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REAL-TIME RELIABILITY OF OECD OUTPUT GAP ESTIMATES AND SOME INVESTIGATIONS INTO IMPROVING IT

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1. Introduction

1. Whilst the output gap ought to be a useful guide for macroeconomic policy, both for assessing inflationary pressures and fiscal sustainability, its usefulness has been called into question given the uncertainty about its measurement, underlined by the sometimes large revisions to output gap estimates [for example, Orphanides and Van Norden (1999), Pain and Koske (2008) and Deutsche Bundesbank (2014)]. Such uncertainties are likely to have been magnified in the aftermath of the global financial crisis. Against this background, the current paper reviews the real-time reliability of OECD published estimates of the output gap for the G7 economies, before reporting the results of some investigations into methods aiming to reduce the extent of such revisions.

2. OECD potential output calculations are based on an aggregate Cobb-Douglas production function (summarised in Appendix 1), which are built up from contributions from capital, trend labour input and a measure of the trend labour efficiency, where the latter is the smoothed residual after subtracting factor inputs from GDP. Given the role of filters in calculating the trend components, an important source of revision is likely to be related to well-known end-point problems associated with such filters, even though some attempt is made to mitigate such problems by extending the sample with forecast data and by using information on inflation to assess unemployment gaps.

3. The paper is organised as follows. Section 2 examines revisions to successive vintages of OECD published output gaps for the major seven OECD economies. The paper then focuses on the contribution to output gap revisions from the end-point issue that arises from filtering and considers some variants to the standard OECD methodology to try to reduce such revisions. Section 3 sets out some considerations for evaluating success in reducing real-time revisions. Section 4 examines the extent of real-time revisions using a multi-variate filter. Section 5 considers the extent to which survey information on manufacturing capacity utilisation can be used to reduce real-time revisions. Some tentative conclusions are drawn in Section 6.

2. An examination of revisions to OECD output gaps

4. There are a number of reasons why output gap estimates are revised: revisions to the underlying data, especially GDP; changes in the methodology used to derive potential output between vintages; and instability in any given method used to derive potential output, particularly concerning end-point estimates, which arise as the data sample is extended.

5. Previous OECD analysis (Koske and Pain, 2008) over a period pre-dating the financial crisis found that: "Differences between initial and final outturn estimates of the output gap for a particular year are attributable primarily to revisions in actual rather than potential GDP in two-thirds of the countries considered, and almost all of the G7 economies. This suggests that much of the uncertainty about the size of the output gap simply reflects the uncertainty of the actual GDP data and projections."

6. There have also been significant changes to the OECD's production function methodology which have had an impact on output gap estimates including: switching between a measure of capital services and capital stock; a number of changes to the method of estimating equilibrium unemployment, notably to provide a closer link to inflation (Rusticelli *et al*, 2015); and a set of changes designed to produce a more uniform approach across a broader range of countries[2] and to link the estimates of potential output to longer-term projections (Johannson *et al*, 2012). The introduction of the last and most far-reaching of these changes in May 2012 led to the largest average revision across all G7 countries between successive vintages of output gap estimates over the period examined in Appendix 2.[3]

7. Revisions to output gap estimates tend to be markedly larger around cyclical turning points (Koske and Pain, 2008; Orphanides and Van Norden, 1999) which is borne out by a comparison of output gap estimates for the G7 economies covering the immediate pre-crisis period until 2014 (see the tables in

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2. This involved dropping average hours, the use of standardised parameters for the wage share across countries and the introduction of human capital into the production function.

3. Taking the average of all absolute output gap revisions across successive vintages of estimates across all G7 countries, the largest revision occurs between *Economic Outlook* numbers 91 and 90, corresponding to the major change in potential output methodology discussed in the text.

Appendix 2). Output gap revisions tended to be positive especially for the immediate pre-crisis years, consistent with a tendency to revise potential output downwards following the crisis, in particular, the potential output estimates published in 2008 implied that output was close to potential in the preceding years, so output gaps were small. In the following years, downward revisions to potential output led to positive output gap revisions typically by about 2-3 percentage points for G7 economies (with the revisions being greater for Italy and less for Canada). Relatedly, there are numerous examples of the output gap estimates switching sign during the immediate pre-crisis period.

8. Revisions are also large in the immediate post-crisis period 2009-10, mostly in the direction of making the output gap less negative (consistent with a lowering of potential) although revisions are less systematic across countries; for Japan, France and the United Kingdom, the largest upwards revisions to the output gap are between 2-3 percentage points; for Italy and Canada, between 1-2 percentage points; for the United States, the largest revision is only about ½ percentage point; and Germany is the only country for which (relatively small) revisions tend to widen the negative output gap, consistent with upwards revisions to potential output.

9. Whilst it seems likely that important contributions to output gap revisions continue to come from revisions to actual GDP (as identified by Koske and Pain, 2008) and that methodological changes have also contributed, both the large magnitude and systematic nature of revisions across countries, both immediately before and after the crisis, suggest that methodological issues associated with filtering end-points are dominant over this period. Accordingly, the remainder of the paper examines alternatives to the standard OECD methodology which might help reduce such revisions.

3. Criteria for evaluating output gap estimates

10. While minimising revision to output gap estimates is certainly a desirable and necessary condition for them to be useful for policy purposes, it should not be the only criteria used to judge their usefulness. A simple example to illustrate this point compares output gap revision from using a

Hodrick-Prescott filter on quarterly US GDP using different smoothing parameters, (lambda). By using a lower value of lambda (16 rather than 1600) revisions are substantially reduced when comparing output gap estimates from a short sample and the full sample (Figure 2). However, the reduction in real-time revisions is achieved at the cost of a series for "potential output" which closely follows actual GDP, so implying potential growth is highly cyclical and unlikely to be useful for policy purposes (Figure 1). This trivial example serves to emphasise that real-time reliability should not be the only criteria for evaluating output gaps. Other criteria might include:

- Given that most definitions of potential output refer to a sustainable level of output consistent with stable inflation, an obvious criteria for evaluating output gaps is their ability to explain inflation.
- A further criteria for evaluating alternative methods of deriving potential output is whether they can be consistently applied across many countries. This partly reflects the viewpoint from an international organisation which routinely has to generate output gap estimates across many countries. In addition however, being able to apply the same method across different countries also provides a further test of the robustness of any method.
- Finally, although difficult to formulate formally, output gap estimates should also pass a "smell test" in that they don't depart too widely from what country experts believe to be plausible.

11. Bearing these criteria in mind, the following sections consider some variants to the standard OECD methodology to try to reduce such revisions.

Figure 1. US GDP growth

(quarter-on-quarter, annualised %)

