DISCUSSION PAPER SERIES

DP14290

'STALL SPEED' AND 'ESCAPE VELOCITY': EMPTY METAPHORS OR EMPIRICAL REALITIES?

Paul Diggle and Luke Bartholomew

OCCASIONAL PAPER

ISSN 0265-8003

'STALL SPEED' AND 'ESCAPE VELOCITY': EMPTY METAPHORS OR EMPIRICAL REALITIES?

Paul Diggle and Luke Bartholomew

Discussion Paper DP14290
Published 08 January 2020
Submitted 18 December 2019

Centre for Economic Policy Research
33 Great Sutton Street, London EC1V 0DX, UK
Tel: +44 (0)20 7183 8801
www.cepr.org

'STALL SPEED' AND 'ESCAPE VELOCITY': EMPTY METAPHORS OR EMPIRICAL REALITIES?

Abstract

‘Stall speed’ and ‘escape velocity’ are commonly heard but often vaguely defined physics metaphors used to describe apparent business cycle dynamics. Using GDP data for the OECD economies, we find evidence for the existence of a weak and a strong form of stall speed in the majority of these economies, but reject weak and strong form escape velocity everywhere. Specifically, we find higher probabilities of recession following periods of low growth, including non-linear increases in these probabilities around certain thresholds; but no equivalent decrease in recession probabilities after periods of high growth. We then employ Markov switching models as a secondary technique to test for distinct business cycle phases that might equate to stalls and escapes. This analysis rarely picks out stall speed and escape velocity as separate business cycle regimes, and instead points to a broader and more idiosyncratic suite of regimes rooted in individual economies’ economic history. Taken together, these results suggest that stall speed dynamics are present in the GDP data generating process for many OECD economies, but they are not a strong enough feature to emerge as a defining characteristic of the business cycle. Our findings caution against the overuse of the stall speed and escape velocity metaphors in a macroeconomic context.

JEL Classification: E32, C22, C14

Keywords: Stall speed, escape velocity, business cycle asymmetry, kernel densities, conditional probabilities, Markov switching

Paul Diggle - paul.diggle@aberdeenstandard.com
Aberdeen Standard Investments

Luke Bartholomew - luke.bartholomew@aberdeenstandard.com
Aberdeen Standard Investments

'Stall Speed' and 'Escape Velocity': Empty Metaphors or Empirical Realities?

Paul Diggle[1] & Luke Bartholomew[2]

December 2019

Abstract

‘Stall speed’ and ‘escape velocity’ are commonly heard but often vaguely defined physics metaphors used to describe apparent business cycle dynamics. Using GDP data for the OECD economies, we find evidence for the existence of a weak and a strong form of stall speed in the majority of these economies, but reject weak and strong form escape velocity everywhere. Specifically, we find higher probabilities of recession following periods of low growth, including non-linear increases in these probabilities around certain thresholds; but no equivalent decrease in recession probabilities after periods of high growth. We then employ Markov switching models as a secondary technique to test for distinct business cycle phases that might equate to stalls and escapes. This analysis rarely picks out stall speed and escape velocity as separate business cycle regimes, and instead points to a broader and more idiosyncratic suite of regimes rooted in individual economies’ economic history. Taken together, these results suggest that stall speed dynamics are present in the GDP data generating process for many OECD economies, but they are not a strong enough feature to emerge as a defining characteristic of the business cycle. Our findings caution against the overuse of the stall speed and escape velocity metaphors in a macroeconomic context.

Keywords: Stall speed, escape velocity, business cycle asymmetry, kernel densities, conditional probabilities, Markov switching

JEL classification: E32, C22, C14

[1] Aberdeen Standard Investments Research Institute (E-mail: paul.diggle@aberdeenstandard.com)
[2] Aberdeen Standard Investments Research Institute (E-mail: luke.bartholomew@aberdeenstandard.com)

1 Introduction

Business cycle dynamics have long been an area of academic economic inquiry. This paper adds to that literature by unearthing the empirical content, if any, behind the commonly-heard, at least in business economics and financial commentary circles, metaphors of ‘stall speed’ and ‘escape velocity’ to describe the economy. A modest literature exists on the concept of an economic stall speed, but no empirical work appears to have specifically addressed the concept of escape velocity.

As used in physics, stall speed is the minimum speed at which an aircraft must fly to stay afloat, while escape velocity is the necessary velocity to escape a planet’s gravity well. But when used metaphorically to describe apparent business cycle dynamics, the terms can become unhelpfully vague. We offer, and test for, a definition that distinguishes between a weak form and a strong form of these concepts. In the weak form, the probability of a recession following a period of low growth increases (stall speed), and the probability of a recession following a period of high growth decreases (escape velocity). In the strong form, the probability of a recession increases *non-linearly* once growth has fallen through a certain threshold (stall speed), and the probability of a recession decreases non-linearly once growth has risen through a certain threshold (escape velocity)[3].

First, however, we frame our discussion in terms of broader debates about the theoretical and empirical time-series properties of business cycles and the relevant existing literature.

1.1 Business cycle dynamics and Friedman's plucking model

The standard view of business cycle dynamics – the natural rate model – conceives of real activity fluctuating around a trend rate, which may itself alter over time. Fluctuations around trend are broadly symmetric in the sense that there can be both booms – when activity is well above trend – and busts or recessions – when activity is well below trend (see Figure 1).

A literature dating back to Friedman (1964) suggests an alternative model to the natural rate model. In these 'plucking' models, activity moves around a ceiling value imposed by the supply side of the economy (see Figure 2). Activity can either be up against this ceiling level, which essentially corresponds to full employment of resources, or be 'plucked' downwards from this ceiling by various demand shocks. Activity is therefore asymmetric around trend.

[3] Another use of the terms, not present in the literature, but sometimes used in business economics and financial commentary circles, draws in monetary policy. In this usage, stall speed embeds the idea of a rate of growth low enough such that recession is unavoidable even in the presence of monetary policy easing; while escape velocity embeds the idea that the achievement of trend or above trend growth is no longer dependent on monetary policy being on the accommodative side of neutral. However, this definition is problematic, because in standard formal models of the economy the persistent achievement of above-trend growth is only possible if policy is sufficiently easy relative to the neutral rate, while policy that is overly tight relative to the neutral rate is the cause of below-trend or negative growth. As such, policy rates are intrinsically bound up in the level of growth, and it is difficult to see what a well-formed counterfactual asking what the rate of growth would be ‘in the absence of policy support’ might mean.

1.2 Empirical work on business cycle dynamics

Building on Friedman, a large body of empirical literature has sought to characterise business cycle dynamics. In particular, researchers have tested for asymmetry between expansions and contractions, particularly in national accounts, industrial production, employment, and unemployment data. The generalised finding is that contractions are steeper than expansions. One data generating process seems to best describe the time series properties of expansion periods, and another the time series properties of contraction periods.

Seminal work by Neftci (1984) characterises the economy as being in one state when unemployment is rising, and another when unemployment is falling, with transition between the two states modelled as the outcome of a two-state Markov process. Hamilton (1989) also uses the Markov switching model as a way to identify two phases in post-war US GNP data, one with positive growth and one with negative growth, as well as transition probabilities between these phases.

Sichel (1993) distinguishes between 'steepness' and 'deepness' in business cycle dynamics. Steepness refers to the differing rate of change of a variable in an expansion and a contraction, while deepness refers to troughs being further below trend than peaks are above. He finds steepness in post-war US unemployment data, but does not find steepness in industrial production or GNP data, and finds evidence for deepness in unemployment and industrial production data, but weaker evidence that deepness is present in GNP data. McQueen and Thorley (1993) distinguish another aspect of asymmetry, which they call 'sharpness', or the relative curvature of time series around peaks and troughs. They detect rounded peaks and sharp troughs in post-war US unemployment and industrial production data around NBER turning points.

1.3 Existing work on 'stall speed' and 'escape velocity'

Although not explicitly labelled as such, much of this literature can be related to the concepts of 'stall speed' and 'escape velocity' as commonly used in business economics and financial commentary. 'Steeper' and 'deeper' contractions than expansions hint at the existence of stall speed but not escape velocity. On the other hand, 'sharpness' around troughs hints at the existence of both stall speed and escape velocity when heading into, or bouncing out of, recessions.

More recently, a subset of the literature on business cycle dynamics has explicitly investigated the issue of stall speed, although no authors have looked at its close cousin escape velocity.

Nalewaik (2011) defines stall speed as “particular values for output growth and other variables, such that when these values are reached during an expansion, the economy has tended to move into a recession within a fairly short time span”. He identifies the presence of stall speed in post-war US real GDP and real GDI through a three-state Markov switching model, and by comparing the kernel density estimates of quarter-on-quarter annualised GDP and GDI growth in the four quarters ahead of recessions to those for all other periods. He finds support for a stall speed of 1% quarter-on-quarter annualised.

Sheets (2011) defines stall speed in a similar but subtly different way: a threshold for GDP growth such that, once growth has moved below this rate, it has a tendency to decline further. Working with post-1970

US real GDP, he uses two different specifications of a linear regression model - one where the dependent variable is GDP growth and another where it is the output gap - to test for stall speed. For the absolute level of growth, he identifies a stall speed of 1.5% year-on-year; in terms of output gaps, he finds a stall speed at positive output gaps between 0.5 and 1.5 percentage points.

Sheets and Sockin (2012) apply the first model specification from Sheets (2011) to a broader range of economies. Stall speeds between 1% and 2% year-on-year are found for the UK, Euro area, Japan and Mexico; Canada and Australia have stall speeds of 0%; while stall speed is not detected in China on its own or the emerging markets in aggregate[4].

Ho and Yetman (2012) look at two different definitions of stall speed: in the first, a stall is a perod of low but positive growth leading to further low growth or recession; in the second, a stall is a decline in the growth rate below a certain threshold, which then leads to further low growth or recession. Using post-1960 US real GDP data, they employ kernel density estimates, probit models and Markov switching models, finding no evidence for the first defintion of stalls - a period of low growth is as likely to be followed by higher growth as by a recession - while finding that stalls in the second sense are present in the historical data.

In a subsequent paper, Ho and Yetman (2013) use a larger data set of 51 economies to investigate stall speed. Using regressions of year-on-year GDP growth with stall threshold dummies, similar to Sheets (2011), they find evidence of stalls in just 14 of these 51 economies. They go on to consider whether time-varying thresholds better reveal stalls, but find that just 11 of the 51 economies display stalls in this sense.

1.4 Outline of the rest of this paper

Our reading of the existing literature is that it is broadly consistent with asymmetric business cycle dynamics, with quite distinct phases of activity. We consider this prima facie evidence for the possibility of stall speed and escape velocity. Indeed, the existing literature specifically addressing the topic seems to find evidence of stall speed in US economic activity, but more limited evidence of stall speed in other economies.

In the present paper, we extend this literature by applying non-parametric analysis and Markov switching models to GDP data in all 36 OECD economies, taking seriously the cross-economy heterogeneity in the data generating process for the first time. We introduce a new distinction between, and a test for, a 'strong form' and 'weak form' of stall speed and escape velocity.

