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STRUCTURAL BREAKS IN POTENTIAL GDP OF THREE MAJOR ECONOMIES: JUST IMPAIRED CREDIT OR THE "NEW NORMAL"?[3]

This paper investigates the factors behind the recent growth slowdown (so-called Secular Stagnation) in the US, the euro area and Japan using the metrics of potential output growth. Specifically, our results offer limited support for an impaired credit transmission channel hypothesis (Reinhart and Rogoff, 2009a), while not supporting a supply slowdown hypothesis (Gordon, 2012). We propose a unified framework to test those hypotheses based on structural break tests of potential output. We estimate a variety of potential output growth models accounting for inflation, unemployment, and private credit dynamics (finance-neutral estimates) with multivariate Kalman filters and subject our estimates to structural break tests. We detect structural breaks between 2008 and 2010 for all three countries with Bai-Perron search procedure, the result being robust to the model specification and sample choice, with no significant difference between ordinary and finance-neutral estimates. We proceed with the Chen-Liu test to detect negative temporary change outliers in the Great Recession for the US and the euro area and negative level shift outliers for Japan. Moreover, original breaks in the Chen-Liu test disappear in the US and the euro area once we account for private credit and labour market dynamics, but do not change for Japan.

JEL Classification: C53, E17, F44, O57

Keywords: New Normal, Secular Stagnation, Great Slump, potential GDP, Kalman filter, Bai-Perron test, Chen-Liu test

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1. Introduction

World GDP grew at 4.0% on average between 2010 and 2014 against 5.1% between 2003 and 2008. According to the IMF, the global economy is set to grow even more slowly in 2015, the prediction being 3.1%. This underperformance after the global economic crisis is often considered a sign of transition to a new trend of economic growth.

Academics and practitioners offer different names for this new trend. Gross (former PIMCO) coined the term The New Normal in 2009, forecasting a period of sluggish economic growth for a period between 2010 and 2015. The Second Great Contraction (Reinhart and Rogoff, 2009b), The Great Slump (Hall, 2011), and, finally, Secular Stagnation (Summers, 2014) have been offered along with several interpretations of the growth slowdown. Fischer (2014) points out the absence of a single opinion on the nature of a current slowdown, despite plenty of available post-crisis data, and emphasizes distinguishing a cyclical slowdown from a structural one as the key to successful macroeconomic policy.

The literature distinguishes between cyclical and structural slowdown using the concept of potential (or trend) output[4]. In line with the literature we treat a structural slowdown as a decrease in the potential GDP growth rate (e.g. at a constant UR). The rest of GDP dynamics are cyclical and can be explained by the relationships between potential output, unemployment and other fundamentals.

In this paper we test whether the recent global growth slowdown is structural. We estimate the potential output for three major economies with a variety of methods typically used in the literature, taking into account dynamics of a neutral UR and other fundamentals. Specifically, we try to isolate the effects of the impaired credit transmission channel on potential output noted by Reinhart and Rogoff (2009a), by using finance-neutral potential output estimates. We then subject these estimates to a barrage of structural break tests to determine whether we can find and date structural slowdowns taking place and whether the results change for finance-neutral potential output estimates.

We find that much of the post-crisis slowdown in major economies is of a structural nature, but private credit plays a crucial role in it. We identify post-crisis structural breaks around 2009. This result is robust across samples, most model specifications, and estimation methods. In all three major economies, there is a significant difference between potential output estimates and their finance-neutral versions. We find that the on-going growth slowdown is sometimes connected to the impaired credit transmission channel: structural breaks in potential output change after the financial cycle is taken into account. The results of the Chen-Liu tests partly confirm this outcome.

[4] See Lazear and Spletzer (2012) for extensive discussion on what the term "potential output" might mean in the literature.

The contribution of this paper is as follows. First, we propose a unified framework to test two hypotheses related to the causes of the low post-Great Recession growth (namely, the impaired credit transmission channel of Reinhart and Rogoff (2009a) and the supply slowdown of Gordon (2012)). Second, we establish that, for the US, the euro area and Japan, the Great Recession period was characterized not only by a cyclical slump but also by structural changes, which confirms findings of Huang and Luo (2014) and contests those of Stock and Watson (2012) and Furceri and Mourougane (2012). Third, we provide evidence that the nature of those structural changes was different for each region, and some are likely to be associated with private credit dynamics (the impaired credit transmission channel). Fourth, the structural change we detected in the US took place during the Great Recession, not before, so the supply slowdown hypothesis of Gordon (2012) is not confirmed. Fifth, we find that for the US and the euro area the changes were mainly linked to labour market — labour participation rate and UR, respectively.

This paper is organized as follows. Section 2 provides a review of the literature. Section 3 contains brief review and interpretation of the statistical methods we use to provide potential GDP estimates. Section 4 contains a description and comparison of potential GDP estimates. In section 5 we test our data for structural breaks. Section 6 concludes. Appendix 1 lists Kalman filter specifications for potential output estimates. Appendix 2 contains estimated model coefficients. Appendix 3 contains charts of potential output and output gap estimates. Appendix 4 contains descriptions of the structural break and outlier tests we use. Appendix 5 provides results of the Chen-Liu test.

2. Literature review

The literature can be separated into two groups. The first deals with the economic policy debate on Secular Stagnation in the US and globally. The second is dedicated to detecting structural breaks in economic growth data.

2.1. Growth slowdown and the Secular Stagnation debate

There are two main lines of the so-called Secular Stagnation debate (Teulings and Baldwin, 2014) on the post-Great Recession slowdown in GDP growth rates, namely demand-side and supply-side causes of the growth slowdown.

The first is the original demand-side Secular Stagnation hypothesis reiterated by Summers (2014), which focuses on the implications of a zero interest rate constraint in developed economies. Some authors like Paul Krugman (Teulings and Baldwin, 2014) and Hall (2011) find it to be a variant of a liquidity trap.

One of the main causes for that trap could be the impaired credit transmission channel, as noted by Lo and Rogoff (2015). If that is the case, Reinhart and Rogoff (2009a) imply the potential output-unemployment-inflation relationship should be back to normal as the financial sector recovers and credit again starts to flow. In our paper we test this hypothesis from the potential output aspect, contributing to the literature including Reinhart and Rogoff (2009a) that mostly limits itself to historical financial crises case studies. The impaired credit transmission channel hypothesis implies that a shift in the dynamics of potential output should fall into the temporary change category rather than the level shift category (in terms of Chen-Liu (1993) outlier test here). Furceri and Mourougane (2012) find that financial crises have a permanent effect on the levels of potential GDP, but not on growth rates. Another method to model the impaired credit transmission channel is offered by Borio et al. (2013). They assume potential output is materially affected by financial cycles and thus the latter have to be taken into account in potential output estimations. Using Borio's finance-neutral potential output, we test whether the break in the potential output-unemployment-inflation relationship disappears once we isolate financial cycle impact.

The second line is the supply-side restriction debate which includes argument about the long-term stability of the relationship between GDP, unemployment and inflation.

Stock and Watson (2012) argue that the Great Recession is fully explained by the information contained in the historical macroeconomic relationships with the exception of negative expected interest rates, which amounts to the impaired credit transmission channel hypothesis. Lazear and Spletzer (2012) assert that no significant cross-industry labour mismatch remains, thus the problem of high unemployment is mostly cyclical and the GDP-unemployment relationship (Okun's Law) holds. We test those findings directly in our paper with respect to potential output-unemployment-inflation relationships.

Some authors disagree that those relationships are robust in the long run. There is a vast body of evidence on productivity growth slowdowns during the post-Great Recession period, starting with the US economy, documented by, among others, Fernald (2014), Gordon (2012, 2014). Those slowdowns are mainly explained by the lack of innovation, with the IT boom productivity acceleration of the last 20 years slowly receding. However, the macroeconomic and policy effects of that slowdown have long been on the periphery of the research. Gordon (2014) was among the first who posed the conundrum for new potential GDP forecasts implying significant supply-side (labour market) restrictions. He used a growth accounting approach while assuming the relationship between potential output and unemployment to be roughly the same over the previous 60 years. In our paper we test whether it stays the same, i.e., first, whether there is a break in the relationship between potential output, unemployment and inflation on a smaller sample, and second, whether the break persists after correcting for impaired transmission channel effects.

If the recent productivity slowdown pointed at by Fernald (2014), Gordon (2014) and others has significantly affected supply-side performance (namely, potential output), a break in the output-production factor relationship should be resilient to the impaired credit transmission channel impact. Moreover, the structural break dates should roughly correspond to the productivity slowdowns indicated and not to the financial crisis.

2.2. Structural breaks in GDP data

Changes in growth regimes in developed economies are usually associated with business cycle fluctuations, and are modelled via the regime-switching approach after Hamilton (1989). However, the studies applying this approach rarely use less than 40 years of data (Kang et al., 2009; Mitra and Sinclair, 2012; Kim et al., 2014). We do not model structural breaks explicitly due to data availability considerations with respect to the euro area (data available since 1995).

For developing economies, however, shifts in growth trends occur more often, and are tested for using the structural break approach (e.g. Kar et al. (2013)). Papell and Prodan (2012) propose an approach to growth regime changes using structural break analysis. They develop a two-break detection procedure for detecting both the entrance and exit to the contraction in the same test based on Bai (1999). In contrast to our paper, they ignore the dynamics of other important variables including unemployment and financial variables. Also, they search for consecutive pairs of breaks instead of a single break while considering only GDP and not the potential output.

