Core Inflation: A Review of Some Conceptual Issues

Mark A. Wynne

Research Department
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2200 North Pearl Street

Dallas TX 75201

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Abstract: This paper reviews various approaches to the measurement of core inflation that have been proposed in recent years. The objective is to determine whether the ECB should pay special attention to one or other of these measures in assessing inflation developments in the euro area. I put particular emphasis on the conceptual and practical problems that arise in the measurement of core inflation, and propose some criteria that could be used by the ECB to choose a core inflation measure.

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1. INTRODUCTION.

The notion of core inflation has played an important role in the deliberations of monetary policymakers for the past twenty-five years. However, despite the central role of this concept, there is still no consensus on how best to go about measuring core inflation. The most elementary approach, and the one that is probably the most widely used, consists of simply excluding certain categories of prices from the overall inflation rate. This is the so-called "Ex. food and energy" approach to core inflation measurement, and it reflects the origin of the concept of core inflation in the turbulent decade of the 1970's. More recently, however, there have been a variety of attempts to put the measurement of core inflation on a more solid footing. The newer approaches have two key features in common. First, they adopt a more statistical rather than behavioural approach to the problem of price measurement. And second, they invoke an alternative, monetary, concept of inflation, as opposed to the traditional microeconomic cost of living concept, as the guiding theory.

This paper critically reviews various approaches to measuring core inflation. I do so by linking these approaches in a single theoretical framework, the so-called stochastic approach to index numbers. I evaluate the competing merits of the different approaches, and argue that a common shortcoming is the absence of a well-formulated theory of what these measures of inflation are supposed to be capturing. The notion that they somehow better capture the "monetary" component of inflation, or the component of inflation that ought to be of primary concern to central bankers, is of questionable validity.

2. THE CONCEPT OF CORE INFLATION

Implicit in all discussions of core inflation is the idea that this type of inflation is fundamentally different to changes in the cost of living. The theory of the cost of living index is by far the most well developed and coherent framework for inflation measurement that currently exists. The basic theory takes as its point of departure the expenditure or cost function of a representative household at a given point in time. The change in the cost of living between some base period, *0*, and some subsequent comparison period, *1*, is then defined as the change in the minimum cost of attaining the reference utility level u between the two periods. This theory, appropriately elaborated, forms the framework for the design of the Consumer Price Index in the United States. However, the theory of the cost of living index is not the theoretical framework for the Harmonised Index of Consumer Prices (HICP) that is used to assess inflation developments in the euro area: at the time of writing there is no fully articulated theoretical framework for the HICPs, although there is a relatively well-defined price concept, namely "final household monetary consumption." By eschewing the use of the cost of living concept, Eurostat can legitimately motivate the exclusion of certain categories of prices from the HICP. The category that has attracted the most attention by it omission is the costs of owner occupied housing.

One measure of core inflation that is often constructed is one that seeks to exclude the effects of changes in indirect taxes from the overall inflation rate. Donkers et. al. (1983-4) discuss how this is done in a number of European countries. This is potentially of interest from a monetary policy perspective, as arguably an acceleration in headline inflation that is in some sense attributable to an increase in indirect taxes ought not to be of concern to the central bank. Current practice, as reviewed by Donkers et al, is to employ various ad hoc methods to derive an estimate of the inflation rate net of indirect taxes. The exact methods employed differ from country to country. One approach is to simply assume that all of the observed price change reflects the change in the tax and calculate an alternative CPI on the basis of this assumption.[1] The problem with this approach is that the implicit assumption about supply elasticities (perfectly elastic) is unlikely to be a good approximation to reality for many products. A more sophisticated approach might allow for the effects of a change in indirect tax rates on the structure of production prices, but the variant analysed by Diewert and Bossons (1987) still requires restrictive assumptions about the invariance of the input-output structure of the economy to changes in indirect tax rates.

These calculations raise the question of what it is we want a core inflation statistic to measure. If the object we are pursuing is a true cost of living index, then it is not clear that we should be eliminating the effects of tax increases from our price measure. Furthermore, the reasoning above is only partial equilibrium. A proper treatment of the effects of indirect taxes on a measure of the price level would require a detailed general equilibrium analysis of the effects of the tax increase that would go well beyond current practice.[2] Diewert and Fox (1998) suggest a method for handling tax changes for the purposes of using inflation measures to make welfare comparisons.[3] Note also that in principle the distortionary effect of large infrequent changes in

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[1] For details see, for example, Diewert and Bossons (1987).

[2] Diewert (1997) notes that "...there is no unambiguous, completely accurate method for removing all indirect commodity taxes...any attempt to do this will be a complex exercise in applied general-equilibrium modelling rather than in economic measurement. Moreover, the fact that the government has caused consumer prices to increase rather than some other economic phenomenon seems somewhat immaterial: In either case, households are facing higher prices, and we may want to measure this fact!"(Diewert, 1997, 134)

[3] See also Diewert and Bossons (1987).

indirect taxes on the inflation signal may be adequately handled by some or all of the approaches reviewed below. Indirect tax changes that apply to some commodities but not others would be reflected in large price changes for the commodities in question. Limited influence estimators of core inflation of the sort proposed by Bryan and Pike (1991) and Bryan and Cecchetti (1994) would omit these observations from the calculation of inflation. However large changes in relative prices induced by changes in indirect taxes are arguably different from large changes due to other possibly more difficult to identify factors, since the indirect tax rates are (presumably) directly observable and therefore it ought in principle be easier to filter out their effects on the overall inflation rate.

The common point of departure for almost all analyses of core inflation is the idea that there is a well-defined concept of monetary inflation that ought to be of concern to monetary policy makers and that this type of inflation, being conceptually different to the cost of living, is not adequately captured by the standard price statistics.[4] Thus it is argued that central banks ought to target a price index whose rate of increase corresponds to the inflation that generates the costs that central banks are seeking to avoid by focusing on an inflation-control objective. Inflation is costly to society because it disrupts the co-ordination of economic activity and discourages the use of fiat money in market transactions. While it is possible that some of the costs of inflation are captured by changes in the cost of living, some of them may require a much broader measure of market transactions. One conclusion from this line of reasoning is that for the purposes of monetary policy what is needed is not a microeconomic theory of the cost of living, but a macroeconomic theory of the cost of inflation. Thus we can interpret various measures of core inflation as attempts to better measure this more appropriate measure of inflation for monetary policy purposes.