We proceed as follows. Section 2 describes the cross-economy dataset used, and presents kernel densities and conditional probabilities in an attempt to unearth the existence, or otherwise, of stall speed and escape velocity. This section largely reproduces existing literature in the field, but extends the analysis to a wider range of economies. Section 3 introduces an original formal distinction between weak form and strong form stall speed and escape velocity, and tests for their existence. Section 4 employs Markov switching models to look for the presence of distinct stall speed and escape velocity regimes of the business

[4] Sheets and Sockin (2012) use an emerging markets GDP aggregate consisting of 14 economies: Brazil, Chile, Mexico, Hungary, China, Hong Kong, India, Indonesia, Korea, Malaysia, Singapore, Taiwan, Thailand, and South Africa

cycle. This section acts as a cross-check on the analytical methods used in the previous sections, using a different statistical tool to try to tease out distinct data generating processes across the cycle. Again, this section in part replicates some of the existing literature, but extends the analysis beyond the US. Section 5 concludes.

2 The dataset, and its non-parametric properties

2.1 Outline of the data

Our data are quarterly real GDP growth (quarter-on-quarter annualised, seasonally adjusted) for the 36 OECD member economies[5], downloaded from the Thomson Reuters International Comparable Economics (TRICE) database. The sample period is between Q1 1950 and Q4 2018, albeit data availability creates a ragged edge at the start of the panel. The full sample, along with summary statistics, is given in Table 1.

We focus on the rate of growth rather than growth in relation to trend for several reasons. Estimating trend growth is a heavily debated topic, with strengths and weaknesses to the various approaches used. The Hodrick Prescott (HP) filter is a commonly implemented de-trending method, but we worry its usage may systematically bias our results if used in this case. For example, during a recession phase the HP filter's estimate of trend growth will be pulled lower (even though 'true' economic trend may be unaffected) by the period of weak activity associated with the recession. As such, when calculating the post-recession gap between growth and potential, any given level of growth will be biased higher by a lower estimate of trend. This may create the impression of an ‘escape velocity phase’, where growth is more rapid following a recession, but would only be a statistical artefact rather than a genuine economic phenomenon. A production function approach to measuring trend would be less subject to this statistical biasing, but there are not enough reliable, timely estimates of potential using this approach across our data set. Given that discussion of stall speed and escape velocity are normally framed in terms of growth, and these data issues, this approach makes most sense to us[6].

We choose a simple recession-identification algorithm, rather than relying on national business cycle dating committees' identification of recessions, given the lack of availability of the latter across all the 36 economies in our sample. A recession is defined as a continuous period of negative quarter-on-quarter annualised GDP growth lasting at least two quarters. Summary statistics of the recessions in our sample are given in Table 2. Under our definition, we find that the mean length of a recession is 3.4 quarters and is

[5] Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States.

[6] Our focus on growth rates, rather than growth in relation to trend, is not without its drawbacks, of course. The broad slowing in trend growth across the OECD economies over our sample period means that growth is simply closer to being negative at any given point in the recent past than the more distant past, which may influence the frequency of stall speed and escape velocity occurrences. In a similar vein, stall speed may be harder to identify, and escape velocity easier to identify, in structurally high growth economies relative to structurally low growth economies.

associated with a mean peak-to trough contraction of 4%. The distributions of recession length and depth are illustrated in Figures 3 and 4. There is unsurprisingly a positive relationship, albeit one that shows heteroscedasticity, between recession length and depth, seen in Figure 5.

2.2 Non-parametric analysis

We start by characterising rates of GDP growth during and outside of recessions. The top two lines of Table 3 describe the distribution of growth outcomes in recessions and outside of recessions. Obviously, growth is much higher outside of a recession, with a mean of 3.9%, versus -4.2% in a recession. Unsurprisingly this is a statistically significant difference.

Figure 6 presents kernel densities[7] for quarter-on-quarter percentage changes in real GDP across the entire dataset, during and outside of recessions. As expected, the densities during recessions have a mode, and significantly more probability mass, to the left relative to the densities fitting expansionary periods. While this result is close to being definitional - of course periods in recession (as we have defined them) have growth outcomes skewed lower than non-recessionary periods - this example helps illustrate the intuitive way of thinking about what the subsequent kernel densities we present are telling us. To the extent that distributions for different 'phases' of the business cycle are distinct from each other, they may be governed by different data-generating processes.

Growth conditional on being proximate to recession. Using this framework, we next consider the behaviour of GDP growth in four potential 'phases' of the business cycle: recessions, immediately before recessions, immediately after recessions, and all other time periods which (definitionally) are more distant from recessions. We employ three different definitions of 'immediately before' and 'immediately after': two, four and eight quarters either side of a recession.

The reason we do this is that one potential interpretation of stall speed and escape velocity is that growth just before a recession is much lower than is otherwise the case - a stall speed phase - and that growth just after a recession is much higher than is otherwise the case - an escape velocity phase. Certainly, much stronger growth immediately after a recession would be consistent with a plucking-style model.

Table 3 describes growth outcomes in each of these 'phases'. We find that growth is statistically significantly lower than 'normal' times in the four quarters prior to a recession, and lower, but not significantly lower, at the two and eight quarters windows. This is evidence for stall speed as we have loosely defined it above.

Interestingly, we find that growth is also statistically significantly lower at the two, four, and eight quarters windows *after* a recession. This seems to contradict the existence of an escape velocity phase.

Figure 7 plots the kernel densities for the four quarter window, and - making the same point graphically - we can see the distribution of growth outcomes before and after a recession skewed slightly to the left (i.e. lower) relative to normal times.

[7] The estimates throughout this paper are based on the Epanechnikov kernel and the default bandwidth setting in Eviews.

Summarising, we find that GDP growth slows heading into recessions, and remains weaker than normal in the initial aftermath of recessions. This may be evidence for stall speed, but argues against escape velocity.

Recessions conditional on being proximate to high or low growth. Our analysis so far has effectively asked 'given a recession occurs, is growth lower (or higher) in the vicinity?' We now invert this conditionality, asking 'given low (or high) growth, has a recession typically occurred in the vicinity?'

Forming the conditional in this way gives a different interpretation to the concepts of stall speed and escape velocity, which is less associated with the theoretical apparatus of a plucking-style model. Stall speed under this approach is associated with the idea that once growth falls below a certain level it is very hard to avoid a recession, while escape velocity captures the idea that higher growth unlocks further periods of higher growth. These kinds of dynamics might make sense if the economy is characterised by strong positive feedback loops. Perhaps low growth causes low confidence, which causes lower investment and consumption, which causes lower growth, which causes lower confidence, etc, in the case of stalls, and vice versa for escapes. Sheets (2011) argues for the existence of such self-reinforcing endogenous dynamics in his investigation of stall speed. Alternatively, monetary policy could help create runaway periods of high or low growth, if tranmission lags cause policymakers to set policy overly loose or overly tight relative to neutral. By the time that policymakers have realised their monetary policy error, growth may have accelerated substantially, or slowed into a recession.

The top panel of Table 4 shows the probability of falling into recession two, four, and eight quarters after a quarter in which growth was less than 6, 5, 4, 3, 2, 1, 0, and -1%. The broad pattern is clear: as growth slows, the probability of being in a recession in the future tends to pick-up. The chance of being in a recession over all time horizons is on average around four percentage points higher following a quarter of less than 1% growth than after a quarter of 6% growth. While this gentle increase in recession risk following slower growth is consistent with something like stall speed, the data are not overwhelmingly convincing, and the fact that there is not a spike higher in recession probability at any given growth level suggests there may not be some unique stall speed threshold when the dynamics of the economy fundamentally change.

We now turn to how the economy behaves following a period of high growth. Figure 9 plots the kernel density estimate for growth outcomes after a quarter of growth exceeding 4%. This distribution is clearly skewed to the right compared to the distribution for other outcomes, suggesting that high growth seems to beget future periods of high growth, moving the economy into a new phase of the cycle. This is potentially consistent with escape velocity.

The lower panels of Table 4 ask how recession probabilities vary following periods of high growth. We find no notable decrease in recession risk following periods of high growth over the two, four, and eight quarters windows. This is inconsistent with another definition of escape velocity, in which high growth takes the economy away from some danger-zone of high recession risk. Perhaps there are offsetting economic forces that explain this result - as noted above, high growth tends to beget higher growth which all else equal seems to reduce recession risk, but perhaps higher growth is also associated with the build-up of various imbalances which tend to increase recession risk.

Summarising, the non-parametric analysis points to four main stylised facts across the OECD economies as a whole:

1. Low growth both before and after recessions, which is suggestive of a version of stall speed, but not escape velocity;
2. Low growth begetting low growth, and high growth begetting high growth;
3. A linear increase in the probability of recession following low growth;
4. No decrease (linear or otherwise) in the probability of recession following high growth.

3 Weak and strong form stall speed and escape velocity

3.1 Defining weak form and strong form stall speed and escape velocity

As is clear from our discussion up to this point, the concepts of stall speed and escape velocity can be unhelpfully vague. Various different forms of business cycle behaviour can plausibly be said to be consistent with the concepts depending on how they are defined.

We therefore propose a distinction between weak form and strong form stall speed and escape velocity, which gives us formal, testable definitions of these concepts.

In the case of strong form, we treat the metaphors of stall speed and escape velocity seriously, which we take to imply that there is some critical point where the dynamics of the system fundamentally change. So strong form stall speed means that once growth falls below a certain threshold, the chance of subsequently falling into a recession increases in a *non-linear* fashion. Similarly, strong form escape velocity means that once growth rises above a certain threshold, the chance of subsequently falling into a recession declines in a non-linear fashion.

Put another way, strong form stall speed means that:

$$\Delta \Pr(y_{t+i} \cap \ y_{t+i+1} < 0 \mid y_t \ < x) > 0 \ as\ x\ declines \tag{1}$$

and:

$$\Delta\Delta \Pr(y_{t+i} \cap \ y_{t+i+1} < 0 \mid y_t \ < x) > 0 \ as\ x\ declines \tag{2}$$

while strong form escape velocity means that:

$$\Delta \Pr(y_{t+i} \cap \ y_{t+i+1} < 0 \mid y_t \ > z) < 0 \ as\ z\ increases \tag{3}$$

and:

$$\Delta\Delta \Pr(y_{t+i} \cap \ y_{t+i+1} < 0 \mid y_t \ > z) > 0 \ as\ z\ increases \tag{4}$$

where x is the candidate stall speed, y is the growth rate of GDP, and z is the candidate escape velocity.

By contrast, weak form stall speed means that following a period of weak growth the probability of recession increases, but there is no non-linear increase around a certain threshold. Similarly, weak form escape velocity means that following a period of strong growth the probability of recession decreases, but there is no non-linear increase around a certain threshold.

Put another way, weak form stall speed means that:

$$\Delta \Pr(y_{t+i} \cap \; y_{t+i+1} < 0 \mid y_t \; < x) > 0 \; as\; x\; declines \tag{5}$$

but:

$$\Delta\Delta \Pr(y_{t+i} \cap \; y_{t+i+1} < 0 \mid y_t \; < x) \ngtr 0 \; as\; x\; declines \tag{6}$$

while weak form escape velocity means that:

$$\Delta \Pr(y_{t+i} \cap \; y_{t+i+1} < 0 \mid y_t \; > z) < 0 \; as\; z\; increases \tag{7}$$

but:

$$\Delta\Delta \Pr(y_{t+i} \cap \; y_{t+i+1} < 0 \mid y_t \; > z) \ngtr 0 \; as\; z\; increases \tag{8}$$

On first glance, weak form stall speed and escape velocity could seem trivial definitions of a phenomenon that we might expect to find as a matter of course. However, it is important to stress that there is no reason why these kinds of dynamics need be true. It is perfectly plausible that economies go through something like a 'late cycle surge', exhibiting very strong growth before suddenly falling into recession (perhaps because of the imbalances built up in this period), or more generally, that very large positive or negative exogenous shocks could hit the economy at any given level of growth.