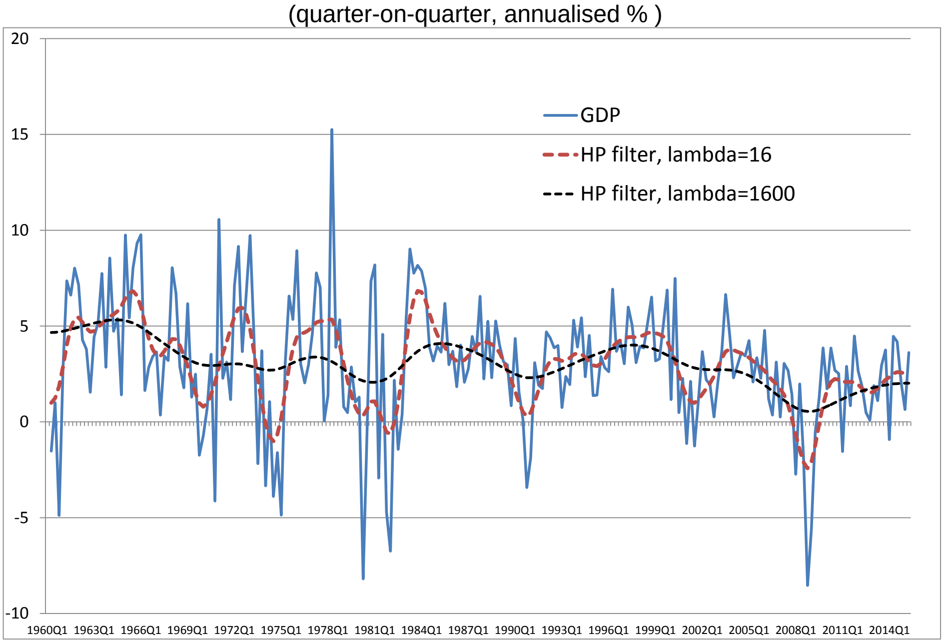
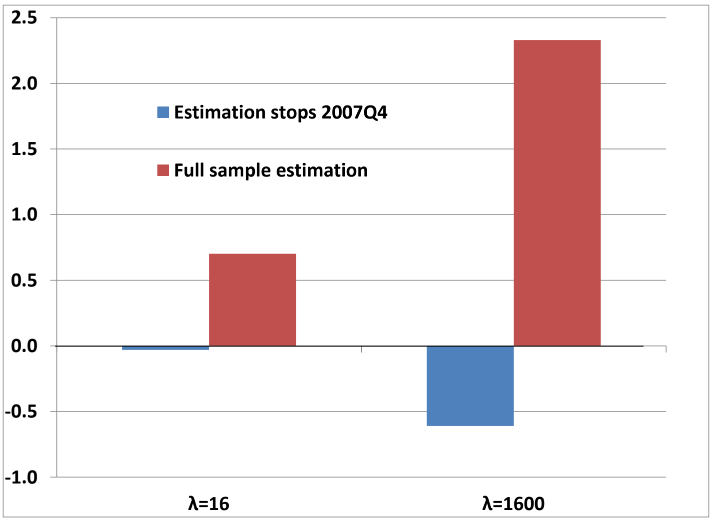


Figure 2. Estimates of the US Output Gap in 2007 Q4 using an HP filter



4. A multi-variate filter approach

12. One approach to better anchoring potential output estimates is to make use of additional information from other economic time series which can be formally incorporated through the use of multi-variate filters. The remainder of this section describes one such multi-variate filter to estimate potential output, using quarterly data, for the G7 economies, inspired by recent IMF work (Blagrave *et al.*, 2015), but with important differences as described below, most importantly the method is applied to quarterly rather annual data.

13. The process for potential output is described by equations (1) – (4). An important difference with the IMF approach is that instead of potential growth tending to a steady-state which is judgementally imposed at a particular constant value, it is influenced by a weighted average of the growth rate of the working-age population and the growth rate of the capital stock. This might be important, for example, if a country is experiencing a gradual decline in the growth rate of its working-age population, which, *ceteris paribus,* would be expected to reduce potential growth.

<u>Potential output equations</u>

$$y = Y - Y^* \tag{1}$$

$$Y_t^* = Y_{t-1}^* + G_t \tag{2}$$

$$G_t = \vartheta G_{t-1} + \gamma + (1 - \vartheta)\left(\tfrac{2}{3}\Delta PWA + \tfrac{1}{3}\Delta K\right) + \varepsilon_t^G \tag{3}$$

$$y_t = \varphi y_{t-1} + \varepsilon_t^y \tag{4}$$

where:
y = output gap
Y = log of real GDP
Y^* = log of potential GDP
G = potential growth
PWA= log of working-age population
K = log of capital stock

14. A centre-piece of the MVF is a Phillips curve equation (5), which follows closely the specification in Rusticelli *et al.* (2015). The specification assumes inflation expectations are anchored and

therefore constant over the estimation period, which implies the presence of an intercept term (τ) in the specification. The implied level of stable inflation expectations is then given by (τ/θ), and when there is an explicit central bank numerical objective for inflation the restriction that (τ/θ) is equal to this objective is imposed when consistent with the data. While the general specification is similar to that adopted in the IMF MVF, apart from the quarterly rather than annual frequency, there are number of other important differences: the dependent variable is core rather than headline inflation; supply shock variables are included (most importantly import inflation, but possibly also oil price inflation or dummies for indirect tax changes); and allowance is made for the introduction of explicit inflation targeting. One drawback of using this equation is that it has generally only been found to fit well from the period beginning in the mid- or late 1990's, so this limits the period over which the entire MVF can be estimated.

Phillips curve

$$\Delta\pi_t = \tau - \theta\pi_{t-1} - \alpha(L)\Delta\pi_{t-1} + \beta(y_{t-1}) + supply\ shocks + \varepsilon_t^{PC} \qquad (5)$$

where
π = Core CPI inflation

15. Finally, the system is completed with an Okun type relationship (6), linking the output gap and unemployment gap where the equilibrium value of the unemployment rate is determined using the standard OECD approach described in Rusticelli *et al* (2015). This requires a separate multi-variate model incorporating a Phillips curve where the equilibrium unemployment is treated as an unobserved component to be estimated.

Okun equation

$$u_t = \tau_1 u_{t-1} + \tau_2 u_{t-2} + \tau_3 y_t + + \tau_4 y_{t-1} + \varepsilon_t^u \qquad (6)$$

where
u = unemployment gap

16. In order for the model to be operational, assumptions need to be made about the variance of the error terms ε_t^G, ε_t^y , ε_t^{PC} and ε_t^u with results often being sensitive to these choices. While these variances do vary from country to country, a set of guidelines have been devised so as to form the basis of choosing the variances (see Appendix 3).

17. In order to examine the real-time reliability of this multi-variate approach, the focus is on revisions to output gap estimates around the turning points that occur as the sample is extended. Specifically the MVF is run over a sample ending in 2007 and then over the full sample, and the output gaps for 2007 are then compared across the two samples. As a benchmark, these revisions are compared with revisions resulting from a Hodrick-Prescott filter which produces *ex post* a similar degree of volatility in potential output growth to the MVF. The implied revisions to the output gap in 2007 using the MVF are relatively modest in absolute terms and in comparison to those of the HP filter, but with important differences across countries (Table 1 and Figure 3):

- For the United States, Japan and Germany, the MVF appears to anchor the output gap estimates well.
- For France and Italy, the upwards revisions of the output gap are larger at 0.9 and 2.2 percentage points, respectively, although these remain well below the corresponding revisions from the HP filter.
- For Canada and the United Kingdom, the modest extent of revisions in 2007, understates the extent of real-time revisions over the period 2000-7. In the case of Canada, such revisions average 2½ percentage points over the period 2000-7.

Table 1. The extent of real time revisions to the output gap and significance in explaining inflation

	Revision to 2007Q4 output gap		Significance of inflation	
	MVF, % points[1]	HP, % points[1]	Significance of GAP in Phillips curve[2]	Correlation of core inflation wrt GAP[3]
USA	0.8	3.6	***	***
JPN	0.1	2.3	*	***
DEU	0.2	2.1	**	
FRA	0.9	1.9	**	**
GBR	0.0	4.5	**	
ITA	2.2	3.4	***	***
CAN	-1.0	2.5	*	

Notes:
1) Difference between output gap in 2007Q4 based on full sample estimation and estimation ending in 2007.
2) Statistical significance of output gap term in Phillips curve over full sample.
3) Correlation coefficient of core CPI inflation with MVF output gap (over the full sample).
Statistical significance is denoted by "***", "**", "*" for significance at 1%, 5% and 10% level, respectively.

