the skew, i.e. from the left-hand tail. The larger is the average coefficient of skewness the larger is the proportion of the trim that must be taken from the left-hand tail to avoid average rate bias.

Since theory prescribes neither the optimal size of the trim, nor the extent to which it should be asymmetric, a benchmark is needed to compare the range of trimmed means. This paper examines how closely various trimmed means track a proxy for the trend, or persistent, component of inflation. The range of trimmed means can be compared using the mean absolute deviation (MAD) and root-mean-squared error

(RMSE) between the trimmed mean quarterly rate of inflation and the proxied trend series. The MAD penalises all deviations from the trend series equally, while the RMSE places a higher penalty on those deviations further from the trend.

Bryan, Cecchetti and Wiggins (1997) use a 36-month-centred moving average of the mean inflation rate as a proxy for the trend component of US CPI inflation. Higher import penetration, and the resultant dependence of the CPI on exchange rate movements, suggests that the Australian CPI is likely to demonstrate considerably less inertia than the US CPI, so that a shorter moving average may be more appropriate. Since the exact length of the moving average that best represents the trend component of inflation remains unknown, however, this paper uses several moving averages. Several Hodrick-Prescott filters of the quarterly mean inflation rate are also used to proxy the trend component of inflation. Hodrick-Prescott filters have the advantage that for relatively large smoothness parameters, they will be affected less by a one-off shock to the mean inflation rate.

3.4 Comparing Trimmed Means

Figure 3 presents a comparison of trimmed means against an initial benchmark. It plots the MADs for a range of trimmed means from a five-quarter-centred moving average of total CPI inflation. The side axis shows the size of the trim, ranging from 0 (the total CPI basket is retained) to 100 (a complete trim). In the latter case, the trimmed mean rate of inflation is the price change for the component that covers the given percentile. If that percentile is the 50th, the trimmed mean is the weighted median rate of inflation.[13] The front axis shows the proportion of the trim taken from the left-hand tail. Only the range from 40 to 60 per cent is shown because, outside this range, large trimmed mean rates of inflation differ markedly from the moving average rate of inflation. The vertical axis shows the inverted MAD for each of the trimmed means from the moving average. By the chosen criteria, the smaller the MAD for a given trimmed mean, the better that series performs as an indicator of core inflation. The MAD is reduced substantially by trimming even a small proportion from the tails, so providing a better measure of core inflation. While the incremental gain from increasing the size of the trim beyond around 50 per cent declines rapidly, it is nonetheless positive.

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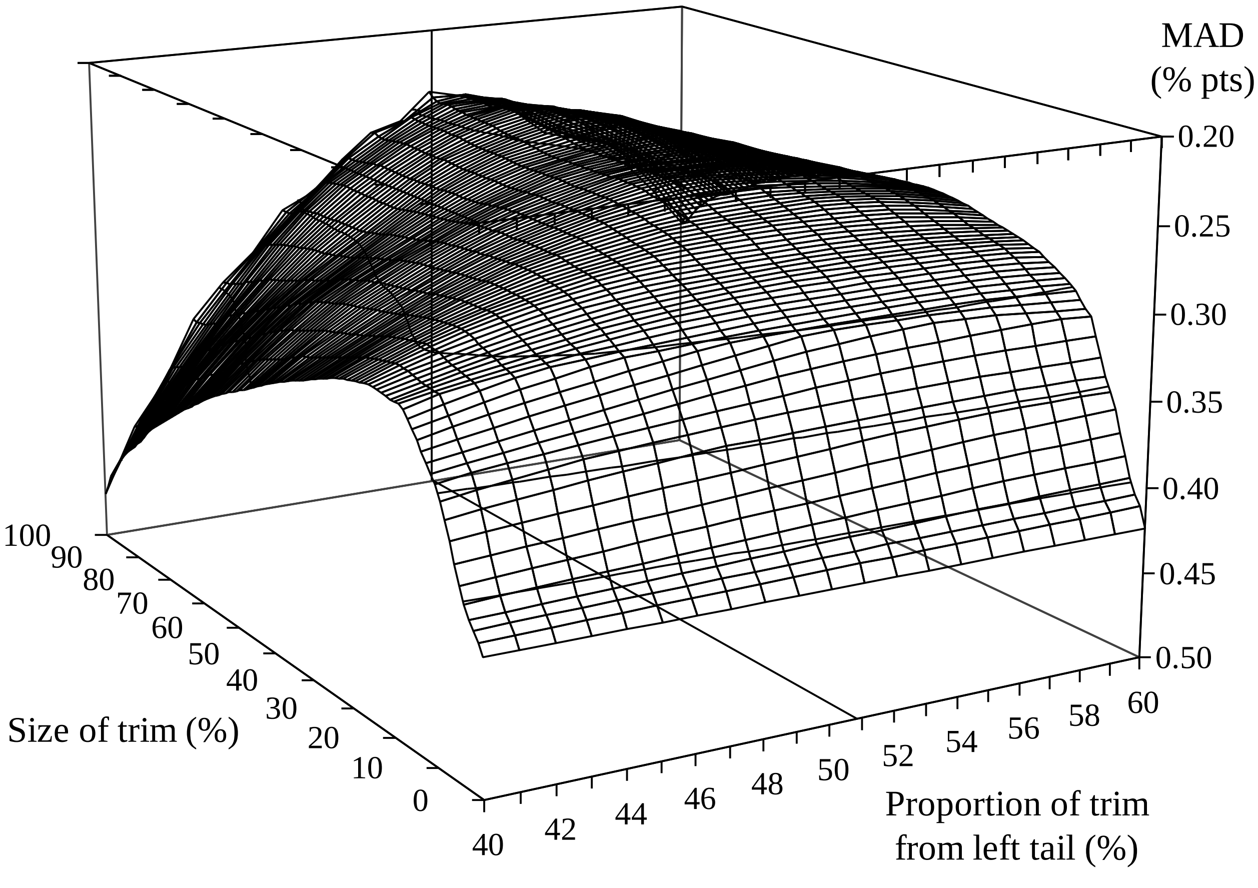
[13] Note, alternatively the median can be calculated as the weighted average of inflation rates from adjacent components in the distribution as demonstrated in Appendix C.

