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A dissection of Indian growth using a DSGE filter

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ABSTRACT

In order to build a strong and sustainable recovery post the COVID-19 pandemic, we need to draw important observations from the growth experience of the past. In this context, this paper uses a dynamic stochastic general equilibrium (DSGE) model that takes into account persistent growth rate shocks to decompose the Indian GDP into potential output and output gap. Apart from analysing the trajectory of potential output-output gap, it also examines their underlying drivers. The results suggest that a combined deceleration in neutral and investment-specific technology growth post 2016, brought down the potential growth to around 6 per cent in 2020Q1. The output gap also witnessed a persistent decline since 2018Q1, primarily due to weak demand and a rise in investment adjustment costs reflecting heightened stress in the investment and financial sectors. A forecasting exercise is also undertaken which shows that the estimates of output gap from the model possess competing inflation forecasting ability compared to HP filtered output gap.

1. Introduction

India, like many other countries across the globe, has undertaken a host of measures, both fiscal and monetary, to shield the economy in the aftermath of the COVID crisis. While the short-term stimulus is important as an emergency measure, it is important not to lose sight of the bigger picture while framing policies for a post-COVID economy. In India, growth was slowing even before the advent of the pandemic – GDP growth witnessed a sustained deceleration from 8.2 per cent in Q4:2017–18 to 3.0 per cent in Q4:2019–20. Understanding the nature of the slowdown can help design appropriate mitigation measures. To the extent that the slowdown is cyclical in nature, stabilisation policies through counter-cyclical fiscal and monetary measures would be able to arrest the slowdown. A structural slowdown in the growth process, on the other hand, would necessitate reforms targeting the fundamental nature of the economy. In this context, the paper makes a novel attempt in using a dynamic stochastic general equilibrium (DSGE) model to dissect Indian GDP into potential output (determined by economy’s fundamentals) and output gap (fluctuations from the trend). The objective of this paper extends beyond obtaining a quantitative estimate of potential growth and output gap – the use of a DSGE framework enables us to analyse the growth process qualitatively by explaining the underlying factors driving the change in trend and cycle. The analysis of the trajectory and drivers of India’s economic growth from the late 1990s till the advent of the pandemic, as undertaken in this paper, is useful as it can provide insights beyond the immediate future into the medium term.

Traditionally, potential output has been estimated using either statistical smoothing methods (e.g., the Hodrick-Prescott [HP] filter)
or the production function approach. However, recently, the dynamic stochastic general equilibrium (DSGE) models, the workhorse for macroeconomic analysis in central banks, have found a place in the literature to study potential output dynamics (Fueki, Fukunaga, Ichiue, & Shirotá, 2016; Kiley, 2013; Primiceri & Justiniano, 2009). A major advantage of DSGE models over the conventional methods is that the former are conceptually closer to the economic theory, and can be used to analyse the plausible economic reasons for any observed macro-economic phenomena. Thus, while the statistical methods dissect economic data into trend (potential output) and cycle (output gap), the DSGE models are useful in explaining the underlying factors driving them. At the same time, their general equilibrium character ensures that information contained in a variety of macro variables is effectively utilised to estimate the unobserved variables (potential output and output gap).

However, measures of potential growth and output gap from DSGE models are not free from criticism. The efficient level of output, generally considered for the calculation of output gap in DSGE models, is the level of output generated in an environment without nominal rigidities in goods and labour markets and without shocks to price and wage markups. This is also known as “flexible-price equilibrium output” or “natural level of output”. Since both the classification of shocks (into real and nominal) and their quantitative significance in the DSGE model depends on the framework designed by the researcher, the efficient level of output and the associated output gap become subject to model specification. It is also observed that this flexible-price equilibrium output tends to be more volatile than conventional measures of potential output based on a production function approach or statistical filters which try to capture the medium-term growth trends of output (Vetlov, Hlédik, Jonsson, Henrik, & Pisani, 2011).

In order to address the concerns mentioned above, the paper follows the approach of Vetlov et al. (2011) and Fueki et al. (2016) by considering alternative notions of potential output. Principally, two measures of potential output are considered in this study. First, the flexible price (natural) output, common in the DSGE literature, is the output that prevails in the absence of nominal rigidities and shocks to price and wage markups. This is referred to as “short-run efficient output”, where the nominal rigidities are the only significant distortions (Kiley, 2013). Alternatively, we also consider the output that is generated solely by persistent growth rate shocks – referred to as “long-run efficient output”. Thus, the short-run efficient output captures the impact of all real shocks in the economy, whereas the long-run efficient output captures the impact of only permanent real shocks, i.e., non-stationary shocks. While the short-run efficient output is volatile and closely follows actual output, the long-run efficient output is smoother and tracks the conventional measures of potential output (e.g., estimates from HP filter) relatively well. It also fits with the policymakers’ view that an efficient level of output is driven mainly by permanent technological changes (Fueki et al., 2016). Additionally, the long-run efficient output has been found to be less prone to model specification errors (Fueki et al., 2016).

In this paper, two types of long-run efficient output are estimated: (i) the level of output based only on labour augmenting/neutral technology; and (ii) the level of output that takes into account both neutral technology and investment-specific technology (IST) shocks. In the neoclassical growth literature, a technological progress which directly enhances the productivity of both labour and capital, is termed as “balanced” or “neutral technological progress”\(^2\). This type of growth is generally unable to capture the improvement in efficiency that is specific to the investment sector alone. In other words, the neutral technological progress does not capture productivity growth driven by technology that is embodied in new types of capital equipments. Given which, accounting for IST growth becomes important especially in the Indian context. In the post-1991 period, India witnessed a visible upward trend in investment to GDP ratio along with an increase in the efficiency of investment as signalled by a declining trend in relative price of investment. In such a scenario, traditional growth theory, which emphasises the role of disembodied or neutral technological progress, may prove to be deficient in explaining growth driven by improvement in the quality of investment goods that becomes embodied in productive capital stock (Pakko, 2002). Thus, IST growth needs to be incorporated in the modelling structure.