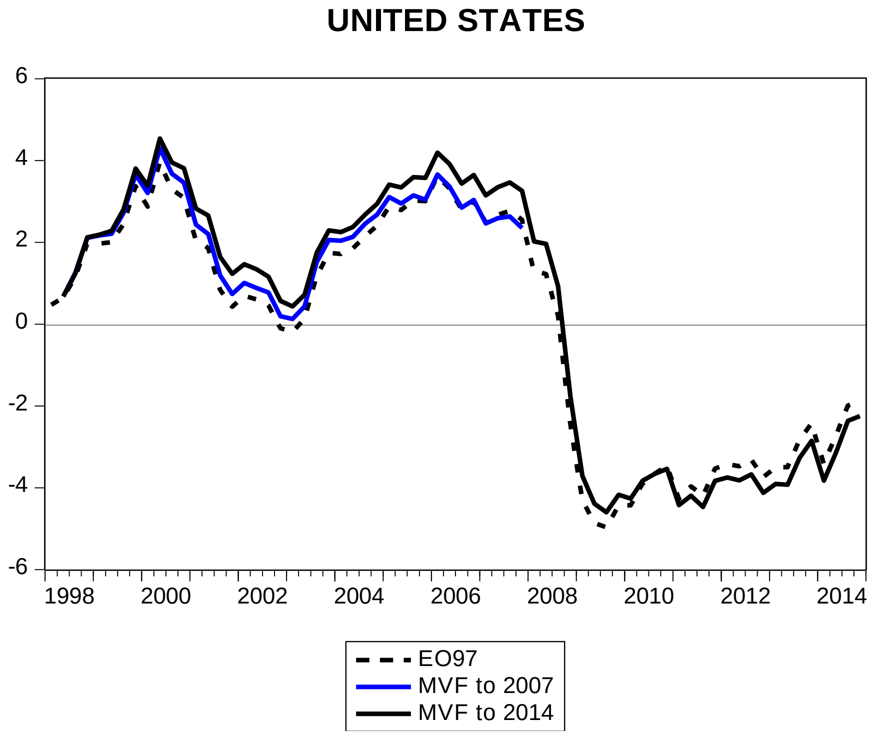
18. The extent to which the output gap is positively correlated with the core inflation also differs across countries (Table 1, third and fourth columns). The output gap is significant in the Phillips curve to at least the 5% level in all countries when estimated over the full sample, except for Japan and Canada. However, when estimated over a shorter sample ending in 2007, the output gap becomes insignificant also for the United Kingdom.

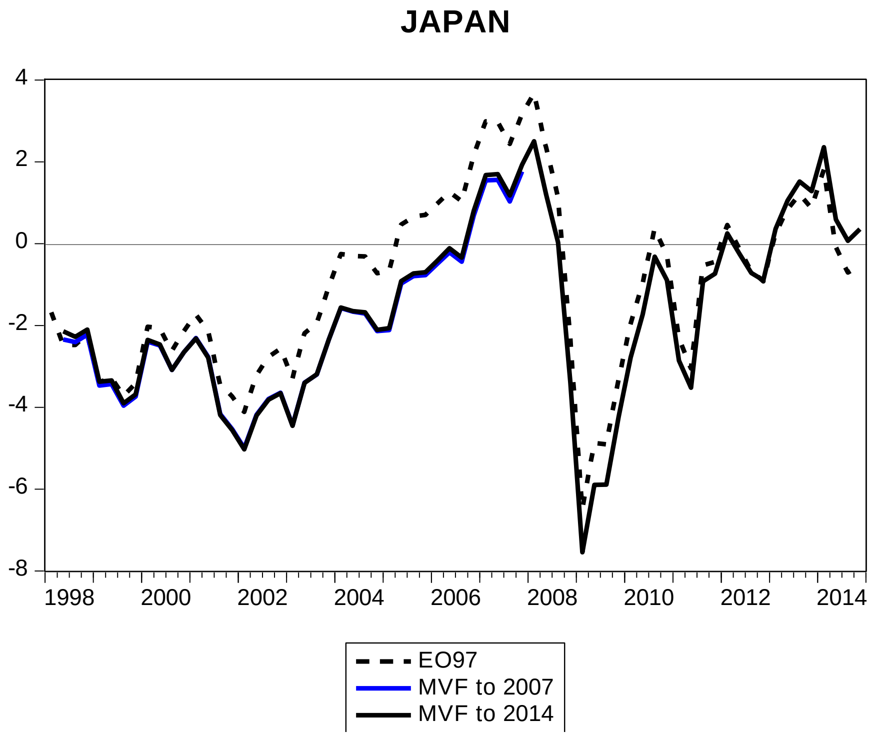
19. Finally, in order to provide a "smell test", the output gaps estimated over the full sample with the MVF can be compared with the latest vintage of OECD published output gaps. For the United States, Japan, France, Italy and Canada, the differences seem relatively small. There are, however, bigger differences for the other two countries:

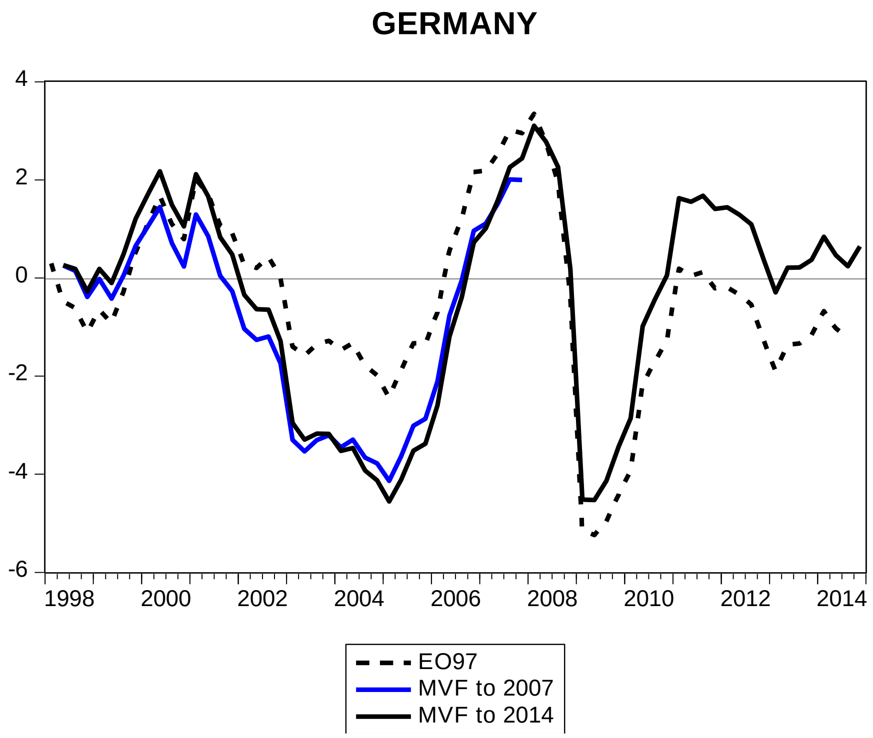
- For Germany, the MVF filter would suggest a mostly positive output gap since 2011, whereas the published output gap is mostly negative;
- For the United Kingdom, the whole profile of potential output is much lower leading to a much more positive output gap. However, the magnitude of both the peak pre-crisis MVF output gap (of

nearly 6%) and the post crisis trough (of only -2%) are so different from the published *Economic Outlook* estimates as to raise questions to their credibility.

