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Could an economy get stuck on a rational pessimism sunspot path? The case of Japan ☆

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ABSTRACT

Developed economies have experienced slower growth since the 2008 financial crisis, creating fears of "secular stagnation." Rational expectations models have forward-looking sunspot solutions, which could cause this; here we investigate the case of Japan. We show that a New Keynesian model with a weak equilibrium growth path driven by pessimism sunspot belief shocks matches Japanese economic behaviour. Another possibility is a conventional model where productivity growth has simply slowed down for unknown reasons. Nevertheless, a welfare-optimising approach implies fiscal policy should commit to eliminating the potential sunspot while being prepared to revert to normal policy if inflation rises.

1. Introduction

It is a well-known feature of rational expectations models of the future that they imply sunspot solutions where expectations of future explosive reactions to current sunspots underpin these current sunspot effects. Thus, people can expect a current shock to prices which is underpinned by the expectation that it will lead to future price movements; a hyperinflation can occur with such a shock which is self-validating. Prices rise today, with people expecting future rises which stimulate the demand to rise today that creates the price shock — Minford and Peel (2015, chapter 2) set out these mechanics and explain how these sunspots can be eliminated from the model solution by a monetary commitment to stable prices by the central bank.

For output it is usual to assume that it tends to a natural rate equilibrium gradually over time and that it is not affected by expectations of future events; thus typically output does not depend on the future via a forward root in the model, as prices do. This implies that there will be no sunspot element in the output solution. However, in recent decades we have observed puzzling stagnation episodes in output in several economies, especially since the financial crisis, leading to a wide range of views suggesting that the modern economy is vulnerable to weak self-perpetuating demand — termed 'secular stagnation'. In particular, Summers (2014) has urged in a series of policy-oriented papers that there should be expansionary fiscal policy to ward off the threat of secular stagnation. He suggests that weak demand can become converted into low long term growth by hysteresis. He postulates a world savings glut as the cause of this demand weakness. Eichengreen (2015) and Backhouse and Boianovsky (2016) review various possible causes of secular stagnation, a theory with a long history much associated with Alvin Hansen (e.g. Hansen, 1954). However, the main problem with applying any of these theories to the current situation is that today's stagnation only appeared after the financial crisis, whereas before it, growth seemed strong and assured. This link to the crisis is more suggestive of a sudden sunspot cause, triggered by a crisis contraction that destroyed business confidence.

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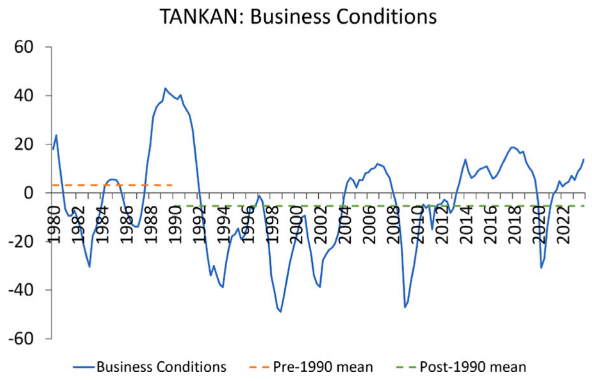

Fig. 1. Business conditions. Note: Business Conditions has a threshold of 0.

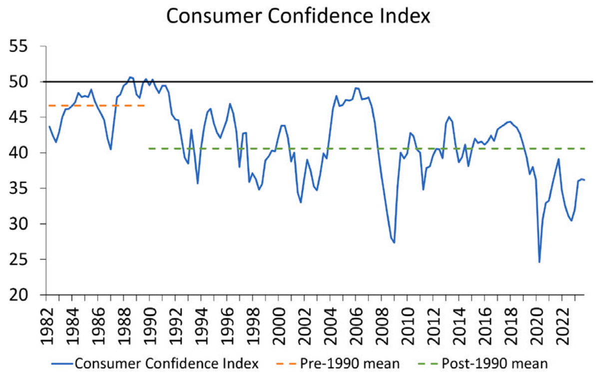

Fig. 2. Consumer confidence. Note: Consumer Confidence has a threshold is 50.

Meanwhile, another series of papers, such as Farmer (e.g. Farmer, 2020), and others reviewed below, has argued persistently for the presence in the economy of real sunspot equilibria such as can occur in rational expectations models — in this case as real sunspots fed by a forward root in output determination. If permitted by models through such a forward root, such equilibria are usually ruled out by transversality and other terminal conditions, such as general business knowledge of true long run productive potential or a government commitment via fiscal policy; plainly if no such conditions exist then these sunspot equilibria can occur and achieve the effects postulated by Summers for hysteresis — for which in itself there is not really a clear theoretical cause. Episodes of persistently weak growth have occurred in many western economies after the financial crisis — including the US and the UK. However, in one economy, Japan, this type of stagnationary behaviour has occurred systematically since the 'bursting of the financial bubble' in 1989 — as the sudden adoption of a sharply tighter monetary policy then is generally called — a long period now stretching over more than thirty years. It therefore seems a prime candidate for a sunspot-created stagnation episode.

We can gauge this by looking at confidence indices. In Fig. 1 and Fig. 2 we show Business Conditions from the TANKAN survey and the Consumer Confidence Index from the Japan Cabinet Office.[1] What we can see is that following a large increase in business confidence in the late 1980s there was a long period of low confidence lasting until the mid 2000s. Since then there have been some large drops in confidence around the Global Financial Crisis and Covid. The situation for consumer confidence looks far worse. From 1990 there has been a trend of worsening consumer confidence, that has systematically moved away from the threshold.

In this paper we examine whether a sudden bout of pessimism in business opinion can account for the collapse in growth in Japan. We investigate this question through a DSGE model estimated over a sample from 1989 to 2022. In this model, the Bank of Japan (BOJ) eliminates the possibility of a monetary sunspot via its well-known commitment to price stability in the form of a low inflation target, which has the side-effect of preventing a higher inflation equilibrium; but the Japanese business sector does not appear to believe in a high output potential equilibrium while the Government of Japan (GOJ) refuses to commit via fiscal policy to eliminating persistently weak growth, so that there is nothing to prevent a stagnationary output sunspot path. At the heart of our model is an output production function in which the current natural rate depends on expectations of future output via their effects on capital and labour supply. Our aim is to see whether a model including such a pessimism shock could account for the behaviour of the Japanese economy over this period. We do this using the indirect inference approach, which tests a model according to how

[1] Note that for Business Conditions the value of 0 is the threshold, whereas for Consumer Confidence the threshold is 50.

well its simulated behaviour matches the actual behaviour found in the data — here we use the cyclical behaviour in our test. This approach provides a powerful test in small samples, such as this one for Japan. We create our estimate of the sunspot pessimism shock by first estimating the predictions of a model of Japan without the sunspot, which passes our test on the cyclical behaviour; the sunspot is then derived as the extra shock needed for the model to predict the observed trend output path in Japan, which the model over-predicts otherwise. It turns out that such a model passes the test for this Japanese episode with good probability; nevertheless, so does an orthodox model without any such pessimism shock. This poses an interesting question for fiscal policy, of whether to react against possible pessimism, when it cannot be known with certainty whether such a pessimism shock is happening or not. We find that whichever model is the true one, aggressive fiscal policy can improve welfare, whether by eliminating the pessimism output sunspot or simply by stabilising output around its equilibrium growth path; monetary policy in the model has only weak effects on demand, output and prices. Hence, we conclude from this Japanese experience that pessimism shocks can happen and that fiscal policy should not be afraid to suppress them if suspected.

To reiterate, sunspot model solutions have been widely dismissed in DSGE models via the device of imposing stable saddle-path solutions on them. However, this imposition needs to be justified by some restriction on the solution space. Any variable in these models that depends on a forward root (aka a 'jump' variable) and is not therefore determined purely by its past (aka a 'state' variable) can have a sunspot solution according to the model. To stop this taking hold, some mechanism must prevent this solution. With price sunspots, it is natural to assume that the central bank would arrest them by a 'whatever it takes' monetary response — this side function of the central bank is widely assumed — thus for example a Taylor rule (Taylor, 1993) has an inflation response that would 'blow up' the economy, were inflation to follow a sunspot solution — hence ruling it out. With output sunspots, it is usually implicitly assumed that business expectations rule out unstable solutions, dismissing them as 'unrealistic'. However, the basis for this is unclear; indeed the idea that business confidence can be weak or strong for unknown reasons has a long history, at least going back to Keynes' 'animal spirits'. Were business confidence to be weak for a sunspot reason, then this would require some policy response to prevent the resulting solution — in Japan we assume that would have to be fiscal policy, owing to the weakness of monetary policy in reviving the economy, whether demand or prices.