The other strand of literature on shifts in growth trends is dedicated to the phenomenon of Great Moderation. In recent years a vast body of literature on whether the Great Recession interrupted the Great Moderation (a decrease in growth volatility since 80s) has emerged. However, most research on this topic tests for the breaks in the mean GDP growth rate along with its volatility. For instance, Gadea-Rivas et al. (2014) dismiss the possibility of any structural breaks in mean GDP growth in 2008–2009 by a visual analysis of the series for US GDP growth 1878–2012. On the contrary, Charles et al. (2014) used data for 1970–2011 to find breaks in GDP growth associated with Great Recession for 10 OECD countries including the US, Japan and the euro area economies. The break type they detected using the Chen-Liu test is temporary change rather than level shift, which indicates those breaks are transitory rather than permanent. Our results are closer to Charles et al. (2014), though we test potential output rather than actual data, and we find the breaks around the dates of the Great Recession with both the Chen-Liu test and the Bai-Perron test.

3. Statistical methods to estimate potential GDP

Potential GDP is defined as the long-term GDP trend[5] which differs from actual GDP by an output gap. The literature usually associates output gap with the cyclical component of GDP growth:

$$GDP \equiv GDP^{potential} + Output\ gap \tag{1}$$

We build on the framework proposed in the seminal work of Laxton and Tetlow (1992) and extended by Borio et al. (2013). The variety of methods we use is typical for the literature, as both Cotis et al. (2004) and Andrle (2013) stress there is no single formal criterion or test to choose between potential GDP estimators, although Cotis et al. propose “consistency with priors” and “the difference between real-time and final estimates” as comparison criteria. In this paper we test whether our results are robust to the choice of sample and model specification.

3.1. Methods overview

There is a barrage of methods and model specifications (most of them production function or filter-based) to estimate potential GDP, extensively covered in a number of sources, including Andrle (2013), Gerlach (2011) and Johnson (2013). Here we provide brief coverage. Methods to estimate potential GDP can be divided into three groups:

1) *structural* — usually production function-based (Cobb, Douglas, 1928; Artus, 1977; De Masi, 1997);
2) *univariate non-structural* — series smoothing, including filtering:
   - Hodrick, Prescott (1997);
   - Kalman (1960);
3) *multivariate non-structural* — allowing for structural restrictions in smoothing, but not necessarily requiring production factor data which are scarce and unreliable for developing economies (Hamilton, 1995; Laxton, Tetlow, 1992; Kuttner, 1994).

Production Function (PF) is usually log Cobb-Douglas with constant returns to scale. Potential output is based on least-squares-calibration, actual capital stock series and smoothed (usually Hodrick-Prescott (HP)-filtered) labour stock series (or smoothed capital stock and actual labour stock).

HP-filtering is smoothing for actual series of output to this rule:

[5] The actual definitions could differ, but, as Borio et al. (2013) sum up, “A common thread tying together the various concepts of potential output is that of sustainability: potential output is seen as representing a level of output that is sustainable given the underlying structure of the economy”. As noted above, Lazear and Spletzer (2012) also give an extensive discussion to the differing concepts of potential GDP.

$$L = \sum_{t=1}^{T} \left(y_t - \bar{y}_t \right)^2 + \lambda \sum_{t=2}^{T-1} \left(\Delta\bar{y}_{t+1} - \Delta\bar{y}_t \right)^2, \tag{2}$$

where y_t is the actual output, $\bar{y}_t$ is the smoothed series (aka potential output), λ is the smoothing degree, for quaterly data $\lambda = 1600$.

The unobservable components model (UCM) assumes the actual data are the sum of two series. The specific form of UCM may be modified depending on research objectives. The univariate version of the model is specified in this paper as follows, and is estimated with a univariate Kalman filter:

$$\begin{aligned} y_t &= y_t^p + z_t, \\ y_t^p &= y_{t-1}^p + \mu_{t-1}, \\ \mu_t &= \mu_{t-1} + \zeta_t, \\ z_t &= \varphi_1 z_{t-1} + \varphi_2 z_{t-2} + \gamma_t, \end{aligned} \tag{3}$$

where y_t^p is the potential output (trend), z_t is a cyclical component (output gap), ζ_t and γ_t are white noise.

A multivariate version of the model allows for additional relationships on top of GDP. It is estimated with a multivariate Kalman filter. For Okun’s law this means adding one equation for labour market indicators.

$$\begin{aligned} ur_t &= nairu_t + g_t, \\ nairu_t &= nairu_{t-1} + \xi_t, \\ g_t &= \alpha_1 g_{t-1} + \alpha_2 z_{t-1} + \varepsilon_t, \end{aligned} \tag{4}$$

where ur_t is the UR, $nairu_t$ is the non-accelerating inflation rate of unemployment (NAIRU), g_t is a cyclical component of unemployment, ζ_t, γ_t, η_t, ξ_t, and ε_t are white noise.

3.2. The choice of methods and specifications

We use a HP-filter and multivariate Kalman filter methods to estimate potential output. Along with the output trend equation, for each specification we include the following additional structural relationships:

1) inflation dynamics to account for aggregate supply (or Phillips curve) relationship (a bivariate filter notated GDP+CPI) in line with;
2) UR/LFPR, akin to Okun’s law relationship. Along with inflation dynamics this forms trivariate filters notated GDP+CPI+UR and GDP+CPI+LFPR, respectively;

3) versions of the above filters with the private credit ratio in the output gap equation, to include financial cycles and credit transmission channel impairment after Borio et al. (2013)[6].

The filtering procedure (identification requirement) does not allow for numerous structural relationships given a sample of 52–116 observations for each economy.

We do not use PF estimators in our paper and concentrate more on the variety of multivariate filter estimates.

Our dataset includes GDP, inflation, UR, LFPR and the private credit to GDP ratio for the US, the euro area and Japan, collected conditional on data availability. The sample covers 1986–2014 for US, 1999–2014 for the euro area, 1995–2014 for Japan. We use data both at yearly and quarterly frequency, the latter being seasonally adjusted by the providers. We estimate the potential output for differing overlapping samples starting at the full available sample and then moving forward to the starting point by one year (or four quarters, respectively). This is provides us with a robustness check of our results.

In their series of papers, Borio et al. (2013) point at the importance of accounting for financial cycles when estimating potential GDP. This approach seems consistent with our idea to estimate potential GDP while isolating the impaired credit transmission channel. Borio et al. (2013) test the impact of three financial variables on potential GDP, namely the real interest rate, the private credit ratio and house prices and find that the real interest rate has a negligible impact on potential GDP while both the private credit ratio and house prices matter.

We build on that foundation to include the private credit to GDP ratio as a proxy for the impaired credit transmission channel on potential GDP. Unfortunately, because of degrees of freedom constraints we can only use the first lag of the dependent variable (potential output) together with independent factors, thus for this version of Kalman filter we use only the first autoregressive lag for the output gap equation.

We use OLS estimates on HP-filtered data as our starting values for the Kalman filter estimation. For all the estimates we used a code for the Eviews 8 statistical package.

We list the results for the samples and specifications we use in Appendices 2–3 and compare them in Section 4[7]. In this paper we are interested in testing whether our results are robust to the choice of sample and model specification.

We do not use procedures integrating different estimators like the methodology of thick modelling proposed by Granger and Leon (2004), as the forecasting exercises are not the primary focus of our paper. However, we employ the Cotis et al. (2004) logic of the preference of

[6] The exact specified systems are listed in Appendix 1.
[7] We used more samples and specifications than listed, but the inclusion of all the estimates will overload the paper. We list the scheme of our total estimation results, which we are ready to provide on request.

economic intuition over statistical procedures when choosing our model specification for filter estimation.

4. Potential GDP estimates

In this section, we list and compare estimation results, namely potential GDP and the output gap for US, the euro area, and Japan. The Kalman filter estimation results for the model specifications we use in this section are listed in Appendix 2.

We use only the specifications with mostly significant coefficients, and we choose the same trivariate functional form for all three countries. As US labour market was adjusting post-2009 more with a change in the labour participation ratio and less with the unemployment ratio, we use specification with LFPR instead of UR like in other countries.

To compare our estimates to the most widespread benchmarks, we plot our estimator +CPI+LFPR along the dynamics of capacity utilization and IMF potential output estimates for the respective economies. Selected method-wise, specification-wise and sample-wise results for potential output estimation are listed in Appendix 3. We plan to elaborate on comparing the properties of different potential output and output gap estimates and forecast these indicators in a separate paper.

We provide estimates for potential output and output gap based on current-vintage data in Figures 1–12.

The dynamics of capacity utilization closely correlate with output gap estimates: for the US, the value of correlation coefficient is 0.81 (1986–2014), for the euro area it is 0.87 (1999–2014), and for Japan it is 0.72 (1995–2014). We compare the estimates to potential GDP dynamics inferred from the IMF World Economic Outlook (WEO) October 2015. Our estimates of potential output growth are highly correlated with IMF WEO for the US (0.77), for the euro area (0.83) and somewhat less for Japan (0.72).

Figures 2, 6, 10 also contain estimates of the output gap calculated by IMF WEO. Our estimates of the output gap are larger than the IMF WEO estimates for US, the euro area and lower for Japan.

System (3) defines the output gap as a stationary autoregressive process of either the first or the second order.