For a given size trim, the MAD is smallest when more of the trim is removed from the left- than the right-hand tail. The need to trim asymmetrically arises because the distribution of price changes is, on average, positively skewed. The smallest MAD from a five-quarter moving average of the CPI quarterly inflation rate occurs for a 100 per cent trim, with 51 per cent of the trim from the left-hand tail. This trimmed mean – the price change of the component at the 51st percentile of the distribution of price changes in each quarter – reduces the MAD relative to the mean rate of inflation by 43 per cent.

Figure 3: Determining the Optimal Trimmed Mean

MAD from a five-quarter moving average of inflation for a range of trimmed means with varying degrees of asymmetry

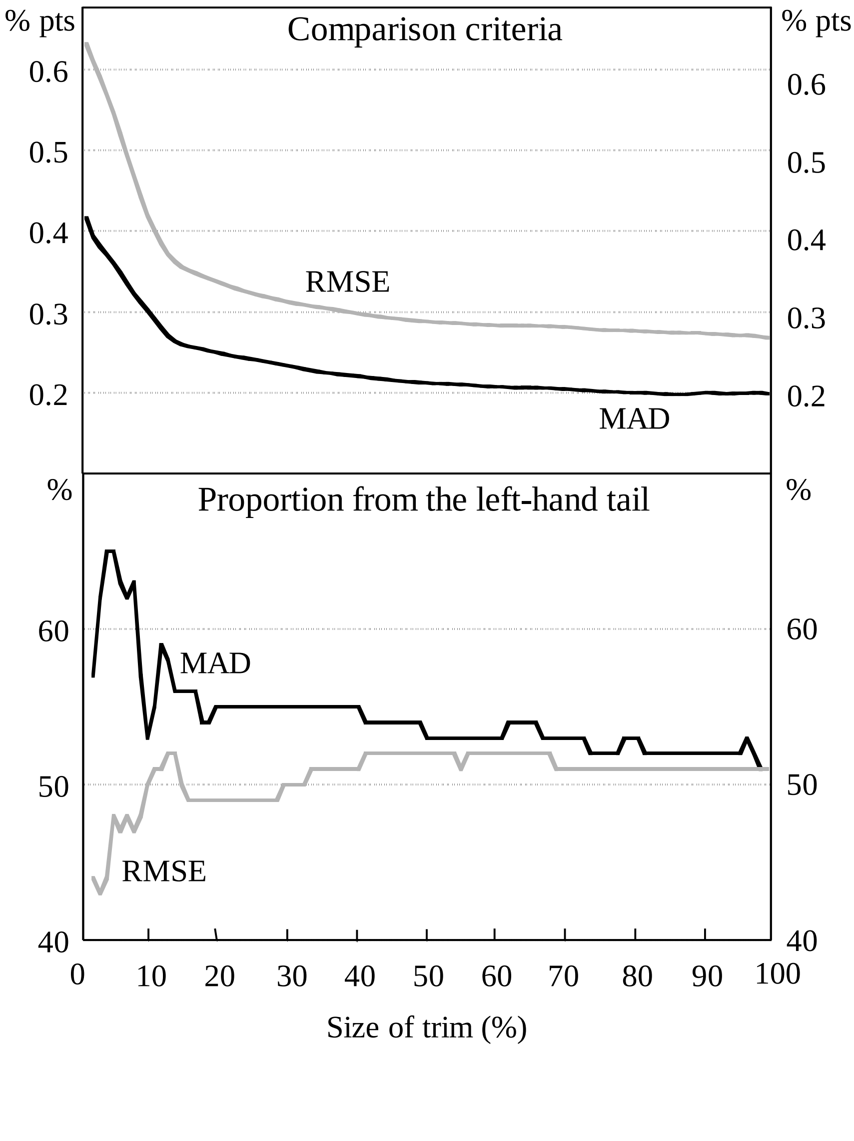


The RMSE from a five-quarter moving average declines even more sharply than the MAD for very small trims. Like the MAD, the RMSE falls monotonically as the proportion trimmed increases. The skew of the distribution again leads to the 51st percentile (a 100 per cent trim) being the preferred trimmed mean. The RMSE from the moving average rate of inflation for the 51st percentile rate of inflation is 48 per cent lower than for the mean rate of inflation.

The sensitivity of the result to the use of a five-quarter moving average of quarterly inflation can be tested using different lengths of moving averages. Both seven- and nine-quarter moving averages, using the MAD and RMSE, show that there are significant gains to removing even a small proportion from the tails of the distribution. The top panel of Figure 4 shows the smallest MAD and RMSE for each size trim from a seven-quarter moving average, while the lower panel shows the proportion taken from the left tail for each of those trimmed means.

Figure 4: Determining the Optimal Trimmed Mean

Minimum RMSE and MAD for various sizes of trimmed means and the associated degree of asymmetry



Again, after large decreases in the average deviation from the trend term for small trims, larger trims continue marginally to improve the measure of core inflation. Using the longer moving averages, the optimal trims are either 100 per cent or around 90 per cent. The seven- and nine-quarter moving averages derived trimmed means centred on the 51st and 52nd percentiles.

Because a centred moving average contains past values of inflation, its use to proxy trend inflation could possibly derive a trimmed mean that is not a timely indicator of turning points in inflation. To assess the nature of the trimmed means that provide the best indicators of turning points in inflation, a leading moving average can be used to compare the trimmed means. When the five-quarter moving average is shifted forward one or two quarters, the preferred trimmed mean based on both the MAD and RMSE is always large (again around 90 to 100 per cent) and typically centred on a percentile higher than the 50th. The finding that asymmetric trimmed means which remove a large proportion of the distribution perform best as estimators of core inflation therefore seems robust to the use of a leading moving average.