This paper uses micro-founded DSGE methodology with a Bayesian approach to estimate output gap and potential output for the Indian economy following the standard medium-scale DSGE framework as propounded by Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007). The modelling structure allows for estimating multiple measures of output gap and potential output. A key feature of the model is that it takes into account persistent growth rate shock(s) as proposed by Fueki et al. (2016), so that we can estimate the model without de-trending the data. This is important for the estimation of long-run efficient output. As against the standard practice of including only neutral\(^3\) technological progress, investment-specific technological progress is also included in the standard structure. According to Fisher (2006), IST shocks are a unique source of the secular trend in the real price of investment goods. Therefore, we estimate IST growth separately from the relative price of investment and then use it in the model as one of the observed variables.

The results suggest that India’s potential growth (long-run efficient output growth) increased from around 4.6 per cent in 2002 to around 8 per cent in 2007, mainly on account of an uptick in neutral growth during the period. Thereafter, neutral growth declined but the potential growth remained at around 8 per cent till 2016 as an increase in IST growth made up for the shortfall in neutral growth. Post 2016, a combined deceleration in neutral and IST growth brought down the potential growth to around 6 per cent in 2020Q1. It is also observed that IST growth trails behind neutral growth, indicating a relative absence of investment-led growth phenomenon in India. The output gap also declined since 2018Q1 suggesting that an economic slowdown was underway even before the advent of COVID-19, primarily due to weak demand and a rise in investment adjustment cost reflecting heightened stress in the investment and financial sector.

The estimates of output gap from the model show superior inflation forecasting ability compared to HP filtered output gap, which

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\(^2\) When the production function is Cobb-Douglas, neutral and labour-augmenting growth are in principle the same, and can be used interchangeably.

\(^3\) In the case of the Cobb-Douglas production function, neutral and labour-augmenting technical progress are indistinguishable.
The capacity utilisation estimate from the model also closely tracks actual data (from OBICUS survey\(^4\)) generating further confidence in our results. Given that the OBICUS measure is released with a lag of more than one quarter, the model-based estimate could provide lead information on the capacity utilisation in the economy.

The remainder of this paper is organised as follows: Section 2 covers the literature survey, Section 3 describes our model, Section 4 explains the estimation procedure, and Section 5 discusses the results. A comparison of the predictability of inflation across different measures of output gap is presented in Section 6 and Section 7 concludes.

2. Literature review

After several decades of research on potential output, there remains considerable confusion over its understanding and how to measure it precisely. The concept of potential output is not uniquely defined and estimation method also can differ significantly (Odor and Jurasekova Kucerova, 2014). While there is no disagreement in the literature that potential output refers to the maximum level of output that an economy can sustain at full capacity utilisation without any inflation pressure, the notion has emerged over time to bifurcate potential output into the short-term and the long-term. Accordingly, the recent literature (Basu & Fernald, 2009; Group, 2018; Kiley, 2013; Vetlov et al., 2011) divided the concept of potential output into three types - (i) trend output; (ii) efficient output; and (iii) natural output. The corresponding measures of output gap are estimated by taking the deviation of actual output from the corresponding measure of potential output.

The estimates of output gap based on trend measures of potential output generally correspond to the usual business cycle component of output. The trend output refers to the conventional measure of potential output and is estimated either by using various statistical filters or production function approach. The potential output estimated from purely statistical filters, particularly a univariate filter, does not have a structural interpretation, while the measures that use a multivariate filter or production function are closer to general equilibrium models. Recently, DSGE models are also developed to estimate potential output by taking into account only the permanent technology shocks (Alichi et al., 2018; Bechný, 2019; Kiley, 2013; Fueki et al., 2016; Vetlov et al., 2011). This measure of potential output has a long-run dimension as it is affected only by permanent (unit root) technology shocks. Therefore, policymakers, while talking about potential output often refer to trend output. The estimation of trend output is straightforward, cost-effective and relies on few explicable assumptions. It often produces smooth growth series and volatile output gap estimates. Since this measure aims to produce smoothed values of growth, the shocks affecting the economy at business cycle frequencies have no significant influence on potential output. Basu and Fernald (2009) noted “neither macroeconomic theory nor existing empirical evidence suggests that potential output is a smooth series. Policymakers, however, often appear to assume that, even in the short run, where potential output is well approximated by a smooth trend”.

As opposed to the trend level of output or long-term measure of output, New-Keynesian methodology provides a different notion of potential output by incorporating short-run technology shocks where factors of production cannot immediately relocate in response to the shocks. Accordingly, the efficient and natural level of output are defined under flexible prices and wages by considering perfectly competitive and imperfectly competitive market conditions, respectively. The efficient level of output is the level that would prevail if goods and labour markets were perfectly competitive, where both steady-state markups and markup shocks are zero. The related output gap (equals the difference between actual output and efficient output), therefore, measures the relevance of imperfect competition and nominal rigidities. The natural level of output differs from the efficient level of output only because the steady-state markup and markup shocks are different from zero in the case of the former. Hence, the output gap based on natural level of potential output, measures the magnitude of nominal rigidities.

While all the above three approaches are used to estimate potential output and the output gap, the first measure is more popular and easier to estimate. Hence, policymakers and most of the empirical literature focus on trend measures of potential output. Most multilateral organisations (e.g., International Monetary Fund, Organisation for Economic Co-operation and Development, World Bank, World Economic Forum) and authorities responsible for providing country/economy-specific potential output use the production function approach. Moreover, only a few recent studies estimated potential output using the other two approaches (Basu & Fernald, 2009; Bechný, 2019; Edge, Kiley, & Laforet, 2008; Fueki et al., 2016; Kiley, 2013; Leist & Neusser, 2010; Primiceri & Justiniano, 2009; Vetlov et al., 2011). In the Indian context, most studies use either statistical methods (Bhoi & Behera, 2017; Bordoloi, Das, & Jangili, 2009; Goyal & Arora, 2012) or a production function-based measure (Anand & Prasad, 2010; Bhoi & Behera, 2017; Bosworth & Collins, 2008; Mishra, 2013; Oura, 2007; Ranjan, Jain, & Dhal, 2007; Rodrik & Subramanian, 2004) to estimate potential output or output gap. There are few recent studies which focus on multivariate filters, taking into account both structural relationships along with statistical methods to estimate potential output for India (Bhoi & Behera, 2017; Blagrave, Garcia-Saltos, Laxton, & Zhang, 2015; Rath, Mitra, & John, 2017). Using varied methodologies and different sample periods, the studies have reported India’s potential growth estimates in the range of 6.5 per cent to 9.5 per cent. The most recent estimates of potential growth for India were 7.3 per cent by the IMF (2019),\(^5\) 6.7 per cent by Bhoi and Behera (2017), 7 per cent by Jorgenson (2016)\(^6\) and Kutascovic (2017).