Reinterpreting our stylised findings above in light of these new definitions, they are suggestive of the existence of weak form stall speed, but the non-existence of strong form stall speed and escape velocity.

3.2 Testing for weak form and strong form stall speed and escape velocity

In this section, we introduce a formal test for the existence of weak form and strong form stall speed and escape velocity. For every economy in our sample, we plot the three-dimensional surface of the conditional probabilities of recession over subsequent time horizons following different growth outcomes. We then undertake a novel application of the tests developed in Perron and Yabu (2009a) (2009b) to characterise the slope of this surface and to identify structural breaks in the slope.

As above, a statistically significant and correctly signed slope would be evidence of weak form stall speed or escape velocity (subsequent recession probability rises/falls as growth decreases/increases); the addition of a structural break in the slope would be evidence of strong form stall speed or escape velocity (a non-linear increase/decrease in subsequent recession probability around a specific growth threshold); and a zero or incorrectly signed slope would be a reason to reject both weak form and strong form stall speed and escape velocity.

Conditional probability surfaces. We start by plotting, for each OECD economy, the three-dimensional surface of the conditional probabilities of recession over subsequent time horizons following growth outcomes either below or above successive thresholds. Illustrative examples for the US economy are shown in Figures 10 and 11[8].

In Figure 10, we plot the probability of a recession (z axis) occurring in the one to 12 quarters (y axis) following growth rates below candidate stall speed thresholds (x axis). And in Figure 11, we plot the probability of a recession occurring in the one to 12 quarters following growth rates *above* candidate escape velocity thresholds.

A number of features of these surfaces stand out. Firstly, both are upwardly sloping along the y axis – that is, as the time horizon over which we are looking for recessions increases, the probability of there being a recession increases. Second, and much more substantively, Figure 10 is clearly downward sloping along the x axis – that is, as the growth rate in any given quarter decreases, the probability of a recession following that quarter increases. This is consistent with our weak form definition of stall speed. In Figure 11, it is not necessarily obvious from visual inspection that there is any slope, positive or negative, along the x axis, leaving it ambiguous at this point whether the data reveal escape velocity. Third, visual inspection doesn't necessarily reveal a break point or non-linear change in the conditional probability of a recession around any particular growth rate in either Figure 10 or 11, which leaves it unclear whether strong form stall speed or escape velocity can be identified.

Trend and break tests. Clearly, visual inspection alone isn't sufficient to identify weak form or strong form stall speed and escape velocity from the conditional probability surfaces. We therefore proceed in two further steps.

First, to test for weak form stall speed or escape velocity, we apply the test for the slope of a trend function from Perron and Yabu (2009a) to examine the slope of the conditional probability surfaces at each of the 12 time horizons. The advantage of this test is that it is still effective even without any prior knowledge of whether the series is trend-stationary or contains a unit root. The results of the test are shown in Table 5 (weak form stall speed) and Table 6 (weak form escape velocity).

Table 5 shows that, with the exception of Poland (where there are no recessions within our sample), the mean and median slope of the stall speed conditional probability surfaces are negatively signed. Across the OECD, subsequent recession probability increases by between 1% and 10% for every one percentage point decrease in the growth rate in any given quarter. In 19 of the 36 economies in our data[9], the slope of the conditional probability surface is significant at the 5% level for every subsequent time horizon between one and 12 quarters. We can therefore reject the null hypothesis of the stall speed conditional probability

[8] The full conditional probability surfaces for all 36 economies are available from the authors on request.
[9] Australia, Czech Republic, Estonia, Finland, France, Germany, Greece, Israel, Korea, Latvia, Lithuania, Mexico, New Zealand, Portugal, Slovak Republic, Slovenia, Sweden, Switzerland, United States.

surfaces being without slope, which is consistent with every economy in our sample showing weak form stall speed.

Table 6 shows that the mean and median slopes of the escape velocity conditional probability surfaces are a much more mixed bag. For every one percentage point increase in the growth rate in any given quarter, the subsequent recession probability can decrease by as much as 4%, but in many cases actually *increases*. Moreover, there is no economy in which the decrease in recession probability is statistically significant at the 5% level for every subsequent time horizon that we consider. Therefore, we cannot reject the null hypothesis of the escape velocity conditional probability surfaces being without slope, which is consistent with every economy in our sample *not* showing weak form escape velocity.

Second, to test for strong form stall speed, we apply the Perron and Yabu (2009b) test for structural changes in trends[10]. This approach is robust for stationary or integrated noise component, and is valid whether the break is known or unknown. The results of the test applied to those economies where we have already found weak form stall speed are shown in Table 7. Among the 19 economies that display weak form stall speed, 13 also have structural breaks in the stall speed conditional probability surface at every subsequent time horizon[11]. These structural breaks occur at growth rates between 0.6% and 3.1% quarter-on-quarter annualised. This is a fairly large spread of stall speeds, and somewhat above earlier findings.

Summarising, we reject the existence of both weak and strong form escape velocity. Just over 50% of the economies in our sample seem to exhibit weak form stall speed. Of these, the majority also demonstrate behaviour consistent with strong form stall speed. However, the range of growth rates at which these breaks occur is quite wide, suggesting that cross-country idiosyncratic differences seem to dominate, rather than there being some unique stall speed from which all economies struggle to recover once growth has fallen below this threshold.

4 Markov switching models

In this section, we use Markov switching models to formally identify distinct stall speed or escape velocity phases of the business cycle. This allows us to further investigate the idiosyncratic nature of cross-country business cycle dynamics we identified in the previous section, and acts as a cross-check on our prior analysis by employing complementary analytical technique. If stall speed or escape velocity are systematic features of the business cycle, they should be revealed in the regimes of the Markov switching framework.

Specifically, for each OECD economy, we estimate a model of the form:

$$y_t = \mu(s) + \sigma\varepsilon_t, \quad \varepsilon_t \sim N(0,1) \tag{9}$$

[10] In the case of strong form escape velocity, these tests are unnecessary, given that we have rejected weak form escape velocity in every economy in our sample.
[11] Australia, Czech Republic, Finland, Germany, Greece, Israel, Korea, Latvia, Lithuania, New Zealand, Portugal, Slovak Republic, Slovenia.

where the state is defined by s, μ is the mean growth rate in state s, and the dynamics of the transition probabilities from state to state are governed by the following matrix:

$$\begin{bmatrix} \Pr(s_t = 1) \\ \vdots \\ \Pr(s_t = x) \end{bmatrix} = \begin{bmatrix} p_{11} & \cdots & p_{x1} \\ \vdots & \ddots & \vdots \\ 1 - \sum_{n=1}^{x-1} p_{1n} & \cdots & 1 - \sum_{n=1}^{x-1} p_{n1} \end{bmatrix} \begin{bmatrix} \Pr(s_{t-1} = 1) \\ \vdots \\ \Pr(s_{t-1} = x) \end{bmatrix} \qquad (10)$$

where x can take the value 2, 3 or 4, depending on whether additional distinct states are identified by the model.

We begin with four state specifications, looking for stall speed and escape velocity phases, in addition to normal growth and recession phases. We then trim the number of states one at a time, if additional distinct states are not found. Finally, following Nalewaik (2011) and Ho and Yetman (2012), we form a qualitative interpretation as to the appropriate description of distinct states, looking at coefficients, transition dynamics, and smoothed regime probabilities.

By way of a worked example, Figure 12 and Table 8 include detailed results for the US economy. We start with a four state specification, and appear to identify state 1 as a recession phase (coefficient of -2.5%, average duration of 2.7 quarters, and smoothed regime probabilities that line up with actual recessions), state 2 as a normal growth phase (coefficient of 3.8%, average duration of 16 quarters), state 3 as a sluggish recovery phase (coefficient of 0.9%, and smoothed regime probabilities that indicate this phase typically occurs after recessions, rather than before as would be expected from a stall phase), and state 4 as what we might call a surge phase (coefficient of 13.5%). However, state 3 and 4 do not appear to be distinct phases, lasting just 1 quarter, while the model coefficients themselves are not unique.

We therefore move to a three state specification. We identify state 1 as the normal growth phase (coefficient of 2.8%, and average duration just under 8 quarters), state 2 as an escape phase (coefficient of 8.5%, average duration just under 3 quarters, and smoothed regime probabilities that indicate this phase can be transitioned into from the normal growth and recession phases, but itself never transitions into the recession phase), and state 3 as a recession phase (coefficient of -4.0%, and average duration of 2 quarters). Identifying the high-growth escape velocity phase following recessions and at occasional other points of the business cycle is consistent with a Friedman-style plucking model (1964), and is similar to the high-growth phases identified in Nalewaik (2011) and Ho and Yetman (2012). But unlike the latter authors, our chosen interpretation of state 2 is 'escape velocity' rather than what they term a 'surge', given that the state can be arrived at from normal growth and recession phases, but itself does not transition into recessions[12].

Summary results of the above exercise for all OECD economies are shown in Table 9[13]. A number of notable findings emerge.

First and most importantly, the US turns out to be the only economy with an identifiable escape velocity phase, while the Markov switching framework uncovers no stall speed phases (low growth

[12] There is little evidence in this model of escape velocity phases occurring in the US since 1985, consistent with findings in Kim and Murray (2002), Camacho et al (2011), and Bordo and Haubrich (2012). These authors argue, variously, that advances in inventory management techniques and changing residential investment trends explain the disappearance of post-recession bounce-backs. To these explanations we may add constrained monetary policy, and the simple decline in trend growth rates, as additional factors preventing escapes.
[13] The full Markov switching estimation results are available from the authors on request.

regimes, with transition dynamics and smoothed regime probabilities that indicate the regime precedes recessions) across the OECD. Put another way, the gentle increase in recession risk (weak form stall speed) identified in sections 2 and 3 is not a strong enough feature of the data generating process to emerge as a distinct phase in our Markov switching models. Fundamentally, these business cycle phases are swamped by more significant business cycle dynamics, for which the Markov analysis selects. So to the extent to which stall speed and escape velocity exist, they are not an especially important or dominant feature of the data generating process.

Second, in 11 of the 36 OECD economies[14], the distinct business cycle phases that emerge are simply 'normal growth' and recessions. This is essentially a generalisation of Hamilton's (1989) characterisation of the US for a broder set of economies. Generally speaking, the length, depth, and smoothed regime probabilities of the negative growth regimes closely match historical recessions in these economies.