An alternative proxy to moving averages for the trend component of inflation is a Hodrick-Prescott filter of inflation.[14] Hodrick-Prescott filters have the advantage that the trend proxy will be influenced less by a one-off shock to the mean rate of inflation. Three smoothness parameters (l = 5, 50 and 200) are used that produce plausible proxies for the trend component of inflation.[15] Again the MAD and RMSE of the trimmed means against the Hodrick-Prescott filtered inflation series is used to compare the trimmed means. Once again, large trimmed means (typically close to 100 per cent, but occasionally around 80 per cent), centred on the 52nd and 53rd percentiles track the trend proxy most closely.

The size of the optimal trim, and its asymmetry, may also differ episodically as the dispersion and skew of the distribution change. In particular, the rate of inflation has been lower in the 1990s, while the distribution of price changes has also been less dispersed and less skewed, but slightly more leptokurtotic. Using the RMSE and MAD calculated only from September 1990 as the criteria for judging the optimal size of the trim, it is still found that a large trim, in the range of 90 per cent, is the

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[14] The Hodrick-Prescott filter is developed in Hodrick and Prescott (1997).

[15] The smaller l, the closer the filtered series tracks the actual series.

best representation of the trend component of inflation. Surprisingly, however, over the more recent period, the optimal trim is centred on a higher percentile – around the 54th percentile – than that based on the full sample.

3.5 Trimmed Means Based on Seasonally Adjusted Data

The trimmed means that performed best at capturing the trend in inflation in the previous section were all centred on a percentile higher than the 50th. This occurs because, as noted in Section 2.3, the distribution of component price changes is usually positively skewed. This skew is caused, in part, by the seasonal pattern of the price changes of some components, in particular the policy affected components. The need to centre trimmed means on a percentile higher than the 50th may be avoided by seasonally adjusting the component price changes.[16] Further, seasonally adjusting the price changes may reduce the extent to which the tails need to be trimmed.

Seasonal patterns tend to evolve over time. As a result, *ex post* seasonal adjustment is likely to produce a smoother series than seasonal adjustment conducted contemporaneously. To make a fair assessment of the benefits of using seasonally adjusted data, the seasonal factors for each of the CPI components were projected one year out each June, from 1990 onward.[17] Trimmed means calculated from seasonally adjusted price changes were then compared using the MAD and RMSE from a five-quarter moving average from September 1990 onward. Seasonal adjustment reduced both the size and the asymmetry of the trim that minimised the

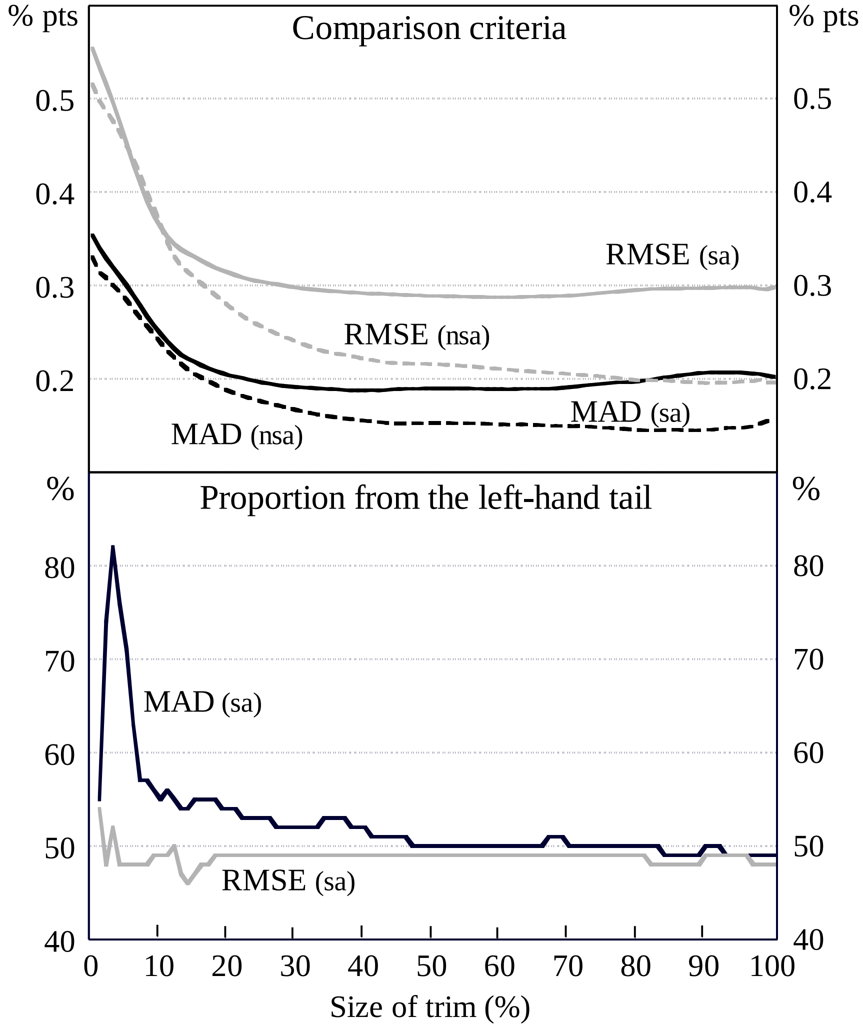
[16] Alternatively, the trimmed mean could be calculated on the basket excluding policy affected components, which is less skewed. However, since the price changes of these components often contain valuable information on inflation it is preferable to retain them in the basket.

[17] All seasonal adjustment was conducted using EZ-X11.

MAD and RMSE. As Figure 5 demonstrates, for nearly all size trims, however, the trimmed means calculated using original data outperform those based on seasonally adjusted data, particularly for those with the lowest RMSE and MAD.