Figure 3. Estimated Output Gaps



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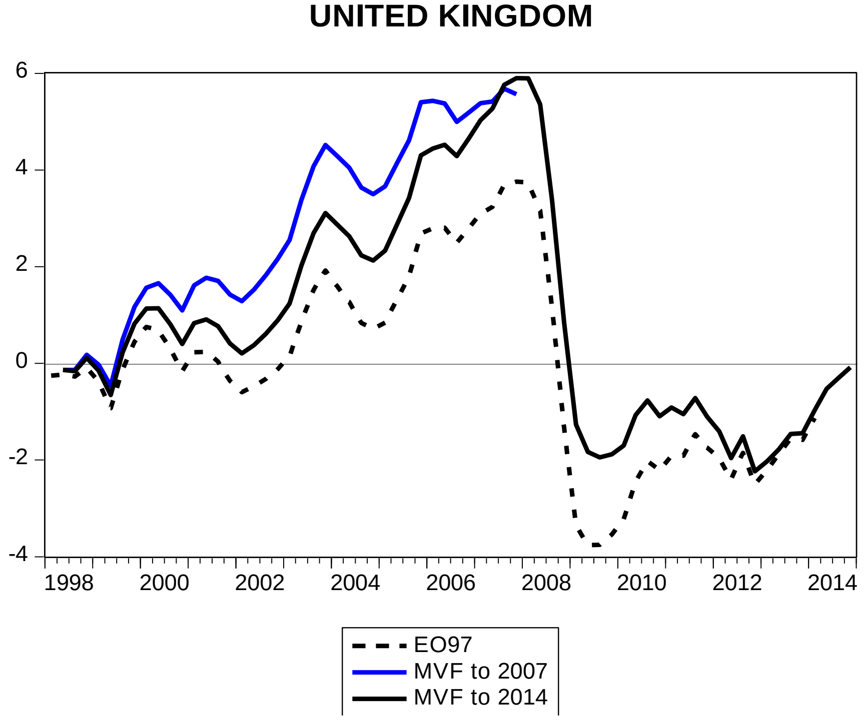
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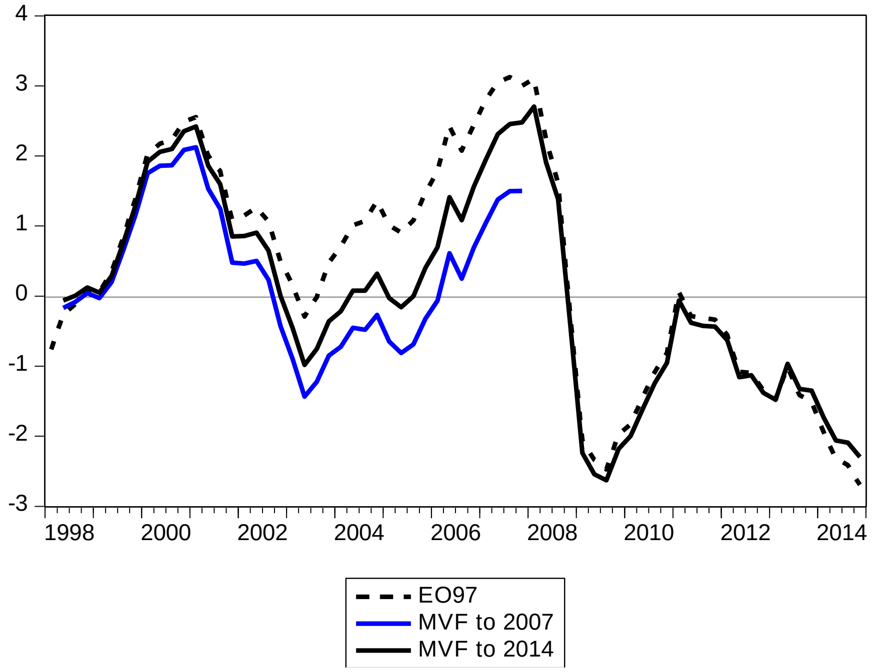
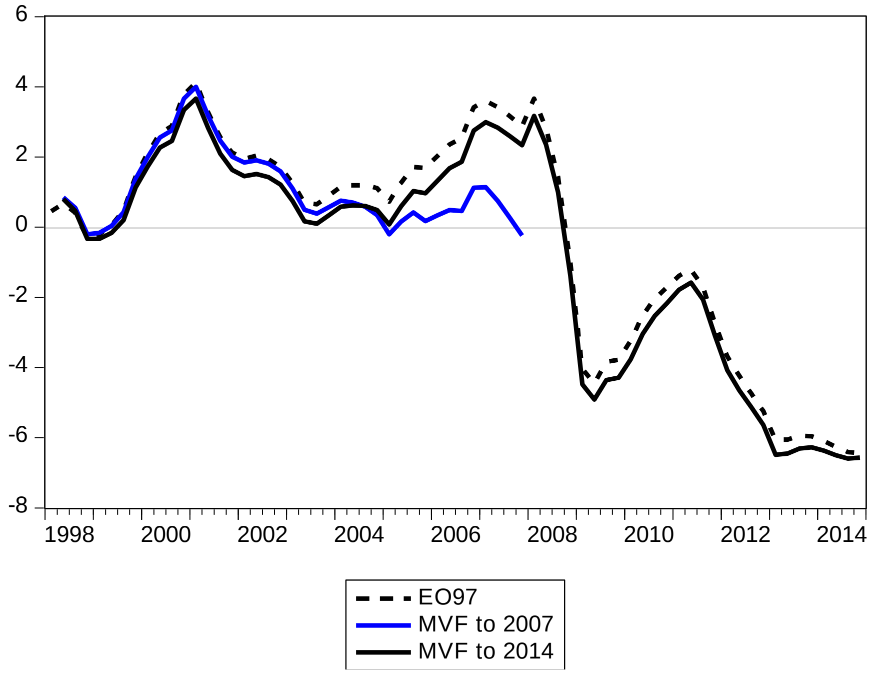
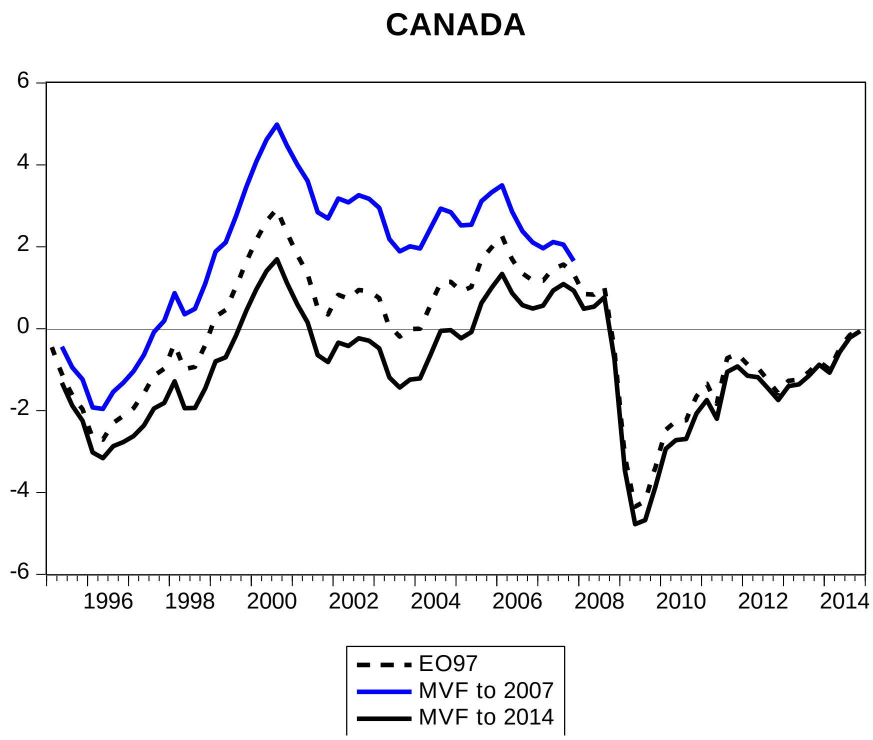


ITALY





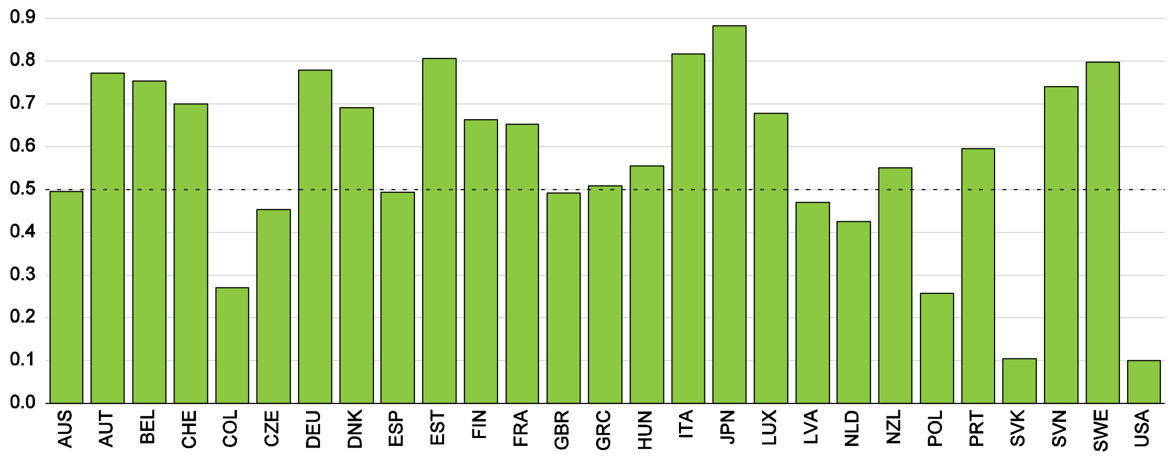
5. Using survey measures of capacity utilisation