Third, in an additional 11 economies[15], the phases that emerge are normal growth and crisis. We distinguish between recession and crisis phases if the negative growth phase has a large absolute coefficient relative to that economy's average recession depth, and the smoothed regime probabilities show the phase occurring during generally known crisis periods and not occurring during other recessionary periods. It is worth reflecting on the fact that, in these economies, the Markov switching framework does not pick out recessions outside crises as a distinct, third phase of the business cycle. This is because of the sheer depth of the crisis-related contractions, in comparison to which both normal growth and run-of-the-mill recession look homogeneous. In the case of Belgium, Germany, Latvia, and Lithuania, the crisis phase is the global financial crisis (GFC) of 2007-2009. In Greece, Italy, Slovenia, and Spain, the crisis phase includes both the GFC and the European sovereign debt crisis of 2010-2013. In Finland, it also includes the Finnish banking crisis of 1991-93. And in Mexico, it encompasses the GFC and the Peso crisis of 1994-95.

Fourth, there are three economies[16] with distinct 'surge' phases. We distinguish surges from escape velocity if the transition dynamics indicate that the phase can transition into recession (recall from the worked example for the US, and our earlier discussion of the concept of escape velocity, that an escape velocity phase would rarely if ever transition directly into a recession). In the case of Austria and Denmark, the surge phase tends to bracket recessions - in other words, it seems to encapsulate both a final spurt of high growth at the end of an expansion phase of the cycle before the dip into recession, as well as the sharp bounce out of recession per a plucking-style framework.

Fifth, in five economies[17], the phases that emerge are an 'old normal' and a 'new normal'. These are positive growth regimes, one higher than the other, which last for a sustained amount of time, before giving way rapidly to the other regime around a structural break. Again, it is worth noting that, in these economies, the Markov switching framework does not identify a separate recession phase in addition to old and new normal. The distinctive feature of the data generating process is the structural break in the growth rate at one point in time, rather than occasional periods of negative growth. In Estonia and Ireland, the structural break is the GFC and Euro crisis; in France it is the ending of *Les Trente Glorieuses* in 1975; in Japan it is

[14] Canada, Chile, Czech Republic, Hungary, Israel, Netherlands, Portugal, Sweden, Switzerland, Turkey, United Kingdom.
[15] Belgium, Finland, Germany, Greece, Italy, Latvia, Lithuania, Mexico, New Zealand, Slovenia, Spain.
[16] Austria, Denmark, Poland.
[17] Estonia, France, Japan, Korean, Ireland

the bursting of the asset price bubble at the start of the 1990s; and in Korea it is the Asian financial crisis in the late-1990s.

And finally, in five economies[18], only a single business cycle phase is revealed by the Markov switching framework. We suspect the volatile nature of the GDP data in these economies masks any underlying phase shifts from the Markov search algorithm.

5 Concluding Remarks

Stall speed and escape velocity are frequently heard, but often only vaguely defined, terms employed in business economics and financial commentary parlance. We have defined and tested for a weak form and a strong form of stall speed and escape velocity. We find weak form stall speed in 19 of the 36 OECD economies, of which 13 also show strong form stall speed. We reject both weak and strong form escape velocity everywhere. Meanwhile, Markov switching models reveal an escape velocity phase in the US, but elsewhere stall speed and escape velocity phases are not picked up by the algorithm. Instead, a rich and idiosyncratic suite of regimes rooted in individual economies' economic history is unearthed across the OECD.

Our interpretation of the non-parametric findings *alongside* the results of Markov switching models is that stall speed dynamics are present in the GDP data generating process for many OECD economies, but they are not a strong enough feature to emerge as a defining characteristic of the business cycle.

We propose several possible future extensions to this work. First, while the focus of this paper has been on the dynamics of headline GDP growth, the dynamics of the individual expenditure components of GDP could display interesting stall speed or escape velocity behaviour. Second, future work could consider how trends in potential growth over time might have affected the analysis. As discussed, we chose to focus on growth rates given issues with finding reliable and robust measures of trend, but for those few countries where the data is available this would be an interesting avenue of further analysis. And third, there is room to consider the role of policy in trying to avert slowdowns becoming recessions – i.e. stall speed – and whether as monetary policy across the developed world has become increasingly constrained by the effective lower bound on rates, this has increased the probability and occurrence of stall speed.

We conclude with two thoughts. The first is a warning against the generalisation of US business cycle dynamics to other economies. The long literature on asymmetric business cycle dynamics has overwhelming drawn on US data. We replicate many of the findings of this literature, which are broadly consistent with a plucking framework, at least pre-1985. But our application of the techniques developed in that literature to a broader set of economies reveals a rich set of idiosyncratic data generating processes, closely tied to the economic history of the economy.

The second is on the application of physics metaphors to macroeconomics. As McCloskey (1983) has argued, the use of metaphor is a vital component of the rhetoric of economics; it is how we communicate our models and findings. But, as she notes, we must ask: "is it illuminating, is it satisfying, is it apt?" We

[18] Australia, Iceland, Luxembourg, Norway, Slovak Republic.

find the vagueness of the stall speed and escape velocity metaphors to be more confusing than illuminating. By defining and distinguishing the terms more clearly, we hope we have helped demystify certain features of business cycle dynamics, and shown that some of the more vivid aspects the metaphors seemingly imply are simply not there in the data.

References

Friedman, M. (1964). The Monetary Studies of the National Bureau. *The National Bureau Enters Its 45th Year, 44th Annual Report*, pp. 7-25.

Hamilton, J. D. (1989). A new approach to the economic analysis of nonstationary time series and the business cycle. *Econometrics*, Vol 57, No. 2, 357-384.

Ho, W.-Y., & Yetman, J. (2012). Does US GDP stall? *BIS Working Papers*, 387.

Ho, W.-Y., & Yetman, J. (2013). Do economies stall? The international evidence. *BIS Working Papers*, 407.

McCloskey, D. (1983). The Rhetoric of Economics. *Journal of Economic Literature*, 481-517.

McQueen, G., & Thorley, S. R. (1993). Asymmetric Business Cycle Turning Points. *Journal of Monetar Economics*, 341 -62.

Nalewaik, J. J. (2011). Forecasting recessions using stall speed. *Finance and Economics Discussion Series*, 2011-24.

Neftci, S. N. (1984). Are economic time series asymmetric over the business cycle? *Journal of Political Economy*, 92, 307-328.

Perron, P., & Yabu, T. (2009a). Estimating Deterministic Rrends with an Integrated or Stationary Noise Component. *Journal of Econometrics*, 56-69.

Perron, P., & Yabu, T. (2009b). Testing for Shifts in Trend with an Integrated or Stationary Noise Component. *Journal of Business & Economic Statistics*, 369–396.

Ramsey, J. B., & Rothman, P. (1996). Time irreversibility and business cycle asymmetry. *Journal of Money, Credit and Banking*, 28, 1-21.

Sheets, N. (2011). Is the US economy approaching ‘stall speed’? *Citi Empirical and Thematic Perspectives*,.

Sheets, N., & Sockin, R. A. (2012). Stall speeds and spillovers: some new evidence for the global economy. *Citi Empirical and Thematic Perspectives*.

Sichel, D. E. (1993). Business cycle asymmetry: a deeper look. *Economic Inquiry*, 21, 224-236.

van Dijk, D., & Frances, P. H. (1999). Modeling multiple regimes in the business cycle. *Macroeconomic Dynamics*, 311-40.