Given the divergence between the estimates and the need for a fresh look at the macroeconomic history of the Indian economy, it is

\(^4\) The Order Books, Inventories and Capacity Utilisation Survey (OBICUS), conducted by the Reserve Bank of India, captures actual data from companies in the manufacturing sector.

\(^5\) India: Staff Report for the 2019 Article IV Consultation, IMF Country Report No. 19/385, December.

\(^6\) “Why is India the Most Rapidly Growing Economy in the World?”, Kotak Family Distinguished Lecture, Colombia University – New York, December 2, 2016 by Dale W. Jorgenson.
important to conduct an economic exploration by revisiting India’s potential output and output gap estimates. This present paper contributes to this debate by providing estimates using a medium-scale DSGE model.

3. Model

We build a medium-scale DSGE model with three main economic blocks: households, firms and government. The government constitutes fiscal as well as monetary authorities.

Households are inter-temporal utility maximizers. They supply labour and capital service to the firm sector in return for wage and rental earnings. They can save either in risk-free one-period government bonds or in capital. They also choose how intensively capital is used in the production process. Their decision on how much to save in capital determines the investment level in the economy. The law of motion of capital includes a unit-root IST growth factor attached to investment. This captures the dynamics associated with the productivity improvement embodied in capital goods, as is evident in Indian data in the form of decreasing relative price of investment equipment. We assume

\[
\delta_t \quad \text{denotes the time-varying capital depreciation rate. Unlike standard cases where it is modelled as a constant, we make it a}
\]

The fiscal authority carries out government expenditure, which is assumed to be an exogenous auto-regressive process of first order (AR1). Similarly, we also assume that the net exports of the economy follow an AR1 process. Accordingly, we combine government expenditure and net-exports \((G + NX)\) data, and use it as the exogenous expenditure variable. The monetary authority decides the nominal policy rate based on a Taylor-type rule framework. The interest rate affects two kinds of substitution: intertemporal consumption-savings and intra-temporal bond-capital savings, and through this the other macroeconomic variables in the model.

Since the model includes two trending growth factors, the appropriate variables are transformed/de-trended along their balanced growth-paths. The two kinds of growth, neutral and IST, are combined to form a measure of potential growth. We now turn to a more detailed description of the model.

3.1. Household

The representative household maximises its lifetime utility, which depends positively on consumption \((C_t)\) and negatively on the labour supplied \((N_t)\) to the firms. The expected utility function is given as,

\[
E_0 \sum_{t=0}^{\infty} \text{pref}_t \beta \left[ \log(C_t - hC_{t-1}) - \frac{N_t^{1+\phi}}{1 + \phi} \right]
\]

(1)

where \(\beta\) is the intertemporal discount rate, \(h\) is the degree of habit formation, and \(\phi\) captures the responsiveness of labour supply to a change in real wage \((\frac{P_t}{Z_t})\). \(\text{pref}_t\) is the first order autoregressive intertemporal preference shock that captures changes in household preferences over time.

The household saves in the form of capital \((K_t)\) and one-period government bonds \((B_t)\). It supplies capital service and labour to firms in the domestic sector. The household can use its income from capital service, labour and bond incomes to purchase new bonds, consumption goods or investment goods. Accordingly, its budget constraint is given by,

\[
P_t C_t + P_t I_t + B_t = W_t N_t + R_t U_t K_t + (1 + i_{t-1})B_{t-1} + \Gamma_t - T_t
\]

(2)

where \(P_t\) is the price of the final good in the economy, \(I_t\) is aggregate investment, \(U_t\) is the capital utilisation rate, \(R_t\) is the rate of return on capital service, \(i_t\) is the nominal interest rate, \(\Gamma_t\) denotes aggregate profits, and \(T_t\) are lump sum net transfers to the government. The capital stock in the model evolves according to the following law of motion,

\[
K_{t+1} = \left(1 - \delta_t\right) K_t + Z_t \left[1 - \frac{\kappa}{2} \left(\frac{\text{adj}_t I_t}{I_{t-1}} - 1 \right)^2 \right] I_t
\]

(3)

\[
g_z = \frac{Z}{Z_{t-1}}
\]

(4)

We assume the existence of quadratic investment adjustment cost, where \(\kappa\) denotes the magnitude of this cost. \(\text{adj}_t\) captures the stochastic variation in the investment adjustment cost. We assume it to be a first order autoregressive process. \(Z_t\) captures the IST factor whereas \(g_z\) is the growth in \(Z_t\). It denotes the exogenous innovation in the productivity that is embodied in new types of capital equipment. We assume \(g_z\) to be a first order autoregressive process with drift \(g_{z0}\) and persistence parameter \(\rho_{g_z}\).

\(\delta_t\) denotes the time-varying capital depreciation rate. Unlike standard cases where it is modelled as a constant, we make it a

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7 Capital service is the product of capital and its degree of utilisation.
8 The investment (consumption) deflator is calculated by dividing nominal investment (consumption) by real investment (consumption).
function of the capital utilisation rate \((U_t)\) and, thus, it changes over time. The higher the utilisation rate of capital, the higher is its depreciation. To capture the non-linearity as well as the general nature of this relation, we model it as,

\[
\delta_t = \delta_0 + \delta_1 z \left[ \frac{U_t^{1+\phi}}{1 + \phi} - 1 \right]
\]

(5)

Here \(z\), \(\phi\), and \(\delta_0\) are the parameters governing this dynamics.