Figure 5: Seasonally Adjusted Trimmed Means

Minimum RMSE and MAD for various sizes of trimmed means using seasonally adjusted and original CPI components along with the associated degree of asymmetry



3.6 Choosing the Statistical Core Inflation Series

Using a range of criteria it was shown above that trimmed means that remove a large portion of the tails significantly outperform the sample mean, and smaller size trimmed means, as measures of the trend component of inflation. This result was invariant to the use of a Hodrick-Prescott filter or a moving average to proxy trend inflation, the length of the moving average, whether it was centred or leading, and the time over which the comparison is made. After substantial gains from trimming the initial half of each tail of the distribution, the gains from removing a larger proportion are small. The RMSE and MAD for the 50 per cent trim are no more than 10 per cent greater, about 0.02 percentage points, than the minimum RMSE and MAD trims. However, for most of the criteria used, the 100 per cent trimmed mean outperforms other size trims. The 100 per cent trim is also more intuitive in that it treats all price changes in the same manner.

Because the shape of the distribution may change periodically, any one trimmed mean may not always be the best representation of core inflation. This section develops two trimmed means, the 100 per cent trimmed mean, which is the optimal trimmed mean against many of the criteria used, and the 50 per cent trimmed mean. To increase the acceptance and usefulness of the trimmed means, it is desirable that the average rates of inflation measured by these core series and the full CPI basket are the same.

As Figure 6 demonstrates, the greater the size of the trim, the larger the bias in the average rate of inflation of a symmetric trim relative to the sample mean. As the size of the trim increases, it must be centred on a higher percentile to avoid the bias in the average rate of inflation. The average rates for the 50 per cent and 100 per cent trimmed means, centred on various percentiles, are shown in Table 3. The 50 per cent trimmed mean centred on the 52^{nd} percentile records the same average rate of inflation as the sample mean over the full sample period and the 1990s. The 100 per cent trimmed mean must be centred slightly higher, on the 53^{rd} percentile, to record average inflation equal to the sample mean over the full sample. The MAD and RMSE for the 100 per cent trimmed mean, from a five-quarter moving average, are 43 and 48 per cent lower than for the sample mean; for the 50 per cent trim, they are 41 and 45 per cent lower.

Figure 6: Quarterly Inflation Rates

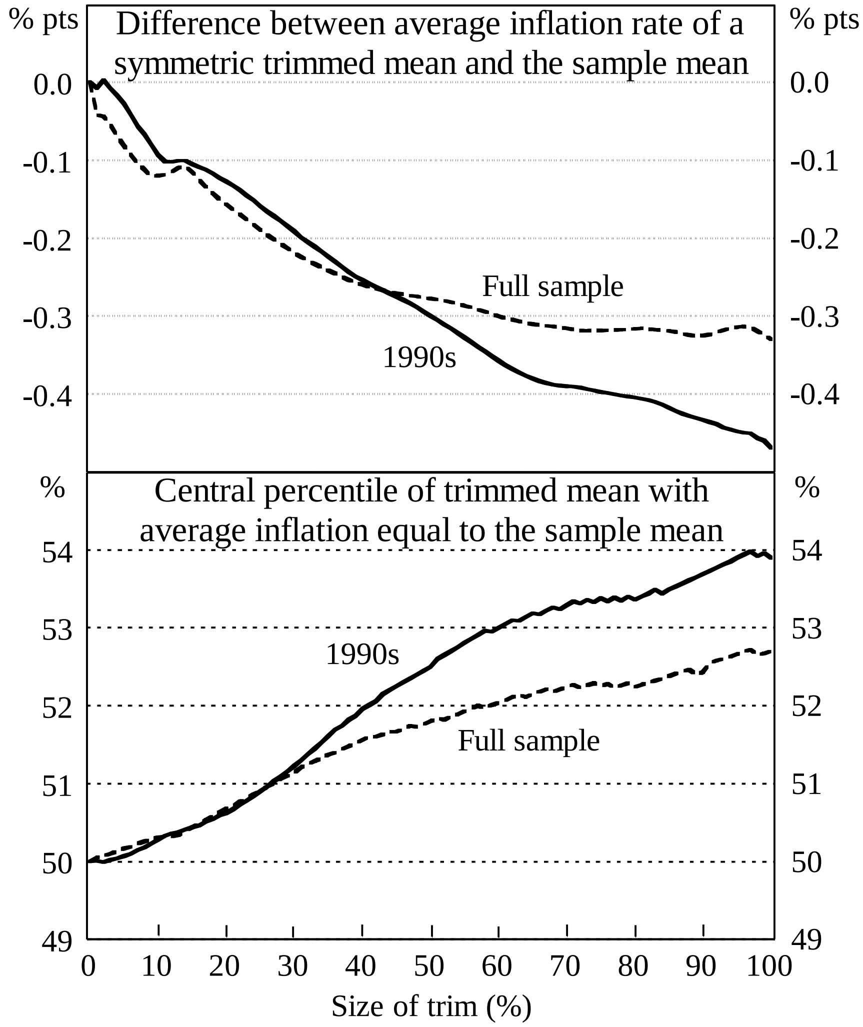


Table 3: Average Annual Rates of Inflation

Per cent

	Mean	Central percentile					
		50th	51st	52nd	53rd	54th	55th
50 per cent trimmed mean							
Sep 1980 to Mar 1998	5.5	5.2	5.4	5.5	5.7	5.8	6.0
Sep 1990 to Mar 1998	2.8	2.5	2.6	2.8	2.9	3.0	3.1
100 per cent trimmed mean							
Sep 1980 to Mar 1998	5.5	5.2	5.3	5.4	5.5	5.6	5.8
Sep 1990 to Mar 1998	2.8	2.4	2.5	2.6	2.7	2.8	3.0

While the average rate of inflation of trimmed means centred on various percentiles differs, trimmed means of the same size centred close to each other exhibit virtually identical quarterly movements. Thus, while the ideal percentile on which to centre a trimmed mean may vary marginally over time, all trimmed means of the same size centred within an appropriate region identify identical turning points.