Figures & tables

Figure 1: Stylised version of the natural rate view

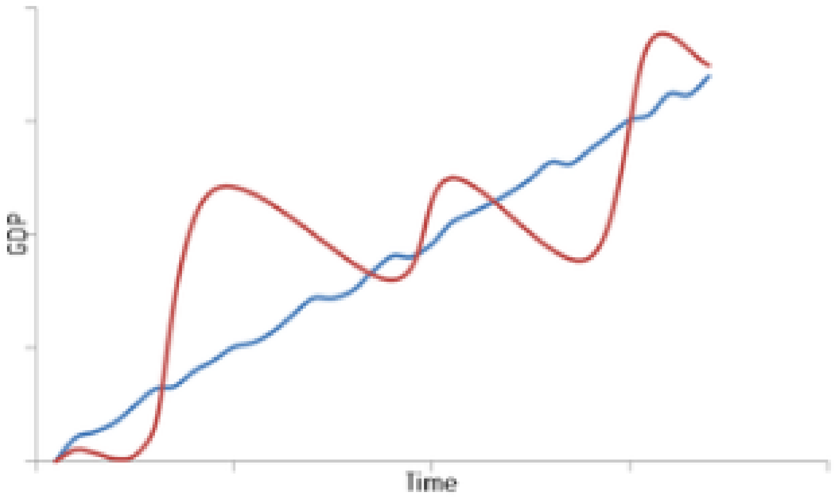


Figure 2: Stylised version of the plucking model

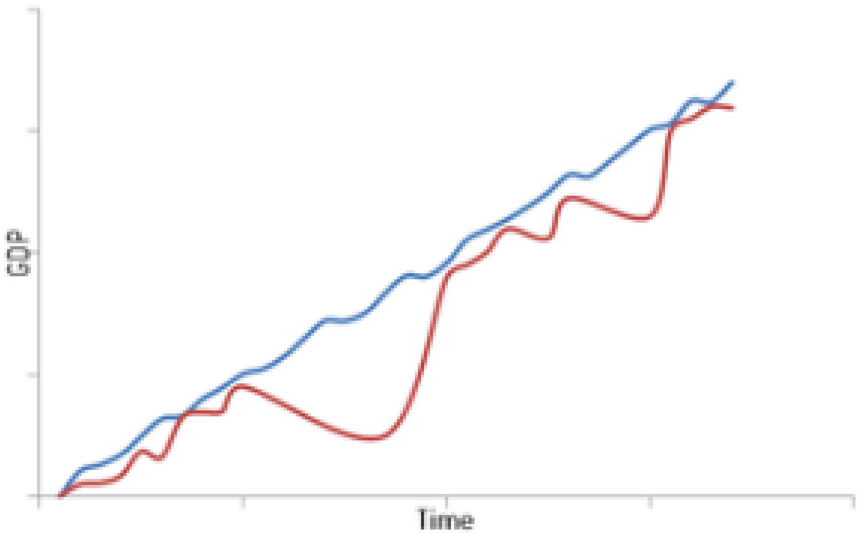


Figure 3: Distribution of recession length

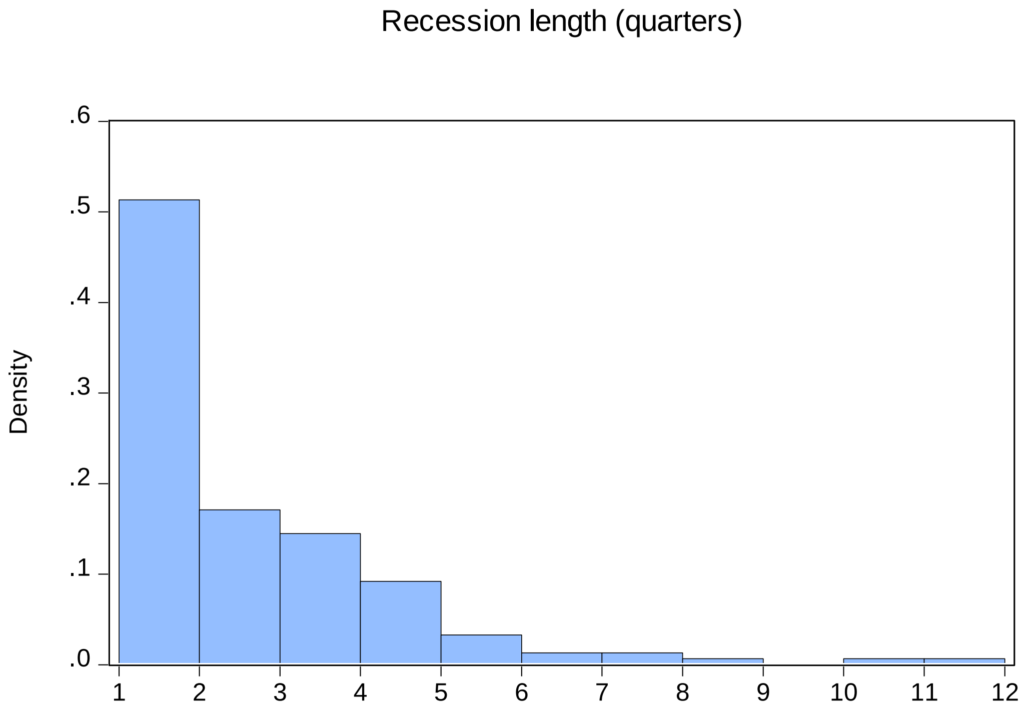


Figure 4: Distribution of recession depth

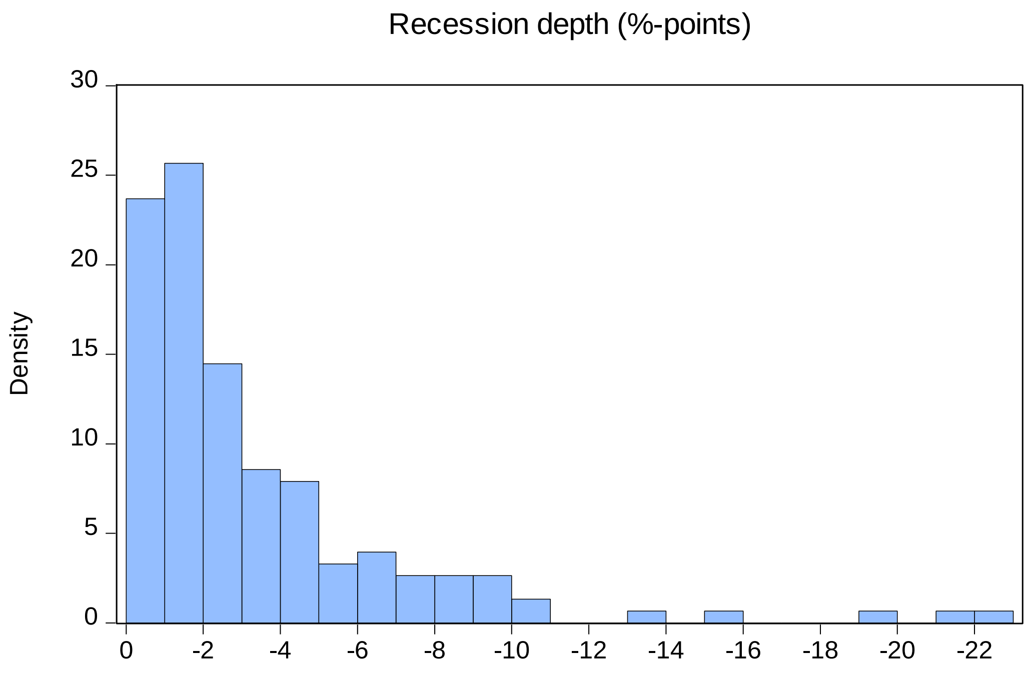


Figure 5: Scatter plot of recession length & depth

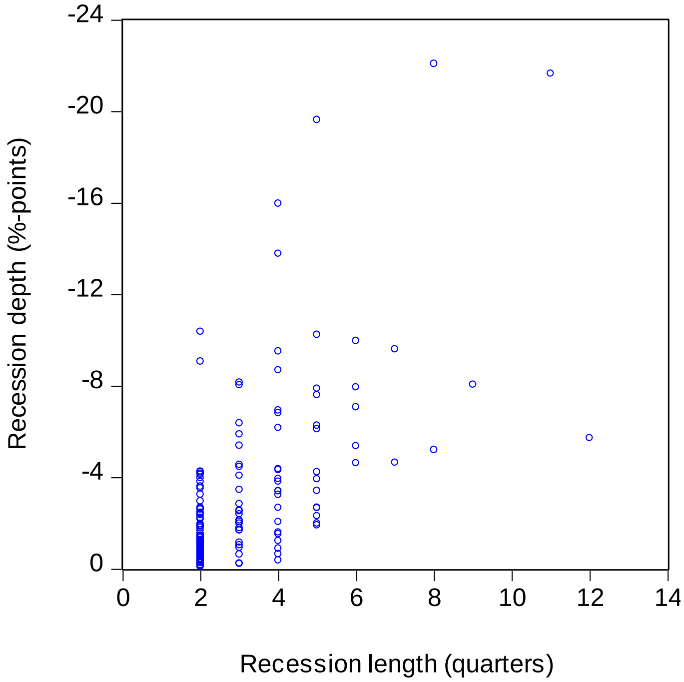


Figure 6: Kernel densities, annualised quarterly growth rates, recession and non-recession quarters

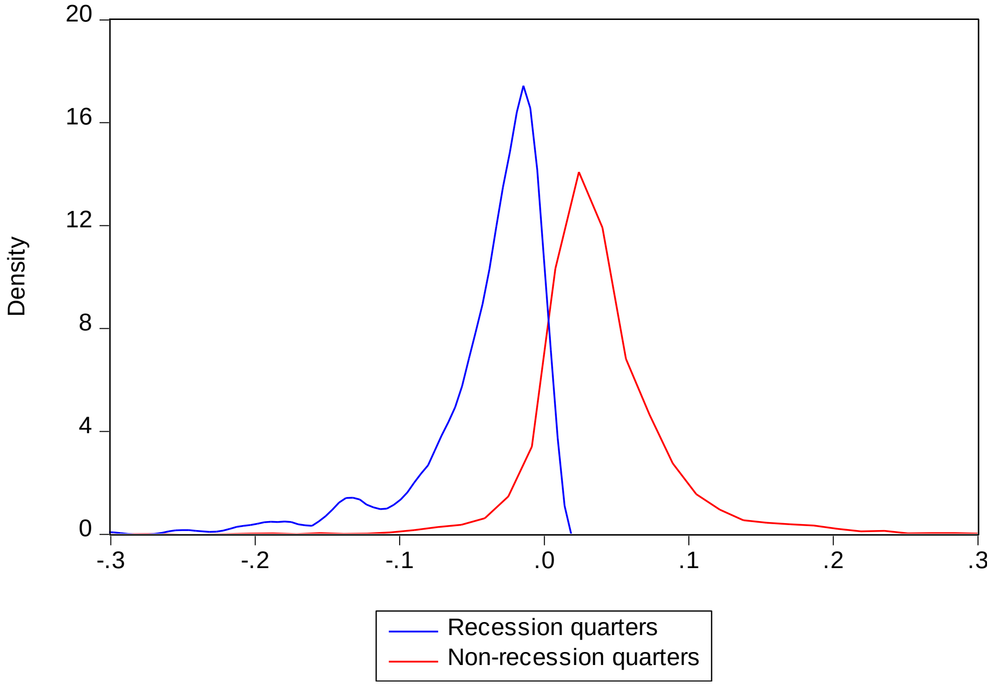


Figure 7: Kernel densities, annualised quarterly growth rates, during & in the vicinity of recession quarters

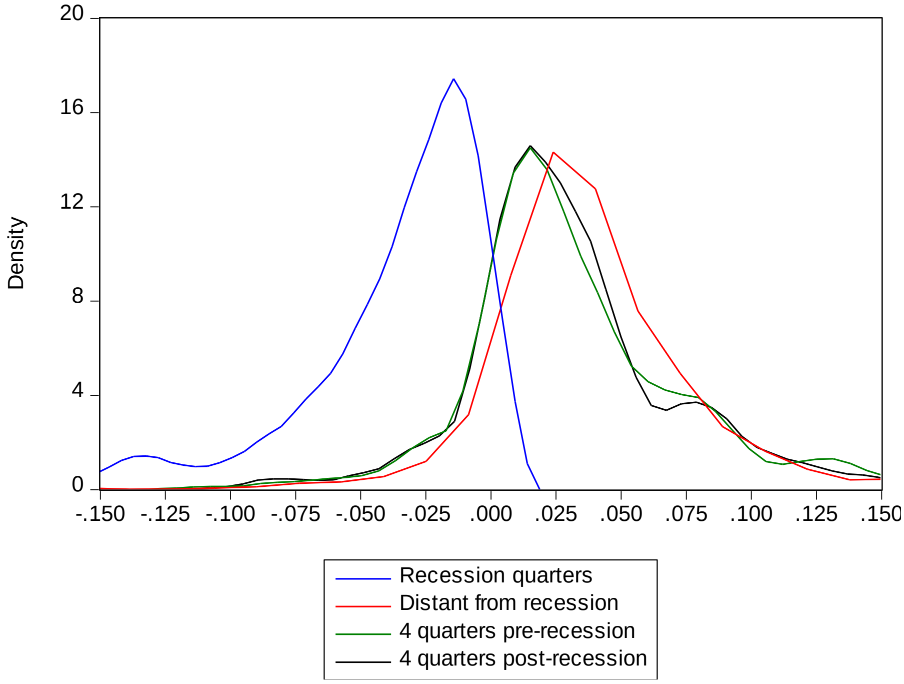


Figure 8: Kernel densities, annualised quarterly growth rates, in the vicinity of low growth

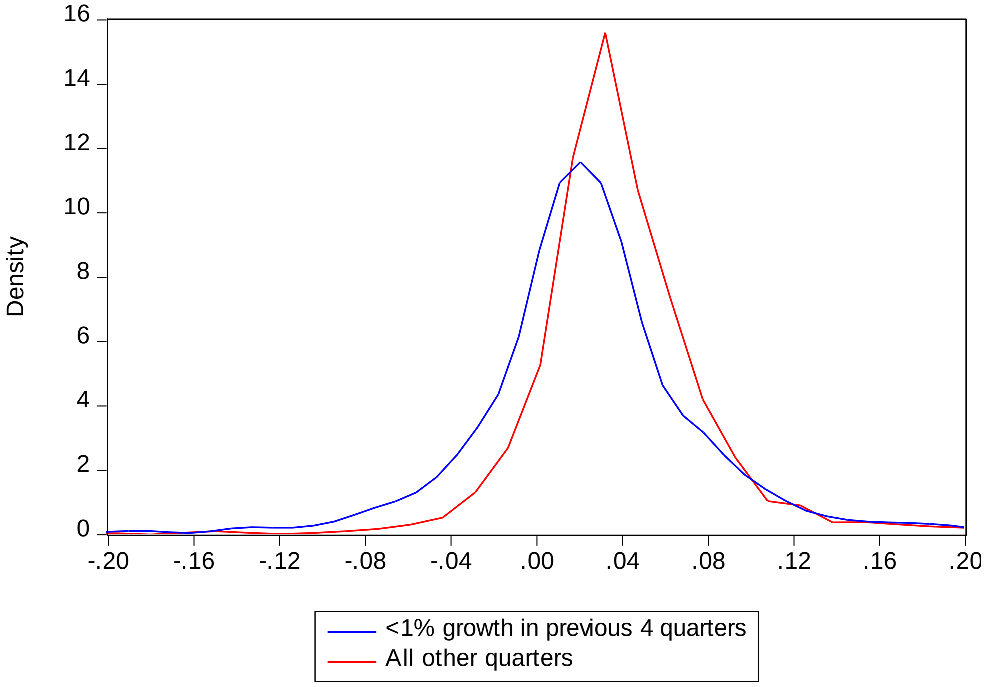


Figure 9: Kernel densities, annualised quarterly growth rates, in the vicinity of high growth