### 3.2. Firms

The productive sector consists of a continuum of monopolistic competitive firms that produce intermediate goods using capital service and labour as inputs. The output from these intermediate firms is then transformed into a homogeneous good by the final good producing (FG) firm. This transformation is governed by the following CES function,

\[
Y_t = \left[ \int Y_{j,t}^{\psi} \frac{\psi - 1}{\psi} dj \right]^{\frac{1}{\psi}}
\]

(6)

where \(\psi\) measures the degree of substitutability among different intermediate goods. The demand function for each intermediate good is given as,

\[
Y_{j,t} = \left( \frac{P_t}{P_{j,t}} \right)^{\psi} Y_t
\]

(7)

where \(P_{j,t}\) is the price charged by firm \(j\) and \(P_t\) is the aggregate price index (or consumer price index [CPI]) given as,

\[
P_t = \left[ \int_0^1 P_{j,t}^{1+\delta} dj \right]^{\frac{1}{\psi}}
\]

(8)

Each monopolistically competitive intermediate firm faces a downward-sloping demand curve (7) for its differentiated product \(Y_{j,t}\). Its production function is given by,

\[
Y_{j,t} = A_t (U_t K_{j,t})^{\alpha} (X_t N_{j,t})^{1-a}
\]

(9)

where \(A_t\) is the stationary productivity shock that follows a first order autoregressive process, \(\alpha\) is the input share of capital service and \(X_t\) is the permanent labour-augmenting growth factor. \(\mu_t = \frac{X_t}{X_{t-1}}\) (which captures the change in \(X_t\)) is assumed to follow a first order autoregressive process with drift.

The IG firms maximise their profits in two rounds. First, they choose the optimal input mix to minimise the cost of production for a given level of output. This optimisation yields the following expression of nominal marginal cost (MC) for \(j^{th}\) firm,

\[
MC_{j,t} = \frac{S_{mc.j}}{A_t} \left[ \frac{W_t}{\alpha X_t} \right]^{\alpha} \left[ \frac{R_t}{(1 - \alpha)} \right]^{1-a}
\]

(10)

where \(S_{mc.j}\) denotes the shock to price markup and is assumed to follow an AR1 process.

Second, each firm chooses an optimal price to maximise profit given the demand constraint. We assume that the firms face Calvo (1983) type price rigidity. Accordingly, \((1 - \theta)\) fraction of the firms (selected randomly) can choose their prices optimally in every period. The remaining \(\theta\) fraction of the firms update their prices as per the simple rule using the previous period’s gross inflation, i.e.,

\[
P_{j,t} = (\bar{\pi}_{t-1})^{index} P_{j,t-1}.
\]

This formulation guarantees the presence of lagged inflation terms in the standard Philips curve. The strength of the dependence upon past inflation is captured by the parameter, \(index\). This gives us the following generalised Philips curve (in log-linearised form),

\[
\bar{\pi}_t = \frac{index \cdot \theta}{\theta + \beta \cdot index \cdot \theta'} \bar{\pi}_{t-1} + \frac{\beta \cdot \theta}{\theta + \beta \cdot index \cdot \theta'} E_t \bar{\pi}_{t-1} + \frac{(1 - \theta)(1 - \beta \cdot \theta)}{\theta + \beta \cdot index \cdot \theta'} \left[ MC_t - P_t \right] + S_{mc,t}
\]

(11)

### 3.3. Government

The government issues bonds and raises lump sum taxes to meet the expenditure on goods and services \((G_t)\) according to the following budget constraint:

\[
P_t = (1 + i_{t-1})B_{t-1} = T_t + B_t
\]

(12)

Public demand, \(G_t\), is treated as an exogenous process that evolves according to:

\[
\log \left( \frac{G_t}{H_t} \right) = (1 - \rho_p) \log (g) + \rho_p \log \left( \frac{G_{t-1}}{H_{t-1}} \right) + \epsilon_g
\]

(13)
where \( H_t \) is the implicit growth factor to be discussed later, \( g \) is calibrated so that the steady-state share of government expenditure in the GDP in the model matches its empirical level.

### 3.4. Central Bank

The central bank sets the short-term nominal gross interest rate, \( g_t = (1 + i_t) \), according to a Taylor-type monetary policy rule,

\[
\ln \left( \frac{g_t}{g_{t-1}} \right) = \rho_g \ln \left( \frac{g_{t-1}}{g_{t-2}} \right) + (1 - \rho_g) \left[ \phi_g \ln \frac{\pi_t}{\pi} + \phi_f \ln \frac{Y_t}{Y} \right] + \epsilon_{mp,t}
\]

where \( g_t \) is the steady state value of gross interest rate, \( \pi_t \) is the CPI inflation rate, \( \pi \) is the inflation target, \( Y^* \) represents the long-run or short-run efficient output as per the case considered, \( \phi_g \) captures sensitivity to inflation, \( \phi_f \) captures sensitivity to output gap and \( \epsilon_{mp,t} \) denotes the monetary policy shock.

### 3.5. Market clearing

Goods market clearing requires that the total production in the economy equals the combined demand for consumption, investment, government expenditure and net exports \((NX_t)\).

\[
Y_t = C_t + I_t + G_t + NX_t
\]

### 3.6. Exogenous processes

The rate of growth of labour augmenting technology, \( \mu_t = \frac{Y_t}{Z_t} \), is assumed to follow an AR1 process with drift,

\[
\log(\mu_t) = (1 - \rho_{\mu}) \log(\mu_{t-1}) + \rho_{\mu} \log(\mu_{t-1}) + \epsilon_{\mu,t}
\]

Similarly, the dynamics of rate of growth in investment specific technology \((IST)\), \( \gamma_t = \frac{Z_t}{X_t} \), is given by:

\[
\log(\gamma_t) = (1 - \rho_{\gamma}) \log(\gamma_{t-1}) + \rho_{\gamma} \log(\gamma_{t-1}) + \epsilon_{\gamma,t}
\]

The other structural shocks that follow AR1 processes evolve according to:

\[
\log(\text{shock}_t) = (1 - \rho_{\text{shock}}) \log(\text{shock}_{t-1}) + \rho_{\text{shock}} \log(\text{shock}_{t-1}) + \epsilon_{\text{shock},t}
\]

for \( \text{shock} = [A_t, \text{pref}_t, \text{SNCt}_t, G_t, \text{adj}_t] \). The remaining exogenous process, \( \epsilon_{mp,t}, \epsilon_{\mu,t}, \epsilon_{\gamma,t}, \epsilon_{\text{SNC},t}, \epsilon_{G,t} \) and \( \epsilon_{\text{adj},t} \) are assumed to be white noise.