But just how much guidance does the concept of monetary inflation provide when it comes to measurement? Consider a very standard money market equilibrium condition:

$$\frac{M^S}{P} = L(Y, R)$$

where the notation is the usual. What is the effect of a supply shock (e.g. a hike in oil prices or tax rates) on the price level?[5] An adverse supply shock that lowers the level of output would, under

[4] See, for example, Howitt (1997).
[5] Bryan and Cecchetti (1994) argue “During periods of poor weather, for example, food prices may rise to reflect decreased supply, thereby producing transitory increases in the aggregate index. Because these price changes do not

standard assumptions about the nature of the demand for money, also lower the demand for real balances. Absent any action on the part of the central bank to alter the stock of money outstanding, M^S, the price level must rise to clear the market for real balances. Is this increase in the price level "monetary" inflation or not? It does not constitute monetary inflation in the sense that its proximate cause is something other than an action on the part of the central bank. It does constitute monetary inflation to the extent that, in principle, an appropriate response on the part of the central bank (cut the stock of base money to match the decline in the demand for base money) could have prevented it from occurring. More generally, the inflation rate is determined by the rate of growth of the stock of money relative to the demand for it. The inflation rate is not uniquely determined by the monetary authorities but by the monetary authorities and the private sector jointly.

3. THE BASIC FRAMEWORK

The approach to price measurement that has (implicitly or explicitly) formed the basis of many recent attempts to improve upon existing core inflation measures is the stochastic approach to index numbers. In the academic literature this approach is exemplified by the papers by Clements and Izan (1981, 1987) as well as a book by Selvanathan and Prasada Rao (1994). The research of Bryan and Pike (1991), Bryan and Cecchetti (1993, 1994) and Cecchetti (1997) has brought this approach to inflation measurement to the attention of monetary policy makers in the United States, while the work of Quah and Vahey (1995), Blix (1995) and Fase and Folkertsma (1996) indicates that this alternative way of thinking about inflation is also influential among the NCBs in the EU. Diewert (1995) provides a critique of this literature from the perspective of the traditional economic approach to price measurement, and some additional discussion is to be found in Wynne (1997).

The point of departure for all attempts to measure core inflation is the observation that the changes in the prices of individual goods and services between two periods contain a common component that constitutes core inflation and an idiosyncratic component that primarily reflects developments in local markets. The problem of core inflation measurement is then to isolate these two components of observed price changes. This idea is formalised by writing

constitute underlying monetary inflation, the monetary authorities should avoid basing their decisions on them."(Bryan and Cecchetti, 1994, 195).

$$\pi_{i,t} = \Pi_t + x_{i,t}$$

This expression defines the rate of change of the price of an individual commodity, $\pi_{i,t} = \ln(p_{i,t}) - \ln(p_{i,t-1})$, as consisting of an aggregate inflation component, $\Pi_t \equiv \ln(P_t) - \ln(P_{t-1})$ and a relative price change component, $x_{i,t}$. The object we are interested in is P_t - the common component of all prices and what we might interpret as the purchasing power of money. Different approaches to the measurement of core inflation can be characterised by how they go about achieving identification.

Table 1 presents a simple schema of how many of the approaches fit together. The presumption in all of these approaches is that the "headline" rate, which is some weighted average of the individual price changes, $\sum_{i=1}^{N} w_{i,t}\pi_{i,t}$, with weights chosen on the basis of expenditure shares, is a poor or second best approximation to Π_t. What differentiates the various approaches to core inflation measurement is the information that is used to arrive at the core measure. One approach is to simply re-combine the price changes of individual goods and services at each point in time to derive a core measure. This is the "Ex. food and energy" approach, and also the essence of the limited influence measures (such as the trimmed mean and weighted median) advocated by Bryan and Cecchetti. Alternatively, we might choose to ignore the information in the cross-section distribution of individual price changes and instead derive a measure of core inflation by smoothing current and previous headline inflation rates. Thus some have advocated constructing a measure of core inflation by taking a moving average of past inflation rates, or applying a Hodrick-Prescott filter to headline rates. Intermediate to these two extremes is the Dynamic Factor Index proposed by Bryan and Cecchetti (1993) which combines information on both the time series and cross section characteristics of individual price changes.

4. ESTIMATING CORE INFLATION USING ONLY CONTEMPORANEOUS PRICE DATA

There is some intuitive appeal to the idea that we can somehow isolate the monetary component of price changes by simply averaging the changes in the prices of individual goods and services. This approach to inflation measurement has a long history, and was perhaps first fully articulated by Jevons (1865). Jevons argued for the use of the geometric mean of price changes in calculating inflation

> "... as it seems likely to give in the most accurate manner such general change in prices as is due to a change on the part of gold. For any change in gold will affect all prices in an equal ratio; and if other disturbing causes may be considered proportional to the ratio of change of price they produce in one or more commodities, then all the individual variations of prices will be correctly balanced off against each other in the geometric mean, and the true variation of the value of gold will be detected." (Jevons, 1865, 296).

If we interpret the relative price term, $x_{i,t}$, in the equation above as an error term that is normally distributed, with mean and variance given by $E(x_t) = 0$, $E(x_t x_t') = \sigma_t^2 I_N$, where $x_t = [x_{1,t}, x_{2,t}, ..., x_{N,t}]'$, it is straightforward to show that the maximum likelihood estimator of the inflation rate, $\hat{\Pi}_t$, is given by a simple unweighted average of the rates of change of the individual price series:[6]

$$\hat{\Pi}_t = \frac{1}{N}\sum_{i=1}^{N}\pi_{i,t}$$

Note that we identify core inflation in this model by defining it as the component of price changes that is orthogonal to relative price changes. By construction, the estimated relative price changes, $\hat{x}_{i,t}$, have the property

$$\sum_{i=1}^{N}\hat{x}_{i,t} = 0$$

That is, the implied relative price changes average to zero.