In what follows, we review the related literature in Section 2, we explain our sunspot model in Section 3, we explain our indirect inference procedure in Section 4, our empirical results for the sunspot and conventional models in Section 5 and our policy findings in Section 6, followed by a concluding section.

2. Related literature

We focus on investigating whether the explanation for the Japan experience can be based on the existence of recurrent negative confidence shocks leading the economy towards an exploding path, as well as how to avoid this exploding path. Therefore, this paper is related to a number of papers investigating the possibility of expectation-driven liquidity traps and remedies to recover from them. Piazza (2016) finds simple theoretical conditions in DSGE models with sticky prices that guarantee the existence of self-fulfilling deflationary paths and most of the policy rules can give rise to these paths. He calibrates such a model with a real shock and a sunspot that leads to the existence of additional equilibria where inflation expectations deviate from the target. He finds that this model can mimic the main empirical features of the Japanese deflationary process. Aruoba et al. (2018) construct and estimate a New Keynesian model with fundamental and non-fundamental shocks. They find a very high probability that non-fundamental shocks caused Japan to move to a deflation regime in the late 1990s and remain there ever since. Further, Cuba-Borda and Singh (2024) modify a standard New Keynesian model by adding endogenous discounting to rationalise the Japanese experience in 1998–2020 both through the deflationary expectations-driven liquidity trap and the secular stagnation hypothesis. They use Bayesian estimation and find that the liquidity trap in Japan is more likely to be a result of a downward revision in inflation expectations. Benhabib et al. (2001) show that the zero lower bound constraint on nominal interest rates can result in two steady states in a model with an interest rate feedback rule. In one steady state, the policy rate is strictly positive and inflation is at target, in the other one, a Taylor rule (Taylor, 1993) can result in unintended self-fulfilling expectations of future low inflation and aggregate fluctuations that give rise to permanent liquidity traps where the zero lower bound constraint is binding and inflation is below the target. Benhabib et al. (2002) propose a strong fiscal stimulus that is automatically activated when inflation begins to decelerate, while monetary policy follows an interest rate rule. This fiscal rule consists of an inflation-sensitive budget surplus, so fiscal deficits become sufficiently large that the low-inflation steady state becomes fiscally unsustainable, and thus the liquidity trap ceases to be a rational expectations equilibrium. They also propose a switch from an interest rate rule to a money growth rate peg when inflation is on a self-fulfilling decelerating path. The success of this policy needs the right fiscal policy that, as nominal interest rates approach zero, makes the government intertemporally insolvent. However, these liquidity traps do not imply a drop in the real interest rate, and can have normal growth, positive real rates and substantial deflation. Extending this model, Schmitt-Grohé and Uribe (2017) focus on the role of a negative confidence shock and its interaction with nominal rigidity to explain the joint occurrence of a liquidity trap and a jobless growth recovery in Japan. The idea is that a negative confidence shock can push inflation below target, with the Taylor rule then implying nominal interest rate cuts, but eventually the central bank is faced with the zero lower bound problem and the economy is in a liquidity trap. The newly added downward nominal wage rigidity element in the model then ensures that nominal wages fall less than product prices so that real wages become too high and then also cause persistent unemployment. To avoid this situation they propose raising the nominal interest rate to its intended target for an extended period of time, boosting inflation expectations. Nakata and Schmidt (2022) investigate the role of a self-fulfilling decline in people's confidence in causing liquidity traps in a standard New Keynesian model with a lower bound on the nominal interest. The idea is that when confidence declines, people become more pessimistic about the economic outlook and lower inflation expectations. The central bank cuts the policy rate to stabilise inflation which would reinforce the decline in inflation expectations. The resulting feedback would push the policy rate to the zero bound, inflation below target and subdue economic activity. Given this occasional liquidity trap, they study optimal monetary and fiscal policy to improve stabilisation and welfare and find that standard policy recommendations such as raising the inflation target, appointing an inflation-conservative central banker, or using government spending as a stabilisation tool can exacerbate deflationary pressures and demand deficiencies in the liquidity trap episode. They then explore fiscal policies to prevent the economy from falling into this liquidity trap and find that government spending stabilisation can eliminate expectations-driven liquidity traps by responding elastically to deviations of inflation and output gap from target. These conclusions about the expectation-driven source of a liquidity trap are very similar to what we find in our paper, however the difference is the main assumptions we make, in that we focus on the role of pessimism about the growth prospect rather than inflation pessimism.

Our paper complements the paper of Benigno and Fornaro (2018) that constructs an endogenous growth model with nominal rigidities and the zero lower bound on the nominal interest rate, focusing on the role of pessimism about the economy's growth rate as the cause of stagnation traps in the form of liquidity and growth traps. In their model, when agents expect growth to be low, expectations of low future income reduce aggregate demand, lowering firms' profits and investment in innovation, thus lowering potential output which in turn pushes the interest rate toward its zero lower bound so that monetary policy cannot bring the economy to full employment. They find that aggressive policies such as R&D subsidies can generate a regime shift in agents' growth expectations and lead the economy out of a stagnation trap. Our paper however goes a step further than previous studies by estimating and evaluating the model's dynamic fit to that of the Japanese data using the empirical method of Indirect Inference and finds that the Japanese low growth and deflation can be explained by a New Keynesian model with a pessimism sunspot. We use the same estimation and evaluation method to investigate whether fundamental shocks could also cause the Japanese stagnation. The idea is a complement to the studies of Cuba-Borda and Singh (2024) and Aruoba et al. (2018), but differently, we find that both models with fundamental shocks and confidence shocks have the ability to explain the stagnation in Japan. We also find that aggressive fiscal policy can be used to improve welfare in both versions of the model.

3. A DSGE model with real sunspots

Our model (for more details, see Appendix 1) is a small open DSGE New Keynesian model of Japan with real and nominal rigidities (Smets and Wouters, 2007), financial frictions (Bernanke et al., 1999) and a central bank that pursues monetary policy either by setting interest rates on short term government bonds or, if that is nullified by a zero lower bound, by asset purchases (QE, Le et al., 2016a). It also rules out price and other nominal sunspots, including in asset markets, via terminal conditions. In our widely used rational expectations model solution procedure, which is the same as Fair and Taylor (1983), the model is solved backwards from a terminal date T, at which the model's ongoing equilibrium behaviour is imposed; the rational expectations path to that point is then found such that the model solution coincides with the expected path; the T endpoint can be varied to check that the solution is insensitive to moving it. T can be pushed as far ahead as necessary to achieve this. The model converges to an equilibrium where output equals supply potential. However, here we will insert a sunspot in which potential output is suddenly expected to be depressed. This in turn depresses the path of actual output in line, so that the sunspot expectations are verified. Thus in this model pessimism about future output in turn pulls down future output in line.

This distances our model from the literature reviewed above. Our focus is on a real output sunspot arising through a sunspot of pessimism about future output. This produces self-validating falls in capital investment, labour supply (including via lower births), creating a real sunspot solution for output demand and also for output supply potential from a standard production function.

The idea we explore is that Japanese households and firms suffer from random bouts of pessimism about the future fundamental prospects for the economy; these bouts we assume started to happen after the crisis of the end-1980s when the 'financial bubble' was burst by brutally deflationary monetary policy, plunging the economy into deep recession and leaving the banks with weak balance sheets. We model these bouts as sunspots, which affect the expected long term performance of output. These enter the model as the terminal expected value of output. This terminal belief in turn feeds into expected values for earlier consumption, investment and labour supply which are determined by expected output. Expected output in turn reflects these variables; and then goes on to influence expected consumption etc. for still earlier periods. In this way the original bout of pessimism about the long term future cascades back down to current behaviour of the economy.

We solve our DSGE model in repeated bootstrap simulations based on errors retrieved from the model and the data since 1990, the era since the bursting of the nominal 1980s bubble — which we hypothesise caused the situation in which business confidence became prone to sunspots. We then test it by indirect inference against a VECM representation of the Japanese macro data for output, inflation and credit interest rates. Finally, we estimate it by indirect inference — by a search procedure that finds the parameters yielding the closest match of simulated VECM coefficients to those in the data.

The main challenge in this empirical process is finding the sunspot simulation solution paths. We do this by postulating a sunspot path whose terminal rate of expansion is then imposed on the model to find the self-validating solution consistent with it: consumption and investment demand respond to these output expectations, and in turn they generate output demand that determines output under sticky prices; the model then solves backwards from this future state. The model solves for the optimising capital, labour and innovation strategies of private agents, conditional on this evolving solution path.

In the following subsections, we first write a note on sunspot solutions, we then use a simple example to illustrate the sunspot model of output, and then extend this to the full DSGE model for Japan.