20. Another approach to reducing real-time revisions is to make use of survey-based measures of manufacturing capacity utilisation. These are attractive because they measure a similar concept to the output gap and are available on a timely basis. On the other hand, such series only relate to manufacturing industry which only accounts for a small and shrinking share of most OECD countries' GDP. Moreover, survey measures of capacity utilisation are not readily available for all countries. Thus, it should largely be an empirical question as to whether capacity utilisation should be incorporated into potential output methodology.

21. The approach taken here follows the European Commission (Havik *et al.*, 2014) in investigating whether capacity utilisation is useful in stabilising estimates of the labour efficiency/tfp gap. The potential gains from using measures of capacity utilisation are likely to be greater where there is a stronger correlation with measures of the labour efficiency gap (the difference between filtered trend labour

efficiency and actual labour efficiency), although there is considerable difference across countries as shown in Figure 4. Among the G7 countries, the correlation is highest for Japan, Germany and Italy, whereas it is much lower for the United Kingdom and United States. Confirmation that capacity utilisation is likely to be more useful for some countries than others comes from a regression in which the most recent estimate of the output gap is regressed on a constant, the initial real-time estimate of the output gap and the survey measure of capacity utilisation. In this form of regression, the only countries among the G7 in which capacity utilisation helps to explain the final estimate of the output gap are Japan and Germany, whereas for the United States and United Kingdom, the capacity utilisation variable is wrongly signed.

Figure 4. Correlation between survey measures of capacity utilisation and the labour efficiency gap



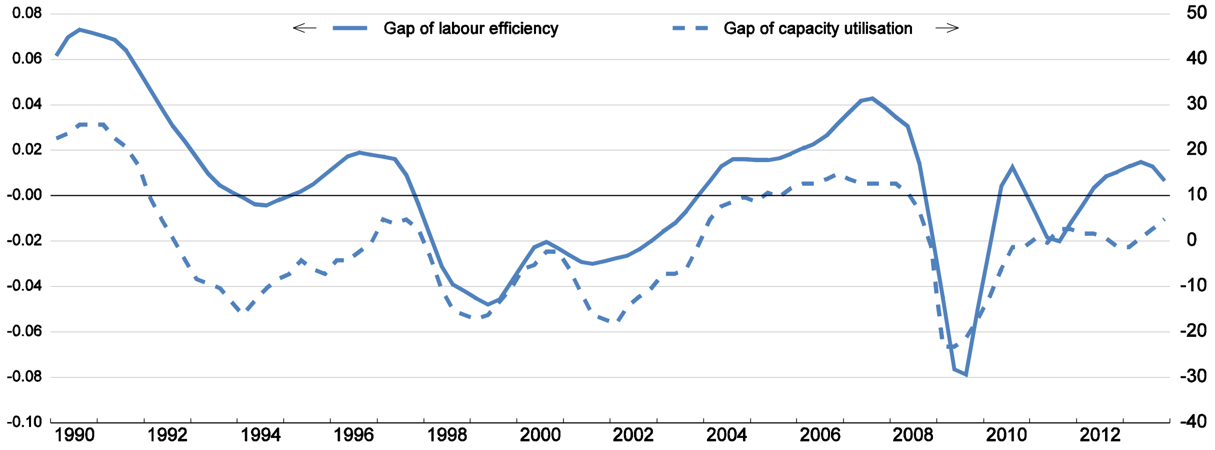
Note: Sample periods differ according to data availability, but end in 2013.

Source: OECD Economic Outlook 97 database; and MEI database.

22. The benefits of using capacity utilisation when the correlation with the labour efficiency gap is high are illustrated for the case of Japan (Figure 5). The first stage is a simple regression of an initial estimate of the labour efficiency gap (e – e*), and demeaned capacity utilisation (CAPU): $(e - e^*) = \alpha + \beta$ CAPU. Instead of HP filtering 'raw' (logged) labour efficiency, e, the filter is applied to capacity-adjusted labour efficiency, (e - β CAPU). The adjusted series is by construction less cyclical than the raw series,

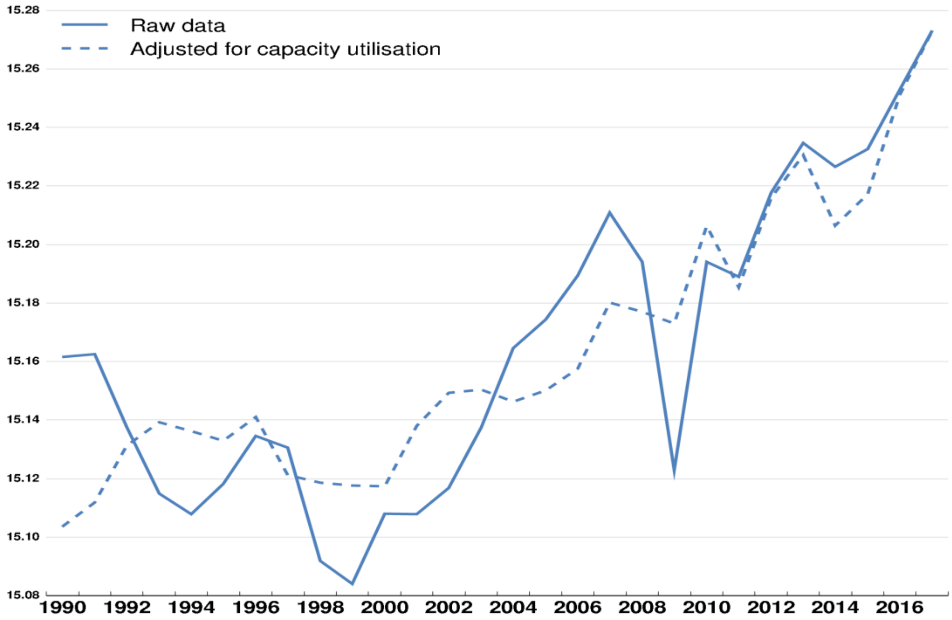
and so is likely to be a better basis for estimating the trend. This advantage may be particularly important if the estimation period ends in a cyclical peak or trough. For example, the real-time experiments considered in the previous section are rerun on the raw labour efficiency data with an HP filter (lambda of 78), then extending the sample from 2007 to the full sample leads to a large upwards revision in the labour-efficiency gap from 1.7 to 4.0 percentage points. Conversely, if capacity-adjusted labour-efficiency gap is HP filtered (using the same lambda) the revision to the labour efficiency gap is relatively minor, from 4.4 to 4.2 percentage points.

Figure 5. Labour efficiency gap and capacity utilisation for Japan



Source: *OECD Economic Outlook* 97 database; and MEI.

Figure 6. The adjustment of logged labour efficiency using capacity utilisation for Japan



Source: OECD.

6. Tentative conclusions

23. Revisions to OECD estimates of the output gap following the financial crisis have been substantial. While previous work suggests that revisions to GDP data have likely contributed to this, as have changes in the methodology for calculating potential output, the magnitude and systematic nature of gap revisions around the crisis strongly suggest that end-point problems associated with filtering have been the major contribution to the revisions over this period.