Exponentiating both sides of the proposed measure of inflation we obtain the geometric mean price index proposed by Jevons (1865) as a way of computing the change in the purchasing power of money over time:

$$\exp(\hat{\Pi}_t) = \prod_{i=1}^{N}\left(\frac{p_{i,t}}{p_{i,t-1}}\right)^{1/N}$$

This measure of inflation has a number of appealing properties, not the least of which is the ease with which it can be calculated. Unlike a simple arithmetic mean of price relatives $(p_{i,t} / p_{i,t-1})$ (the so-called Carli index), this index satisfies the time reversal property. Fase and Folkertsma (1996) argue for the use of simple averages of price changes to isolate core inflation in an SVAR framework (discussed below). However, this measure of inflation also has a number of serious shortcomings, all of which ultimately relate to the strong assumptions made about the behavior of the relative price terms, $x_{i,t}$.

Note that so far nothing has been said about which prices to include in the calculations. The prices to be averaged in arriving at a measure of inflation could be just consumer prices, or could include the prices of all GDP transactions or the prices of all transactions (including intermediate transactions) or could even include the prices of assets. Fisher (1920) argued that when it comes to constructing a measure of the purchasing power of money we ought to look at as many prices as possible:

> "Perhaps the best and most practical scheme [for the construction of an index number] is that which has been used in the explanation of P in our equation of exchange, an index number in which every article and service is weighted according to the value of it exchanged at base prices in the year whose level of prices it is desired to find. By this means, goods bought for immediate consumption are included in the weighting, as are also all durable capital goods exchanged during the period covered by the index number. What is repaid in contracts so measured is the same general purchasing power. This includes purchasing power over everything purchased and purchasable, including real estate, securities, labor, other services, such as the services rendered by corporations, and commodities." (Fisher, 1920, 217-218).

It is interesting to note that the preamble to the European Council Regulation governing the calculation of the HICP which will form the basis for assessing inflation developments in the euro area notes that "• it is recognised that inflation is a phenomenon manifesting itself in all forms of market transactions including capital purchases, government purchases, payments to labour as well as purchases by consumers." (European Commission, 1998) Once we have abandoned the cost of living as the guiding concept for inflation measurement for monetary policy purposes

[6] See Diewert (1995).

there is no reason for confining our attention to changes in the prices of final consumer goods. Changes in the prices received by producers, changes in the prices of intermediate goods and changes in the prices of existing assets all carry information about monetary inflation.

5. ARE ALL PRICES EQUALLY INFORMATIVE?

One possible problem with this approach to estimating inflation is that it treats all prices as being equally informative about inflation and thus equally important.[7] Arguably a more appropriate approach would be to weight the price changes of individual products in terms of their importance, somehow defined.[8] That is, an estimate of inflation of the form

$$\hat{\Pi}_t = \sum_{i=1}^{N} w_{i,t} \pi_{i,t}$$

which assigns weights $w_{i,t}$ to the price changes of individual products in arriving at a measure of overall inflation may be preferable. Diewert (1995) shows that for this expression to be the maximum likelihood estimator of the inflation rate we can retain our original assumption that the relative price changes have zero mean, but need to replace the variance assumption with

$$E(x_t x_t') = \sigma_t^2 W_t^{-1}$$

where $W_t = diag\,[w_{1,t}, w_{2,t}, ..., w_{N,t}]$. This assumption about the distribution of relative price changes was proposed by Clements and Izan (1981). They motivated it by arguing as follows: “If we think in terms of sampling of the individual prices to form ...[$\pi_{i,t}$]... for each commodity group, then it seems reasonable to postulate that the collection agency invests more resources in sampling the prices of those goods more important in the budget. This implies that ...[$Var(x_{i,t})$]...is inversely proportional to ...[$w_{i,t}$].”(Clements and Izan, 1981, 745) Later

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[7] Diewert (1997) sees this property of the Jevons index number as a “fatal flaw.”

[8] The contrary view is taken by Bryan and Pike (1991), who write “...the strength of the inflation signal in goods and services prices is not necessarily related to an item’s share of the typical household budget. As a monetary phenomenon, inflation should influence the price of all goods and services equally. The inflationary signal in the price of a new pair of shoes is theoretically the same as that in the price of shoe leather or, for that matter, in the price of cows. There is no reason to expect movements in the price of one to be a clearer indicator of inflation than movements in the prices of others.” Likewise Fase and Folkertsma (1996) note “...weighting the price index means that some prices get to determine the general price level thus measured more than others. For an assessment of changes in purchasing power, weighting may certainly be useful but there is no clear reason to gauge inflation by way of weighting.”

Clements and Izan (1987) provided a different justification for this assumption, arguing that the larger an item looms in the budget of consumers, the less scope there is for relative price changes in that item. Neither of these justifications is particularly appealing. However, the theory of the cost of living index provides an alternative rationale for weighting individual price changes by shares in consumer's budgets. A fixed-weight Laspeyres measure of the price level at date *t* with period 0 as the base period can be written

$$P_t^L = \frac{\sum_{i=1}^{N} p_{i,t} q_{i,0}}{\sum_{i=1}^{N} p_{i,0} q_{i,0}} = \sum_{i=1}^{N} w_{i,0} \left(\frac{p_{i,t}}{p_{i,0}} \right) = \sum_{i=1}^{N} w_{i,0} p_{i,t}$$

where we set $p_{i,0} = 1, \ \forall i$. Log differentiating this expression we obtain

$$\frac{dP_t}{P_{t-1}} \equiv \Pi_t = \frac{1}{P_{t-1}} \sum_{i=1}^{N} w_{i,0} dp_{i,t} = \sum_{i=1}^{N} r_{i,t} \pi_{i,t}$$