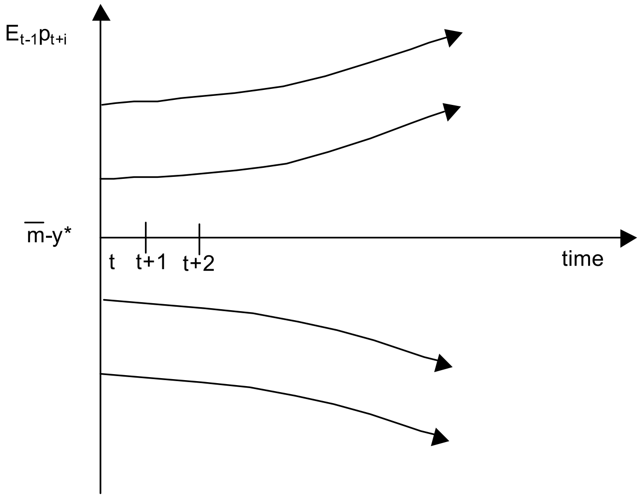

Fig. 3. The solution paths for the price level expected at $t-1$, as in Eq. (4). Note: This phase diagram shows the model's behaviour, where the arrowed line is the saddlepath, and the arrows off it indicate the explosive paths.

3.1. A note on sunspot solutions in rational expectations models

Rational expectations of future events introduce a forward root into the model solution which is a saddle-path in the case of the usual model where all the forward and backward roots lie within the unit circle. In this solution, the saddle path is the unique stable path, and there is also an infinite number of explosive paths, any one of which can be selected by chance, unless there is some mechanism preventing such a selection. For example, if current inflation depends on future inflation through the demand for money, the forward root this introduces permits explosive hyperinflationary or hyperdeflationary solutions, that can be selected by agents at random; such a random selection is known as a sunspot, whereby agents spontaneously come to believe an inflation or deflation will happen in a future period, triggering inflation or deflation in the current period, and implying that in later future periods inflation or deflation will increase along the chosen explosive path. Such spontaneous beliefs could be the result of pure sentiment taking hold — potentially triggered by some current event or a rumour of a future event. What the models imply is that once such a sentiment takes hold, it is validated by future events occurring as expected; hence it is a rationally expected solution.

The mathematics of these solutions is relatively simple. We follow the exposition in Minford and Peel (2015, chapter 2). Suppose we take a simple New Classical model of prices (p_t), money (m_t) and output (y_t):

$$m_t = p_t + y_t - \alpha(E_{t-1}p_{t+1} - E_{t-1}p_t)\ (\alpha > 0) \tag{1}$$

$$p_t = E_{t-1}p_t + \delta(y_t - y^*) \tag{2}$$

$$m_t = \overline{m} + \varepsilon_t \tag{3}$$

The general solution for expected prices is:

$$E_{t-1}p_{t+i} = \overline{m} - y^* + A_1\left(\frac{1+\alpha}{\alpha}\right)^i\ (i \geqslant 0) \tag{4}$$

where $A_1 = [E_{t-1}p_t - (\overline{m} - y^*)]$ from the initial condition. This solution can be conveniently found by solving for expected future prices in terms of lagged prices (the 'backward solution' whereby the forward root, being applied backwards, is inverted and becomes unstable.) The unique stable path is found by setting A_1 to zero. The model's behaviour can be illustrated by a phase diagram (Fig. 3) where the arrowed line is the saddlepath and the arrows off it indicate the explosive paths.

In models like this with saddlepath stability and an infinity of unstable paths for prices, a natural way to rule out all paths except the saddlepath is for the central bank to commit itself to stopping them via a terminal condition in which future prices away from the stable path would be overridden by money supply movements. This ensures that the saddlepath is the unique solution (satisfying the Blanchard and Kahn (1980) conditions).

In this paper we are dealing not with unstable price paths but rather unstable output paths. In the model above these do not arise as expected output equals potential output which is an exogenous constant. However, it is possible for output to depend on expected future events through model behaviour. Thus, in a New Keynesian model output depends on demand which in turn depends on expected future events; also potential output depends on capital investment which in turn depends on expected future output, creating a forward root giving rise to a saddle-path solution for output, with an infinity of explosive paths, similar to the above one for prices. These explosive paths could be similarly eliminated by a government commitment, e.g. through fiscal policy, to prevent them. Notice that our model is Ricardian, in that fiscal policy commits to creating a terminal primary surplus equal to outstanding debt interest, so ensuring solvency; thus it does not conflict with monetary policy as in Leeper (1991) and is free also to commit to eliminating a real sunspot.

3.2. A simple illustrative sunspot model of output

To illustrate the workings of a simple model of this type, suppose that natural rate output, y_t^*, depends on capital invested and that this in turn depends on expectations of future y_t^* via the marginal product of capital; thus current y_t^* depends on expected future y_{t+1}^* via a forward root, σ. We can write the equation for natural rate output as:

$$y_t^* = \sigma E_t y_{t+1}^*$$

For the rest of the model, we will assume here the simple New Classical structure as in Section 3.1:

$$m_t = p_t + y_t \tag{5}$$

$$p_t = E_{t-1} p_t + \delta(y_t - y_t^*) \tag{6}$$

$$m_t = \overline{m} + \varepsilon_t \tag{7}$$

To solve this model, we can first solve for y_t^*. This yields a first order difference equation for the future as a function of the previous expected value as:

$$E_t y_{t+i+1}^* = \sigma^{-1} E_t y_{t+i}^*$$

whose general solution is:

$$E_t y_{t+i}^* = A_1 \sigma^{-i} \quad (i \geq 1)$$

where A_1 is given by the initial value, $E_t y_t^* = A_1$. But this value can be chosen arbitrarily, as nothing in the model ties it down.

We can then find the expected solution for output as $E_t y_{t+i} = \sigma^{-i} E_t y_t^*$ where $E_t y_t^*$ can be chosen at will, and can therefore be treated as a sunspot. It follows that expected prices are $E_t p_{t+i} = E_t m_{t+i} - \sigma^{-i} E_t y_t^*$. This implies that prices can also have a sunspot solution, absent any monetary response. This can be eliminated by setting expected money supply to eliminate the effect of the sunspot on prices, forcing them to a target path, p_{t+i}^*, as follows: $E_t m_{t+i} = p_{t+i}^* + \sigma^{-i} E_t y_t^*$. Once these expected paths are established, actual price and output deviate from them according to the demand shock to the money supply, obtaining: $p_{t+i}^{ue} = \frac{\delta}{1+\delta}\varepsilon_{t+i}$ and $y_{t+i}^{ue} = \frac{1}{1+\delta}\varepsilon_{t+i}$, where the ue superscript denotes 'unexpected.'

It is useful to examine the solution of this very simple model, under plausible assumptions for the sunspot path of the natural rate. Notice that according to this model, output, ignoring iid errors, is equal to expected natural rate output. Due to pessimism about the expected future natural rate output, $E_t y^*$, future output is depressed and continues to diverge from the true potential output path.

In the period after the post-war 'miracle' (when growth was 10%) growth fell to 4.5%; then in the bubble-bursting period from 1990 it fell to about 1%. Since 2000 it has averaged about 0.6%, rising slightly after the financial crisis when fiscal policy became generally stimulative. Most developed countries manage to grow about 2%, which we take to be a reasonable estimate also of the true potential (natural rate) growth in Japan. Some may argue that 2% may be an unreasonable estimate for potential growth given the adverse demographic pattern experienced by Japan in recent decades, which has significantly reduced the labour force. Or, that growth on a per capita basis should be the policy target; growth per capita, with a declining population, has not slowed so markedly. However, this assumes that population growth does not respond to growth of GDP, which is unlikely. The willingness to have children is likely to respond to the outlook for output and jobs — Kearney et al. (2022), Black et al. (2013), Autor et al. (2019). The worse the outlook, the more parents must invest in education and other support for their children, to create lifetime opportunities for them. When looking at working age population data, it can be seen that a slowdown in working age population occurs after 1990, which coincides with the bursting of the financial bubble. This slowdown could be due to pessimism about the growth prospect. Therefore, we contend that, without the pessimism sunspot, Japan could have grown at a rate similar to other developed countries. The four largest developed economies, excluding Japan, have averaged 2.05% growth from 1980, so we believe 2% is a reasonable rate to use. In Fig. 4 one can see the way GDP has fallen steadily further below this 2% trend path from 1992.

We now show the type of sunspot path this simple model implies given Japanese data. If we take the true potential output path to follow the 2% growth trend, then the sunspot-affected path is actual output; and the sunspot can be derived as the gap between this and the 2% growth trend. Using this logic, we get the sunspot series in Fig. 5 reflecting this gap between output and the 2% trend.