24. While small real-time revisions might be a necessary condition for having confidence in estimated output gaps, they should not be the only criteria used to judge their policy-usefulness. An easy way to reduce real-time revisions is to adopt a method such that potential output more closely follows actually GDP. However, a highly cyclical measure of potential output is unlikely to be useful for policy purposes. This underlines that other criteria should also be used to judge the usefulness of output gaps, in

particular, their ability to explain inflation. The robustness of potential output methodologies should also be judged according to how easily they can be applied across different countries, as well as how plausible the resulting estimates are against the judgement of country experts.

25. The current paper explores two possible ways of reducing revisions due to end-point problems, although with only partial success. The use of a multi-variate filter which incorporates information on inflation (via a Phillips curve) and unemployment (via an Okun relationship) does reduce real-time revisions relative to an HP filter. However, there are problems with this approach, notably when the Phillips curve fits poorly; this includes a profile for the UK output gap which is not credible and large real-time revisions to the output gap for Canada over the pre-crisis period. It is also difficult to apply the MVF in exactly the same way, with a common basis for choosing the variance of error terms, across all countries,

26. Similarly, an adjustment to the labour efficiency gap based on survey measures of capacity utilisation appears to work well in reducing real-time revisions for some countries where there is a strong correlation of the labour-efficiency gap with capacity utilisation. However, such an adjustment is not appropriate or possible for more than half of the OECD countries where measures of capacity are either unavailable or poorly correlated with the labour-efficiency gap.

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APPENDIX 1: ESTIMATION OF POTENTIAL OUTPUT

Estimates of potential output are based on an aggregate production function approach using trend input components. For all countries a whole economy approach is employed using a commonly specified production function, namely a constant-returns-to-scale Cobb-Douglas production function with Harrod-neutral labour-augmenting technical progress, which can be represented as the following, using mnemonics as they appear in ADB and EO databases:

$$GDPV = (EFFLAB * ET)^{\alpha} (KPTV)^{1-\alpha} \qquad \text{[A1-1]}$$

where: *ET* denotes total employment (the national account measure where available otherwise a labour force survey based measure); *KPTV* represents the whole economy measure of productive capital (where the source of capital stock data differs between countries as shown in Table A1.1); *EFFLAB* represents labour efficiency, which is not directly observable and is therefore calculated as a residual; and α is assumed to be 0.67 for all countries.

Total employment can be decomposed into the product of: the rate of participation for those aged 15-74 (*LFPR1574*); the population aged 15-74 (*POP1574*); (one minus) the rate of unemployment (*UNR*); and an adjustment to ensure consistency between the labour force definition of employment and the population measure.

$$ET = POP1574 * LFPR1574 * CLF * (1 - UNR) \qquad \text{[A1-2]}$$

Combining [A1-1] and [A1-2], the representation of output becomes:

$$GDPV = (EFFLAB * POP1574 * LFPR1574 * CLF * (1 - UNR))^{\alpha} (KPTV)^{1-\alpha} \qquad \text{[A1-3]}$$

Thus, the level of potential *GDPVTR* is calculated by substituting trend variables in [A1-3], with the exception of capital (which remains at its actual value). The trend level of unemployment (*NAIRU*) is estimated using a Kalman filter within the context of a Phillips curve equation with anchored inflation expectations (see Rusticelli et al, 2015). The trend rate of participation (*LFPRS1574*) is determined by a combination of piece-wise linear regressions on age and gender cohorts and the unemployment gap, which are then filtered. Trend labour efficiency is computed with an HP filter, with historical data extended with projections to try to limit end-point bias.

$$GDPVTR = (EFFLABS * POPS1574 * LFPRS1574 * CLFS * (1 - NAIRU))^{\alpha} (KPTV)^{1-\alpha} \qquad \text{[A1-4]}$$

Where *EFFLABS*, *LFPRS1574*, *POPS1574*, and *CLFS* are the trended counterparts of *LEFFLAB*, *LFPR1500*, *POP1500* and CLF, respectively. Thus equation [A1-4] relates the evolution of potential output to trends in labour efficiency, the quantity of labour or potential employment and capital input.

Table A1.1 Sources of capital stock data

Data from OECD Statistics Directorate	AUS, AUT, BEL, CAN, CHE, DEU, DNK, ESP, FIN, FRA, GBR, IRL, ITA, JPN, KOR, NLD, NZL, PRT, SWE, USA
Constructed using a Perpetual Inventory Method	GRC, CHL, COL, CZE, HUN, ISL, ISR, LVA, LUX, MEX, NOR, POL, SWE, SVK, SVN, TUR, RUS, ARG, BRA, IDN, IND, SAU
Obtained from national sources	CHN, ZAF

APPENDIX 2. VINTAGES OF PUBLISHED OECD OUTPUT GAPS FOR THE G7

The following tables show vintages of output gaps for each of the G7 economies which have been published in successive *OECD Economic Outlooks*. The vintages of estimates are shown in each row of the table, where the heading of the row "EOXX" denotes the number "XX" of the *Economic Outlook* which is published twice a year, in May/June and November/December and begins with the November 2005 issue (EO78) and finishes with the May 2015 issue (EO97). The output gap estimates shown are only those for which at least an initial outturn estimate for GDP would have been available at the time, for example, for the *Economic Outlook* published in May 2015 only the output gap up to 2014 is shown.

At the foot of the table is a summary of the revisions for each year. For any particular output gap estimate the revision is calculated as the difference between it and the estimate for the same year in the latest vintage (EO97). The average revision is then calculated as the average revision across all vintages shown. The largest revision is the largest revision in the absolute terms across all vintages. A final row notes where there has been a switch in the sign of the output gap across vintages.

United States

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
EO97	2.1	3.0	3.2	2.7	0.1	-4.5	-3.8	-3.9	-3.4	-3.0	-2.5
EO96	2.1	3.1	3.3	2.7	0.0	-4.7	-4.0	-4.2	-3.7	-3.4	
EO95	1.9	2.8	3.1	2.4	-0.2	-4.8	-4.2	-4.2	-3.4	-3.5	
EO94	2.0	3.0	3.3	2.8	0.3	-4.2	-3.5	-3.4	-2.6		
EO93	1.9	2.7	3.2	2.9	0.5	-4.2	-3.4	-3.4	-3.0		
EO92	2.0	2.7	3.0	2.6	0.1	-4.6	-4.0	-4.0			
EO91	2.1	2.8	3.1	2.8	0.2	-5.0	-3.7	-3.9			
EO90	1.4	2.3	2.7	2.5	0.2	-4.9	-3.7				
EO89	0.7	1.4	1.6	1.2	-0.8	-5.0	-3.8				
EO88	0.7	1.4	1.7	1.3	-0.7	-4.6					
EO87	0.7	1.2	1.3	0.9	-1.2	-5.1					
EO86	0.2	0.8	1.1	1.0	-0.9						
EO85	0.1	0.7	1.2	0.9	-0.5						
EO84	0.6	1.0	1.2	0.7							
EO83	0.0	0.5	0.7	0.4							
EO82	-0.1	0.4	0.7								
EO81	-0.4	0.1	0.7								
EO80	-0.6	-0.1									
EO79	-0.6	0.0									
EO78	-0.8										
Revision summary											
Average	**1.3**	**1.5**	**1.2**	**0.9**	**0.3**	**0.2**	**0.0**	**-0.1**	**-0.2**	**0.5**	
Largest	**2.8**	**3.1**	**2.6**	**2.3**	**1.3**	**0.6**	**0.4**	**-0.5**	**-0.8**	**0.5**	
Sign switch	**Y**	**Y**	**N**	**N**	**Y**	**N**	**N**	**N**	**N**	**N**	