That is, the standard fixed weight Laspeyres measure of inflation can be written as a weighted average of the rates of change of the prices of individual goods and services. However, note that the weights, $r_{i,t}$, are not the budget share weights of the base period, $w_{i,0}$. Rather they are the "relative importances" of each product, that is, the base period weight adjusted for the extent to which the price of the good in question has grown faster or slower than prices on average. Goods whose prices increase faster than average over time will have an increasing relative importance in a fixed-weight Laspeyres type price index. This is simply another way of expressing the well-known tendency of fixed-weight Laspeyres measures to overstate the true rate of inflation as defined by the cost of living index.[9]

But why do we need to confine ourselves to looking to budget shares for weights? The use of budget shares as weights is best motivated by an appeal to the (atemporal) theory of the cost of living index. Yet implicit in the notion of core inflation that ought to be of primary concern to monetary policymakers is the idea that such inflation is inherently different to inflation as measured by the cost of living index. Thus the weighting scheme that is optimal from the perspective of constructing a cost of living index may no longer be optimal from the perspective of measuring inflation for the purposes of monetary policy.

[9] For further details see Blinder (1981).

A weighting scheme that might be more appropriate for monetary policy purposes would weight prices by the strength or quality of the inflation "signal" they provide. Indeed this is the approach that implicitly underlies the "Ex. food and energy" or "Ex. indirect taxes" approaches to estimating core inflation that are used by many central banks and statistical agencies. In these approaches we attach zero weight to certain prices on the (unstated) grounds that they convey zero information about core inflation. Formally,

$$w_i = 0 \quad \text{if} \quad \sigma_i^2 > \tilde{\sigma}^2$$

where $\tilde{\sigma}^2$ is some "unacceptably high" level of variability in short term price changes. It is worth noting that there is no justification for such a practice from the perspective of the theory of the cost of living index. The rationale for excluding certain prices from an estimate of core inflation must lie other than in the theory of the cost of living index.

One scheme for operationalising the idea of weighting prices in terms of the quality of their inflation signal would be to set the weights as follows:

$$w_i = \frac{\frac{1}{\sigma_i^2}}{\sum_{i=1}^{N} \frac{1}{\sigma_i^2}}$$

That is, choose weights for the various individual prices that are inversely proportional to the volatility of those prices. A weighting scheme along these lines has been investigated by Dow (1994), who termed the resulting measure of inflation a Variance Weighted Price Index, and by Diewert (1995), who termed the resulting measure of inflation Neo-Edgeworthian. Wynne (1997) reports the results of applying a scheme along these lines to US CPI data. The advantage of employing a variance weighting scheme to calculate core inflation is that we do not discard potentially useful information about core inflation that may be contained in food and energy prices, or whatever categories are excluded. The "Ex. food and energy" approach to estimating core inflation is further compromised by the fact that it requires that we make a once and for all judgement about what the least informative categories of prices are for estimating core inflation. A variance weighting scheme such as the above allows weights to change over time as the volatility of different categories of prices changes over time. The speed with which the weights will change in response to changes in volatility will be determined by the choice of the estimation "window" for the variances.

Yet another weighting scheme was proposed informally by Blinder (1997). Starting from a definition of core inflation as the persistent or durable component of inflation, Blinder suggests that when it comes to calculating core inflation, individual price changes should be weighted by their ability to forecast future inflation. Blinder argues that central bankers are a lot more concerned about future inflation than they are about past inflation, and that when thinking about the measurement of core inflation as a signal extraction problem, future inflation is the object about which we are seeking information via current signals. Thus core inflation is defined in terms of its ability to predict future headline inflation. At present there have not been any attempts to operationalize this approach.[10]

6. SOME PROBLEMS

If we think about the problem of core inflation measurement in terms of an estimation problem, we need to ask whether the distribution assumptions that underlie the estimation are borne out by the data. There are two important distributional assumptions that need to be looked at. The first is that individual price changes are normally distributed, and the second is that individual price changes are independent of one another.

The geometric mean of price relatives is the maximum likelihood estimator of core inflation under the assumption that individual price changes are normally distributed. Is this assumption borne out by the data? No. There is an extensive literature documenting the statistical properties of individual price changes, and it is clear that individual $\pi_{i,t}$ are typically not normally distributed. This fact was first noted by Bowley (1928) in a critique of Jevons, and has subsequently been further documented by Vining and Elwertowski (1976), Ball and Mankiw (1995), Cassino (1995), Bryan and Cecchetti (1996), Balke and Wynne (1996) and Wynne (1998). There is evidence of significant skewness and kurtosis in the cross-section distribution of price changes. Skewness in the distribution of price changes may reflect the fact that changes in

[10] However note that Bryan and Cecchetti (1994) evaluate various measures of core inflation in terms of their ability to forecast future inflation.

the money stock do not necessarily affect all prices at the same time,[11] or it may simply reflect skewness in the underlying shocks that causes relative prices to change.[12]

If the distribution of $\pi_{i,t}$ can be characterised in terms of a distribution with a finite number of moments, it may still be possible to estimate core inflation as the solution to a maximum likelihood problem. However, the resulting measure will probably be significantly more complicated than a simple geometric mean of price relatives.

A more constructive response to non-normality in the distribution of $\pi_{i,t}$ is to employ estimators that are robust to departures from normality. This is the approach advocated by Bryan and Pike (1991), Bryan and Cecchetti (1994, 1996) and Cecchetti (1997). Bryan and Pike argue for the use of the median of $\pi_{i,t}$ as an estimate of core inflation on the grounds that the median is a more robust measure of central tendency. Bryan and Cecchetti (1994) examine in more detail alternative approaches to estimating core inflation and conclude that of the various measures they look at the weighted median CPI performs best. More recently Bryan, Cecchetti and Wiggins (1997) investigate the ability of various trimmed means of the cross section distribution of price changes to track trend inflation. To compute the trimmed mean of the cross-section distribution of prices, start by ordering the sample (from largest to smallest price change, say). Then define the cumulative weight from 1 to i as $W_{i,t} = \sum_{j=1}^{i} w_{(j),t}$, where $w_{(j),t}$ denotes the sorted *j*'th weight. This allows us to define the index set $I_\alpha = \{i : \frac{\alpha}{100} < W_{i,t} < 1 - \frac{\alpha}{100}\}$. The α % trimmed mean inflation rate is then defined as

$$\overline{\Pi}_t^k(\alpha) = \frac{1}{1 - 2\frac{\alpha}{100}} \sum_{i \in I_\alpha} w_{(i),t} \pi_{(i),t}^k$$

where $\pi_{(j),t}$ is the sorted *j*'th price change. If $\alpha = 0$ we obtain the weighted sample mean. For $\alpha = 50$ we obtain the weighted sample median.