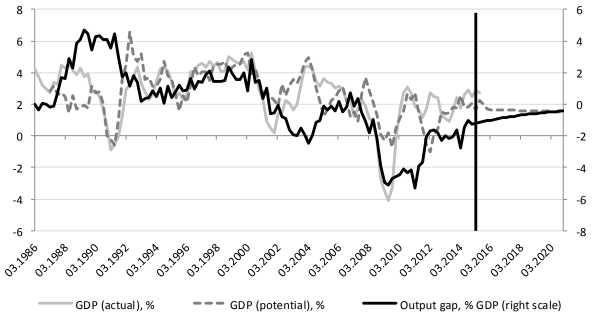

Fig. 1. Kalman filter results (+CPI+LFPR) for US

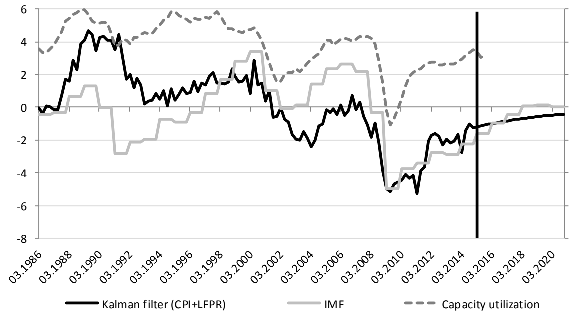

Fig. 2. Output gap measures for US

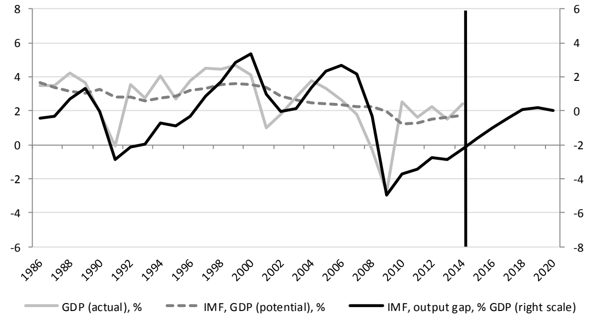

Fig. 3. IMF results for US, yearly data

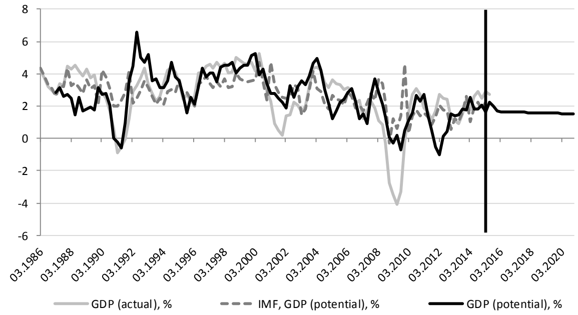

Fig. 4. Potential GDP measures for US

Figure 1 implies the potential output in the US has clearly slowed since 2009, but could edge up a bit after 2014. Both our estimates and the IMF (see Figure 2) indicate the gap would be near-zero in several years due to the slower potential GDP dynamics.

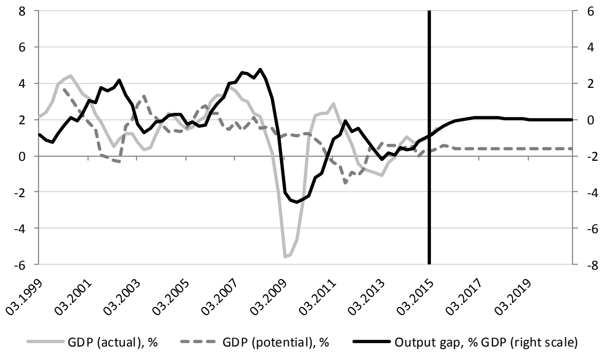

Fig. 5. Kalman filter results (+CPI+UR) for euro area

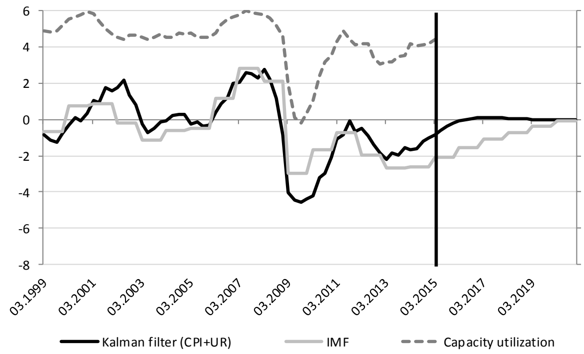

Fig. 6. Output gap measures for the euro area

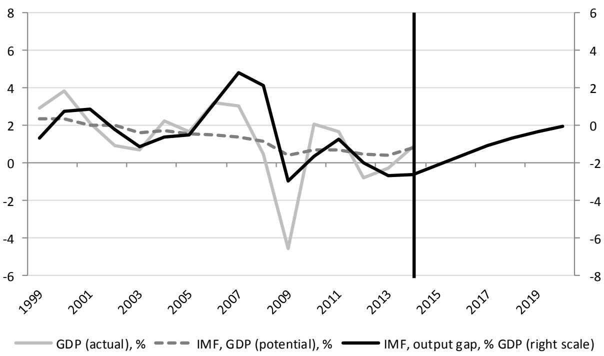

Fig. 7. IMF results for the euro area, yearly data

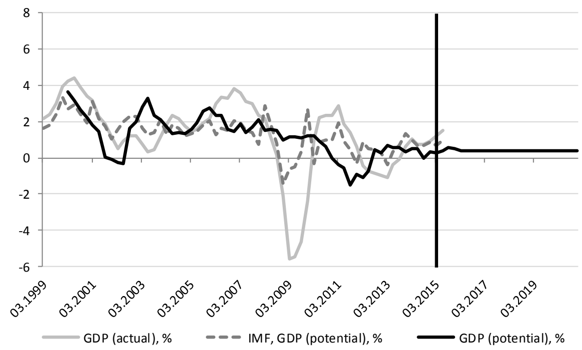

Fig. 8. Potential GDP measures for the euro area

The situation is even more drastic for the euro area — our estimates show potential GDP slows more rapidly than the IMF WEO estimates. This is probably due to the use of UR in the model specification, which stays high during the crisis and rises further in 2011–2013 during the European debt crisis.

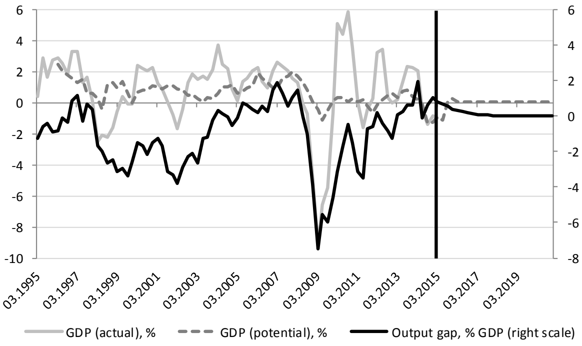

Fig. 9. Kalman filter results (+CPI+UR) for Japan

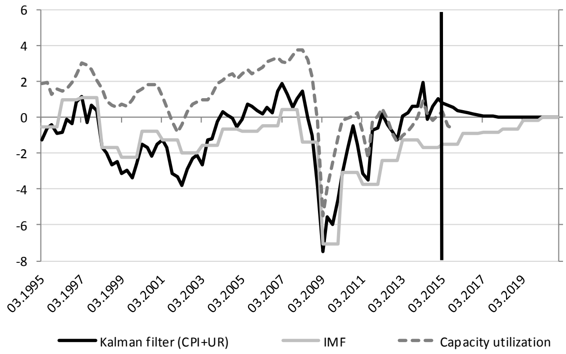

Fig. 10. Output gap measures for Japan

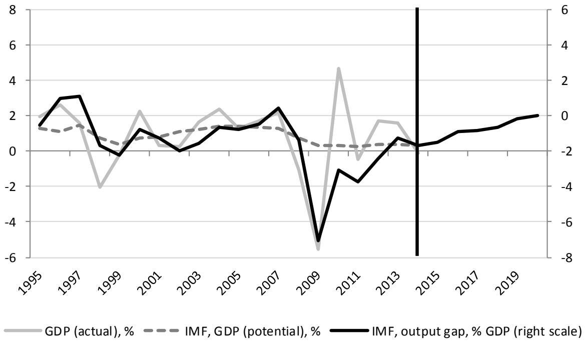

Fig. 11. IMF results for Japan, yearly data

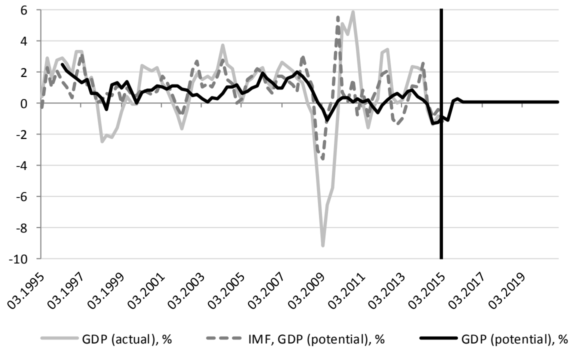

Fig. 12. Potential GDP measures for Japan

For Japan, the output gap appears to start rising after a decline during the Fukushima disaster, but the tax rate rise shock brings it down again, so output gap seems to have converged to zero during 2014.

This analysis leads us to conclude that most of the output gaps created in 2008–2009 were closed through the world economy slowdown in 2011–2014. The remaining part of the negative output gaps are smaller for the US and Japan, and significantly larger for the euro area.

Potential output was the main driver of that rebalancing. For most of the pre-crisis decade, there was a decline in the potential output growth rate in all three economies.

Tab. 1 displays the average annual growth rates of actual and potential GDP for pre-crisis and post-crisis periods. Our estimates for US, the euro area and Japan show that potential GDP slowed considerably post-crisis in line with actual GDP.