When we further decompose this into the sequence of sunspot innovations, that is the necessary revision each period compared with the value implied by the previous sunspot, we obtain Fig. 6.

It can be seen that up to 2007 the innovations fluctuate moderately around a negative mean, driving expected output steadily downwards. However the financial crisis triggers a large negative shock. This was followed by a long period of further pessimism, culminating in another large negative shock in 2020, the period of Covid, with the post-Covid bounceback, followed by the

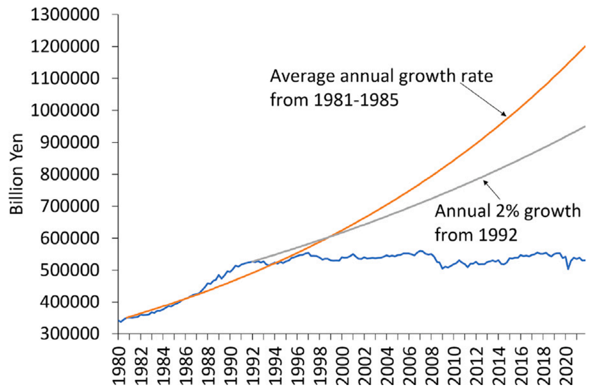

Fig. 4. Real GDP 1980–2020 (blue line). Note: The orange line extends the average growth for 1981–1985 to the end of the sample, whereas the grey line extends a 2% growth line from 1992. The Figure shows how Japanese GDP has steadily fallen below these trend paths.

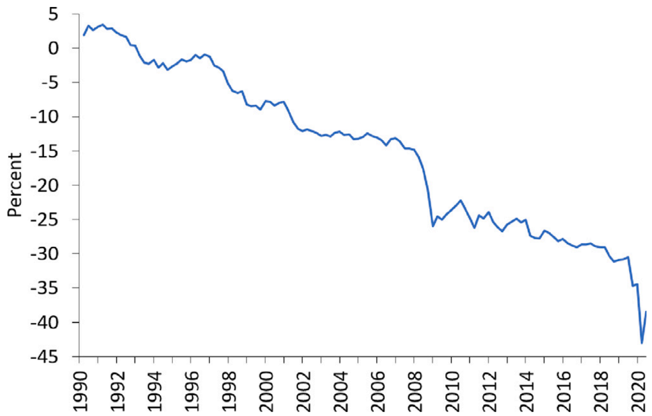

Fig. 5. Sunspot series (output deviations from natural rate). Note: This shows the gap between output and the 2% trend line, which implies the sunspot series.

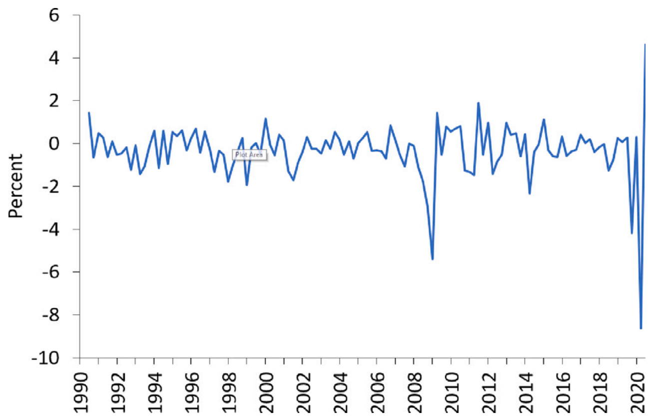

Fig. 6. Sunspot innovations Note: The gap between output and the 2% growth trend is decomposed into a sequence of sunspot innovations.

resumption of further moderate pessimism. With a full set of shocks providing the effect of non-sunspot shocks on output, we would expect these two shocks to be eliminated from the sunspot.

We have shown the type of path this simple model implies given Japanese data. Over the sample period from 1992 the economy has evolved with a succession of negative sunspots, launching the economy on a slowly exploding downward path. We show the contribution of each dated sunspot to the later GDP evolution. It can be seen that the original sunspot around the bursting of the monetary sunspot accounts for much of the later evolution. However additional negative and occasionally positive shocks occurred later.

In the subsequent subsections we develop a full model with the investment path set by future expectations of the marginal product of capital; and with labour supply responding to expectations of future wages. We generate the expected path of y_t^* according to the natural rate model equation set out above. We then embed this in a New Keynesian model of Japan which comes closest to explaining Japanese data behaviour. The natural rate enters the model via the terminal conditions when output has converged on it. Prior to that date output is demand-determined under the usual New Keynesian assumptions. Hence the effect of the natural rate sunspot solution is to change expectations of output from the terminal date backwards towards the initial period. Unlike in the simple New Classical example developed above, expected output is not equal to the expected natural rate, rather it is impacted by it through the demand effects of expected output.

3.3. Solving the Japanese model with a pessimism sunspot

Now we apply this analysis to an estimated DSGE model of Japan. The full model for Japan is based on that of Le et al. (2016a), but with the addition of open economy elements to deal with trade and capital flows — a full account is given in Appendix 1. The Le et al. (2016a) model is developed from the model of Smets and Wouters (2007): it adopts a hybrid price-setting structure, with a fraction of goods markets assumed to be flexprice while the rest set prices for longer durations; similarly with labour markets. Beyond these frictions in labour and goods markets, the model also incorporates financial frictions as proposed by Bernanke et al. (1999) and at the zero lower bound on interest rates allows for cheap money collateral as in Le et al. (2016b) to make monetary policy effective via unconventional monetary measures (base money printing via Quantitative Easing, QE); the way that QE works is by providing more cheap collateral in the form of money, which lowers the cost of credit, so expanding the supply of money and credit used by entrepreneurs. Trade equations enter via an Armington (1969) nested CES utility function of differentiated home and foreign consumption goods, as in Meenagh et al. (2010). On the capital account of the balance of payments uncovered interest parity is assumed between home and foreign bonds.

In this model the difference between external and internal borrowing costs is a central equation driving investment in capital (in log-linearised form)[2]:

$$E_t r_{t+1}^k - (r_t - E_t \pi_{t+1}) = \chi \left(pk_t + k_t - n_t \right) - \vartheta m_t^0 + \epsilon_t^{prem}$$

In this expression expectations of future output demand determine networth (n) so the expected sunspot feeds into n. This in turn depresses investment and capital, reducing current potential output through the production function, and current output via reduced demand. Next we look for the sunspot solution for output and its terminal value that permits the model to generate the data path.

3.4. Calculating the sunspot shock in the full model

We take the 2% growth path from 1990 to be illustrative of the unknown true natural rate growth path, as explained above. To obtain our estimate of the actual sunspot we argue as follows. Our sunspot hypothesis is that the economy is driven by the model and a combination of the normal shocks and the sunspot shock to its lower predicted path, which according to the model should get close to matching the economy's average (HP-filtered) actual behaviour, y_t^*. Thus according to this model, $y_t^* = \hat{y}_t^{normal\ shocks} + \xi_t$, and thus we create the sunspot shock series as $\xi_t = y_t^* - \hat{y}_t^{normal\ shocks}$. In other words, the economy's weak output path is partly caused by normal shocks implied by the model and the data (these are the model equation residuals); the rest is due to the sunspot. We obtain the estimates of the normal shocks and their effects from the model without sunspots, which we find — see below — fits the data behaviour as well as the sunspot model on the basis of our Indirect Inference test. This makes use of the non-trend behaviour of the model and the data; as our measure here implies, the model trend rises faster than the data trend, implying that the sunspot shock is providing the difference that pulls the model trend down.

The resultant sunspot shock series is plotted in Fig. 7, and its innovations in Fig. 8.

The sunspot innovations tend to be negative, pushing the economy further and further away from the supposed true potential path. Thus, if our sunspot hypothesis is correct, Japanese business is beset with steadily increasing pessimism with no basis in the truth. The policy implications of this situation are stark and challenging; we will revert to them in the final section.

4. Estimation and testing by indirect inference

The use of Bayesian estimation, though widespread in applied macroeconomics, gives weight to priors that may be rejected by the data and so lead to bias in estimation. Here instead we use indirect inference both to estimate our model and to test it rigorously against the data behaviour; the aim is to compare the reduced form data behaviour generated by the unknown true model with the simulated reduced form behaviour generated by our candidate models. In estimation we search for the parameters of our candidate model that can most closely match the data behaviour from the true model. Le et al. (2016b) and Meenagh et al. (2019) show that in the small samples we encounter here indirect inference exhibits low bias in estimation and high power in testing.

We use the approach of Indirect Inference proposed by Le et al. (2011) to assess the model's ability to match the data. Le et al. (2016b) provide a full description of the procedure. To generate a description of the data against which the theory's performance is

[2] Equation 22 in Appendix 1, where r^k is the external financing rate, r is nominal interest rate, π is inflation, pk is price of capital, k is capital stock, n is networth, m^0 is monetary base, and ϵ_t^{prem} is the risk premium shock.