Japan

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
EO97	-0.4	0.3	1.4	2.9	1.2	-4.8	-0.7	-1.6	-0.3	0.8	0.1
EO96	-0.4	0.3	1.4	2.9	1.2	-4.8	-0.8	-1.7	-0.7	0.2	
EO95	-0.4	0.3	1.4	3.0	1.3	-4.6	-0.6	-1.5	-0.7	0.2	
EO94	-0.4	0.3	1.4	3.0	1.3	-4.8	-0.9	-2.1	-0.9		
EO93	-0.4	0.3	1.4	3.0	1.3	-4.8	-0.9	-2.0	-0.8		
EO92	-0.4	0.2	1.2	2.8	1.0	-5.0	-1.3	-2.8			
EO91	0.1	0.8	1.8	3.4	1.6	-4.5	-0.8	-2.2			
EO90	-1.1	-0.1	1.2	3.0	1.1	-5.7	-3.2				
EO89	-1.1	-0.3	0.9	2.5	0.6	-6.4	-3.6				
EO88	-1.2	-0.3	0.8	2.4	0.4	-5.3					
EO87	-1.2	-0.3	0.7	2.2	0.1	-5.5					
EO86	-0.6	0.4	1.7	3.5	2.3						
EO85	-0.5	0.8	2.0	3.3	1.3						
EO84	-1.2	-0.5	0.7	1.6							
EO83	-1.4	-0.9	0.0	0.5							
EO82	-1.5	-0.9	-0.2								
EO81	-1.6	-1.2	-0.6								
EO80	-2.1	-1.0									
EO79	-1.9	-0.8									
EO78	-1.5										
Revision summary											
Average	**0.6**	**0.5**	**0.4**	**0.3**	**0.1**	**0.4**	**0.8**	**0.5**	**0.5**	**0.6**	
Largest	**1.7**	**1.5**	**1.9**	**2.4**	**1.1**	**1.6**	**2.9**	**1.2**	**0.6**	**0.6**	
Sign switch	**Y**	**Y**	**Y**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	

Germany

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
EO97	-1.6	-1.7	0.8	2.7	1.9	-4.8	-2.2	0.0	-0.6	-1.4	-0.9
EO96	-1.3	-1.4	1.1	3.0	2.2	-4.6	-2.1	0.2	-0.5	-1.3	
EO95	-2.2	-2.3	0.2	2.2	1.7	-4.5	-1.8	0.3	0.1	-0.6	
EO94	-2.2	-2.3	0.2	2.2	1.6	-4.5	-1.9	0.2	-0.1		
EO93	-1.7	-1.9	0.7	2.6	2.0	-4.2	-1.4	0.5	0.1		
EO92	-1.6	-1.9	0.5	2.4	1.6	-4.8	-2.1	-0.5			
EO91	-1.6	-1.8	0.6	2.5	1.7	-4.6	-2.3	-0.7			
EO90	-2.5	-2.6	0.2	2.2	1.6	-4.5	-2.3				
EO89	-2.2	-2.1	0.4	1.9	1.1	-4.7	-2.5				
EO88	-2.0	-2.0	0.3	1.6	0.6	-5.2					
EO87	-1.8	-1.7	0.4	1.5	0.9	-5.2					
EO86	-1.6	-1.3	1.1	2.6	2.4						
EO85	-1.6	-1.3	1.0	2.6	1.9						
EO84	-1.6	-1.8	0.1	1.2							
EO83	-2.0	-2.3	-0.6	0.5							
EO82	-2.1	-2.6	-1.0								
EO81	-2.0	-2.4	-0.9								
EO80	-1.8	-2.2									
EO79	-1.5	-1.9									
EO78	-1.6										
Revision summary											
Average	0.2	0.3	0.6	0.6	0.3	-0.1	-0.2	0.0	-0.5	-0.5	
Largest	0.9	0.9	1.9	2.2	1.3	-0.6	-0.9	0.7	-0.7	-0.8	
Sign switch	N	N	Y	N	N	N	N	Y	Y	N	

France

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
EO97	1.0	1.1	2.2	3.0	1.7	-2.2	-1.3	-0.2	-1.0	-1.3	-2.3
EO96	1.1	1.1	2.2	3.0	1.7	-2.2	-1.3	-0.2	-0.8	-1.4	
EO95	1.3	1.7	2.9	3.6	1.8	-2.2	-1.6	-0.8	-2.0	-2.9	
EO94	1.0	1.4	2.6	3.3	1.5	-2.5	-1.9	-1.2	-2.3		
EO93	1.2	1.6	2.8	3.5	1.8	-2.3	-1.8	-1.3	-2.4		
EO92	1.3	1.6	2.6	3.2	1.4	-2.7	-2.3	-2.0			
EO91	1.2	1.5	2.5	3.0	1.1	-3.0	-2.7	-2.5			
EO90	-0.2	-0.1	0.9	1.4	-0.4	-3.9	-3.6				
EO89	-0.4	-0.2	0.4	0.8	-0.6	-4.3	-4.1				
EO88	-0.4	-0.2	0.4	1.0	-0.4	-3.8					
EO87	-0.4	-0.3	0.3	0.7	-0.6	-4.5					
EO86	0.0	0.3	1.1	1.8	0.4						
EO85	-0.1	0.2	1.1	1.8	0.2						
EO84	-0.3	-0.1	0.7	0.9							
EO83	-0.4	-0.4	0.1	0.3							
EO82	-0.3	-0.6	-0.3								
EO81	-1.4	-1.9	-1.6								
EO80	-1.4	-2.0									
EO79	-1.3	-1.8									
EO78	-1.2										
Revision summary											
Average	1.1	1.0	1.0	1.0	1.0	0.9	1.1	1.1	0.9	0.8	
Largest	2.4	3.2	3.8	2.7	2.3	2.3	2.8	2.3	1.4	1.6	
Sign switch	Y	Y	Y	N	Y	N	N	N	N	N	

Italy

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
EO97	1.2	1.4	2.6	3.3	1.8	-3.9	-2.4	-1.7	-4.4	-5.8	-6.1
EO96	1.3	1.3	2.4	3.2	1.6	-4.1	-2.4	-1.9	-3.9	-5.6	
EO95	0.8	0.9	2.4	3.2	1.5	-4.3	-2.8	-2.3	-4.3	-5.6	
EO94	0.9	1.1	2.5	3.3	1.5	-4.3	-2.8	-2.4	-4.6		
EO93	1.0	1.1	2.5	3.3	1.6	-4.2	-2.8	-2.4	-4.5		
EO92	1.2	1.3	2.6	3.3	1.5	-4.4	-2.9	-2.8			
EO91	0.9	0.9	2.3	3.0	1.2	-4.6	-3.1	-2.8			
EO90	0.3	0.7	2.3	3.3	1.5	-3.7	-2.2				
EO89	-0.1	0.2	1.6	2.2	0.4	-4.9	-3.6				
EO88	-0.5	-0.3	1.0	1.5	-0.4	-5.5					
EO87	-0.6	-0.4	1.0	1.6	-0.3	-5.5					
EO86	-0.7	-0.5	0.9	1.5	-0.6						
EO85	-0.8	-0.7	0.7	1.2	-0.9						
EO84	-0.5	-0.8	-0.2	0.2							
EO83	-0.9	-1.5	-1.1	-1.2							
EO82	-1.5	-2.4	-1.7								
EO81	-1.2	-2.4	-1.8								
EO80	-0.3	-1.5									
EO79	-0.3	-1.4									
EO78	-0.3										
Revision summary											
Average	1.2	1.6	1.5	1.2	1.0	0.6	0.5	0.7	-0.1	-0.2	
Largest	2.6	3.8	4.4	4.5	2.7	1.5	1.3	1.1	-0.5	-0.3	
Sign switch	Y	Y	Y	Y	Y	N	N	N	N	N	