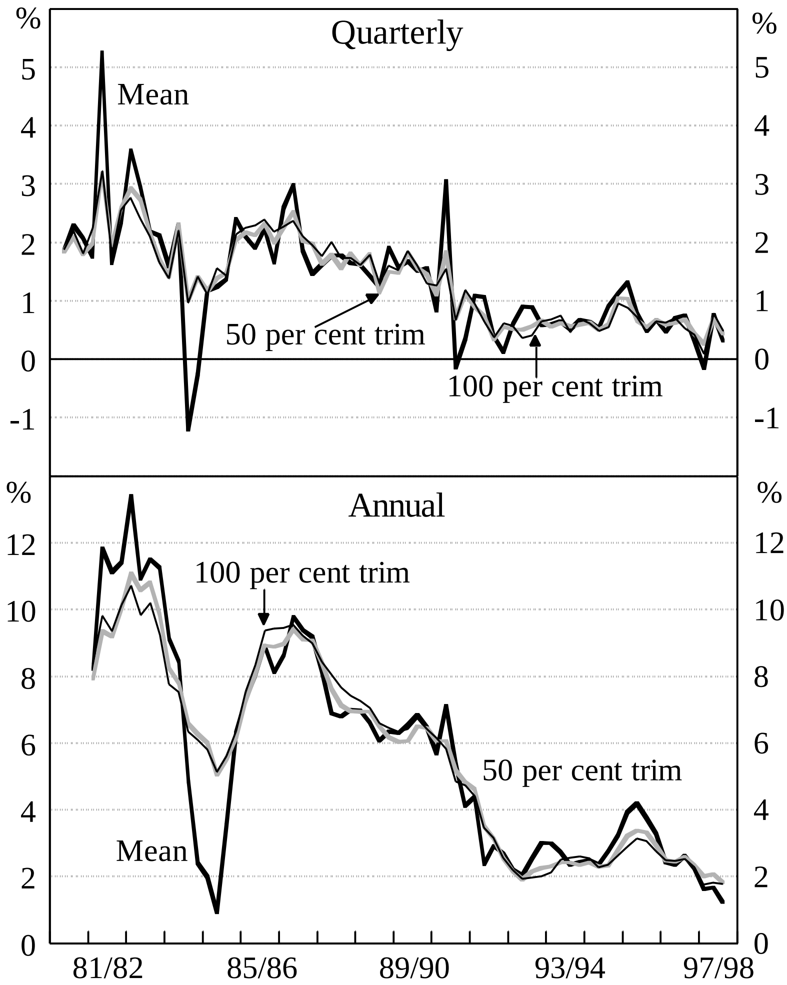
4. Behaviour of the Statistical Core Inflation Series

Figure 7 demonstrates that the statistical measures of core inflation perform well in capturing the trend in quarterly rates of inflation. In most quarters, the core series record similar rates of inflation to the mean. Importantly, however, they differ when there are extreme price changes that have a large effect on the mean rate of inflation. In the early 1980s, the core CPI series did not reflect the enormous changes in medical costs. The mean CPI rose due to increases in prices of imported goods and health and optical services in late 1986 while the core series recorded more moderate price growth. Again in 1990/91, the core series had smoother paths than the mean inflation rate as they were not affected by the large petrol price shocks. While the statistical core inflation series abstract from extreme price changes, they do exhibit cyclical patterns consistent with demand conditions. The core rate of inflation declined in the early 1980s recession and then recorded a subsequent increase in price pressure. Over the remainder of the decade, the core inflation series recorded gradually easing price pressure culminating in the low, stable rates of the 1990s.

The manner in which the core series abstract from unrepresentative price shocks is clearly demonstrated in two episodes in the 1990s. In December 1992 and March 1993, and then again in the June and September quarters of 1995 the quarterly rate of inflation measured by the CPI jumped. However, on both these occasions there were large contributions from policy-induced price changes (cigarettes and tobacco, health and pharmaceuticals) and transitory movements of exchange-rate influenced or inherently volatile prices (cars, and fresh fruit and vegetables). By abstracting from these large volatile contributions, the core series provides a better indication of demand induced inflation.