### 3.7. Balanced growth path

There are two trending variables \((X_t \text{ and } Z_t)\) that we introduce in our model. \( X_t \) captures the effect of labour-augmenting productivity on the output while \( Z_t \) takes into account the effect of IST shocks. Hence, the overall long-run economic growth \( \log(\gamma_t) = \log(\frac{H_t}{\gamma_{t-1}}) \) comes out to be the weighted sum of labour-augmenting technical change and IST growth (reflecting improvement in the quality of capital goods), specifically given by the following expression,

\[
\log(g_t) = \log(\mu_t) + \left( \frac{\alpha}{1 - \alpha} \right) \log(Z_t)
\]

Along the balanced growth path, output, consumption, investment, government expenditure, net exports and real wage grow at the same constant rate \( g \). Due to the presence of IST growth, capital grows at a constant rate of \((g + \gamma)\).

### 4. Estimation

Two types of potential output can be estimated from the model – the short-run efficient output and the long-run efficient output, depending on the number of real shocks used in the estimation of potential output and the output-gap used in the Taylor rule. When all real shocks are included, the short-run efficient output is obtained and when only the persistent growth rate shocks are included, the long-run efficient output is obtained. Corresponingly, two different measures of output gap consistent with our notion of potential output can be computed: first, the deviation of actual output from short-run efficient output \((Y-ngap)\) and second, the deviation of actual output from the long-run efficient output \((Y-pgap)\). The monetary policy authority in the model can respond to either of these output-gaps, i.e., the Taylor rule can include \(Y-ngap\) or \(Y-pgap\). However, we find that the estimate of long-run efficient output largely
remains invariant to whether $Y_{ngap}$ or $Y_{pgap}$ is used in the Taylor rule.\footnote{See Appendix B, where estimated values of parameters under different model specifications are presented. It shows that any change in the measure of output gap used in the Taylor rule results in a concomitant change in the coefficient of output gap ($\phi_g$), thereby leaving the estimate of the “long-run efficient output” largely unchanged.} This serves as a robustness check and shows that $Y_{pgap}$ is relatively less sensitive to model specification. Additionally, two kinds of long-run efficient output are estimated in the model – first, by considering only 1 persistent growth rate shock which is the labour augmenting technical progress and second, by considering investment-specific technology shocks along with labour-augmenting technical progress.

Thus, we estimate two main variants of the model based on the inclusion/exclusion of IST shocks: Model 1, which does not incorporate IST shocks and Model 2, which incorporates IST shocks. Under each of these, we estimate both the short-run efficient output and the long-run efficient output.

4.1. Data

We estimate the model using quarterly data for the period 1996Q2 to 2020Q1. The variables used in the estimation are: GDP, consumption, investment, government expenditure, net-exports, headline CPI inflation, weighted average call rate and relative price of investment. The relative price of investment is obtained by dividing the investment deflator with the consumption deflator. We seasonally adjust all the real variables and CPI using Census X-13 ARIMA-SEATS.

4.2. Calibration

The discount factor ($\beta$), which represents how the agents assess future utility versus present utility, is set to 0.99 as per the standard practice for quarterly models. The elasticity of substitution among different varieties of intermediate goods is taken as 7.02 following (Gabriel, Levine, & Yang, 2016).

The steady-state value of the capital depreciation parameter ($\delta_0$) is assumed at 0.025, broadly in line with the estimates of KLEMS by (Das & Nath, 2019). Following the data on real GDP and its components, we calibrate the steady state share of consumption, investment and government expenditure in GDP equal to 0.56, 0.30 and 0.14, respectively. The output (real GDP) is assumed to grow at a rate of 1.671 per cent (quarter-on-quarter) in the steady state. Similarly, from the data on relative price of investment, IST growth is set to 0.46 per cent (quarter-on-quarter) in the steady state. These figures are based on the average of respective variables over the whole sample period of the study.

4.3. Bayesian estimation

Smets and Wouters (2007) have popularised Bayesian Maximum Likelihood as a standard method for estimating DSGE models. Following which, the same has been used for estimating the present model. The Bayesian approach is theoretically based on the Bayes’ theorem. It requires choosing prior distributions of the parameters to be estimated. These priors represent our previous knowledge. The priors and the information from the observed data are combined to yield posterior distributions, which are then used to compute the parameter estimates.

4.3.1. Estimation procedure

The estimation of DSGE models with Bayesian methods is described in a series of papers by Frank Schorfheide and various co-authors. Here we give a brief outline based on An and Schorfheide (2007).

The optimisation exercise of each agent in the model is solved to get a system of non-linear equations which represents the interconnectedness in the economy. Since persistent growth rate shocks in the system make some of the endogenous variables non-stationary, we divide the non-stationary variables by the corresponding I(1) trends to make them stationary. This gives us a new set of transformed equilibrium conditions. We then log-linearise this set to convert the non-linear system into a linear one. The derived linear rational expectations system and its dynamics, can then be represented by the following equation,

$$\tilde{S}_t = G(\nu)\tilde{S}_{t-1} + H(\nu)\tilde{\nu}_t,$$

where $\tilde{S}_t$ is a properly defined $k \times 1$ vector of stationarised and log-linearised endogenous variables, $\tilde{\nu}_t$ is the $n \times 1$ vector of exogenous i.d. disturbances, and $\nu$ is the $p \times 1$ vector of structural unknown coefficients. $G(\nu)$ and $H(\nu)$ are the conformable matrices of coefficients that depend on the structural parameters $\nu$.

To estimate the model, we specify the observation equation,

$$x_t = J\tilde{S}_t + \gamma + \tilde{\nu}_t^{ME}$$

where $x_t$ is the observed data, $\gamma$ is the vector of constant terms and $\tilde{\nu}_t^{ME}$ denotes the measurement errors if any. Since the variables in our model $\tilde{S}_t$ include persistent growth rate shocks, we do not detrend or demean any data series.

Letting $x^T$ be a set of observable data, the likelihood function $L(\nu, x^T)$ is evaluated by applying the Kalman filter. We combine the
likelihood function $L(\nu, x_T)$ with priors for the parameters to be estimated, $p(\nu)$, to obtain the posterior distribution, which is proportional to $L(\nu, x_T) p(\nu)$. Since we do not have a closed-form solution of the posterior, we rely on Markov chain Monte Carlo (MCMC) methods using Dynare. Draws from the posterior distribution are generated with the Metropolis–Hastings algorithm. We take 500,000 draws from the posterior distribution and discard the first 250,000 as a burn-in. We obtain the posterior mean estimates and posterior intervals of unobserved model variables, including the efficient output, by applying the Kalman smoother.