Tab. 1. Actual vs Potential GDP growth, % and output gap, % potential GDP[8]

Region	2000–2007			2010–2014		
	Potential output	Actual GDP	Output gap	Potential output	Actual GDP	Output gap
US	2.9	2.7	-0.4	1.4	2.1	-2.7
euro area	1.8	2.2	0.7	0.1	0.7	-1.6
Japan	1.0	1.5	-0.7	0.1	1.5	-0.6

While we witnessed a sharp slowdown both in actual and in potential output, it is unclear whether this change is permanent or transitory. To distinguish between temporary corrections and permanent trend growth changes, we perform tests for structural breaks in the series.

5. Testing for structural breaks

In this section we perform several structural break tests on the potential output growth rate estimates discussed in the previous section. The concept of Secular Stagnation implies lower growth rates, so we do not test estimates of the potential output level.

The logic of the New Normal or Secular Stagnation implies that the post-crisis slowdown is not explained by macroeconomic relationships between potential output, employment and inflation. The concept of a structural break in the series implies a change in the properties of the data-generating process, possibly induced by the change in relationships underlying it. Thus, one should expect to detect a structural break in the potential output series estimated while taking into account those relationships.

Beyond testing for incidence and date of the break, we aim at identifying its nature. As discussed earlier (see section 2), literature on Secular Stagnation places special emphasis on the credit transmission channel impairment. The broken transmission channel literature points out that the main cause of the Great Recession (and, probably, Secular Stagnation) was the damage done to the financial system. Consequently, faster growth will be back as the financial system repairs itself. If this is true, we expect to see a temporary change outlier (break) in the growth data. For example, Charles et al. (2014) find a temporary change outlier (break) in mean for 2009 but no evidence of a level shift in GDP growth rates for ten advanced countries. Conversely, Gadea-Rivas et al. (2014) using Bai-Perron test report no evidence of structural break in the mean US GDP growth rate on a sample of 1878–2012.

It is important to bear in mind three important issues related to the structural break tests. First, there are front end sample restrictions: a minimum of three data points required for a

[8] Here we use "finance-neutral" +CPI+LFPR model specification estimated with multivariate Kalman filter for the longest sample used.

regression. This currently does not allow us to parsimoniously test for structural breaks that might have occurred after 2011. Second, break dates determination is problematic. Third, tests need to be able to distinguish transitory breaks (which are in place if we heed the transmission channel damage literature) from permanent ones (which are consistent with the New Normal hypothesis).

We can address the second problem by applying the Bai-Perron (2003) test, which offers an automatic break selection procedure that requires just the maximum number of breaks. We can address the third problem using the Chen-Liu (1993) break detection procedure which allows for a distinction in the type of breaks, including level shifts and transitory changes (for more details see Appendix 4). The absence of a sound statistical remedy for the first problem (other than going to the quarterly level and having to deal with seasonality) is partly compensated by the absence of anecdotal evidence of significant structural shifts (on a scale of a global crisis) in the world economy apart from the Great Recession.

5.1. Bai-Perron structural break test results: The Great Recession breaks and European debt crisis breaks, finance-neutral versions do not differ

We provide Bai-Perron test results for selected samples in Tab. 2–4[9]. A break in the potential GDP growth series is clearly detected, with the exact timing ranging from 2007 to 2012 dependent on the region, sample and version of the test. Recent break dates are mostly clustered in 2009 and 2011.

The results are robust across different samples and model specifications. We can infer from the data that there was a notable breakdown in fundamental macroeconomic relationships in US, the euro area and Japan economies in 2009–2010, during the global crisis and the Great Recession. In Table 2 a structural break between pre- and post-crisis dynamics is evident. Namely, for the US the break for this period[10] (2008Q1 to 2009Q2) is present in 73% (70 out of 96) sample-specification estimates. However, if we consider specifications with LFPR, the share rises to 77.8% (28 out of 36), all of those detected in 2008Q4 or 2009Q1, which could be virtually considered the same quarter.

This supports analogous findings of Huang and Luo (2014) for the US and contrast findings of Stock and Watson (2012), who assume the underlying relationships are stable.

[9] The maximum number of breaks has been assumed to be 2.

[10] We deem it reasonable that a break could have taken place anytime during recession, as opposed to pre-recession period. NBER dates the business cycle contraction in the US corresponding to the notion of Great Recession from December 2007 to June 2009.

Tab. 2. Bai-Perron test results for US potential GDP[11]

Sample	+CPI+LFPR, gap=AR(1)	+CPI+LFPR, gap=AR(2)	+CPI+UR, gap=AR(1)	+CPI+UR, gap=AR(2)	+CPI+LFPR, gap=AR(1)+ +dCR_Y	+CPI+LFPR, gap=AR(2)+ +dCR_Y	+CPI+UR, gap=AR(1)+ +dCR_Y	+CPI+UR, gap=AR(2)+ +dCR_Y
1986–2014	2002Q2, 2008Q4	2006Q3, 2010Q4	2002Q2, 2008Q4	2004Q3, 2008Q4	2002Q2, 2006Q4	2004Q3, 2008Q4	2002Q2, 2007Q2	2002Q2, 2007Q2
1987–2014	2004Q3, 2008Q4	2004Q3, 2008Q4	2002Q2, 2008Q4	2004Q4, 2009Q1	2004Q3, 2008Q4	2004Q3, 2008Q4	2002Q2, 2008Q3	2002Q2, 2008Q2
1988–2014	2002Q2, 2008Q4	2006Q3, 2010Q4	2002Q2, 2008Q4	2004Q4, 2010Q4	2004Q3, 2008Q4	2004Q3, 2008Q4	2002Q2, 2008Q3	2002Q2, 2008Q4
1989–2014	2002Q2, 2008Q4	–	2002Q2, 2008Q4	2004Q4, 2009Q1	2004Q3, 2008Q4	2004Q3, 2008Q4	2002Q2, 2008Q3	2002Q2, 2008Q4
1990–2014	2002Q2, 2008Q3	–	2002Q2, 2008Q4	2004Q4, 2009Q1	2004Q3, 2008Q4	2004Q3, 2008Q4	2002Q2, 2008Q2	2002Q2, 2008Q2
1991–2014	2004Q3, 2008Q4	2002Q2, 2010Q4	2004Q3, 2008Q4	2004Q4, 2009Q1	2004Q3, 2008Q4	2004Q3, 2008Q4	2002Q2, 2008Q4	2002Q2, 2008Q4
1992–2014	2004Q3, 2008Q4	2004Q4, 2009Q1	2004Q3, 2008Q4	2005Q1, 2010Q4	2004Q3, 2008Q4	2004Q3, 2008Q4	2002Q2, 2007Q1	2002Q2, 2007Q2
1993–2014	2004Q3, 2008Q4	2006Q2, 2010Q3	2004Q3, 2008Q4	2004Q4, 2009Q1	2004Q3, 2008Q4	2004Q3, 2008Q4	2002Q2, 2007Q2	2002Q2, 2008Q2
1994–2014	2006Q3, 2010Q4	2006Q3, 2010Q4	2004Q4, 2009Q1	2004Q4, 2009Q1	2004Q3, 2008Q4	2004Q3, 2008Q4	2002Q2, 2007Q2	2002Q2, 2008Q2
1995–2014	2004Q3, 2008Q4	2004Q3, 2008Q4	2004Q4, 2009Q1	2004Q4, 2009Q3	2004Q3, 2008Q4	2004Q3, 2008Q4	2002Q2, 2007Q1	2002Q2, 2007Q1
1996–2014	2004Q3, 2008Q4	2004Q3, 2008Q4	2004Q4, 2009Q3	2004Q4, 2009Q3	2004Q3, 2008Q4	2004Q3, 2008Q4	2002Q2, 2007Q1	2002Q2, 2007Q1
1997–2014	2004Q3, 2008Q4	2004Q4, 2009Q1	2004Q4, 2009Q1	2004Q4, 2009Q1	2004Q3, 2008Q4	2004Q3, 2008Q4	2002Q2, 2006Q4	2002Q2, 2007Q1

[11] Model specifications for abbreviations are listed in Appendix 1.

Tab. 3. Bai-Perron test results for the euro area potential GDP

Sample	+CPI+UR, gap=AR(1)	+CPI+UR, gap=AR(2)	+CPI+UR, gap=AR(1)+dCR_Y	+CPI+UR, gap=AR(2)+dCR_Y
1999–2014	2007Q2, 2011Q1	2006Q3, 2010Q3	2003Q4, 2008Q4	2003Q4, 2010Q3
2000–2014	2008Q1, 2011Q3	2005Q2, 2008Q4	2004Q3, 2009Q1	2004Q3, 2008Q4
2001–2014	2007Q2, 2011Q2	2005Q2, 2008Q4	2005Q2, 2008Q4	2005Q2, 2009Q2
2002–2014	2008Q1, 2011Q2	2007Q2, 2010Q4	2006Q1, 2009Q1	2006Q1, 2009Q1

Tab. 4. Bai-Perron test results for Japan potential GDP

Sample	+CPI+LFPR, gap=AR(2)	+CPI+UR, gap=AR(1)	+CPI+UR, gap=AR(2)	+CPI+UR, gap=AR(1)+dCR_Y
1995–2014	2004Q2, 2008Q4	2004Q2, 2008Q4	2004Q2, 2008Q4	2003Q4, 2008Q3
1996–2014	2004Q2, 2008Q4	2004Q2, 2008Q4	2004Q2, 2008Q4	2003Q4, 2009Q1
1997–2014	2004Q2, 2008Q4	2004Q2, 2008Q4	2004Q2, 2008Q4	2003Q4, 2008Q4
1998–2014	2004Q2, 2008Q4	2004Q2, 2008Q4	2004Q2, 2008Q4	2003Q4, 2008Q4
1999–2014	2004Q2, 2008Q3	2004Q4, 2008Q4	2004Q4, 2008Q4	2003Q4
2000–2014	2004Q3, 2008Q3	2005Q2, 2008Q4	2005Q2, 2008Q4	–

The number of breaks in the Great Recession period for sample-specification estimates which include private credit to GDP (finance-neutral estimates) is the same as for those which do not. Though the structural break date and instance persist even after we account for the financial cycle. This can be interpreted in two ways. Firstly, the persistence of the break could indicate that the impact of the financial crisis on the potential output growth extends far beyond the flow of credit, which contrasts Reinhart and Rogoff's hypothesis. Or, secondly, the persistence of the break could indicate there are other strong factors affecting potential output even after we account for credit ratio dynamics, such as supply restrictions like the productivity slowdown suggested by Fernald (2014) and Gordon (2014), even though including private credit could influence the break dates.