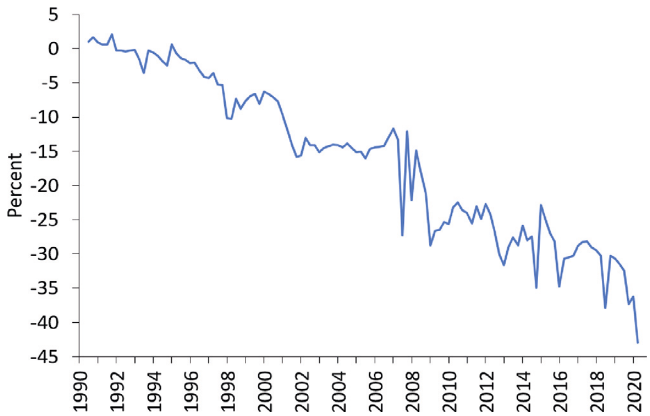

Fig. 7. Sunspot series generated from full model. Note: The sunspot series is generated as the difference between the data, and what a model without a sunspot implies.

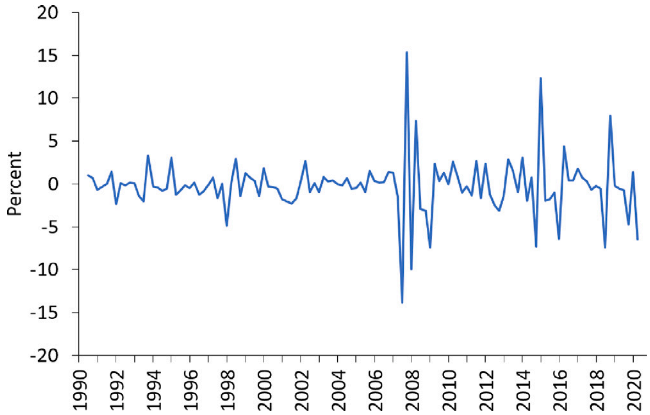

Fig. 8. Sunspot innovations generated from full model. Note: The sunspot series in Fig. 7 is decomposed into a sequence of sunspot innovations.

indirectly evaluated, the approach uses an auxiliary model that is fully independent of the theoretical one. The estimated parameters of the auxiliary model, or functions of these, might be used to summarise such a description; we name them as the 'data descriptors'. While they are viewed as 'reality,' the theoretical model under consideration is simulated to determine its suggested values. In estimation the parameters of the structural model are chosen so that when the model is simulated, the auxiliary model estimates are similar to those obtained from the real data. The structural model parameters that minimise the distance between a given function of the two sets of estimated coefficients of the auxiliary model are the best.

When evaluating the model's data fit, the structural model is simulated, and the auxiliary model is fitted to each set of simulated data, yielding a sample distribution of the auxiliary model's coefficients. A Wald statistic is computed to see if functions of the auxiliary model's parameters calculated on actual data fall within a confidence interval given by the sampling distribution.

The auxiliary model should be a process that describes how the data evolves under any applicable model. It is well known that the reduced form of a macro model with non-stationary data is a VARMA, in which non-stationary forcing factors are used as conditioning variables to accomplish cointegration (i.e. ensuring that the stochastic trends in the endogenous vector are picked up so that the errors in the VAR are stationary). This in turn can be approximated as a VECM. As an auxiliary model, we utilise a VECM with a temporal trend and the productivity residual inserted as an exogenous non-stationary process, which we re-express as a VAR(1) for the three macro variables of interest (interest rate, output, and inflation). The two exogenous elements have the effect of achieving cointegration. The VAR coefficients on the lagged dependent variables and the VAR error variances are treated as the data descriptors, and the Wald statistic is computed from them. Thus, we are essentially determining whether the observed dynamics and volatility of the selected variables can be explained by the simulated joint distribution of these variables at a given confidence level. We exclude the coefficients of trend behaviour from our test here, because the model elements causing these cannot be identified; they come from the numerous errors in the model, any or all of which could be changed to fit the trend coefficients in the data. In our sunspot model, the sunspot is identified as causing the trend overprediction by the model, whereas in the no-sunspot model we attribute it to an unknown combination of error misspecifications. The Wald statistic is given by:

$$(\Phi - \overline{\Phi})' \Sigma^{-1}_{(\Phi\Phi)} (\Phi - \overline{\Phi}) \tag{8}$$

where Φ is the vector of VAR estimates of the chosen descriptors yielded in each simulation, with $\overline{\Phi}$ and $\Sigma_{(\Phi\Phi)}$ representing the corresponding sample means and variance–covariance matrix of these calculated across simulations, respectively.

The joint distribution of the Φ is obtained by bootstrapping the innovations implied by the data and the theoretical model; it is thus a small sample distribution estimate. For small samples, this distribution is usually more accurate than the asymptotic distribution.

This testing procedure is applied to a set of (structural) parameters put forward as the true ones (H_0, the null hypothesis). The test then asks: could these coefficients within this model structure be the true (numerical) model generating the data? We extend our procedure by a further search algorithm, in which we seek other coefficient sets that minimise the Wald test statistic — in doing this we are carrying out indirect estimation.

Thus we calculate the minimum-value Wald statistic using a powerful algorithm based on Simulated Annealing (SA), in which the search takes place over a large range around the initial values, with the search being optimised by random jumps around the space. The benefit of this extended method is that when we ultimately compare model compatibility with data, we use the best possible version of the model.

5. Empirical results

We have found parameters for this model that can match Japanese data (in the form of a VECM) well with a p-value of 0.0994 showing that we do not reject the null hypothesis that the model can generate the data. The key forward root we discover is 0.9929 which gives rise to a moderately exploding solution. What we see is that, similarly to our simple model, the Japanese economy tends to contract systematically towards a very slowly growing 'natural rate' growth path. Besides other normal shocks driving it, there is a sequence of sunspot shocks that push it along this path. These shocks we calculate in a similar way to that in the simple model but with a difference reflecting the greater number of demand channels. There we assumed that gloomy expectations of future potential output drove investment demand: here we assume that these gloomy expectations drive private actions across the whole model. The rational expectations (RE) loop in the model forces the actual output path we observe into equality with the expected output generated by the terminal expected value of potential output, itself determined by the sunspot shock. Thus the RE solution of the model embeds both the effects of normal shocks and those of the sunspot shocks. The economy's demand and supply behaviour responds to this expected path in a way that must replicate the data-based VECM descriptive model to pass the indirect inference test.

The model therefore works as follows. The sunspot output expectations feed into entrepreneurial net worth, and depress investment which reduces output through lower demand. Employment falls also via demand. Real wages fall, clearing the labour market. Labour supply also falls, with the fall in income, consumption and real wages. Output potential falls due to lower capital and labour supply. The output gap versus potential is little changed so inflation moves little. Inflation fluctuations come from demand shocks interacting with this output potential. Table 1 reports the estimated parameters and Wald statistic are reported.

Table 2 shows the auxiliary model estimates on the actual data alongside the mean and 95% confidence bounds from the simulations. Most parameters are within the bounds, but we find that the model underpredicts the output response to lagged output. Similarly for the interest rate response to lagged interest rate. Conversely, the inflation response to lagged inflation is over predicted, by a small margin. The data for interest rate variance is just outside the model's 95% confidence bounds. However, the model fits overall, as shown by the p-value above.

5.1. The behaviour of the model

The IRF for a negative sunspot shock in Fig. 9 shows a persistent and sizeable fall in output, employment and real wages accompanying the slowly exploding sunspot in expected equilibrium output, y^*.

The sunspot enters expected equilibrium output at the terminal date and then induces a fall in consumption, employment and capital investment which in turn depress demand and output. The Taylor rule responds to a rise in $y - y^*$, with output falling less than y^*, by raising interest rates, so also causing real exchange rate appreciation, forcing down net exports which add to the decline in demand and output.

We now turn to the effect of a positive productivity shock (Fig. 10). The productivity shock in non-stationary, so has permanent effects. This paradoxically reduces output. However, it does so through a mechanism already well-known in the New Keynesian literature (an early finding is by Gali, 1999): at given demand, fixing output at pre-set prices, a rise in productivity lowers labour demand, hence employment. This in turn depresses consumption and inflation. However, after initially rising due to the drop in inflation, real interest rates are gradually reduced by the Taylor Rule (Taylor, 1993), pushing up consumption and investment, also net exports via real depreciation; output demand therefore gradually recovers, but both capital and employment remain depressed, largely offsetting the productivity effect on y^*.