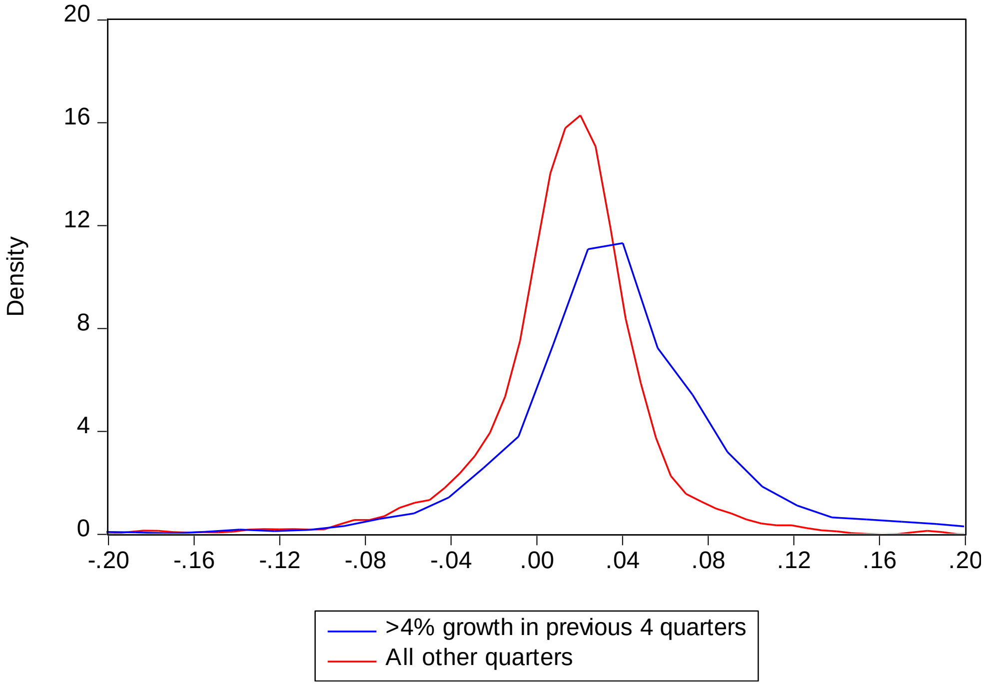


Figure 10: Probability of recession during subsequent quarters following growth below threshold, US economy

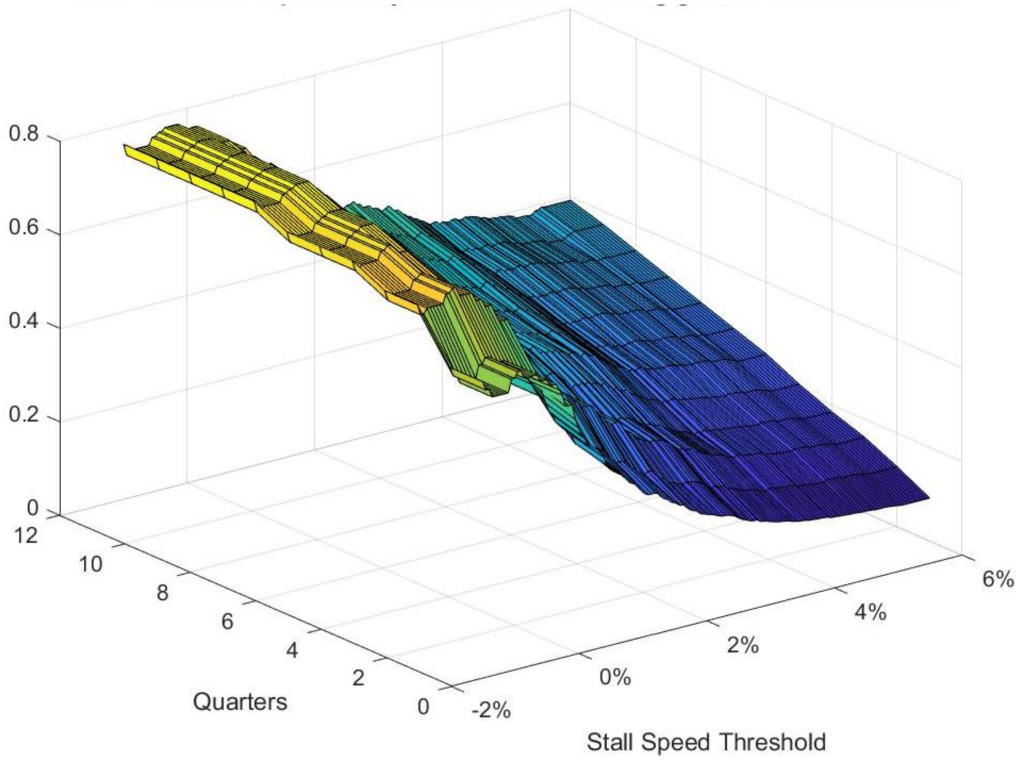


Figure 11: Probability of recession during subsequent quarters following growth above threshold, US economy

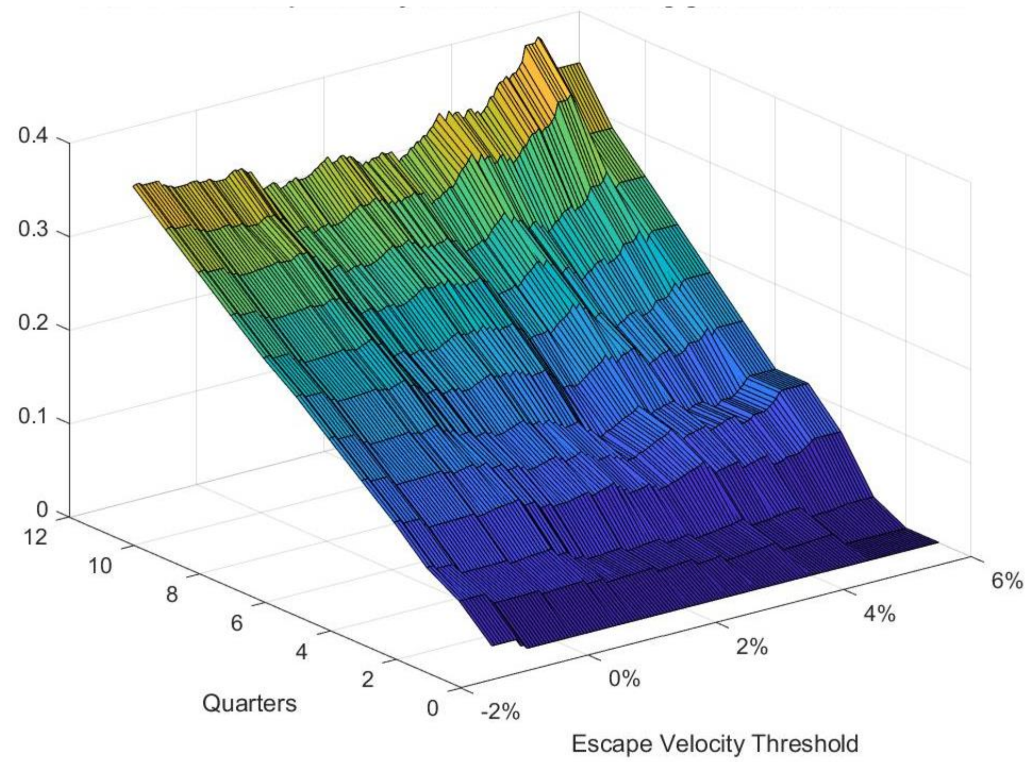
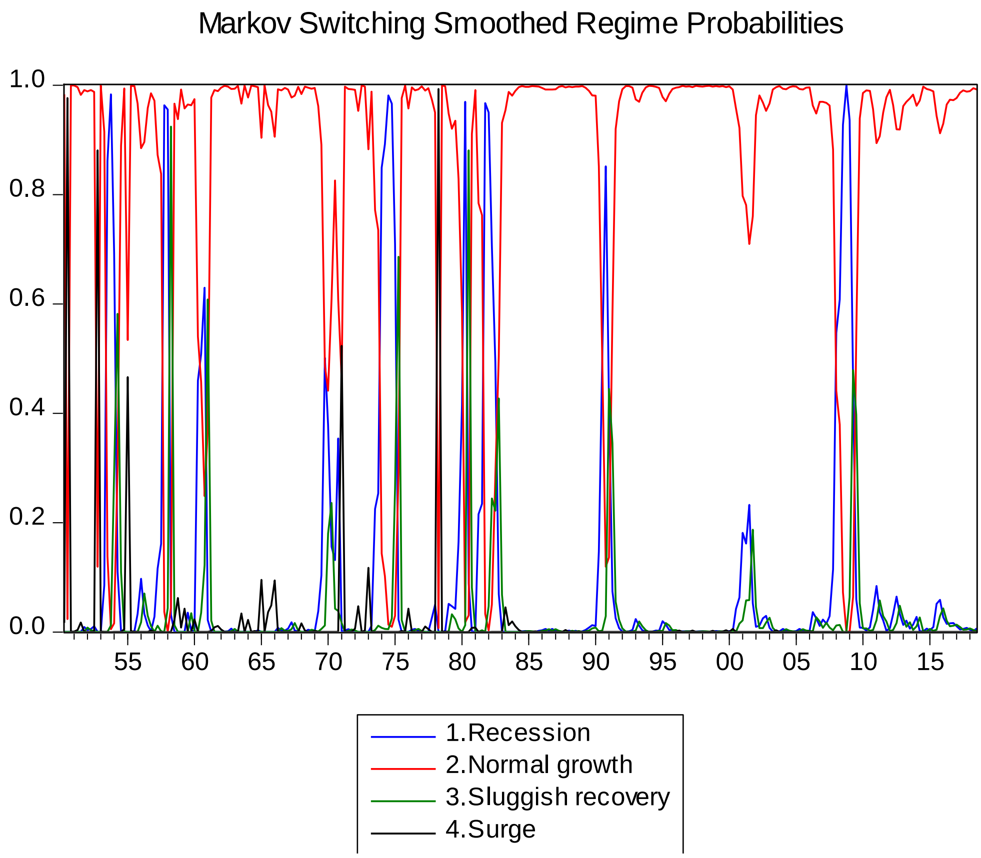