5.2. Chen-Liu test results

There is another way to test for structural breaks which accounts for the nature of the break, namely distinguishing between permanent and transitory breaks. Charles et al. (2014) approached this question with a Chen-Liu test using the tsoutliers package of R. We follow suit with a distinction between the additive-outlier, level-shift and temporary-change types of breaks, and test whether some (or all) of them occur for the break dates selected by the Bai-Perron test.

Two hypotheses for the cause of the Secular Stagnation we surveyed before are not mutually exclusive: indeed, both demand-side and supply-side factors might be at work. In terms of the Chen-Liu test, the impaired credit transmission channel hypothesis of Reinhart and Rogoff implies a temporary change outlier: a significant but transitory reduction in GDP growth rates.

The permanent supply-side changes hypothesis advocated by Robert Gordon, on the other hand, should be supported by a level shift outlier (a permanent reduction in potential output growth rate) in the results of the test.

Appendix 5 contains summary of results for the Chen-Liu test. As the size of full results for all samples makes them inconvenient to display, we list results for model specifications, but limit ourselves to several relevant samples including the longest used.

These results do not appear very stable with respect to method, specification and sample, unlike the Bai-Perron test results. Test results change once credit dynamics are accounted for. Especially stark differences are observed between the country results and the specifications that use UR and those that use LFPR. Most results are stable over sample choice.

Overall, the Chen-Liu test results support the impaired credit channel hypothesis for the US, and probably for the euro area, but not for Japan. For the US the samples which detect level shift breaks (around mid-2009) have those breaks disappear once both LFPR and private credit dynamics are plugged into the specification. For the euro area, on the contrary, the breaks stay, but the inclusion of the private credit dynamics leads to the date change of the temporary change break from 2011 to 2009 with the private credit. This is consistent with the hypothesis that the euro area recession in 2011–2012 was probably credit supply-driven. It looks quite different for Japan, where the breaks in potential output growth rate for 2009 are generally detected regardless of whether the specification includes private credit.

Based on the Chen-Liu test results we conclude that the changes in potential output growth rates in some instances were dependent on private credit and in others were not. This, and the differences between results for estimators and their finance-neutral versions, resembles the results of Bai-Perron test.

The Chen-Liu test detects almost exclusively level shift breaks for the US potential output growth rates in 2008–2009 (one specification implies this for 2011); however, they disappear after we account for either LFPR (for the 2011 break) or private credit (for the 2008–2009 breaks). This looks consistent with the impaired credit channel hypothesis. For the euro area there are several temporary change breaks in mid-2011 detected originally, but after we account for credit dynamics, the 2011 breaks disappear, but breaks in 2009 appear. This means the factors associated with credit played a role in the 2011 euro area recession but not in the Great Recession. In Japan, the inclusion of private credit changes some of the temporary breaks into permanent ones, while the date of 2009 stays the same. We interpret this as a probable productivity shift which was obscured by the credit crisis.

These findings are quite similar to the insights Bai-Perron test results offer, and partially (for the US, and, to lesser extent, the euro area) the impaired credit transmission channel hypothesis, as potential output growth does not appear to heal itself as financial systems would. We can again conclude that either the impaired credit transmission channel hypothesis should imply a permanent reduction in potential output growth rates, or there are other factors at work besides credit-driven factors, such as supply-side factors.

6. Conclusions and discussion

In this paper we infer whether there is a structural slowdown of major world economies in the post-Great Recession period. We find structural breaks in the estimated potential output growth rates for all three economies between 2007 and 2010. The results are generally robust to the choice of the sample and specification, and they hold for the three countries surveyed. This indicates that Secular Stagnation materially and negatively affected the potential output growth rates.

Further examination leads us to conclude this reduction might be permanent rather than transitory for some countries. The absence of pre-crisis negative level shifts gives some evidence against the productivity slowdown affecting macroeconomic relationships.

We provide two arguments why impaired credit transmission channel factors are likely to play a role in the potential output growth slowdown, especially for the US. Firstly, US breaks under the Chen-Liu test disappear once we account for private credit dynamics, and the Bai-Perron break dates are all straightened to 2008Q4. The results are more mixed for the euro area and Japan, but credit also plays a role. Secondly, most changes detected in the potential output growth are classified as transitory rather than permanent breaks, which implies that the financial sector will heal itself and return to normal. Still, breaks under Bai-Perron test, which is more robust to sample changes, are observed for both the standard and finance-neutral versions of the estimates.

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Appendix 1. Model specifications for a Kalman filter

1. Trivariate model specification for a Kalman filter with AR(1) part, Phillips curve-type and Okun's law (unemployment rate) relationships (+CPI+UR, gap=AR(1)):

$$y_t = y_t^p + z_t,$$

$$y_t^p = y_{t-1}^p + \mu_{t-1},$$

$$\mu_t = \mu_{t-1} + \zeta_t,$$

$$z_t = \varphi_1 z_{t-1} + \gamma_t,$$

$$cpi_t = \alpha_0 + \alpha_1 cpi_{t-1} + \alpha_2 z_t + \eta_t,$$

$$ur_t = nairu_t + g_t,$$

$$nairu_t = nairu_{t-1} + \xi_t,$$

$$g_t = \beta_1 g_{t-1} + \beta_2 z_{t-1} + \varepsilon_t,$$

where y_t^p is potential output (trend), z_t is a cyclical component (output gap), cpi_t is CPI, ur_t is unemployment rate, $nairu_t$ is NAIRU, g_t is a cyclical component of unemployment, ζ_t, γ_t, η_t, ξ_t, and ε_t are white noise.

2. Trivariate model specification for a Kalman filter with AR(2) part, Phillips curve-type and Okun's law (unemployment rate) relationships (+CPI+UR, gap=AR(2)):

$$y_t = y_t^p + z_t,$$

$$y_t^p = y_{t-1}^p + \mu_{t-1},$$

$$\mu_t = \mu_{t-1} + \zeta_t,$$

$$z_t = \varphi_1 z_{t-1} + \varphi_2 z_{t-2} + \gamma_t,$$

$$cpi_t = \alpha_0 + \alpha_1 cpi_{t-1} + \alpha_2 z_t + \eta_t,$$

$$ur_t = nairu_t + g_t,$$

$$nairu_t = nairu_{t-1} + \xi_t,$$

$$g_t = \beta_1 g_{t-1} + \beta_2 z_{t-1} + \varepsilon_t,$$

where y_t^p is potential output (trend), z_t is a cyclical component (output gap), cpi_t is CPI, ur_t is unemployment rate, $nairu_t$ is NAIRU, g_t is a cyclical component of unemployment, ζ_t, γ_t, η_t, ξ_t, and ε_t are white noise.

3. Trivariate model specification for a Kalman filter with AR(1) part, private credit to GDP, Phillips curve-type and Okun's law (unemployment rate) relationships (+CPI+UR, gap=AR(1)+dCR_Y):

$$y_t = y_t^p + z_t,$$

$$y_t^p = y_{t-1}^p + \mu_{t-1},$$

$$\mu_t = \mu_{t-1} + \zeta_t,$$

$$z_t = \varphi_1 z_{t-1} + \lambda \Delta cr_t + \gamma_t,$$

$$cpi_t = \alpha_0 + \alpha_1 cpi_{t-1} + \alpha_2 z_t + \eta_t,$$

$$ur_t = nairu_t + g_t,$$

$$nairu_t = nairu_{t-1} + \xi_t,$$

$$g_t = \beta_1 g_{t-1} + \beta_2 z_{t-1} + \varepsilon_t,$$

where y_t^p is potential output (trend), z_t is a cyclical component (output gap), Δcr_t is change of private credit to GDP, cpi_t is CPI, ur_t is unemployment rate, $nairu_t$ is NAIRU, g_t is a cyclical component of unemployment, ζ_t, γ_t, η_t, ξ_t, and ε_t are white noise.

4. Trivariate model specification for a Kalman filter with AR(1) part, Phillips curve-type and Okun's law (labour force participation rate) relationships (+CPI+LFPR, gap=AR(1)):

$$y_t = y_t^p + z_t,$$

$$y_t^p = y_{t-1}^p + \mu_{t-1},$$

$$\mu_t = \mu_{t-1} + \zeta_t,$$

$$z_t = \varphi_1 z_{t-1} + \gamma_t,$$

$$cpi_t = \alpha_0 + \alpha_1 cpi_{t-1} + \alpha_2 z_t + \eta_t,$$

$$lfpr_t = lfpr_t^p + g_t,$$

$$lfpr_t^p = lfpr_{t-1}^p + \xi_t,$$

$$g_t = \beta_1 g_{t-1} + \beta_2 z_{t-1} + \varepsilon_t,$$

where y_t^p is potential output (trend), z_t is a cyclical component (output gap), cpi_t is CPI, $lfpr_t$ is labour force participation rate, $lfpr_t^p$ is trend of labour force, g_t is a cyclical component of labour force, ζ_t, γ_t, η_t, ξ_t, and ε_t are white noise.