Fig. 11 shows the IRF for a positive shock to government spending — a classic demand shock. This has a strong immediate effect on output, but since it raises inflation, the Taylor rule response raises real interest rates which crowd out consumption and investment and (via real appreciation) net export demand. Furthermore the fiscal feedback response offsets some of the initial spending rise. Hence the output expansion dies away fairly rapidly. Similarly, with the other demand shocks to consumption and investment, the output rises are short-lived.

A contractionary monetary shock (Fig. 12) has an IRF that similarly reduces demand sharply on impact but that is quickly reversed via the Taylor rule and fiscal feedback responses. Output, employment, home demand and net exports all recover rapidly; the rise in real interest rates and so also the real exchange rate are steadily reversed.

Table 1
Sunspot model coefficient estimates. Note: This table shows the estimated coefficients for the model with sunspot.

Steady-state elasticity of capital adjustment	8.0073
Elasticity of consumption	2.5387
External habit formation	0.4636
Probability of not changing wages	0.4402
Inverse of Frisch elasticity of labour supply	3.3006
Probability of not changing prices	0.8066
Wage indexation	0.1905
Price indexation	0.4457
Elasticity of capital utilisation	0.9435
Share of fixed costs in production (+1)	1.7772
Taylor Rule response to inflation	1.0612
Interest rate smoothing	0.9735
Taylor Rule response to output	0.0060
Taylor Rule response to change in output	0.0126
Share of capital in production	0.3338
Proportion of sticky wages	0.2384
Proportion of sticky prices	0.4806
Elasticity of the premium with respect to leverage	0.0103
Monetary response in crisis time	0.0978
Monetary response in normal time	0.0406
Elasticity of premium with respect to money	0.0494
Sunspot forward root	0.9929
Fiscal response	0.6470
Wald	21.1524
Transformed Wald (t-stat)	1.1492
P-value	0.0994

Table 2
Auxiliary model parameter bounds. Note: This table shows the auxiliary model estimates for the model with sunspot used in the Indirect Inference procedure for the actual data, alongside the mean and confidence bounds from the simulations. An actual coefficient within the bounds shows the model can match that parameter.

	Actual	Mean	2.5th Percentile	97.5th Percentile	In/Out
y_y	0.8031	0.2770	−0.3191	0.5659	OUT
y_π	0.0554	0.0975	−0.4318	0.7039	IN
y_r	−0.1540	0.0417	−6.5507	4.8900	IN
π_y	0.0810	0.0198	−0.0837	0.1066	IN
π_π	−0.3040	0.0129	−0.2768	0.3085	OUT
π_r	0.6767	0.3366	−0.9463	2.6129	IN
r_y	0.0021	−0.0098	−0.0264	0.0022	IN
r_π	0.0051	0.0063	−0.0257	0.0385	IN
r_r	0.9320	0.6866	0.1467	0.9308	OUT
$var(y)$	1.5653	2.8773	1.0596	7.8494	IN
$var(\pi)$	0.2339	0.3869	0.2328	0.5765	IN
$var(r)$	0.0009	0.0081	0.0012	0.0177	OUT

Cost shocks similarly have a sharp short run stimulationary effect on inflation, which via the resulting fall in the real interest rate also stimulates net export demand and output, before the Taylor rule intervenes to raise real rates and reverse the expansion.

In general, throughout these IRFs we see the combination of the Taylor rule and the fiscal feedback response impart a strongly stabilising impact to the economy.

Overall, it can be seen from the simulations and the IRFs that the model responds to normal shocks in the usual way, since these do not trigger sunspot movements. We can also see that the sunspot shock triggers modestly exploding paths which generate their own inflation/output gap effects, as demand effects fail exactly to match effects on potential output.

5.2. Which shocks cause most variation in the model?

We perform a variance decomposition exercise to see which shocks are the most important. The short-run and long-run analysis are shown in Tables 3 and 4 respectively, where the short-run is 5 periods ahead, and the long-run is 20 periods ahead.

One striking feature of this shock decomposition is the dominant effects on output of the net trade shocks in the short run. In the long run the sunspot shock dominates, with productivity contributing much of the rest. Both shocks are nonstationary which accounts for their relative long run importance. Demand shocks have very limited importance for output, being heavily suppressed by fiscal and monetary feedback.

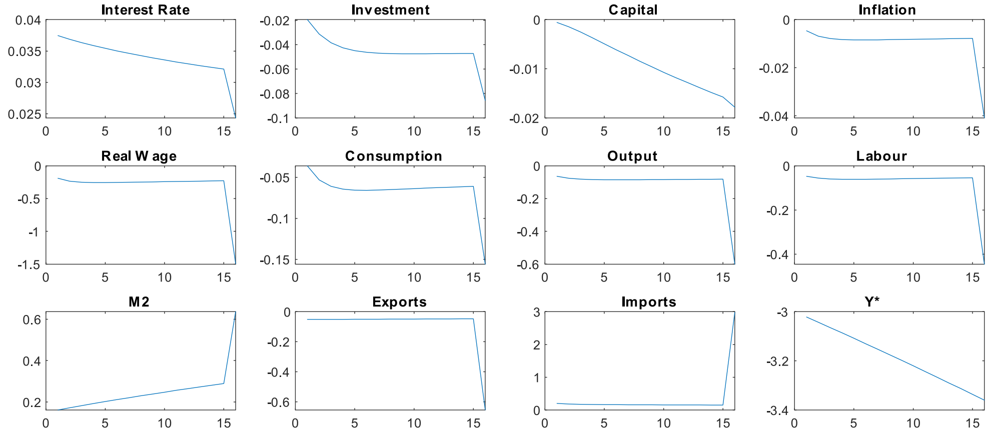

Fig. 9. IRFs for a sunspot shock. Note: These plots show how the variables respond to a one off negative sunspot shock.

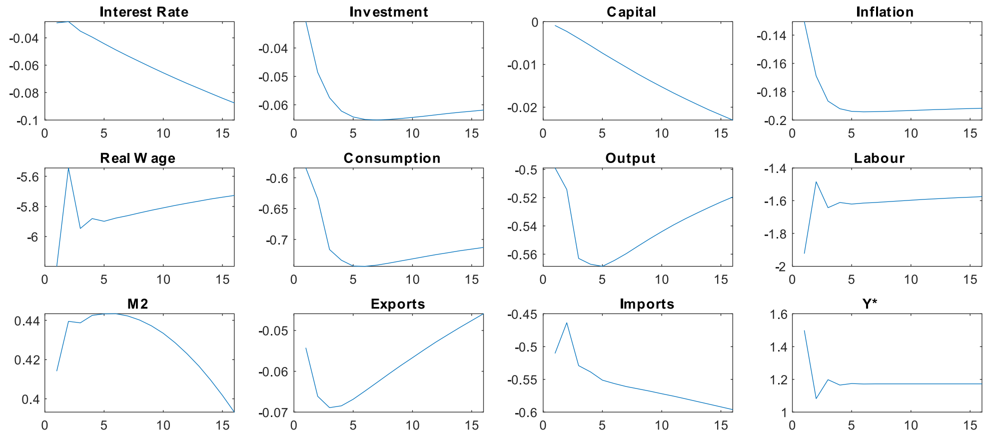

Fig. 10. IRFs for a permanent productivity shock. Note: These plots show how the variables respond to a permanent positive productivity shock.

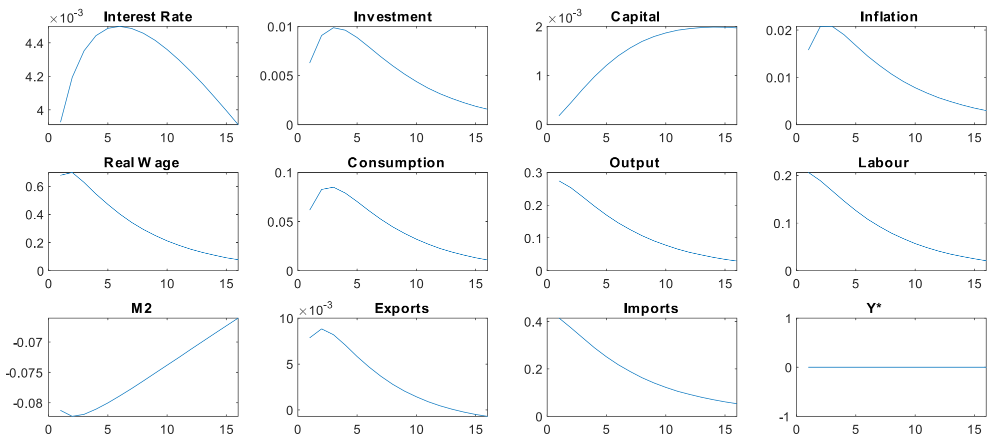

Fig. 11. IRFs for a government spending shock. Note: These plots show how the variables respond to a one off government spending shock.