Figure 12: Smoothed state probabilities from Markov switching models, US economy

Four state model



Three state model

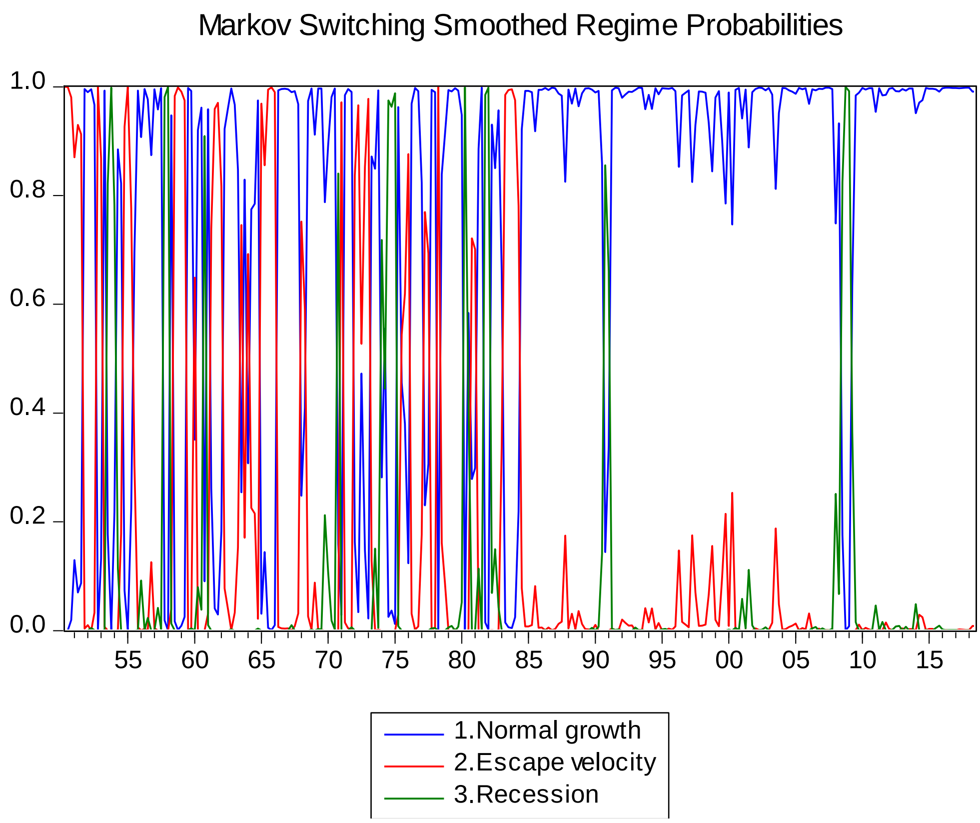


Table 1: GDP, quarter-on-quarter annualised growth, data summary

Country	Code	Start of sample	End of sample	Mean	Standard deviation
AUSTRALIA	AU	Q3 1959	Q4 2018	3.5%	4.3%
AUSTRIA	OE	Q1 1996	Q4 2018	1.9%	3.2%
BELGIUM	BG	Q1 1995	Q4 2018	1.8%	2.1%
CANADA	CN	Q1 1981	Q4 2018	2.4%	3.0%
CHILE	CL	Q1 1996	Q4 2018	3.9%	4.4%
CZECH REPUBLIC	CZ	Q1 1996	Q4 2018	2.5%	3.4%
DENMARK	DK	Q1 1991	Q4 2018	1.7%	3.8%
ESTONIA	EO	Q1 1995	Q4 2018	4.5%	9.1%
FINLAND	FN	Q1 1990	Q4 2018	1.7%	5.1%
FRANCE	FR	Q1 1950	Q4 2018	3.2%	3.9%
GERMANY	BD	Q1 1991	Q4 2018	1.4%	3.1%
GREECE	GR	Q1 1995	Q4 2018	1.0%	5.7%
HUNGARY	HN	Q1 1995	Q4 2018	2.5%	3.6%
ICELAND	IC	Q1 1997	Q4 2018	4.0%	11.3%
IRELAND	IR	Q1 1995	Q4 2018	6.5%	16.2%
ISRAEL	IS	Q1 1995	Q4 2018	3.8%	3.6%
ITALY	IT	Q1 1996	Q4 2018	0.6%	2.7%
JAPAN	JP	Q1 1980	Q4 2018	2.0%	4.0%
KOREA	KO	Q1 1960	Q4 2018	7.8%	8.8%
LATVIA	LV	Q1 1995	Q4 2018	4.3%	9.1%
LITHUANIA	LN	Q1 2005	Q4 2018	3.2%	7.5%
LUXEMBOURG	LX	Q1 2000	Q4 2018	2.9%	5.9%
MEXICO	MX	Q1 1993	Q4 2018	2.5%	5.0%
NETHERLANDS	NL	Q1 1996	Q4 2018	2.0%	2.7%
NEW ZEALAND	NZ	Q2 1987	Q4 2018	2.8%	4.4%
NORWAY	NW	Q1 1978	Q4 2018	2.7%	5.3%
POLAND	PO	Q1 2002	Q4 2018	4.1%	3.9%
PORTUGAL	PT	Q1 1995	Q4 2018	1.4%	3.2%
SLOVAK REPUBLIC	SX	Q1 1995	Q4 2018	4.2%	6.5%
SLOVENIA	SJ	Q1 1995	Q4 2018	2.8%	4.4%
SPAIN	ES	Q1 1995	Q4 2018	2.2%	2.6%
SWEDEN	SD	Q1 1981	Q4 2018	2.3%	3.7%
SWITZERLAND	SW	Q1 1980	Q4 2018	1.8%	2.4%
TURKEY	TK	Q1 1998	Q4 2018	4.9%	9.4%
UNITED KINGDOM	UK	Q1 1955	Q4 2018	2.5%	4.0%
UNITED STATES	US	Q1 1950	Q4 2018	3.3%	3.8%

Table 2: Recession data summary

Country	Code	Total quarters	Recession quarters	% of time in recession	Number of recessions	Avg. recession duration (qtrs)	Std dev recession duration (qtrs)	Min. recession duration (qtrs)	Max recession duration (qtrs)	Avg. recession depth (%)	Std dev recession depth (%)	Min. recession depth (%)	Max recession depth (%)
AUSTRALIA	AU	236	16	7%	7	2.3	0.7	2	4	-1.8%	0.8%	-0.7%	-3.4%
AUSTRIA	OE	90	13	14%	4	3.3	1.3	2	5	-2.4%	2.2%	-0.8%	-6.1%
BELGIUM	BG	94	12	13%	3	4.0	0.0	4	4	-1.6%	1.6%	-0.4%	-3.8%
CANADA	CN	150	15	10%	4	3.8	1.5	2	6	-3.5%	1.7%	-0.8%	-5.4%
CHILE	CL	90	6	7%	2	3.0	1.0	2	4	-3.6%	0.4%	-3.2%	-4.0%
CZECH REPUBLIC	CZ	90	12	13%	3	4.0	0.8	3	5	-3.1%	1.9%	-1.6%	-5.9%
DENMARK	DK	110	18	16%	6	3.0	1.4	2	6	-2.1%	2.3%	-0.2%	-7.1%
ESTONIA	EO	94	13	14%	5	2.6	1.2	2	5	-5.1%	7.3%	-0.6%	-19.6%
FINLAND	FN	114	24	21%	5	4.8	1.6	3	7	-5.2%	3.8%	-1.1%	-10.0%
FRANCE	FR	275	17	6%	5	3.4	1.0	2	5	-1.6%	1.4%	-0.1%	-3.9%
GERMANY	BD	111	16	14%	6	2.7	0.9	2	4	-2.2%	2.2%	-0.8%	-6.9%
GREECE	GR	94	21	22%	5	4.2	3.5	2	11	-6.2%	8.0%	-0.5%	-21.6%
HUNGARY	HN	94	9	10%	3	3.0	1.4	2	5	-3.7%	2.8%	-1.2%	-7.6%
ICELAND	IC	86	14	16%	6	2.3	0.5	2	3	-3.2%	1.4%	-1.4%	-5.4%
IRELAND	IR	94	11	12%	4	2.8	1.3	2	5	-3.9%	3.8%	-0.2%	-10.2%
ISRAEL	IS	95	7	7%	2	3.5	1.5	2	5	-1.8%	1.6%	-0.1%	-3.4%
ITALY	IT	91	22	24%	6	3.7	2.2	2	8	-2.5%	3.0%	-0.2%	-7.9%
JAPAN	JP	155	18	12%	7	2.6	0.7	2	4	-2.5%	2.6%	-0.5%	-8.7%
KOREA	KO	235	5	2%	2	2.5	0.5	2	3	-6.2%	2.0%	-4.2%	-8.1%
LATVIA	LV	94	15	16%	4	3.8	2.5	2	8	-6.5%	9.0%	-1.0%	-22.1%
LITHUANIA	LN	55	4	7%	1	4.0	0.0	4	4	-16.0%	0.0%	-16.0%	-16.0%
LUXEMBOURG	LX	74	11	15%	3	3.7	1.7	2	6	-3.8%	2.9%	-1.2%	-7.9%
MEXICO	MX	103	7	7%	3	2.3	0.5	2	3	-6.5%	3.9%	-1.1%	-10.4%
NETHERLANDS	NL	91	10	11%	3	3.3	0.9	2	4	-2.1%	1.6%	-0.9%	-4.4%
NEW ZEALAND	NZ	125	12	10%	4	3.0	1.2	2	5	-2.9%	0.8%	-2.1%	-4.3%
NORWAY	NW	163	14	9%	7	2.0	0.0	2	2	-2.1%	1.0%	-1.2%	-3.8%
POLAND	PO	64	0	0%	0	NA	NA	NA	NA	NA	NA	NA	NA
PORTUGAL	PT	95	18	19%	4	4.5	2.7	2	9	-3.6%	3.0%	-0.3%	-8.1%
SLOVAK REPUBLIC	SX	94	4	4%	1	4.0	0.0	4	4	-6.2%	0.0%	-6.2%	-6.2%
SLOVENIA	SJ	94	11	12%	2	5.5	1.5	4	7	-7.1%	2.4%	-4.6%	-9.5%
SPAIN	ES	95	18	19%	2	9.0	3.0	6	12	-5.2%	0.6%	-4.6%	-5.7%
SWEDEN	SD	150	10	7%	4	2.5	0.5	2	3	-3.3%	2.2%	-0.6%	-6.4%
SWITZERLAND	SW	154	23	15%	8	2.9	1.1	2	5	-1.4%	1.0%	-0.4%	-3.5%
TURKEY	TK	82	10	12%	4	2.5	0.9	2	4	-6.9%	5.0%	-0.6%	-13.8%
UNITED KINGDOM	UK	255	28	11%	9	3.1	1.4	2	5	-2.3%	2.0%	-0.1%	-6.3%
UNITED STATES	US	274	20	7%	8	2.5	0.7	2	4	-2.4%	1.0%	-0.6%	-3.9%
Total		4460	484	11%	152								
Average						3.4				-4.0%			

Table 3: GDP, quarter-on-quarter annualised, around recessions (asterisks denote statistically significant differences of mean and median relative to the 'non-recession' / 'distant from recession' samples)

	Mean		Median		Std dev	Skew	Kurtosis
Recessions	-4.2%	*	-2.7%	*	4.8%	-2.9	12.8
Non-recessions	3.9%		3.2%		5.1%	4.5	90.2
within 2 quarters							
Pre-recession	3.4%		2.3%	*	5.8%	0.6	6.7
Post-recession	3.1%	*	2.4%	*	4.7%	-0.2	8.7
Distant from recession	4.0%		3.3%		5.1%	5.0	102.0
within 4 quarters							
Pre-recession	3.6%	*	2.5%	*	5.3%	0.8	5.9
Post-recession	3.2%	*	2.6%	*	4.7%	0.3	6.3
Distant from recession	4.1%		3.4%		5.1%	5.5	112.4
within 8 quarters							
Pre-recession	3.8%		3.0%	*	5.0%	0.8	5.6
Post-recession	3.5%	*	2.7%	*	4.6%	0.7	5.4
Distant from recession	4.1%		3.4%		5.4%	6.1	121.3