Yet a further objection to the use of the geometric mean is that changes in relative prices are not independent of each other. Thus if we continue to think about core inflation measurement as an estimation problem, the assumption that $E(x_t x_t') = \sigma_t^2 I_N$ needs to be replaced with the

[11] Indeed Ball and Mankiw (1995) argue that this property of the distribution of price changes is important evidence favouring sticky-price or menu-cost models of real-nominal interactions.
[12] This interpretation is proposed by Balke and Wynne (1998).

more realistic assumption $E(x_t x_t') = \sigma_t^2 \Omega$. In this case the core inflation rate can in principle be estimated as

$$\Pi_t = (\iota_N' \Omega^{-1} \iota_N)^{-1} \iota_N' \Omega^{-1} \pi_t$$

where ι_N is an $N \times 1$ vector of 1's. In practice, however, operationalising this approach would require making strong assumptions about the precise nature of the interaction between relative prices (*i.e.* specification of Ω) and to date there do not appear to have been any attempts to construct estimates of core inflation along these lines.

A more fundamental objection to the use of the geometric mean is that it requires the systematic component of each price change to be the same, thereby precluding any long-term changes in relative prices. Casual empiricism suggests that this restriction is seriously at odds with reality. This criticism of the geometric mean of individual price changes as an estimate of inflation was first made by Keynes (1930).

Clements and Izan (1987) proposed a way around this problem. They start by writing

$$\pi_{i,t} = \Pi_t + x_{i,t} = \Pi_t + r_i + \varepsilon_{i,t}$$

where the relative price term, $x_{i,\,t}$, now contains a non-zero component, r_i, as well as a mean-zero stochastic component, $\varepsilon_{i,t}$. Assume

$$E(\varepsilon_t) = 0\,,\;\; E(\varepsilon_t \varepsilon_t') = \sigma_t^2 W_t^{-1}$$

where $W_t = diag\,[w_{1,t}, w_{2,t}, ..., w_{N,t}]$. To identify Π_t and r_i, add the identifying assumption

$$\sum_{i=1}^{N} w_{i,t} r_i = 0$$

The maximum likelihood estimator of the inflation rate is the same as in the basic model (i.e. a simple weighted average of the individual price changes), but now the expected change in the *i*'th relative price is $E(\pi_{i,t} - \Pi_t) = r_i$. While this model is an advance over the simple framework, it is not obvious that the assumption of constant rates of relative price changes is any more palatable than the assumption of no systematic changes in relative prices. For many products, their relative prices tend to follow a U-shaped pattern over their lifetimes, with rapid relative price declines following the introduction of a product, followed by relative price stability as the product reaches maturity, followed by relative price increases as the product is displaced by newer products before finally disappearing from the market.

7. COMBINING CONTEMPORANEOUS AND TIME SERIES INFORMATION TO ESTIMATE CORE INFLATION

Perhaps a more serious shortcoming of these models is that they fail to take account of persistence in both individual price changes and the inflation rate. Some of the dynamic models that have been proposed in recent years seek to remedy this problem, and succeed to varying degrees. We will start by looking at the Dynamic Factor Index (DFI) model proposed by Bryan and Cecchetti (1993) and Cecchetti (1997). This model is of interest for many reasons, not least of which is the fact that it is the only model that attempts to combine information on both the cross-section and time series characteristics of individual price changes in deriving a core inflation measure.

The DFI model starts with the equation

$$\pi_t = \Pi_t + x_t$$

where as before $\pi_t = [\pi_{1,t}, \pi_{2,t}, ..., \pi_{N,t}]'$ and $x_t = [x_{1,t}, x_{2,t}, ..., x_{N,t}]'$. Identification of the common inflation component in all price changes (core inflation) is accomplished by positing time series processes for inflation and the relative price change components of individual price changes as follows:

$$\Psi(L)\Pi_t = \delta + \xi_t$$

$$\Theta(L)x_t = \eta_t$$

where $\Psi(L)$ and $\Theta(L)$ are matrix polynomials in the lag operator L and ξ_t and η_t are scalar and vector *i.i.d.* processes respectively. If $\Psi(L) = 1$ and $\Theta(L) = 1$, we obtain the static model discussed at length above. Another special case of this model where $\Psi(L) = 1 - \psi_1 L$ and

$\Theta(L)=1$ has been studied by Dow (1994). Bryan and Cecchetti (1993) and Cecchetti (1997) estimate versions of this model assuming that $\Psi(L)=1-\psi_1 L-\psi_2 L^2$ and $\Theta(L)=1-\theta_1 L-\theta_2 L^2$.

In the DFI model the common element in all price changes, Π_t, is identified by assuming that it is uncorrelated with the relative price disturbances at *all* leads and lags instead of just contemporaneously. This is clearly a much stronger identifying assumption than is used in the simple static factor models discussed above (where inflation is defined as the component or price changes that is uncorrelated with relative price changes contemporaneously). It is not clear what is obtained by employing this stronger assumption. The DFI model is also susceptible to the criticism that it only allows for constant trends in relative prices. But perhaps the biggest shortcoming of the DFI approach to measuring core inflation is that history changes each time a new observation is obtained and the model is re-estimated. This problem is common to all measures of core inflation constructed using econometric procedures. While this is not usually ranked as a major concern in choosing and constructing a measure of core inflation, it is of great importance to a central bank that plans to use a core measure as an integral part of its communications with the general public about monetary policy decisions.