The price mark-up is the overwhelming source of inflation variation in the short run, followed by productivity. Otherwise inflation is largely unaffected by shocks, remaining essentially stable around costs. Productivity also destabilises wages and employment as

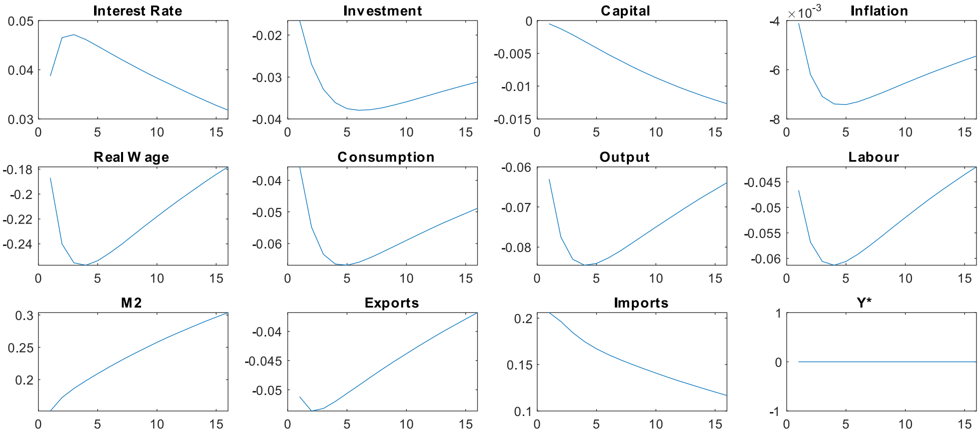

Fig. 12. IRFs for a monetary policy shock. Note: These plots show how the variables respond to a one off contractionary monetary policy shock.

Table 3
Short variance decomposition. Note: This table reports the variance decomposition for the model with the sunspot. It shows the relative importance of each shock to each variable for the short-run, which we consider 5 periods ahead.

Shock	Interest Rate	Investment	Tobin's Q	Capital	Inflation	Real Wage	Consumption	Output	Labour
Government Spending	0.0017	0.0001	0.0054	0.0000	0.0035	0.0073	0.0088	0.0359	0.0085
Consumer Preference	0.0004	0.0000	0.0001	0.0000	0.0006	0.0065	0.0897	0.0122	0.0026
Investment	0.0011	0.9851	0.0032	0.9994	0.0015	0.0089	0.0084	0.0454	0.0122
Monetary Policy	0.1814	0.0006	0.0430	0.0000	0.0004	0.0011	0.0052	0.0043	0.0010
Productivity	0.1158	0.0019	0.2962	0.0001	0.3107	0.6851	0.7079	0.2051	0.8109
Price Mark-up	0.0218	0.0000	0.0041	0.0000	0.6334	0.0002	0.0006	0.0018	0.0006
Wage Mark-up	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000
Labour Supply	0.0020	0.0000	0.0088	0.0000	0.0226	0.1568	0.0002	0.0019	0.0004
Premium	0.0000	0.0007	0.0624	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
Net Worth	0.0006	0.0013	0.1228	0.0000	0.0014	0.0024	0.0022	0.0118	0.0027
M0	0.0000	0.0010	0.0630	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
Exports	0.0162	0.0000	0.0064	0.0000	0.0154	0.0933	0.1068	0.4939	0.1173
Imports	0.0052	0.0000	0.0024	0.0000	0.0051	0.0293	0.0323	0.1535	0.0364
Sunspot	0.6539	0.0092	0.3822	0.0004	0.0054	0.0089	0.0379	0.0339	0.0076

Table 4
Long variance decomposition. Note: This table reports the variance decomposition for the model with the sunspot. It shows the relative importance of each shock to each variable for the long-run, which we consider 50 periods ahead.

Shock	Interest Rate	Investment	Tobin's Q	Capital	Inflation	Real Wage	Consumption	Output	Labour
Government Spending	0.0013	0.0002	0.0012	0.0000	0.0017	0.0023	0.0006	0.0095	0.0030
Consumer Preference	0.0001	0.0000	0.0000	0.0000	0.0002	0.0013	0.0040	0.0021	0.0006
Investment	0.0037	0.7205	0.0024	0.9835	0.0049	0.0154	0.0040	0.0216	0.0230
Monetary Policy	0.1189	0.0023	0.0214	0.0004	0.0006	0.0014	0.0010	0.0059	0.0017
Productivity	0.4125	0.0086	0.1743	0.0013	0.4482	0.5643	0.1419	0.1808	0.7484
Price Mark-up	0.0135	0.0004	0.0023	0.0000	0.2086	0.0007	0.0002	0.0033	0.0011
Wage Mark-up	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Labour Supply	0.0075	0.0005	0.0023	0.0000	0.0139	0.0537	0.0004	0.0091	0.0032
Premium	0.0001	0.0017	0.0230	0.0003	0.0000	0.0004	0.0001	0.0021	0.0006
Net Worth	0.0018	0.0050	0.0781	0.0009	0.0020	0.0020	0.0005	0.0086	0.0025
M0	0.0001	0.0041	0.0425	0.0007	0.0001	0.0006	0.0001	0.0023	0.0008
Exports	0.0074	0.0005	0.0013	0.0000	0.0064	0.0237	0.0062	0.1067	0.0343
Imports	0.0045	0.0005	0.0006	0.0000	0.0029	0.0112	0.0029	0.0512	0.0165
Sunspot	0.4284	0.2557	0.6505	0.0128	0.3106	0.3229	0.8382	0.5967	0.1641

we see from the IRF, contributing most of their variation. Interest rates and the real exchange rate are mainly disturbed by monetary policy, productivity and the price mark-up, the last two via their effects on costs and so inflation.[3]

[3] In Appendix 3 we show the variance decomposition for the model without the sunspot. In the short-run, the results are very similar as the sunspot shock is not so important. In the long-run, the nonstationary productivity shock is more important for most variables.

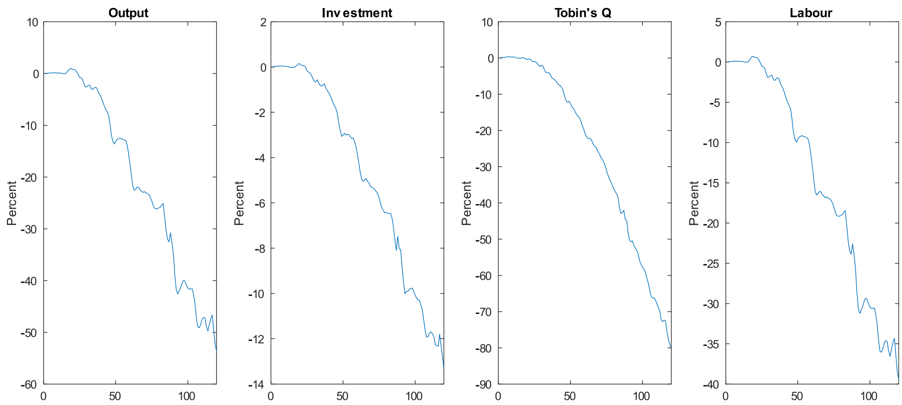

Fig. 13. Longrun effects of the sunspot shock. Note: These plots show the effects on the longer term trends in the model as the sunspot shock evolves over time.

Table 5
Effects on volatility of sunspot. Note: This table shows the welfare comparison between the model with the sunspot, and the model without the sunspot. The welfare cost is the sum of the variances of output, inflation and interest rate.

	$var(Y)$	$var(\pi)$	$var(R)$	Welfare Cost
Sunspot	3.2989	0.8154	0.1572	4.2715
No Sunspot	2.6270	0.8532	0.1262	3.6064

We can now consider the effects of the sunspot shock on the longer term trends in the model. We show in Fig. 13 the timelines in response to this shock as it evolves, for the main variables: output is depressed by 54% at the terminal date; in other words growth over the sample is depressed by 1.8% p.a. This in turn depresses investment by 13%, Tobin's Q by 80%, and employment by 39%.

When we accumulate the effects of the sunspot shocks on expected terminal output, we find the picture above of a steadily worsening expected future growth rate. This is how the sunspot undermines Japanese growth. Investment in Japan is linked to these expectations via the marginal product of capital equation with the cost of capital. Employment is depressed by much the same percentage as output, and since consumption falls with output, lowering the demand for leisure, labour supply is reduced at the same time, forcing down real wages strongly.