5. Trivariate model specification for a Kalman filter with AR(2) part, Phillips curve-type and Okun's law (labour force participation rate) relationships (+CPI+LFPR, gap=AR(2)):

$$y_t = y_t^p + z_t,$$

$$y_t^p = y_{t-1}^p + \mu_{t-1},$$

$$\mu_t = \mu_{t-1} + \zeta_t,$$

$$z_t = \varphi_1 z_{t-1} + \varphi_2 z_{t-2} + \gamma_t,$$
$$cpi_t = \alpha_0 + \alpha_1 cpi_{t-1} + \alpha_2 z_t + \eta_t,$$
$$lfpr_t = lfpr_t^p + g_t,$$
$$lfpr_t^p = lfpr_{t-1}^p + \xi_t,$$
$$g_t = \beta_1 g_{t-1} + \beta_2 z_{t-1} + \varepsilon_t,$$

where y_t^p is potential output (trend), z_t is a cyclical component (output gap), cpi_t is CPI, $lfpr_t$ is labour force participation rate, $lfpr_t^p$ is trend of labour force, g_t is a cyclical component of labour force, ζ_t, γ_t, η_t, ξ_t, and ε_t are white noise.

6. Trivariate model specification for a Kalman filter with AR(1) part, private credit to GDP, Phillips curve-type and Okun's law (labour force participation rate) relationships (+CPI+LFPR, gap=AR(1)+dCR_Y):

$$y_t = y_t^p + z_t,$$
$$y_t^p = y_{t-1}^p + \mu_{t-1},$$
$$\mu_t = \mu_{t-1} + \zeta_t,$$
$$z_t = \varphi_1 z_{t-1} + \lambda \Delta cr_t + \gamma_t,$$
$$cpi_t = \alpha_0 + \alpha_1 cpi_{t-1} + \alpha_2 z_t + \eta_t,$$
$$lfpr_t = lfpr_t^p + g_t,$$
$$lfpr_t^p = lfpr_{t-1}^p + \xi_t,$$
$$g_t = \beta_1 g_{t-1} + \beta_2 z_{t-1} + \varepsilon_t,$$

where y_t^p is potential output (trend), z_t is a cyclical component (output gap), Δcr_t is change of private credit to GDP, cpi_t is CPI, $lfpr_t$ is labour force participation rate, $lfpr_t^p$ is trend of labour force, g_t is a cyclical component of labour force, ζ_t, γ_t, η_t, ξ_t, and ε_t are white noise.

Appendix 2. Estimated coefficients

Tab. 5. Coefficients for the US model specification

Exogenous variables	CPI+LFPR, gap=AR(1)	CPI+LFPR, gap=AR(2)	CPI+UR, gap=AR(1)	CPI+UR, gap=AR(2)	CPI+LFPR, gap=AR(1)+ +dCR_Y	CPI+LFPR, gap=AR(2)+ +dCR_Y	CPI+UR, gap=AR(1)+ +dCR_Y	CPI+UR, gap=AR(2)+ +dCR_Y
Gap equation								
gap(-1)	0.96*** (0.06)	1.31*** (0.07)	0.95*** (0.04)	1.26*** (0.10)	0.94*** (0.05)	1.08*** (0.13)	0.81*** (0.01)	1.05*** (0.05)
gap(-2)	-	-0.34*** (0.07)	-	-0.31*** (0.10)	-	-0.20* (0.12)	-	-0.26*** (0.05)
cr_y-cr_y(-4)	-	-	-	-	5.04*** (0.93)	5.30*** (1.50)	2.49*** (0.78)	5.30*** (1.03)
Phillips curve								
cpi(-1)	0.98*** (0.04)	0.96*** (0.04)	0.97*** (0.03)	0.97*** (0.02)	1.00*** (0.02)	0.84*** (0.07)	0.94*** (0.02)	0.93*** (0.02)
gap*1000	0.26** (0.12)	0.22* (0.12)	0.25*** (0.09)	0.22** (0.09)	0.18** (0.09)	0.36*** (0.13)	0.24*** (0.02)	0.23*** (0.03)
const	0.05 (0.14)	0.09 (0.14)	0.07 (0.10)	0.08 (0.09)	-0.06 (0.07)	0.27* (0.15)	0.10** (0.05)	0.11** (0.05)
Okun's law								
lfpr(-1) or ur(-1)	0.85*** (0.09)	0.86*** (0.09)	0.55*** (0.07)	0.52*** (0.09)	0.82*** (0.08)	0.94*** (0.06)	0.61*** (0.02)	0.64*** (0.02)
gap(-1)*1000	0.28*** (0.09)	0.24*** (0.09)	-1.80*** (0.26)	-1.87*** (0.33)	0.30*** (0.09)	0.24*** (0.08)	-2.15*** (0.11)	-2.05*** (0.14)
N	116	116	116	116	112	72	112	112

Note. *, **, *** - estimate is significant at 10, 5, 1-% level, respectively. Standard errors of the estimated coefficients are in brackets.

Tab. 6. Coefficients for the EA model specification

Exogenous variables	CPI+UR, gap=AR(1)	CPI+UR, gap=AR(2)	CPI+UR, gap=AR(1)+dCR_Y	CPI+UR, gap=AR(2)+dCR_Y
Gap equation				
gap(-1)	0.99*** (0.05)	1.56*** (0.17)	0.67*** (0.01)	1.32*** (0.06)
gap(-2)	-	-0.64*** (0.16)	-	-0.49*** (0.05)
cr_y-cr_y(-4)	-	-	12.97*** (3.95)	12.82*** (2.83)
Phillips curve				
cpi(-1)	0.89*** (0.06)	0.91*** (0.06)	0.85*** (0.03)	0.82*** (0.04)
gap*1000	0.64** (0.26)	0.73** (0.30)	0.83*** (0.06)	0.75*** (0.05)
const	0.21 (0.13)	0.13 (0.12)	0.19*** (0.06)	0.19*** (0.07)
Okun's law				
ur(-1)	0.32** (0.15)	0.29 (0.21)	0.70*** (0.04)	0.66*** (0.05)
gap(-1)*1000	-2.18*** (0.43)	-2.12** (0.91)	-1.60*** (0.24)	-2.62*** (0.41)
N	64	64	60	60

Tab. 7. Coefficients for the Japan model specification

Exogenous variables	CPI+LFPR, gap=AR(2)	CPI+UR, gap=AR(1)	CPI+UR, gap=AR(2)	CPI+UR, gap=AR(1)+dCR_Y
Gap equation				
gap(-1)	1.05*** (0.10)	0.85*** (0.08)	1.13*** (0.09)	0.38*** (0.02)
gap(-2)	-0.23* (0.12)	-	-0.29** (0.12)	-
cr_y-cr_y(-4)	-	-	-	53.12* (31.40)
Phillips curve				
cpi(-1)	0.79*** (0.06)	0.80*** (0.07)	0.77*** (0.07)	1.01*** (0.03)
gap*1000	0.02** (0.01)	0.03*** (0.01)	0.03*** (0.01)	0.02*** (0.001)
const	-0.002 (0.11)	0.06 (0.17)	0.15 (0.18)	-0.13** (0.06)
Okun's law				
lfpr(-1) or ur(-1)	1.00*** (0.12)	0.66*** (0.08)	0.66*** (0.08)	0.81*** (0.02)
gap(-1)*1000	0.004* (0.002)	-0.012*** (0.002)	-0.012*** (0.002)	-0.027*** (0.003)
N	80	80	80	72

Note. *, **, *** - estimate is significant at 10, 5, 1-% level, respectively. Standard errors of the estimated coefficients are in brackets.

Appendix 3. Potential output and output gap estimates

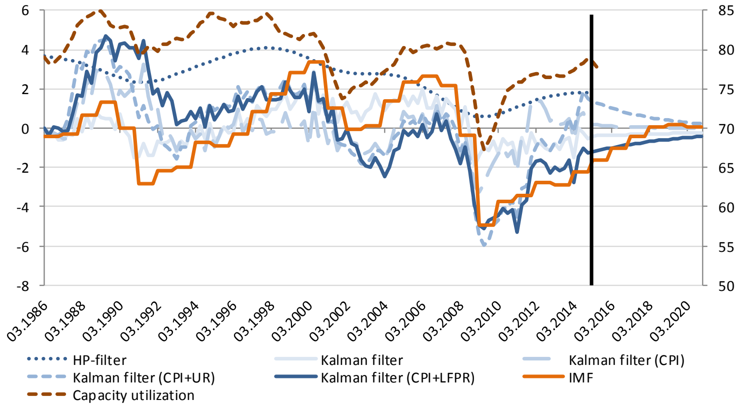

Fig. 13. Output gap estimates (% potential output), capacity utilization and IMF output gap measure for the US (sample 1986-2014)

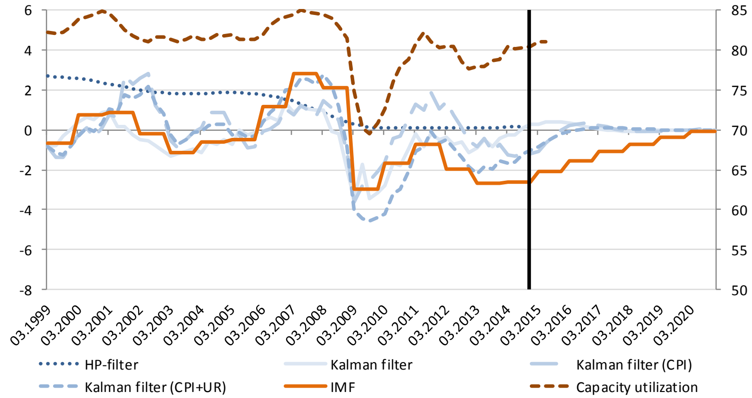

Fig. 14. Output gap estimates (% potential output), capacity utilization and IMF output gap measure for the euro area (sample 1999-2014)