United Kingdom

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
EO97	1.1	1.7	2.8	3.5	1.7	-3.5	-2.4	-1.7	-2.2	-1.8	-0.8
EO96	1.3	1.8	2.8	3.5	1.5	-3.7	-2.7	-2.0	-2.4	-1.9	
EO95	0.9	2.0	3.0	4.9	2.6	-3.4	-2.5	-2.1	-2.8	-2.4	
EO94	0.9	2.0	3.0	4.9	2.6	-3.3	-2.3	-1.9	-2.7		
EO93	1.1	1.7	2.4	4.4	1.9	-2.9	-1.8	-1.5	-2.1		
EO92	1.2	1.7	2.5	4.4	2.0	-2.8	-1.7	-1.4			
EO91	1.6	1.6	2.5	4.4	1.8	-3.5	-2.4	-2.6			
EO90	1.6	1.4	1.8	3.2	0.7	-4.4	-3.5				
EO89	1.2	1.3	2.0	2.7	1.1	-4.6	-3.6				
EO88	1.0	1.0	1.8	2.6	1.0	-5.0					
EO87	1.0	0.9	1.5	1.8	0.1	-6.4					
EO86	1.0	0.9	1.5	1.8	0.0						
EO85	0.7	0.5	1.1	1.9	0.4						
EO84	0.5	0.0	0.4	1.3							
EO83	0.9	-0.3	-0.2	0.2							
EO82	0.7	-0.1	0.0								
EO81	0.6	-0.1	-0.2								
EO80	0.6	-0.3									
EO79	0.6	-0.5									
EO78	0.5										
Revision summary											
Average	**0.2**	**0.8**	**1.1**	**0.5**	**0.4**	**0.5**	**0.1**	**0.2**	**0.3**	**0.4**	
Largest	**0.7**	**2.2**	**2.9**	**3.3**	**1.7**	**2.8**	**1.1**	**0.9**	**0.7**	**0.6**	
Sign switch	**N**	**Y**	**Y**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	

Canada

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
EO97	0.7	1.4	1.6	1.4	0.5	-3.7	-2.1	-1.1	-1.2	-1.1	-0.5
EO96	1.0	1.7	2.0	1.8	1.0	-3.1	-1.5	-0.4	-0.4	-0.2	
EO95	1.2	1.9	2.2	2.0	1.2	-3.0	-1.4	-0.7	-0.9	-0.8	
EO94	1.2	1.9	2.2	2.0	1.3	-2.9	-1.2	-0.4	-0.5		
EO93	1.3	1.9	2.2	2.2	1.4	-2.8	-1.2	-0.4	-0.4		
EO92	1.3	1.9	2.2	2.1	1.2	-2.9	-1.4	-0.7			
EO91	1.4	1.9	2.4	2.4	1.1	-3.1	-1.5	-1.1			
EO90	0.9	1.3	1.5	1.3	-0.1	-4.4	-2.8				
EO89	0.6	0.9	1.0	0.7	-1.1	-5.2	-3.9				
EO88	0.7	0.9	0.9	0.7	-0.9	-5.1					
EO87	0.7	0.9	0.9	1.0	-1.0	-5.3					
EO86	0.8	1.2	1.3	1.6	-0.2						
EO85	0.4	0.9	1.2	1.5	-0.4						
EO84	0.6	0.8	1.3	1.6							
EO83	0.4	0.5	0.4	0.2							
EO82	0.5	0.6	0.6								
EO81	0.5	0.4	0.0								
EO80	0.5	0.4									
EO79	0.2										
EO78	0.1										
Revision summary											
Average	**0.0**	**0.3**	**0.2**	**-0.1**	**0.2**	**0.1**	**-0.3**	**-0.5**	**-0.6**	**-0.6**	
Largest	**0.6**	**1.4**	**1.6**	**1.2**	**1.6**	**1.7**	**1.8**	**-0.8**	**-0.8**	**-0.9**	
Sign switch	**N**	**Y**	**N**	**N**	**Y**	**N**	**N**	**N**	**N**	**N**	

APPENDIX 3. DETAILS OF THE MULTI-VARIATE FILTER ESTIMATION

Detailed estimation results

Phillips Curve estimation

	USA		JPN		DEU		FRA		ITA		GBR		CAN	
Dependent variable $\Delta\pi$	1998Q3-2014Q4		1998Q4-2014Q4		1998Q3-2014Q4		1998Q2-2014Q4		1998Q2-2014Q4		1998Q3-2014Q4		1995Q2-2014Q4	
	COEF	*PVALUE*	*COEF*	*PVALUE*	*COEF*	*PVALUE*	*COEF*	*PVALUE*	*COEF*	*PVALUE*	*COEF*	*PVALUE*	*COEF*	*PVALUE*
Cst	0.318	0.000	-0.065	0.147										
$\Delta\pi(-1)$	-0.863	0.000			-0.677	0.000	-0.858	0.000	-0.986	0.000	-0.708	0.000	-0.843	0.000
$\Delta\pi(-2)$					-0.481	0.001	-0.253	0.067			-0.620	0.000		
$\Delta\pi(-3)$					-0.216	0.075					-0.607	0.000		
$\Delta\pi(-4)$											-0.640	0.000		
$\Delta\pi(-5)$											-0.624	0.000		
$\pi(*)$	-0.801	0.000	-0.962	0.000	-0.124	0.173	-0.088	0.277	-0.860	0.000	-0.364	0.014	-0.809	0.000
$Y\text{-}Y^*$							0.031	0.030	0.031	0.000			0.029	0.027
$Y(-1)\text{-}Y^*(-1)$	0.018	0.002			0.018	0.060					0.026	0.030		
$Y(-2)\text{-}Y^*(-2)$			0.026	0.097										
$\omega^m *(\pi^m - \pi(-1))$	0.176	0.000							0.030	0.481	0.176	0.000		
$\omega^m(-1)*(\pi^m - \pi(-1))$							0.011	0.837						
$\omega^{oil} *(\pi^{oil} - \pi(-1))$											0.166	0.030		
Dummies					2004						VAT			
Adj R2	0.509		0.488		0.361		0.490		0.500		0.153		0.427	

Note: $\Delta\pi$ is the change in Q-o-Q core CPI inflation for all countries except for the United Kingdom, for which headline CPI inflation has been chosen. $\pi(*)$ is the level-term of inflation, whose lag follows the number of lags of the change in inflation. Y and Y* represent the logarithm of actual GDP and of potential GDP, respectively. $\omega^m *(\pi^m - \pi(-1))$ indicates the real import price inflation weighted by import penetration and $\omega^{oil} *(\pi^{oil} - \pi(-1))$ indicates real oil price inflation weighted by oil intensity of production.

Variance assumptions underlying the multi-variate filter

The error terms in the multi-variate filter are all assumed to be normally distributed with zero-mean, and while their variance differs across countries, an attempt has been made to follow a common set of rules as follows:

- The variance of the stochastic term in the AR(1) process for the output gap, $\sigma^2_{\varepsilon^y}$, is assumed to be equal to the observed quarterly volatility of real output growth over the estimation sample.
- The variance of the error in the Phillips Curve equation (ε_t^{PC}) is assumed to be equal to 0.03 times the variability of the corresponding variance of ε_t^y, thus implying a signal-to-noise ratio for the Kalman filter of the output gap of 0.03 for all countries.
- For four countries (USA, DEU, GBR and DEU), the variance of the disturbance term in the Okun's relationship (ε_t^u) is set equal to the residual variance of an equivalent relationship estimated with previously published OECD measures of the output and unemployment gap. For

three countries (ITA, JPN, FRA) this approach produced unsatisfactory results and so no constraint was placed on the variance which was freely estimated.

- Finally, the parameter $\sigma^2_{\varepsilon G}$, governing the stochastic behaviour of potential growth, is equal to the variance of the error term from a regression of published estimates of potential growth on $\frac{2}{3}\Delta PWA + \frac{1}{3}\Delta K$.

Table A3.1. Assumed variances for the shock terms of the multivariate filter models, by country

	ITA	JPN	FRA	CAN	USA	DEU	GBR
$\sigma^2_{\varepsilon G}$	0.0008	0.0001	0.0005	0.0005	0.0001	0.002	0.01
$\sigma^2_{\varepsilon y}$	0.5	1.2	0.27	0.38	0.41	0.7	0.34
$\sigma^2_{\varepsilon PC}$	0.02	0.04	0.01	0.01	0.01	0.022	0.01
$\sigma^2_{\varepsilon u}$	endogenous	endogenous	endogenous	0.04	0.04	0.01	0.1