8. DYNAMIC MODELS II: BRINGING SOME MONETARY THEORY TO BEAR ON THE DEFINITION OF CORE INFLATION

Core inflation as identified by the static and dynamic factor models above is essentially a statistical concept that it is difficult to attach much economic meaning to. Unlike the economic or cost of living approach to inflation measurement, no substantive economic theory is used to derive these estimates of core inflation. The motivation is usually some simple variant of the quantity theory of money, whereby a given change in the stock of base money is presumed to affect all prices equiproportionately (see the quote from Jevons above). Thus the best estimate of monetary inflation is whatever best estimates this average or common component in price changes. Bryan and Cecchetti (1994) do evaluate their measures of core inflation using basic propositions from monetary theory (core inflation should be caused by but not cause money growth; and core inflation should help to forecast future headline inflation). However these ex post evaluations of the performance of various proposed measures are not quite the same thing as using monetary theory to construct a measure of inflation. If there is a meaningful distinction between the cost of living and monetary inflation that is of concern to central bankers, then presumably we should be able to draw on monetary theory to help us measure this alternative concept of inflation.

This is the approach adopted by Quah and Vahey (1995), who adopt a more monetary-theoretic approach to the measurement of core inflation. They define core inflation as the component of measured inflation that has no impact on real output in the long run, and motivate this definition on the basis of a vertical long run Phillips Curve. Their measure is constructed by placing long-run restrictions on a bivariate VAR system for output and inflation. Quah and Vahey assume that both output and inflation have stochastic trends, but are not cointegrated. Thus they write their system in terms of output growth and the change in the inflation rate:

$$\mathbf{Z}_t = \begin{bmatrix} \Delta Y_t \\ \Delta \Pi_t \end{bmatrix} = \sum_{j=0}^{\infty} D(j)\eta(t-j)$$

where $\eta = [\eta_1, \eta_2]'$ with the disturbances assumed to be pairwise orthogonal and $Var(\eta) = I$. Here Π_t denotes inflation at date t as measured by a conventional price index such as the CPI or RPI. Note that Quah and Vahey do not use any information on the cross-section distribution of individual price changes to construct their core inflation measure. The long-run output neutrality restriction is $\sum_{j=0}^{\infty} d_{11}(j) = 0$. The inflation process can be written

$$\Delta \Pi_t = \sum_{j=0}^{\infty} d_{21}(j)\eta_1(t-j) + \sum_{j=0}^{\infty} d_{22}(j)\eta_2(t-j) .$$

Quah and Vahey's candidate measure of *changes* in core inflation is simply $\sum_{j=0}^{\infty} d_{21}(j)\eta_1(t-j)$.

The Quah and Vahey approach to measuring core inflation has also been implemented by Fase and Folkertsma (1996), Claus (1997), Jacquinot (1998), Gartner and Wehinger (1998), and Alvarez and Matea (forthcoming). Fase and Folkertsma relate this measure of inflation to Carl Menger's concept of the inner value of money. However rather than measuring the inflation rate using the CPI, the take as their measure the *unweighted* average rate of change of the component series, calculated on the basis of 200 component price series for the Netherlands, arguing that "•weighting may certainly be useful but there is no clear reason to gauge inflation [as a monetary phenomenon] by way of weighting." Fase and Folkertsma also calculate a core inflation measure for the EU by aggregating price and output data for Austria, Belgium, France, Germany, Italy, the Netherlands, Spain, Sweden and the UK.

As noted, the theoretical justification for the Quah-Vahey approach is the presumption that the Phillips Curve is vertical in the long run. While this might appear to be a relatively innocuous assumption, upon reflection it is clear that it is not without problems. If we accept that the Phillips Curve is indeed vertical in the long run, we are essentially saying that inflation is neutral in its effects on the real economy.[13] It is not obvious that all monetary economists would accept this proposition, still less central bankers charged with the pursuit of price stability. Even fully anticipated constant inflation can have real effects, as documented in the well-known study by Fischer and Modigliani (1978). More generally, insofar as inflation constitutes a tax on holdings of base money, changes in this tax rate may be expected to have implications for agents' decisions about how much money to hold, which will in turn have other real effects (except under limiting assumptions). Another way of thinking about this problem is in terms of the widely held view that the sole objective of monetary policy should be price stability.[14] If we accept that core inflation as measured by Quah and Vahey does in fact correspond to the component of inflation that is under the control of the monetary authority, and also that this component of inflation is in fact neutral with respect to output in the long run, it invites the question of why a central bank would ever want to be concerned about price stability. After all, if all the central bank controls is the price level in the long run, and if the rate at which the price level increases has no implications for the level of real economic activity, then one inflation rate is just as good in welfare terms as another. There is no reason to prefer a steady state inflation rate of 2% over one of, say, 20%. Price stability or zero inflation ought not to play any particular role in the setting of objectives for monetary policy. Of course nobody seriously believes this. A more realistic assumption might be that the Phillips Curve is not vertical in the long run, but rather upward sloping, from left to right, as proposed by Friedman (1977). Such an assumption would better capture the notion that steady-state or long-run inflation is indeed costly from society's perspective, but would probably be a lot more difficult to operationalise.

Blix (1995) also implements the Quah and Vahey model. However Blix's implementation of the model differs in important respects from Quah and Vahey. To start with, the long run identifying restriction is implemented in a common trends framework rather than a VAR. That is, the model estimated is

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[13] The price level is superneutral.
[14] Although not universally: see for example Aiyagari (1990).

$$\begin{pmatrix} Y_t \\ P_t \end{pmatrix} = x_0 + \begin{pmatrix} \alpha_{11} & 0 \\ \alpha_{21} & \alpha_{22} \end{pmatrix} \begin{pmatrix} r_t \\ n_t \end{pmatrix} + \Phi(L) \begin{pmatrix} \varphi_{r,t} \\ \varphi_{n,t} \end{pmatrix}$$

with the growth terms given by the vector random walk process

$$\begin{pmatrix} r_t \\ n_t \end{pmatrix} = \mu + \begin{pmatrix} r_{t-1} \\ n_{t-1} \end{pmatrix} + \begin{pmatrix} \varphi_{r,t} \\ \varphi_{n,t} \end{pmatrix}$$

However, the most substantive difference between this specification and that of Quah and Vahey is the fact that the system is specified in terms of output and the *price level* rather than the inflation rate.[15] Arguably, the proposition that changes in the money stock, and by extension the price level, are neutral in their effects on real economic activity is less controversial than the proposition that changes in the growth rate of the money stack (and by extension the inflation rate) are also neutral in the long run. The distinction is important. Estimating core inflation on the basis of posited neutrality of changes in the price level is surely a lot more appealing from a central banker's perspective than estimation based on the long run neutrality of inflation.