Figure 7: Mean and Trimmed Mean Inflation

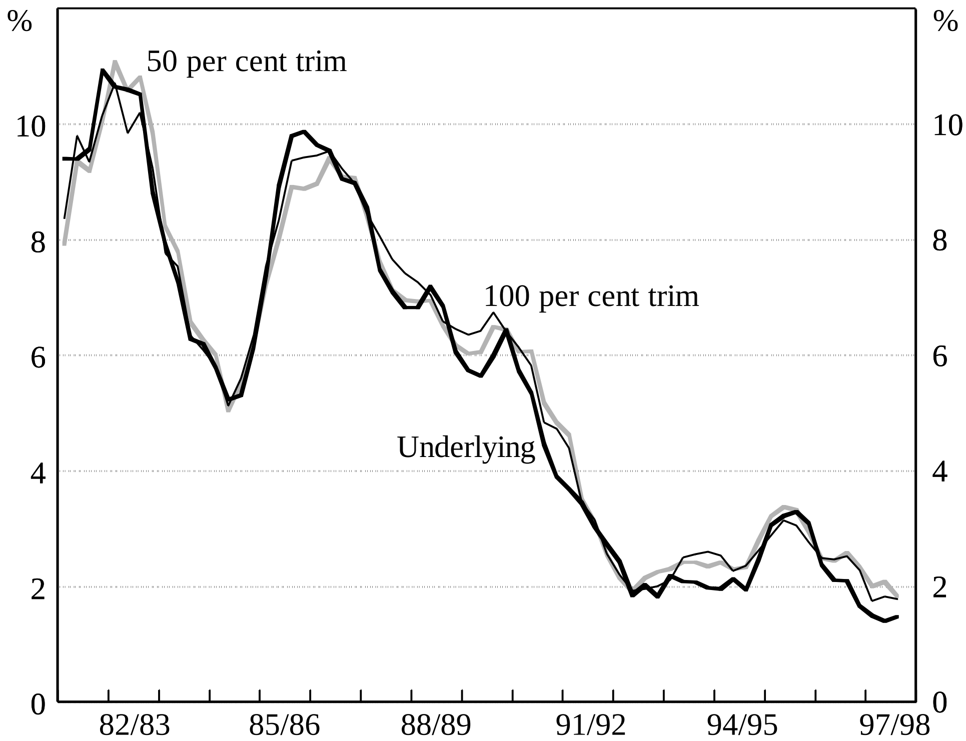
Percentage change



As demonstrated in Figure 8, the core series behave similarly to the Treasury underlying rate of inflation, a series that has been widely used as a measure of core inflation. However, while the cyclical movements have been similar, over the later part of the sample, the core series often lie above the underlying inflation rate. The higher average rate of inflation recorded by the core series largely reflects the faster growth in the prices of policy-affected components, which are permanently excluded from the Treasury underlying CPI, over the 1990s. The higher inflation rate of the non-market components has resulted from an increased emphasis on user-pays principles of pricing. Like the underlying series, the core inflation rate captured the demand induced rise in inflation in 1995/96. Since then the core inflation series has not slowed as markedly as the underlying series. The appreciation of the $A and the subsequent fall in import prices contributed to the decline in the underlying rate of inflation. The core series largely abstracts from these currency induced extreme price movements, and so has recorded slightly higher inflation over the past year and a half.

Figure 8: Measures of Inflation

Annual rate



5. Conclusion

An understanding of the distribution of price changes is useful in establishing how the inflation process operates, and the implications for the measurement of inflation. This paper found that consumer price changes are widely dispersed and not normally distributed; the distribution typically has a longer right-hand than left-hand tail (it is positively skewed) and always has fat tails (leptokurtosis).

The extreme price changes in the tails of the distribution are usually considered to be unrepresentative of the persistent component of inflation caused by the interaction of aggregate demand and supply. These extreme price changes have a disproportionate impact on the mean rate of inflation, so that the mean is not always a good indicator of persistent inflation. Consequently, measures of core inflation which abstract from unrepresentative price changes are useful to policy-makers.

This paper examined the value of trimmed means for measuring core inflation, and concluded that they are useful for this purpose. There are significant gains from trimming even a small proportion of the tails of the distribution. The benefits typically rise as the size of the trim increases. The great majority of the improvements from trimming have been obtained once half of each tail is removed, that is, a 50 per cent trim. In almost all of the trials conducted, the advantages of trimming continue up to the 100 per cent trim. The 100 per cent trim may, therefore, be considered the best trimmed mean measure of inflation.

It was also found that because the distribution of CPI component price changes is systematically positively skewed, trimmed means should be centred on a percentile higher than the 50th. This ensures that they record the same average rate of inflation as the entire sample. In fact, the larger the size of the trim, the higher the percentile on which the trimmed mean must be centred. These findings highlight that an understanding of the distribution of price changes in the CPI is valuable in deciding on a core inflation measure.

Appendix A: Derivation of the Weights

The data used in this paper cover the 9th through 12th CPI series. The CPI is based in the 11th series at 1989/90 = 100. New weights were introduced, for each of the new series, on March 1982, December 1986 and June 1992. These dates will be denoted k_1, k_2 and k_3. Each series is spliced to the base period. The level of the CPI at time t is:

$$P_t = \sum_{i=1}^{n} w_i^j P_{it} S_j \tag{A1}$$

for

$$\begin{array}{rl} t < k_1 & j = 1 \\ k_1 \le t < k_2 & j = 2 \\ k_2 \le t < k_3 & j = 3 \\ k_3 \le t & j = 4 \end{array}$$

where P_{it} is index level for the ith component at time t, w_i^j is the weight for the ith component in the jth series, and the splicing factors are:

$$\begin{aligned} S_1 &= \frac{\sum_{i=1}^{n} w_i^2 P_{ik_1}}{\sum_{i=1}^{n} w_i^1 P_{ik_1}} \bullet \frac{\sum_{i=1}^{n} w_i^3 P_{ik_2}}{\sum_{i=1}^{n} w_i^2 P_{ik_2}} \\ S_2 &= \frac{\sum_{i=1}^{n} w_i^3 P_{ik_2}}{\sum_{i=1}^{n} w_i^2 P_{ik_2}} \\ S_3 &= 1, \\ S_4 &= \frac{\sum_{i=1}^{n} w_i^3 P_{ik_3}}{\sum_{i=1}^{n} w_i^4 P_{ik_3}} \end{aligned} \tag{A2}$$

Temporarily omitting the splicing factors

$$\begin{aligned} P_t &= \sum_{i=1}^{n} w_i P_{it} \\ &= \sum_{i=1}^{n} w_i (1+p_{it}) P_{it-1} \end{aligned} \tag{A3}$$

where

$$p_{it} = P_{it} / P_{it-1} - 1$$

Manipulating Equation (A1) in the same manner as Equation (A3), the aggregate quarterly inflation rate can be derived as a weighted sum of the quarterly component inflation rates:

$$p_t = \sum_{i=1}^{n} w_{it} p_{it} \tag{A4}$$

where

$$w_{it} = \frac{w_i^j P_{it-1}}{P_{t-1}} S_j \tag{A5}$$

for

$$\begin{array}{rl} t \le k_1 & j = 1 \\ k_1 < t \le k_2 & j = 2 \\ k_2 < t \le k_3 & j = 3 \\ k_3 < t & j = 4 \end{array}$$

Appendix B: Component Frequency in the Distribution Tails

Table B1 lists the components of the Australian CPI and the number of quarters each is further than one, one-and-a-half, and two standard deviations from the mean rate of inflation in the left- and right-hand tails of the distribution.