6. Policy discussion

At the centre of this model fitted to Japanese data is its sunspot solution in which the forward root drives the model downwards in an explosive way towards a very slow growth path. The model generates poor growth outcomes because of this 'pessimism sunspot'. It is a key function of government to eliminate such sunspots. It has long been recognised that central banks need to enunciate terminal conditions that eliminate nominal sunspots. Real sunspots like the one here are however rare because usually eliminated by private sector recognition of the true trend in output potential — what Keynes termed 'animal spirits' — so little attention has been given to any government role in eliminating real sunspots. Yet we have shown here that Japan's weak growth performance can be accounted for by a real sunspot not suppressed by private sector beliefs. It follows that in this situation the government needs to step in to suppress it. It cannot do so via monetary means, instructing the central bank, as this only affects nominal outcomes; of course we have observed that the BOJ's policy of targeting higher inflation has, as the model would imply, been ineffective in raising growth. It follows that fiscal policy needs to create the necessary terminal condition, which could take the form of a commitment to raise demand up to the true output potential level. We now show how the model behaves when this commitment is included, eliminating the sunspot shocks. This complements the existing fiscal feedback rule in which fiscal policy responds to the output gap; this helps to create output stability but on its own cannot eliminate the sunspot that creates long term pessimism and undermines long run growth.

In Table 5 we show the variances of output and inflation with and without the sunspot ('without' implying that the government suppresses it via a terminal condition on ystar). It can be seen that suppressing the sunspot reduces the variance of output markedly and makes little difference to the variance of inflation, so that welfare overall improves substantially; the overall illustrative welfare cost shown is the sum of the variances of output, inflation and interest rates.

This suggests that fiscal policy should be committed to suppressing any sunspot. So far the GOJ has expressed no interest in such a policy. This suggests it does not believe there is a sunspot. In the next section we review a model without a sunspot that they implicitly must believe.

Table 6
Effects on volatility of sunspot suppression in no-sunspot model. Note: This table shows the welfare comparison when suppressing the sunspot if the no-sunspot model is true. The welfare cost is the sum of the variances of output, inflation and interest rate.

No Sunspot model — HP=y^*	$var(Y)$	$var(\pi)$	$var(R)$	Welfare Cost
No Sunspot base line	2.6270	0.8532	0.1262	3.6064
Fiscal policy	0.1837	0.8160	0.1074	1.1071

6.1. Can we account for Japan's weak growth without the pessimism sunspot?

Japan shifted in the 1990s to a sharply slower growth rate than before. In this paper we have suggested that this came from a sunspot pessimism shock engendered by the economy's collapse when the 'financial bubble' was burst by a brutal monetary squeeze in 1989. What we have shown is that this model cannot be rejected by the behaviour of Japanese data since 1990. However, of course this does not also imply that there is no alternative model of Japan, with no sunspot, that could also match Japanese data behaviour. As we noted earlier, we have found that such a model can also fit the data behaviour. Our test is based on the non-trend behaviour, which our no-sunspot model matches as well as our sunspot model. As we noted above our no-sunspot model does not match the trend in the data — which is not part of the test — indeed it over-predicts the trend which is why the sunspot shock is implied by the difference between the model output prediction and the data trend. In this model we are assuming that any real sunspot is eliminated by private sector recognition of the true trend in output potential — what Keynes termed 'animal spirits' — so that there is no need for the government to intervene.

Thus we can also match this behaviour with a 'normal model' in which agents expected stronger trend output than actually occurred. We have also fitted this model to the data and its estimated parameters turn out to be the same as for the sunspot model; the model also matches the data behaviour about as well, with a p-value of 11%, as compared with 10% for the sunspot model — we have put the results in an Appendix 3. Thus this model is good on the business cycle but omits the factors causing the output trend to grow more slowly in the data.

What this reveals is that, though we cannot reject the sunspot model, an equally probable model of Japan's low growth recent history is one in which the output growth trend slowed down for trend reasons omitted by the model, but other than a sunspot — possibly in the productivity process. Given the difficulty in estimating trend elements in stochastic behaviour, it is not difficult to believe that such other reasons reducing growth could enter the model through its many stochastic processes.

As noted in the previous section, the GOJ must believe in this no-sunspot model since it has not taken action to eliminate a sunspot. The operative question for policymakers, given that both models are roughly equally probable, is what risks are taken in getting the model wrong. In Table 5 above, we showed that if the sunspot model was the true one, there would be a welfare gain of 32% from suppressing the sunspot. Now we must ask what the loss, if any, would be of doing so if the no-sunspot model is true — we model this by assuming fiscal policy is highly aggressive in pushing the economy to the higher ystar no-sunspot path above the true one. In this case fiscal policy would force output to lie above the true ystar value and equal the supposed higher ystar path. It might well be thought that such a policy would be highly inflationary and would be resisted by the BOJ via sharp interest rate increases; since this would be a conflict that cannot be won by either government or Bank, we model fiscal policy as strongly pushing downwards the output difference from its targeted ystar path; we assume a fiscal feedback coefficient of 5.0 compared with 0.647 in the estimated model, seven times as large. Table 6 shows our simulated welfare results.

For this simulation the no-sunspot model has a ystar trend given by an HP filter of actual output and the fiscal suppression policy has strong fiscal feedback on the log difference of output from this HP ystar augmented to match the 2% growth trend. This feedback rule replaces the weak one assumed in the sunspot model; it is therefore substantially more aggressive, as besides stabilising output fluctuations, it is forcing output up to the assumed no-sunspot trend. However, our simulation results for this aggressive fiscal policy in the no-sunspot model also reveal a gain in welfare, with the variance of output falling sharply. Furthermore interest rate variance hardly changes either; and the inflation trend is barely affected; it turns out that this aggressive fiscal policy raises average inflation across all simulations by 0.24% p.a., which is pretty small. This might seem highly surprising. But when one considers how little inflation reacted to the huge monetary stimuli applied by the BOJ during our sample period it is less surprising that inflation reacts little to the very large fiscal stimuli implied by our simulated policy, or that in consequence interest rate policy also changes little.

The rather surprising policy conclusion we reach from this analysis is that the GOJ should act to suppress sunspot pessimism on the assumption that the sunspot model is correct; this is because even in the equally probable case that it is incorrect, such an aggressive fiscal policy would still give welfare gains. We may note further that in the event the sunspot model is incorrect, the government will have evidence from the higher inflation rate- even though only slightly higher- that it is indeed incorrect, and it would then abandon its aggressive policy. Equally it may conclude from the evidence of only slightly higher inflation that the sunspot model is correct; in this case it can trumpet its strategy of killing any sunspot, and — this generally understood — can revert to a normal fiscal policy, confident that any sunspot can no longer arise. We would therefore argue that the GOJ would be best advised to embark on such an aggressive fiscal policy. If we examine the policy rule we estimated the GOJ was following, it reveals that this was a long way from such an aggressive policy. The GOJ has instead weakly stabilised output around a slowly rising potential output trend. It might be argued that this relative restraint was forced on it by fear of insolvency. Yet throughout our sample since the end of the 1990s long term Japanese bond yields have been close to zero, creating little threat to solvency. Debt issues have been held domestically, with Japanese residents unwilling to shift their holdings to foreign stocks. In this paper we assume the model estimated on this sample holds for our policy experiments.

7. Conclusions

In recent decades following the financial crisis the major economies of the OECD have slowed down and lost momentum, leading some economists to argue that 'secular stagnation' has emerged and should be fought by stimulative policies, including fiscal stimulus given that monetary stimulus has been undermined by interest rates hitting the zero lower bound. One possible reason for this loss of momentum since the financial crisis could be a rise in pessimistic beliefs about future potential output growth triggered by a loss of business confidence from the crisis — such a rise could trigger a sunspot equilibrium in a rational expectations New Keynesian model. We examine in this paper whether this theory could account for the slow growth behaviour of the Japanese economy since the crisis of 1989 produced there by the 'bursting of the financial bubble' that had arisen due to the loose money policies of the 1980s. We show in this paper that a New Keynesian model with a weak equilibrium growth path driven by pessimism sunspot belief shocks does match the behaviour of the Japanese economy as represented by a VAR. We also found that an equally probable model of Japan post-1989 remains a conventional one where productivity growth simply slowed down for unknown reasons. Nevertheless, we find that from the welfare viewpoint Japanese fiscal policy should have committed to eliminating the possible sunspot but stood ready to revert to a normal policy in the face of rising inflation.

CRediT authorship contribution statement

Vo Phuong Mai Le: Writing – review & editing, Investigation, Formal analysis. **David Meenagh:** Writing – review & editing, Software, Methodology, Investigation, Formal analysis, Data curation. **Patrick Minford:** Writing – original draft, Methodology, Formal analysis, Conceptualization.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.intfin.2025.102142.

Data availability

Data will be made available on request.

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