Quah and Vahey express agnosticism about the exact determinants of underlying inflation. However, Blix extends the Quah and Vahey framework to make the role of money even more explicit by estimating the following extended system:

$$\begin{pmatrix} Y_t \\ P_t \\ M_t \end{pmatrix} = x_0 + \Xi_0 \begin{pmatrix} \alpha_{11} & 0 \\ \alpha_{21} & \alpha_{22} \end{pmatrix} \begin{pmatrix} r_t \\ n_t \end{pmatrix} + \Phi(L) \begin{pmatrix} \varphi_{r,t} \\ \varphi_{m,t} \\ \varphi_{p,t} \end{pmatrix}$$

In addition a cointegration restriction is imposed that requires that velocity, i.e. $Y_t + P_t - M_t$, is stationary. The restriction requires that

$$\Xi_0 = \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 1 \end{pmatrix}$$

[15] As justification Blix notes that "Dickey-Fuller tests suggest that the vector $\Delta x_t = (\Delta Y_t, \Delta P_t)'$ is stationary for all countries considered" including the UK. Quah and Vahey claim that "The standard tests confirm that measured *inflation* and output can be treated as I(1)" (emphasis added) using UK data. There is a puzzling inconsistency here.

This extension thus brings further hypotheses about real and nominal interactions to bear on the estimation of core inflation. Blix reports that the measures of core inflation obtained in the basic and the extended Quah and Vahey model are quite similar. Unfortunately he does not provide details of the data used. Monetary theory tells us that, under a fiat monetary standard, the price level is ultimately determined by the stock of base money outstanding relative to the demand for it. Therefore the appropriate measure of M in the system above is a measure of the base money stock. However, the assumption of stationary velocity of base money is probably at odds with the data for several, if not all, industrialised countries.

While Blix's approach to estimating core inflation is more plausible in many respects than the original Quah and Vahey implementation, the fundamental problem of what can be achieved via long run restrictions when we only have a finite sample of data available remains. Faust and Leeper (1997) and Cooley and Dwyer (1998) explore this problem in some detail. The latter provide a series of compelling examples that demonstrate how sensitive inferences from SVAR models are to seemingly innocuous auxiliary assumptions (about whether the data are trend stationary or difference stationary, the number of underlying shocks and so on). So far there has been no attempt to evaluate the sensitivity of core inflation estimates from the SVAR approach of Quah and Vahey to alternative auxiliary assumptions. The SVAR approach to core inflation estimation is also subject to the criticism levied against the DFI, that because it is based on econometric estimates, history will change each time a new observation is added.

9. CRITERIA FOR CHOOSING A MEASURE OF CORE INFLATION

Table 2 presents a set of criteria that could be used to settle on a measure of core inflation, and gives some indication of the extent to which various proposed measures meet these criteria. Note that included in the table are moving average type measures of core inflation, which we have not discussed in any detail. The simplest such measure is a year-on-year inflation rate, which is simply an average of the inflation rate over the past twelve months. The exponential weighted measure of Cogley (1998) could also be included in this category. The major drawback of all such measures is their inherently backward looking nature.

First among the criteria listed is that the measure should be computable in real time. Almost all proposed measures meet this criterion. The only exceptions are measures based on two-sided filters of some sort (such as the band-pass filters proposed by Baxter and King (1995)).

Note also that while a measure of core inflation constructed using the well-known Hodrick-Prescott filter is computable in real time, the "end of sample" problems with this filter documented by Baxter and King (1995) make it particularly unappealing as a basis for core inflation measurement.

The second criterion listed is that the measure should be forward looking in some sense. Most of the proposed measures are not inherently forward looking, but they may have some predictive power for future headline inflation. Only the SVAR measures are forward looking by construction. One way in which it is possible to induce an element of forward lookingness into the various measures is to calibrate them to predict future headline inflation or track a trend that is defined in a two-sided manner. Thus Bryan, Cecchetti and Wiggins (1997) calculate the optimal trim on the basis of the ability of the trimmed mean to track a 36-month centred moving average of headline inflation.

The third proposed criterion is that the measure have a track record of some sort. Trivially, all of the measures meet this criterion, but some have been more thoroughly explored than others. The Edgeworth index and the Dynamic Factor index are probably the two least examined measures of core inflation.

The fourth proposed criterion is that the measure be understandable by the public. The inclusion of this criterion is only important insofar as a central bank wishes to compute a measure of core inflation and use it as an integral part of its regular communications with the general public to explain monetary policy decisions. It is questionable whether *any* of the more sophisticated core inflation measures could easily be explained to the general public.

If a core inflation measure is to be used by a central bank to communicate with the general public, it is also important that history not change each time we obtain a new observation. This is the fifth criterion listed, and it essentially rules out (or at least severely compromises the attractiveness of) any core measure that is derived from econometric procedures. It would be worthwhile to discover just how sensitive econometric based estimates of core inflation are to the addition of new information.

Finally it is desirable that the chosen measure have some theoretical basis, ideally in monetary theory. The only measure that really satisfies this criterion is the SVAR measure proposed by Quah and Vahey. However, not all attempts to implement this approach are careful to distinguish between long-run neutrality and long-run superneutrality of money. I have argued that only identification of core inflation based on the neutrality of money should be of interest to a central bank.