Table B1: Number of Quarters Each Component is in the Distribution Tails

	Outside one standard deviation[(a)]		Outside one-and-a-half standard deviations[(a)]		Outside two standard deviations[(a)]	
	Left	Right	Left	Right	Left	Right
Food						
Milk and cream	1	1	1	0	0	0
Cheese	8	7	5	3	2	0
Butter	11	8	4	5	3	1
Other dairy products	4	9	0	4	0	1
Bread	2	6	0	2	0	1
Cakes and biscuits	1	2	0	2	0	1
Breakfast cereals	3	4	1	2	1	1
Other cereal products	6	6	0	1	0	0
Beef and veal	8	4	1	1	0	1
Lamb and mutton	22	17	17	10	15	8
Pork	6	3	2	2	0	0
Poultry	17	8	9	3	3	2
Bacon and ham	11	5	3	1	2	0
Processed meat	4	1	2	0	1	0
Fish	9	11	3	9	1	6
Fresh fruit	28	27	22	19	15	15
Fresh potatoes	28	29	25	27	23	26
Other fresh vegetables	29	32	27	31	22	30
Processed fruit	8	4	1	0	0	0
Fruit juice	0	1	0	0	0	0
Processed vegetables	2	6	0	1	0	0
Soft drinks and cordials	1	1	0	0	0	0
Ice cream and ice confectionary	2	8	1	3	0	2
Confectionery	0	2	0	0	0	0
Meals out	0	0	0	0	0	0
Take away foods	1	0	1	0	0	0
Eggs	6	11	2	5	1	3
Sugar	9	12	5	7	3	4
Jams, honey and sandwich spreads	5	4	1	1	1	1
Tea, coffee and food drinks	9	11	5	6	1	5
Food additives, sauces and spices	3	5	0	0	0	0
Margarine	17	13	13	7	5	6
Cooking oils and fats	13	5	7	3	3	3
Other food	2	1	1	0	0	0

Table B1: Number of Quarters Each Component is in the Distribution Tails

(*continued*)

	Outside one standard deviation[(a)]		Outside one-and-a-half standard deviations[(a)]		Outside two standard deviations[(a)]	
	Left	Right	Left	Right	Left	Right
Clothing						
Men's outer clothing	5	2	2	0	1	0
Men's knitwear	4	8	0	6	0	4
Men's shirts	4	2	1	0	1	0
Men's underwear, nightwear and socks	3	1	1	0	1	0
Boy's clothing	9	5	3	4	2	2
Women's outer clothing	3	4	0	2	0	0
Women's knitwear	4	9	0	6	0	4
Women's underwear, nightwear and hosiery	1	1	0	1	0	0
Girl's clothing	2	2	0	0	0	0
Fabrics and knitting wool	5	1	2	0	0	0
Men's footwear	9	2	4	0	2	0
Women's footwear	7	7	2	2	0	1
Children's footwear	12	4	6	2	4	2
Dry cleaning and shoe repairs	1	1	1	0	0	0
Household Equipment and Operation						
Electricity	1	8	1	5	0	2
Gas	1	6	0	1	0	0
Other fuels	4	5	2	1	1	1
Furniture	5	3	1	1	0	0
Floor coverings	0	2	0	1	0	0
Appliances	1	0	0	0	0	0
Bedding	5	6	1	2	1	0
Towels, linen and curtains	1	1	0	1	0	0
Tableware, glassware and cutlery	14	3	8	0	4	0
Kitchen and cooking utensils	9	5	2	1	1	1
Cleaning utensils	6	9	3	4	2	1
Tools	3	3	1	1	0	0
Household cleaning agents	4	2	1	2	0	1
Household paper products	6	8	3	5	0	2
Other household non-durables	6	5	2	1	1	0
Stationery	7	9	4	7	3	4
Watches and clocks**	14	10	7	9	3	5
Veterinary services**	4	2	0	1	0	0
Pet foods	4	8	1	2	1	1
Travel goods	11	6	6	3	3	3
House contents insurance*	4	4	1	0	0	0
Repairs to appliances	1	4	1	3	0	1
Postal services	2	6	0	4	0	3
Telephone services	3	3	0	3	0	2

Table B1: Number of Quarters Each Component is in the Distribution Tails

(*continued*)

	Outside one standard deviation[(a)]		Outside one-and-a-half standard deviations[(a)]		Outside two standard deviations[(a)]	
	Left	Right	Left	Right	Left	Right
Housing						
Privately-owned dwelling rents	0	0	0	0	0	0
Government-owned dwelling rents	2	5	0	4	0	3
Local government rates and charges	4	13	2	4	2	0
House repairs and maintenance	0	0	0	0	0	0
House insurance	2	8	0	4	0	3
Transportation						
Motor vehicles	5	2	4	0	1	0
Automotive fuel	20	18	11	12	6	6
Vehicle insurance	2	11	1	8	1	5
Motoring charges	2	9	1	3	1	0
Tyres and tubes	2	0	0	0	0	0
Vehicle servicing, repairs and parts	0	1	0	1	0	0
Urban transport fares	0	8	0	6	0	2
Alcohol and Tobacco						
Beer	1	0	0	0	0	0
Wine	1	2	1	0	0	0
Spirits	0	0	0	0	0	0
Cigarettes and tobacco	0	14	0	7	0	7
Health and Personal Care						
Hospital and medical services	5	19	4	9	4	6
Optical services**	6	3	1	1	0	0
Dental services	0	0	0	0	0	0
Pharmaceuticals	22	16	17	16	15	14
Toiletries and personal products	1	1	1	1	0	0
Hairdressing services	0	1	0	0	0	0
Recreation and Education						
Books, newspapers and magazines	0	3	0	0	0	0
Video and sound equipment	25	0	10	0	4	0
Records, cassettes and tapes	11	4	5	2	3	1
Sports and photographic equipment and toys	6	2	2	0	2	0
Holiday travel and accommodation in Australia*	10	14	7	10	6	6
Holiday travel and accommodation overseas*	20	17	13	11	9	9
Photographic services	5	3	1	1	1	1
Repairs to recreational goods	1	2	0	1	0	0
Entertainment	1	4	0	0	0	0
Education fees*	3	15	0	13	0	12
Child care fees*	3	10	3	5	3	2

Notes: (a) Number of quarters each component is more than 1, 1.5 or 2 standard deviations from the mean out of 70 quarters, apart from those marked with * or ** which are in the sample for 65 and 46 quarters.