Table 4: Share of quarters in recession following growth below or above threshold

Growth of less than:	**6.0%**	**5.0%**	**4.0%**	**3.0%**	**2.0%**	**1.0%**	**0.0%**	**-1.0%**
within 2 quarters	7%	7%	8%	9%	10%	10%	8%	9%
within 4 quarters	13%	14%	15%	16%	18%	18%	16%	18%
within 8 quarters	24%	24%	24%	25%	28%	29%	28%	30%
Growth of more than:	**6.0%**	**5.0%**	**4.0%**	**3.0%**	**2.0%**	**1.0%**	**0.0%**	**-1.0%**
within 2 quarters	7%	6%	6%	6%	6%	7%	7%	7%
within 4 quarters	13%	13%	11%	11%	11%	12%	13%	13%
within 8 quarters	25%	25%	24%	23%	22%	23%	24%	24%

Table 5: Test results for weak form stall speed

Country	Code	Mean slope	Median slope	Std dev of slope	Share of horizons over which slope is 5% significant & correctly signed
AUSTRALIA	AU	-5.3%	-5.2%	0.3%	100%
AUSTRIA	OE	-5.3%	-5.5%	1.0%	25%
BELGIUM	BG	-6.7%	-6.8%	1.9%	25%
CANADA	CN	-9.1%	-9.0%	1.1%	33%
CHILE	CL	-6.9%	-6.9%	0.5%	92%
CZECH REPUBLIC	CZ	-9.6%	-9.5%	1.4%	100%
DENMARK	DK	-3.8%	-4.0%	0.9%	33%
ESTONIA	EO	-5.2%	-5.3%	0.5%	100%
FINLAND	FN	-6.3%	-6.4%	0.7%	100%
FRANCE	FR	-7.7%	-7.7%	1.0%	100%
GERMANY	BD	-6.6%	-6.8%	1.2%	100%
GREECE	GR	-5.5%	-5.9%	1.0%	100%
HUNGARY	HN	-5.0%	-4.8%	1.4%	58%
ICELAND	IC	-1.1%	-1.1%	0.8%	33%
IRELAND	IR	-2.4%	-2.3%	0.6%	42%
ISRAEL	IS	-5.2%	-5.2%	0.5%	100%
ITALY	IT	-4.8%	-4.5%	2.0%	50%
JAPAN	JP	-5.1%	-5.5%	1.3%	83%
KOREA	KO	-2.3%	-2.2%	0.2%	100%
LATVIA	LV	-5.5%	-5.4%	0.2%	100%
LITHUANIA	LN	-9.1%	-9.4%	0.6%	100%
LUXEMBOURG	LX	-2.5%	-2.6%	0.7%	58%
MEXICO	MX	-7.8%	-7.8%	0.7%	100%
NETHERLANDS	NL	-6.6%	-6.4%	1.1%	92%
NEW ZEALAND	NZ	-6.4%	-6.5%	0.7%	100%
NORWAY	NW	-2.6%	-2.7%	0.6%	67%
POLAND	PO	NA	NA	NA	NA
PORTUGAL	PT	-5.8%	-5.4%	1.3%	100%
SLOVAK REPUBLIC	SX	-8.0%	-8.3%	1.0%	100%
SLOVENIA	SJ	-9.1%	-8.9%	0.9%	100%
SPAIN	ES	-10.0%	-9.9%	0.8%	58%
SWEDEN	SD	-4.0%	-3.8%	0.6%	100%
SWITZERLAND	SW	-6.2%	-6.0%	1.2%	100%
TURKEY	TK	-1.8%	-1.8%	0.5%	25%
UNITED KINGDOM	UK	-6.1%	-6.1%	0.3%	92%
UNITED STATES	US	-6.5%	-6.6%	0.7%	100%

Table 6: Test results for weak form escape velocity

Country	Code	Mean slope	Median slope	Std dev of slope	Share of horizons over which slope is 5% significant & correctly signed
AUSTRALIA	AU	0.1%	0.1%	0.4%	8%
AUSTRIA	OE	2.2%	1.5%	1.8%	8%
BELGIUM	BG	-4.2%	-4.1%	1.9%	17%
CANADA	CN	-2.0%	-2.2%	1.0%	42%
CHILE	CL	1.2%	1.2%	0.7%	0%
CZECH REPUBLIC	CZ	-1.4%	-1.5%	0.7%	33%
DENMARK	DK	0.2%	0.4%	1.2%	0%
ESTONIA	EO	0.8%	0.9%	0.6%	0%
FINLAND	FN	-0.1%	0.0%	0.5%	0%
FRANCE	FR	-1.3%	-1.3%	0.5%	83%
GERMANY	BD	2.3%	1.2%	2.9%	0%
GREECE	GR	1.3%	1.4%	1.1%	0%
HUNGARY	HN	-2.0%	-2.1%	0.9%	17%
ICELAND	IC	-0.3%	-0.2%	0.3%	0%
IRELAND	IR	-1.0%	-1.2%	0.4%	0%
ISRAEL	IS	1.5%	1.9%	0.9%	0%
ITALY	IT	0.0%	-0.6%	2.1%	0%
JAPAN	JP	-1.8%	-1.4%	1.2%	25%
KOREA	KO	0.0%	0.0%	0.1%	0%
LATVIA	LV	0.9%	1.1%	0.9%	0%
LITHUANIA	LN	2.2%	2.4%	1.7%	0%
LUXEMBOURG	LX	0.8%	0.8%	0.8%	8%
MEXICO	MX	-0.9%	-0.8%	0.4%	0%
NETHERLANDS	NL	-1.2%	-2.0%	2.4%	8%
NEW ZEALAND	NZ	-0.2%	-0.3%	0.5%	0%
NORWAY	NW	0.0%	0.0%	0.3%	0%
POLAND	PO	NA	NA	NA	NA
PORTUGAL	PT	-3.3%	-2.9%	1.7%	8%
SLOVAK REPUBLIC	SX	0.7%	0.6%	0.3%	0%
SLOVENIA	SJ	-0.2%	-0.5%	1.0%	0%
SPAIN	ES	-2.3%	-2.3%	0.9%	33%
SWEDEN	SD	-0.6%	-0.7%	0.5%	17%
SWITZERLAND	SW	1.4%	0.7%	2.3%	8%
TURKEY	TK	-0.6%	-0.5%	0.2%	8%
UNITED KINGDOM	UK	0.8%	0.5%	1.1%	8%
UNITED STATES	US	-0.4%	-0.4%	0.2%	8%

Table 7: Test results for strong form stall speed

Country	Code	Mean breakpoint	Median breakpoint	Std dev of breakpoint	Share of horizons over which breakpoint is significant
AUSTRALIA	AU	3.1%	3.0%	0.3%	100%
CZECH REPUBLIC	CZ	1.5%	1.7%	0.5%	100%
ESTONIA	EO	3.0%	3.2%	0.6%	25%
FINLAND	FN	1.4%	1.5%	0.6%	100%
FRANCE	FR	2.1%	2.3%	0.7%	17%
GERMANY	BD	1.6%	1.5%	1.0%	100%
GREECE	GR	2.0%	1.8%	0.7%	100%
ISRAEL	IS	0.6%	0.7%	0.2%	100%
KOREA	KO	2.7%	2.8%	0.4%	100%
LATVIA	LV	1.5%	1.2%	0.6%	100%
LITHUANIA	LN	1.1%	1.1%	0.1%	100%
MEXICO	MX	2.3%	2.4%	0.2%	83%
NEW ZEALAND	NZ	1.9%	2.2%	1.0%	100%
PORTUGAL	PT	2.3%	2.2%	0.7%	100%
SLOVAK REPUBLIC	SX	2.7%	2.7%	0.0%	100%
SLOVENIA	SJ	2.8%	3.1%	0.9%	100%
SWEDEN	SD	2.6%	2.9%	0.6%	50%
SWITZERLAND	SW	2.4%	2.5%	0.7%	58%
UNITED STATES	US	2.8%	2.6%	0.4%	58%

Table 8: Markov switch model regression results, US

Four state model

		μ_1	μ_2	μ_3	μ_4
coefficient		-0.025	0.038	0.009	0.135
p-values		NA	NA	NA	NA
expected duration (qtrs)		2.7	16.0	1.0	1.0
transition probabilities		1	2	3	4
P(i, k) = P(s(t) = k | s(t-1) = i)	1	0.63	0.00	0.36	0.02
(row = i / column = j)	2	0.04	0.94	0.00	0.02
	3	0.00	1.00	0.00	0.00
	4	0.00	1.00	0.00	0.00

Three-state model

		μ_1	μ_2	μ_3
coefficient		0.028	0.085	-0.040
p-values		0.00	0.00	0.00
expected duration (qtrs)		7.6	2.6	2.0
transition probabilities		1	2	3
P(i, k) = P(s(t) = k | s(t-1) = i)	1	0.87	0.08	0.05
(row = i / column = j)	2	0.38	0.62	0.00
	3	0.43	0.07	0.50

Table 9: Summary of Markov switching model regimes for all OECD economies

Country	Code	No. of states in preferred model	Qualitative interpretation of states						
			Normal growth	Recession	Crisis	Surge	Escape	Old normal	New normal
Normal and recession phases									
CANADA	CN	2	x	x					
CHILE	CL	2	x	x					
CZECH REPUBLIC	CZ	2	x	x					
HUNGARY	HN	2	x	x					
ISRAEL	IS	2	x	x					
NETHERLANDS	NL	2	x	x					
PORTUGAL	PT	2	x	x					
SWEDEN	SD	2	x	x					
SWITZERLAND	SW	2	x	x					
TURKEY	TK	2	x	x					
UNITED KINGDOM	UK	2	x	x					
Normal and crisis phases									
BELGIUM	BG	2	x		x				
FINLAND	FN	2	x		x				
GERMANY	BD	2	x		x				
GREECE	GR	2	x		x				
ITALY	IT	2	x		x				
LATVIA	LV	2	x		x				
LITHUANIA	LN	2	x		x				
MEXICO	MX	2	x		x				
NEW ZEALAND	NZ	2	x		x				
SLOVENIA	SJ	2	x		x				
SPAIN	ES	2	x		x				
Surge phase									
AUSTRIA	OE	3	x	x		x			
DENMARK	DK	3	x	x		x			
POLAND	PO	2	x			x			
Escape phase									
UNITED STATES	US	3	x	x			x		
Old and new normals									
ESTONIA	EO	3		x				x	x
FRANCE	FR	2						x	x
JAPAN	JP	2						x	x
KOREA	KO	2						x	x
IRELAND	IR	2						x	x
Single distinct phase									
AUSTRALIA	AU	1	x						
ICELAND	IC	1	x						
LUXEMBOURG	LX	1	x						
NORWAY	NW	1	x						
SLOVAK REPUBLIC	SX	1	x						