10. CONCLUDING OBSERVATIONS

This paper reviewed various approaches to the measurement of core inflation. A common theme linking many of these approaches is the idea that there is some concept of monetary inflation that is distinct from changes in the cost of living and that is a more appropriate target of monetary policy. Reasoning from a traditional quantity theory perspective, this has motivated several authors to look at alternative estimates of the central tendency of the distribution of prices as the best estimate of core or monetary inflation. Other authors have used dynamic frameworks along with neutrality propositions from monetary theory to try to estimate core inflation. All of these approaches suffer from the fact that there is simply no agreed upon theory of money that can serve as a basis for inflation measurement that could plausibly replace the theory of the cost of living.

I have also addressed (somewhat tangentially) the question of how measures of core inflation ought to be evaluated. Many of the measures of core inflation that have been proposed in recent years eschew the theory of the cost of living index as the basis for measurement. This makes evaluation difficult. The theory of the cost of living index provides a coherent framework for the evaluation of measures of headline inflation such as the CPI or the HICP. Essentially we deem a measure of headline inflation to be reliable by the degree to which it approximates the theoretical ideal. There is no theoretical ideal for a monetary measure of core inflation. Rather they are evaluated by their consistency with various loosely formulated propositions from monetary theory. Thus a measure of core inflation that is designed to capture "monetary" inflation might be evaluated by the extent to which it is (Granger) caused by some measure of the money stock but does not (Granger) cause money. Or a measure might be evaluated by the degree to which it forecasts future inflation. This is an approach suggested by Blinder (1997). The problem with this is we start to leave the area of economic measurement and enter the domain of formal theorising and forecasting. It needs to be asked why we would want a measure of core inflation that forecasts future headline inflation. Surely the central bank would be more interested in forecasting future inflation (and would get better results) using multivariate rather than univariate approaches?

This review of various approaches to core inflation measurement also suggests a large number of questions for future research.

First and foremost before choosing a measure of core inflation we need to specify what it is we want the measure for. Do we want a measure of core inflation to answer the question "What would the inflation rate have been if oil prices (or indirect taxes) had not increased last month?" If so, then none of the approaches reviewed above will help. This question can only be answered in the context of a full general equilibrium model of the economy. Furthermore if the measure of inflation we are interested in is the cost of living, then it is not clear why we would ever want to exclude the effects of oil price increases or indirect taxes. Thus it must be the case that when measuring core inflation we have some other inflation concept in mind. Ideally a central bank would be most interested in a measure of inflation that measured the rate of decline in the purchasing power of money. Unfortunately there is no well developed and generally agreed upon theory that can serve as a guide to constructing such a measure. Thus in practical terms we left with the options of constructing a core inflation measure so as to better track the trend inflation rate (somehow defined) in real time, or what in many circumstances may amount to the same thing, forecast the future headline inflation rate.

To start with it might be useful to take a cue from the recent work of Cecchetti (1997) and Bryan, Cecchetti, and Wiggins (1997) and define the problem of core inflation measurement as that of tracking changes in the trend inflation rate. They define the trend as a simple 36-month centred moving average of headline inflation, and then estimate using Monte Carlo methods how much to trim from the cross-section distribution of price changes so as to best track this trend using a trimmed mean measure of core inflation. Their use of a trimmed mean is motivated by the by now well-documented skewness and kurtosis in the cross-section distribution of changes in consumer and producer prices in the US. Thus a first step in constructing a core measure for the ECB would be to document the statistical characteristics of the cross section distribution of HICP price changes.[16] Assuming (as seems reasonable) that the distribution exhibits similar characteristics to that of the US CPI, it would then be useful to investigate the ability of some of the core measures discussed above to track this trend. Note that in doing so we will rapidly come up against the very binding constraint of the short time series of observations for the HICP. With only four years of data it will not be possible to assess the ability of core measures to track the trend in the actual data. The best that can be hoped for is that the inferences drawn from the Monte Carlo experiments are robust. One way around this data constraint would be to investigate various core measures using national CPI data for which longer time series ought to be available. One problem here is that the characteristics of the national CPI data may reflect a particular type

[16] Preliminary results are presented in Wynne (1998).

of relative price variability that will disappear after the start of EMU, namely that due to exchange rate changes.

The discussion above was highly critical of the various dynamic approaches to core inflation measurement, such as the DFI and the SVAR approach of Quah and Vahey. I asserted that the major shortcoming of the DFI model is that history changes each time a new observation is added. It would be useful to know before dismissing this approach completely by how much history changes each time the model is re-estimated. This should also be done for the other econometric based measures of core inflation. If it turns out that the amount by which the addition of new information causes previous estimates of core inflation to change is trivial, this criticism might lose a lot of its force. There would also be some merit in further exploring the SVAR approach of Quah and Vahey. The great merit of this approach is that it has some basis in monetary theory, but it only makes sense if it is operationalised on the basis of neutrality of money rather than superneutrality. Here what needs to be done (in addition to assessing the sensitivity of estimates to the addition of new information) is to see how sensitive the measures of core inflation are to violations of the auxiliary assumptions.

Table 1

Schema of approaches to core inflation measurement

		Time perspective	
		Cross-section	Time series
Raw data	Individual price changes	"Ex. Food and Energy", Limited influence estimators, Neo-Edgeworthian (variance weighted) Index	Dynamic Factor Index
	Headline inflation rate	NA	Moving averages, filtered series, Exponentially smoothed series
	Price data (either headline or disaggregated) plus other aggregates	NA	SVAR measures

Table 2 Criteria for selecting a measure of core inflation						
	"Ex. food and energy"	Moving averages	Trimmed mean	Edgeworth (variance weighted) index	Dynamic factor index	VAR measures
Computable in real time	Yes	Maybe	Yes	Yes	Yes	Yes
Forward looking	No	No (?)	No	No	No	Yes
Track record	Yes	Yes (?)	Yes	Yes (?)	Yes	Yes
Understandable by public	Yes	Yes (?)	Maybe	No	No	No
History does not change	Yes	Maybe	Yes	No	No	No
Theoretical basis	No	No	No	No	No	Yes

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