Appendix C: Example of the Calculation of Trimmed Means

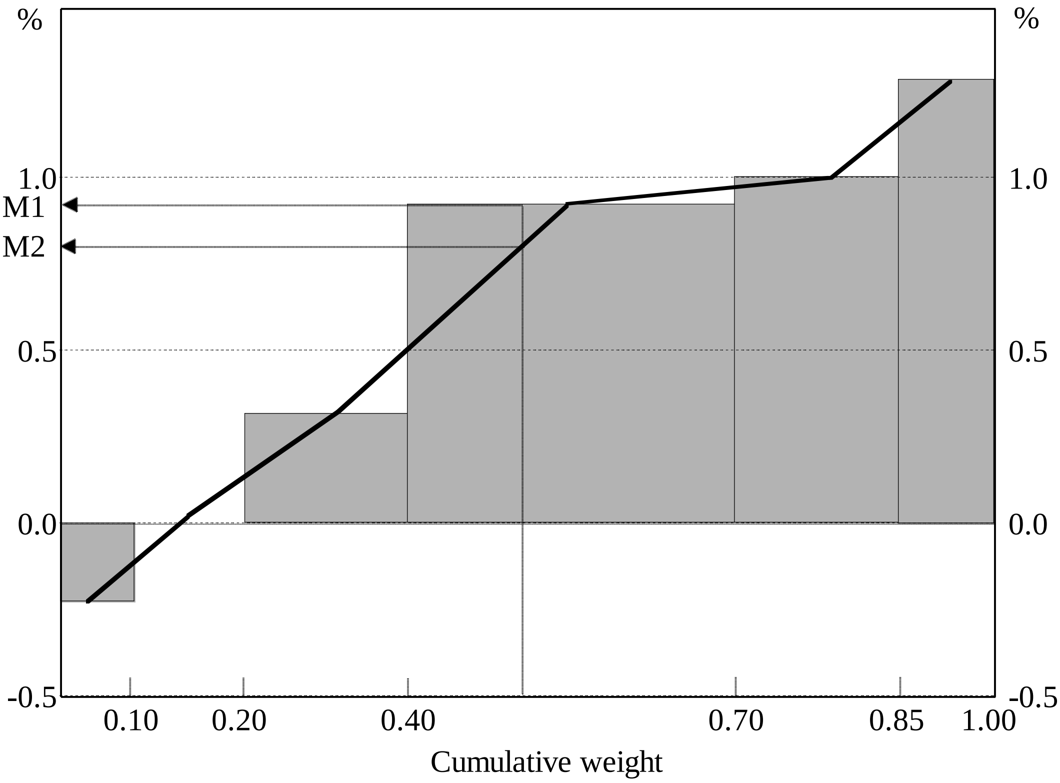
This appendix briefly describes the calculation of trimmed means, and in particular the 100 per cent trimmed mean, and gives a simple example of their construction in Table C2 using data in Table C1. All series use the time-varying weights as defined in Appendix A.

The *X* per cent *trimmed mean* removes *X* per cent of the components of the CPI basket whose price changes lie in the tails of the cross-sectional distribution of price changes. For example, the symmetric 50 per cent trimmed mean removes both the 25 per cent of the basket with the largest and smallest price changes. An asymmetric trimmed mean will remove a different proportion from the left- and right-hand tails. A component that lies partially in the tail removed, has its weight reduced proportionately. The weights of the remaining components are then scaled to sum to unity, with the trimmed mean calculated as the sum of the products of the component inflation rates and scaled weights.

The *median*, or 100 per cent trim, in this paper, as in Shiratsuka (1997) is calculated as the price change of the component covering the 50th percentile. If the 100 per cent trim is asymmetric, it is the price change of the component covering the percentile on which the trimmed mean is centred. For example, if 53 per cent of a 100 per cent trim is taken from the left tail, it will be the price change of the component covering the 53rd percentile.

Alternatively, the median can be calculated as a weighted average of the component covering the 50th percentile and the adjacent component as in Laflèche (1997). This method seeks to make the discrete distribution of price changes continuous. Laflèche (1997) joins the components through the upper percentile of each component. Since the price change for each CPI component is the average price change for all goods and services in that component, the distribution should be joined through the middle percentile of each component, as in Figure C1. This method can also be applied to asymmetric 100 per cent trimmed means or smaller trimmed means. The price change of a given component is used as the 100 per cent trimmed mean in this paper, as it is less complex and so more intuitive. Because the CPI data used in this study are highly disaggregated, and price changes are tightly clumped at the centre of the distribution, the two methods of calculating the median produce almost identical results. From December 1980 to March 1998, the MAD between the medians based on the alternative definitions is 0.0001 of a percentage point.

Figure C1: Distribution of Price Changes



Note: M1 is the median as calculated in this paper, M2 is the alternative definition of the median.

Table C1: Example Distribution of Price Changes

Component	A	B	C	D	E	F
Price change (per cent)	-1.00	0.00	0.30	0.80	0.90	2.00
Time-varying weight	0.10	0.15	0.20	0.25	0.15	0.15
Cumulative weight	0.10	0.25	0.45	0.70	0.85	1.00
Weight for 50 per cent trim	0.00	0.00	0.40	0.50	0.10	0.00

Table C2: Calculation of Measures of Inflation

Measure	Calculation	Result
Mean	$(0.1\times-1)+(0.15\times0)+(0.2\times0.3)+(0.25\times0.8)+(0.15\times0.9)+(0.15\times2)$	0.60
50 per cent trimmed mean	$(0.4\times0.3)+(0.5\times0.8)+(0.1\times0.9)$	0.61
Median – used in this paper	price change of component D	0.80
Median – alternative definition	$0.45+(0.8-0.3)\times(0.50-0.45)/(0.70-0.45)$	0.63

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