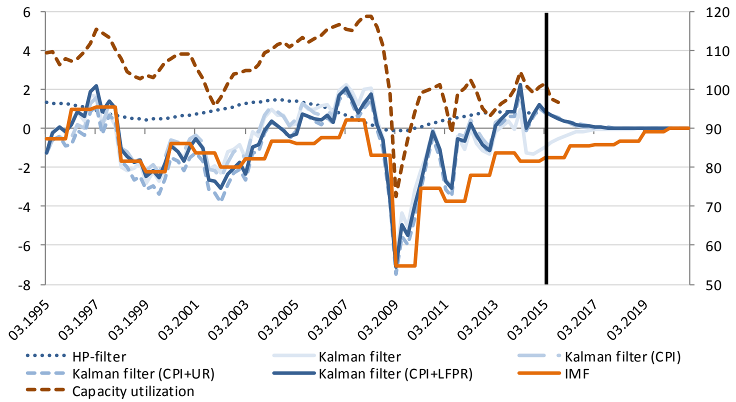

Fig. 15. Output gap estimates (% potential output), capacity utilization and IMF output gap measure for Japan (sample 1995-2014)

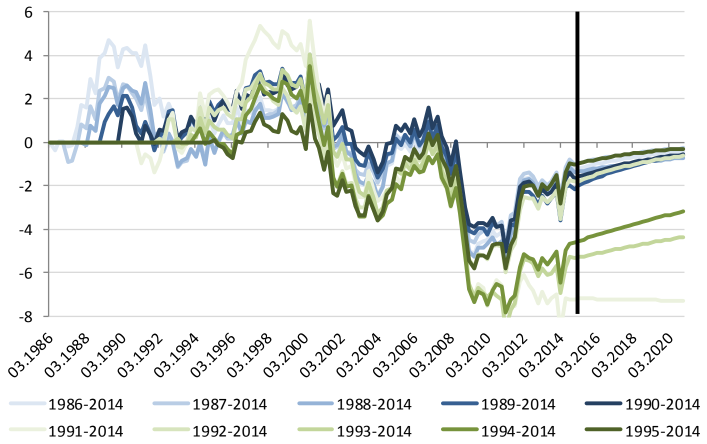

Fig. 16. Output gap estimates (+CPI+LFPR, gap=AR(2)) for the US (all samples), % potential output

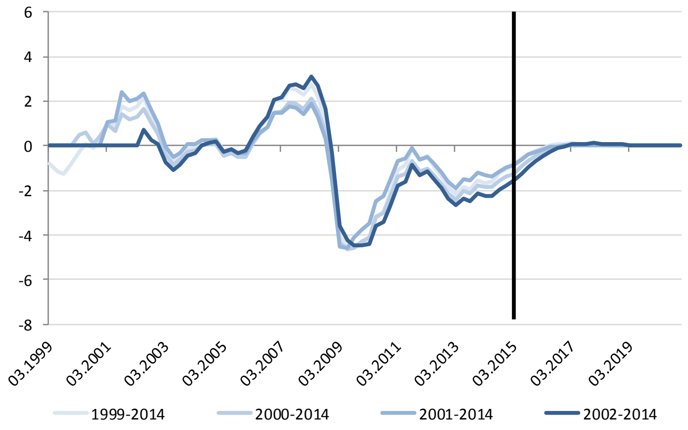

Fig. 17. Output gap estimates (+CPI+UR, gap=AR(2)) for the euro area (all samples), % potential output

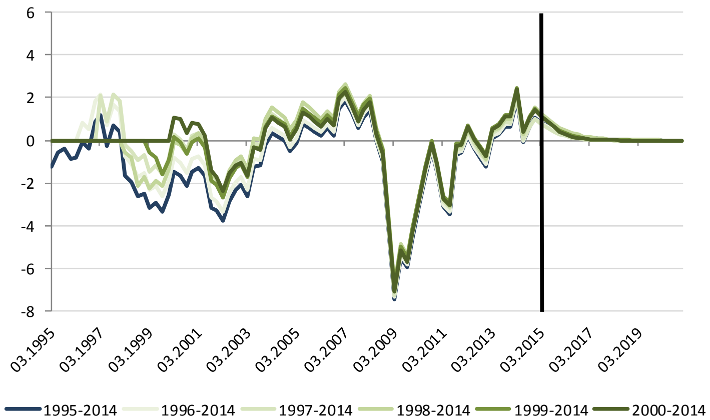

Fig. 18. Output gap estimates (+CPI+UR, gap=AR(2)) for Japan (all samples), % potential output

Appendix 4. Testing for structural breaks in the series

Testing for structural breaks can be done in several ways:

1) exact dates of probable structural breaks are known; researches test did they happen or not in each point (for example, Chow, 1960);

2) the maximum number of structural breaks is only known; researches find exact dates, but there is still the possibility of no structural breaks in the series (Bai, Perron, 2003);

3) there is no information about dates and number of structural breaks in the series (Chen, Liu, 1993, Gómez, Maravall, 1997).

Bai and Perron test

In this paper the second way is presented by Bai and Perron (2003) test. It is assumed that the series have the maximum possible number of breaks. The test is based on the multiple linear regression with m breaks including parameters β which are constant in each $m+1$ regimes:

$$y_t = x_t'\beta + z_t'\delta_j + u_t, \quad t = T_{j-1}+1,\dots,T_j, \quad j = 1,\dots,m+1, \tag{5}$$

where y_t is the dependent variable at time t, x_t' $(p\times 1)$ and z_t' $(q\times 1)$ are vectors of independent variables at time t, β and δ_j $(j = 1,\dots,m+1)$ are corresponding vectors of parameters, u_t is the disturbance at time t. It is also assumed that there is no break in variance.

(5) is estimated for each m-partition using least-squares method:

$$S_T\left(T_1,\dots,T_m\right) = \min_{\beta,\delta_j}\left[\sum_{i=1}^{m+1}\sum_{t=T_{i-1}+1}^{T_i}\left(u_t\right)^2\right] = \min_{\beta,\delta_j}\left[\sum_{i=1}^{m+1}\sum_{t=T_{i-1}+1}^{T_i}\left(y_t - x_t'\beta - z_t'\delta_j\right)^2\right] \tag{6}$$

Derived estimates of coefficients are substituted in the objective function $S_T\left(T_1,\dots,T_m\right)$ which depends only on break points. Then this function is minimized over all partitions $\left(T_1,\dots,T_m\right)$. Thus final dates of structural breaks are global minimizers of the objective function:

$$\left(\hat{T}_1,\dots,\hat{T}_m\right) = \arg\min_{T_1,\dots,T_m} S_T\left(T_1,\dots,T_m\right). \tag{7}$$

However when $m > 2$ this statistic becomes difficult to compute. Therefore several alternative methods exist to determine optimum estimates of break points. All calculations have been made in the Eviews8.

Chen and Liu test

In case of no information about dates and number of structural breaks in the series Chen and Liu (1993) have offered test for outliers and determination their types. There are three main types of outliers: additive outlier (AO), level shift (LS) and temporary change (TC). It is assumed that the testing series is composed of two parts:

$$y_t = z_t + f(t), \quad t = 1, ..., n. \tag{8}$$

The first part z_t is an ARMA process: $\phi(L)z_t = \theta(L)a_t, \quad a_t \sim N(0, \sigma_a^2)$, where L is lag operator. The second part $f(t)$ contains structural breaks. However in practice estimation y_t as ARMA model gives not pure white noise a_t but noise combined with structural breaks effects:

$$\hat{a}_t = \pi(L)z_t, \quad \pi(L) = \alpha(L)\phi(L) / \theta(L) = 1 - \pi_1 L - \pi_2 L^2 - ... \tag{9}$$

This equation can be written in another way for each type of breaks:

(AO) $\hat{a}_t = a_t + \omega_{AO}\pi(L)I_t(\tau),$

(LS) $\hat{a}_t = a_t + \ \omega_{LS}\pi(L)/(1-L)\ \ I_t(\tau),$

(TC) $\hat{a}_t = a_t + \ \omega_{TC}\pi(L)/(1-\delta L)\ \ I_t(\tau).$

Commonly the parameter δ equals 0.7. In the simplest form these regressions are as follows:

$$\hat{a}_t = \omega_i x_{i,t} + a_t, \quad i = AO, LS, TC, \tag{10}$$

where for all i:

$x_{i,t} = 0$ for $t < \tau$,

$x_{i,t} = 1$ for $t = \tau$,

for $t > \tau$ and $k \geq 1$ (with $k = 1, ..., T - \tau$) $\quad x_{AO,t+k} = -\pi_k$ (AO),

$x_{LS,t+k} = 1 - \sum_{j=1}^{k} \pi_j$ (LS),

$x_{TC,t+k} = \delta^k - \sum_{j=1}^{k-1} \delta^{k-j} \pi_j - \pi_k$ (TC).

The next general t-statistics (with $t(n-1)$ distribution) for an OLS-estimate of the parameter ω_i is used for detection outliers:

$$\hat{\tau}_i(\tau) = \ \hat{\omega}_i(\tau) / \hat{\sigma}_a \ \ / \left(\sum_{t=\tau}^{n} x_{i,t}^2 \right)^{1/2}, \quad i = AO, LS, TC, \tag{11}$$

where $\hat{\sigma}_a$ is an estimate of the standard deviation of white noise a_t from (10.