### Table 1
Estimated parameter values (prior and posterior distribution) of Model 1.

| Parameter | Description | Prior distribution | Prior mean | Prior S. D. | Posterior mean | 10th Percentiles | 90th Percentiles |
|-----------|-------------|--------------------|------------|-------------|----------------|------------------|------------------|
| $\theta$ | Calvo price stickiness | Beta | 0.6 | 0.05 | 0.63 | 0.55 | 0.71 |
| $\phi$ | Frisch elasticity of labour supply | Gamma | 2 | 1 | 2.70 | 1.08 | 4.28 |
| $\alpha$ | Share of capital service | Normal | 0.33 | 0.05 | 0.36 | 0.27 | 0.45 |
| $h$ | Degree of habit formation | Beta | 0.5 | 0.15 | 0.13 | 0.04 | 0.22 |
| $e$ | Magnitude of investment adjustment cost | Gamma | 5 | 4 | 14.06 | 2.90 | 24.65 |
| $\phi_\nu$ | Capacity utilisation parameter | Gamma | 2 | 1 | 0.58 | 0.18 | 0.98 |
| $\phi_\pi$ | Degree of responsiveness of policy to inflation | Normal | 1.5 | 0.08 | 1.55 | 1.42 | 1.67 |
| $\phi_\psi$ | Degree of responsiveness of policy to output gap | Beta | 0.6 | 0.15 | 0.68 | 0.46 | 0.90 |
| $\phi_{\text{index}}$ | Degree of responsiveness of policy to change in output | Beta | 0.01 | 0.009 | 0.01 | 0.00 | 0.02 |
| $\phi_{\text{index}}$ | Degree of indexation to previous period price | Beta | 0.5 | 0.15 | 0.20 | 0.08 | 0.32 |
| $\rho_\pi$ | Persistence of shock to short-term productivity | Beta | 0.35 | 0.17 | 0.34 | 0.04 | 0.64 |
| $\rho_\phi$ | Persistence of shock to neutral growth | Normal | 0.98 | 0.005 | 0.98 | 0.97 | 0.99 |
| $\rho_{\text{IST}}$ | Persistence of shock to IST growth | Normal | 0.98 | 0.005 | NA | NA | NA |
| $\rho_{\text{pref}}$ | Persistence of shock to preferences | Beta | 0.5 | 0.2 | 0.51 | 0.23 | 0.78 |
| $\rho_\iota$ | Persistence in nominal interest rate | Beta | 0.75 | 0.1 | 0.81 | 0.77 | 0.85 |
| $\rho_\phi$ | Persistence of price mark-up shock | Beta | 0.5 | 0.2 | 0.31 | 0.10 | 0.51 |
| $\rho_\gamma$ | Persistence of shock to government spending | Beta | 0.5 | 0.2 | 0.93 | 0.87 | 0.98 |
| $\rho_{\text{adj}}$ | Persistence of shock to investment adjustment cost | Beta | 0.5 | 0.2 | 0.22 | 0.07 | 0.37 |
| $\epsilon_a$ | Standard deviation of shock to short-term productivity | Gamma | 0.02 | 0.01 | 0.0102 | 0.0038 | 0.0164 |
| $\epsilon_\phi$ | Standard deviation of shock to policy rate | Gamma | 0.009 | 0.008 | 0.0047 | 0.0040 | 0.0054 |
| $\epsilon_\pi$ | Standard deviation of shock to neutral growth | Gamma | 0.001 | 0.0009 | 0.0010 | 0.0004 | 0.0016 |
| $\epsilon_{\text{IST}}$ | Standard deviation of shock to IST growth | Gamma | 0.001 | 0.0009 | NA | NA | NA |
| $\epsilon_{\text{pref}}$ | Standard deviation of shock to preferences | Gamma | 0.03 | 0.02 | 0.1065 | 0.0942 | 0.1184 |
| $\epsilon_{\text{index}}$ | Standard deviation of shock to change in output | Gamma | 0.02 | 0.01 | 0.0094 | 0.0067 | 0.0123 |
| $\epsilon_{\text{adj}}$ | Standard deviation of shock to investment adjustment cost | Gamma | 0.03 | 0.02 | 0.0383 | 0.0324 | 0.0440 |
| $\epsilon_{\text{pref}}$ | Standard deviation of shock to preferences | Gamma | 0.02 | 0.01 | 0.02689 | 0.0215 | 0.0325 |

### Table 2
Variance decomposition.

| T = 1 | Output growth | Inflation | Capacity Utilization | Yngap | Ypgap |
|-------|---------------|-----------|----------------------|-------|-------|
| Short-term Productivity Shock | 3.86 | 6.03 | 14.68 | 25.95 | 3.88 |
| Monetary Policy Shock | 6.52 | 22.07 | 4.15 | 23.68 | 6.55 |
| Government Expenditure Shock | 33.12 | 3.91 | 15.64 | 3.83 | 33.28 |
| Long-term Productivity Shock | 0.60 | 1.24 | 1.13 | 0.44 | 0.12 |
| Price Markup (Supply) Shock | 4.05 | 52.12 | 2.49 | 14.72 | 4.07 |
| Investment Adjustment Cost Shock | 20.82 | 3.39 | 14.88 | 1.52 | 20.92 |
| Intertemporal Preference Shock | 31.03 | 11.23 | 47.02 | 29.86 | 31.18 |
| T = 100 | Output growth | Inflation | Capacity Utilization | Yngap | Ypgap |
| Short-term Productivity Shock | 3.53 | 5.55 | 1.15 | 19.24 | 3.00 |
| Monetary Policy Shock | 6.82 | 24.26 | 0.42 | 21.47 | 2.77 |
| Government Expenditure Shock | 28.32 | 5.50 | 8.43 | 3.23 | 30.92 |
| Long-term Productivity Shock | 6.05 | 4.96 | 79.12 | 0.53 | 0.07 |
| Price Markup (Supply) Shock | 3.97 | 44.03 | 0.60 | 29.57 | 3.81 |
| Investment Adjustment Cost Shock | 16.66 | 5.23 | 5.58 | 2.00 | 46.67 |
| Intertemporal Preference Shock | 34.65 | 10.46 | 4.70 | 23.97 | 12.77 |
4.3.2. Estimation results