These statistics are calculated for each type of break and for each probable date of break. Then the largest absolute value of a statistic over all types is chosen to define the most probable type of break at each point. If the value of a corresponding statistic at time t is higher than the critical value, the test indicates the presence of a structural break of a given type at time t.

Appendix 5. Results of Chen-Liu test[12]

Tab. 8. Chen-Liu test results for the US, par 1

Sample	CPI+LFPR, gap=AR(1)				CPI+LFPR, gap=AR(2)				CPI+UR, gap=AR(1)				CPI+UR, gap=AR(2)			
	year	type	coef	tstat	year	type	coef	tstat	year	type	coef	tstat	year	type	coef	tstat
1986-2014					09.2007	LS	1.73	2.17	06.2011	LS	-1.18	-2.94	06.2011	LS	-1.29	-2.51
1987-2014					09.2007	LS	1.68	2.09	06.2011	LS	-1.25	-3.17	06.2011	LS	-1.27	-2.70
1988-2014					09.2007	LS	1.87	2.12	06.2011	LS	-1.28	-3.21	06.2011	LS	-1.29	-2.79
1989-2014					09.2007	LS	1.85	2.16	06.2011	LS	-1.22	-2.93	06.2011	LS	-1.24	-2.50
1990-2014									06.2011	LS	-1.17	-2.68	06.2011	LS	-1.19	-2.56
1991-2014	09.2007	LS	1.63	2.31	09.2007	TC	1.84	3.10	06.2011	LS	-1.27	-3.32	06.2011	LS	-1.30	-3.06
	09.2009	TC	-1.54	-2.35	09.2008	LS	-1.50	-2.46								
					12.2008	TC	-1.34	-2.26								
1992-2014					09.2007	LS	1.90	2.37	12.2007	TC	0.68	2.00	06.2011	LS	-1.39	-3.07
									06.2011	LS	-1.29	-3.37				
1993-2014	09.2007	LS	1.56	2.42	09.2007	LS	1.99	2.44	09.2010	TC	0.70	2.00	12.2007	TC	0.73	2.03
	09.2009	TC	-1.46	-2.46					06.2011	LS	-1.30	-3.31	06.2011	LS	-1.25	-3.12
1994-2014	09.2007	LS	1.55	2.86	09.2007	LS	1.82	3.42	12.2007	TC	0.68	2.00	06.2011	LS	-1.32	-3.26
	09.2009	TC	-1.35	-2.67	09.2008	LS	-1.12	-2.10	09.2010	LS	0.80	2.09				
	12.2009	LS	1.10	2.03	12.2008	TC	-1.03	-2.03	06.2011	LS	-1.30	-3.41				
1995-2014	09.2007	LS	1.56	2.46	09.2007	LS	1.91	2.49	06.2011	LS	-1.36	-3.13	06.2011	LS	-1.34	-3.19
	09.2009	TC	-1.41	-2.40												
1996-2014	09.2007	LS	1.42	2.16	09.2007	LS	1.65	2.30	06.2011	LS	-1.30	-3.01	12.2007	TC	0.70	2.05
													06.2011	LS	-1.24	-3.26
1997-2014					09.2007	LS	1.64	2.31	06.2011	LS	-1.11	-3.06	12.2007	TC	0.70	2.14
													06.2011	LS	-1.28	-3.48

[12] Model specifications for the filters like "+CPI, gap=AR(1)" is provided in Appendix 1.

Tab. 9. Chen-Liu test results for the US, par 2

Sample	CPI+LFPR, gap=AR(1)+dCR_Y				CPI+LFPR, gap=AR(2)+dCR_Y				CPI+UR, gap=AR(1)+dCR_Y				CPI+UR, gap=AR(2)+dCR_Y			
	year	type	coef	tstat	year	type	coef	tstat	year	type	coef	tstat	year	type	coef	tstat
1986-2014					03.2010	LS	1.29	2.15	03.2009	TC	-1.14	-2.43				
									03.2010	LS	1.38	2.64				
1987-2014					03.2010	LS	1.34	2.08	03.2009	LS	-0.78	-2.07				
1988-2014					03.2010	LS	1.40	2.24	03.2009	LS	-0.80	-2.39				
									03.2010	LS	0.73	2.17				
1989-2014									03.2009	LS	-0.87	-2.19				
									03.2010	LS	0.84	2.12				
1990-2014																
1991-2014																
1992-2014																
1993-2014					03.2010	LS	1.28	2.05	03.2009	LS	-1.05	-2.08	06.2010	TC	-1.00	-2.00
									03.2010	LS	1.12	2.21				
1994-2014																
1995-2014																
1996-2014									03.2011	TC	0.73	2.10	03.2011	TC	1.07	2.38
1997-2014													03.2011	LS	1.18	2.81

Tab. 10. Chen-Liu test results for the euro area

Sample	CPI+UR, gap=AR(1)				CPI+UR, gap=AR(2)				CPI+UR, gap=AR(1)+dCR_Y				CPI+UR, gap=AR(2)+dCR_Y			
	year	type	coef	tstat	year	type	coef	tstat	year	type	coef	tstat	year	type	coef	tstat
1999-2014									03.2007	TC	1.57	2.40				
									06.2009	TC	-2.17	-3.33				
									06.2010	LS	0.94	2.74				
									06.2011	LS	0.78	2.07				
2000-2014					09.2011	TC	-0.91	-2.54	06.2009	TC	-2.39	-2.85	12.2007	TC	1.36	2.01
									09.2009	TC	-2.46	-2.93	03.2009	TC	-1.51	-2.23
									09.2010	LS	1.13	2.11	06.2009	TC	-2.07	-3.05
													09.2009	TC	-1.50	-2.22
													03.2011	LS	1.06	2.26
													06.2011	TC	1.42	2.10
2001-2014	09.2010	TC	0.94	2.47	09.2011	AO	-0.58	-2.10	03.2007	TC	1.24	2.13				
	09.2011	TC	-0.87	-2.30					09.2009	TC	-1.55	-2.66				
2002-2014	09.2011	TC	-0.90	-2.35	09.2011	TC	-1.06	-2.69	06.2009	TC	-2.47	-2.53	06.2010	LS	0.86	2.01
									09.2009	TC	-2.90	-2.97				
									12.2009	TC	-2.17	-2.23				
									09.2010	LS	1.15	2.05				

Tab. 11. Chen-Liu test results for Japan

Sample	CPI+LFPR, gap=AR(2)				CPI+UR, gap=AR(1)				CPI+UR, gap=AR(2)				CPI+UR, gap=AR(1)+dCR_Y			
	year	type	coef	tstat	year	type	coef	tstat	year	type	coef	tstat	year	type	coef	tstat
1995-2014	06.2007	TC	0.60	2.22	03.2006	TC	0.88	2.69	03.2006	TC	0.88	2.54	06.2009	TC	-1.04	-3.27
	12.2007	TC	0.73	2.71	06.2007	TC	0.66	2.01	06.2009	TC	-0.75	-2.14	06.2010	LS	0.95	2.63
	09.2009	TC	0.66	2.43	06.2009	TC	-0.79	-2.42					12.2010	TC	0.94	2.95
													03.2011	TC	-0.71	-2.23
1996-2014	03.2006	TC	0.65	2.04	03.2006	TC	0.96	2.60	03.2006	TC	0.89	2.31	06.2009	LS	-0.41	-2.36
	06.2009	TC	-0.94	-2.94	06.2009	TC	-0.75	-2.03	06.2009	TC	-0.81	-2.11	06.2010	LS	0.37	2.15
													12.2010	LS	0.48	2.77
1997-2014	12.2007	TC	0.67	2.43	03.2006	TC	1.00	2.84	03.2006	TC	0.88	2.50	06.2010	LS	0.35	2.02
	06.2009	TC	-1.06	-3.86	06.2007	TC	0.71	2.01	06.2009	TC	-0.86	-2.45	12.2010	LS	0.44	2.50
					06.2009	TC	-0.72	-2.05					09.2011	TC	-0.33	-2.16
1998-2014	03.2006	TC	0.52	2.71	03.2006	TC	1.10	3.13	03.2006	TC	1.04	2.90	06.2008	TC	0.10	2.04
	06.2007	TC	0.63	3.30	06.2007	TC	0.78	2.22					09.2008	LS	-0.11	-2.01
	12.2007	TC	0.84	4.37	06.2009	TC	-0.76	-2.15					09.2009	TC	-0.11	-2.03
	12.2008	LS	-0.49	-2.59									06.2010	TC	0.15	2.65
	09.2009	TC	0.61	3.20									12.2010	LS	0.21	2.97
	03.2010	TC	0.45	2.36									09.2011	TC	-0.18	-2.72
	03.2011	LS	-0.48	-2.48												
1999-2014	03.2006	TC	0.71	2.63	03.2006	TC	1.06	2.88	03.2006	TC	1.00	2.57	09.2009	TC	-4.09	-2.02
	06.2007	TC	0.58	2.16	06.2007	TC	0.76	2.06								
	12.2007	TC	0.66	2.45	06.2009	TC	-0.77	-2.10								
	06.2009	TC	-0.93	-3.43												
2000-2014	03.2006	TC	0.71	2.25	03.2006	TC	1.11	2.93	03.2006	TC	1.04	2.51				
	12.2007	TC	0.69	2.17	06.2007	TC	0.80	2.13								
	09.2009	TC	0.66	2.08	06.2009	TC	-0.76	-2.02								

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