A full list of the estimated parameters of Model 1 are presented in Table 1. Here we report a few important parameters. The Calvo price rigidity parameter $\theta$ has a posterior mean of 0.63, which is smaller than the corresponding value for advanced countries. The Frisch elasticity of labour supply is estimated at 2.7, which is close to the value assumed in Anand, Cheng, Rehman, and Zhang (2014). The share of capital service ($\alpha$) is 0.36. The degree of habit formation, $h$, is estimated to be significantly low at 0.13 compared to much higher values found in the literature for advanced countries. The low value of the parameter of habit persistence is consistent with the higher relative volatility of consumption in Indian data. The business cycle literature on India (Ghate, Pandey, & Patnaik, 2013) also finds that consumption is more volatile than output in the post-reform period. The estimated parameter $\rho_i$ at 0.81 implies a very slow adjustment of policy rate over the sample period. The response of policy rate to inflation is somewhat standard with $\phi_{\pi}$ estimated to be 1.55. On the other hand, the response to output gap is large, as captured by $\phi_y$ being equal to 0.67. At the same time, the parameter capturing the degree of indexation to previous period inflation by the Calvo rigid firms, comes out to be 0.2.

Next, we report the variance decomposition, based on Model 1, in Table 2. It shows the forecast error variance decomposition of output (real GDP) growth, inflation, capacity utilisation, gap from short-run efficient output and gap from long-run efficient output at forecast horizon $T = 1$ and 100. The fluctuations in output growth, both in the short run as well as the long run, are caused mainly by demand shocks (intertemporal preference shock, government expenditure shock) and investment adjustment cost shock. The fluctuations in inflation, on the other hand, are driven predominantly by shocks to price markup and monetary policy. Looking at the two measures of output gap, we find that $Y_{pgap}$ is mainly driven by the same set of shocks which drive output growth as well. On the other hand, the dynamics in $Y_{ngap}$ depend on a wide range of shocks which include shocks to short-term productivity, monetary policy, price markup and intertemporal preference. Going from short run to long run, the contribution of productivity and demand shocks to $Y_{ngap}$ decreases, while that of price markup shock increases.

The dynamics of capacity utilisation is interesting in the sense that it differs widely across time horizons. If we compare the short-run dynamics of capacity utilisation with that of $Y_{ngap}$, we find that the former is driven more by demand shocks and lesser by productivity, monetary policy and price markup shocks. Therefore, our model suggests, in the short-run, capacity utilisation is a better measure of demand condition than the output gap. However, in the long-run, the driving factors of capacity utilisation change completely, with long-term productivity (neutral technological growth) shocks turning out to be the predominant factor. This result is consistent with the findings of the seminal work of Greenwood, Hercowitz, and Huffman (1988) which noted “increases in the efficiency of newly produced investment goods stimulates the formation of new capital and more intensive utilisation and accelerated depreciation of old capital”. Hence, the long-run dynamics of capacity utilisation may have important information about the long-run productivity process.

5. Results

The Bayesian DSGE models allow for the estimation of historical paths of unobserved structural shocks. Once these shocks are estimated, it becomes possible to derive the historical smoothed estimates of endogenous variables, which have structural interpretation.

This section is divided into three sub-sections: the first sub-section presents the time-varying DSGE estimates of potential output, output gap, and capacity utilisation from Model 1 (i.e., without IST shocks) and compares them with conventionally used measures; the

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10 Parameter estimates from Model 2 and Model 3 are almost similar to Model 1, and therefore, are not reported here. Instead they are presented in Appendix B.
11 Variance decomposition based on Model 2 and Model 3 are presented in Appendix B.
12 Recently, Goyal and Kumar (2019) also confirms this finding for the Indian data.
second sub-section presents the DSGE estimates of potential output and output gap from Model 2 (i.e., with IST shocks) and analyses their driving factors; the final sub-section compares the inflation forecasting performance of the output gap from both the models with conventional measures.

5.1. Estimates from Model 1 (without IST shocks)

5.1.1. Potential output

The growth rates of short-run efficient output, the long-run efficient output, and actual output are plotted in Chart 1. The short-run efficient output, which captures the impact of real shocks only, moves closely with the actual output (that captures all shocks – real and nominal). This shows that a large part of the fluctuation in actual output is caused by real shocks in our framework. The difference between the actual output and the short-run efficient output reflects the extent of nominal imperfections or rigidities in the economy. The long-run efficient output, on the other hand, captures the impact of labour-augmenting/neutral technological progress on output, and displays a higher degree of smoothness. It, therefore, gels well with the traditional view among policymakers that potential output is a medium-term concept and is driven by permanent technological changes rather than short-term frictions.

Moreover, the long-run efficient output moves closely with other conventional measures of potential growth like the HP-filtered output (Chart 2). The trajectory of long-run efficient output suggests that potential growth saw an uptick from 2002 onwards. It reached its peak of around 8 per cent in 2007Q1 before slowing down to about 6.5 per cent by 2013Q2. The growth rate picked up subsequently to around 7 per cent by 2016Q4 but decelerated thereafter and was about 6 per cent in 2020Q1. The conventional measure of potential growth (i.e., HP-filtered output) shows broadly the same dynamics. However, it signals a more clear and steady deceleration in potential growth in the post-global crisis period.

Both short-run efficient output and long-run efficient output are obtained from Model 1 by varying the number of real shocks (all real shocks are included to estimate the short-run efficient output, and only one real shock – the labour-augmenting/neutral technological progress is included to estimate long-run efficient output) and using the short-run efficient output gap and the long-run efficient output gap alternately in the Taylor rule specification.
5.1.2. Output Gap

Output gap is measured as the deviation of actual output from the respective measure of potential output. Accordingly, we estimate two measures of output gaps – the gap from short-run efficient output ($Y_{ngap}$) and the gap from long-run efficient output ($Y_{pgap}$). We find that $Y_{ngap}$ is less volatile than $Y_{pgap}$, because the short-run efficient output moves more closely with the actual output than does the long-run efficient output (Chart 3).

The volatility of $Y_{pgap}$ is comparable to the volatility of the HP-filtered output gap and both estimates track each other closely (Chart 4). However, the two gaps show wider divergence in some periods which can be explained as follows. The model estimates the output gap based on the trajectory of observed variables such as output, inflation, interest rates, etc. Given which, in a period when inflation is high, the implied model-based output gap would be high or at least higher than the HP-gap (which does not use inflation data in its calculation). Therefore, $Y_{pgap}$ is higher than HP-gap during periods of high inflation in the post-global financial crisis (GFC) period. In contrast, $Y_{pgap}$ is lower than HP-gap during periods of low and stable inflation such as the period before the GFC.

It is also observed that although the various measures of output gap differ in terms of magnitude, but their peaks and troughs broadly coincide. In recent times, nearly all estimates stipulate a steady economic downturn since 2018.

5.1.3. Capacity utilisation

The results of variance decomposition (Table 2) suggest that capacity utilisation is a better metric of demand conditions than the output gap. In this regard, it becomes important to see how well the model-based estimate of capacity utilisation compares with the OBICUS survey-based measure. Chart 5 plots the two measures of capacity utilisation together, starting from the time OBICUS data is available. Despite the fact that the model-based measure is an unobserved estimate derived from the macro data, it tracks the capacity utilisation data from the OBICUS survey quite well. The high correlation of 0.72 between the two adds credibility to our estimation results. Given that the OBICUS measure is released with a lag of more than one quarter, the model-based estimate could provide lead information on the capacity utilisation in the economy.
5.2. Estimates from Model 2 (after incorporation of IST shocks)

5.2.1. The case for including IST shocks

The long-run efficient output that is discussed in the previous section is mainly driven by persistent labour-augmenting or total factor productivity (TFP) shocks. This type of growth is often termed “balanced” or “neutral technological progress” in the neoclassical growth literature, since it directly enhances the productivity of both labour and capital. However, this type of growth does not reflect the improvement in efficiency that is specific to the investment sector alone. In other words, the neutral technological progress is deficient in capturing productivity growth driven by technology that is embodied in new types of capital equipments. This kind of growth is often called investment specific technological (IST) progress in the literature. The importance of IST-led growth in the Indian context is suggested by Charts 6 and 7. Chart 6 plots the demeaned shares of investment, consumption, government expenditure and net exports to GDP for the post-1991 period. Compared with the ratios related to consumption, government expenditure and net exports, the investment to GDP ratio shows a secular upward trend over a large part of the sample period.

In Chart 7, the relative price of investment (\( r_{pi} = \frac{I_{t}}{C_{t}} \)) shows a remarkable decline during the same period. Both these evidences broadly suggest that the investment sector has grown faster than the rest of the economy for a sufficient period of time and this growth is being fuelled by improvement in efficiency, reflected in the declining trend of relative price of investment. This empirical fact gels well with the belief that the opening up of the economy in the post-1991 era led to increased access to new technology in terms of capital goods and other related imports into India which resulted in rapid advancement in information and communications technologies.

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14 When the production function is Cobb–Douglas, neutral and labour-augmenting growth are in principle the same, and can be used interchangeably.
5.2.2. Estimates of potential output

As per the standard growth literature (Pakko, 2002), the IST growth is generally calculated as the change in the inverse of relative price of investment. Since Indian data shows evidence of IST growth (Chart 7), we append the model to explicitly capture its effect. Specifically, the IST growth as calculated from the data, is fed to the model through the following observation equation.

\[
\Delta \left( \frac{1}{\Pi_t} \right)_{\text{data}} = g_Z
\]

To remove short-run fluctuations from the calculated IST growth, we apply HP-filter and then feed it into the model.
The re-estimation of the model with this change gives a new estimate of potential output that takes into account the contributions coming from both neutral and IST progress. The growth rates of short-run efficient output, the long-run efficient output, and actual output are plotted in Chart 8. As in Section 5.1 (without IST shocks), the short-run efficient output is volatile and moves closely with the actual output, whereas the long-run efficient output displays a higher degree of smoothness.

A comparison of long-run efficient output from Models 1 and 2 shows that the inclusion of IST shocks causes an upward revision in the potential growth estimate (Chart 9a). In order to find out the contribution of IST shocks to potential output (long-run efficient output), a decomposition of potential growth into the contributions coming from neutral technical progress, IST progress and population growth is undertaken (Chart 9b). On average, neutral technical progress contributes the most to potential growth followed by population growth and IST progress. The contribution of population growth has been steadily declining overtime, which suggests an increasing role of neutral and IST progress in sustaining potential growth’s momentum.

The trajectory of potential growth can be explained by observing the growth rates of its constituents. A plot of neutral and IST growth suggests that the uptick in potential growth from 2002 onwards is mainly on account of the increase in neutral growth (Chart 10). IST growth appears to be following neutral growth. With an upward trajectory from 2005 onwards, IST growth reached its peak in 2013. Since then, it has been on a decreasing path, which possibly reflects the deteriorating investment dynamics in the country. Since mid-2016, a combined deceleration in neutral and IST growth has brought down the potential growth.

It is interesting to note that neutral technical progress directly affects output by increasing the amount of production that can be carried out from a given set of factor inputs (labour and capital). In contrast, IST progress affects output indirectly – since IST refers to the efficiency of investment, IST progress requires that investment is undertaken so as to have an effect on final output. Given this theoretical backdrop, the fact that neutral growth picks up prior to IST growth in India indicates that movement in the final output precedes movement in investment thereby indicating a relative absence of investment-led growth phenomenon.

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16 The short-run efficient output is obtained by including all real shocks, and the long-run efficient output is estimated by including only two real shocks – the labour-augmenting/neutral technological progress and the investment-specific technological progress. The short-run efficient output gap is used in the Taylor rule specification.

17 Since the model has been estimated using aggregate data (consumption, investment, GDP, etc.) in place of per capita counterparts (per capital consumption, per capital investment, per capital GDP, etc.), we have to factor in the effect of population growth. Accordingly, the actual contribution of neutral technical progress to potential growth is derived by controlling for the effect of population growth.
5.2.3. Output gap

In this sub-section, we wish to analyze the major factors driving the output gap over our sample period. Since, the short-run output gap (Y-\text{ngap}) is more responsive to different kind of shocks (as seen in Table 2), we construct a historical decomposition\(^{18}\) of the Y-\text{ngap} to explore the structural drivers of output gap. To do this, different shocks of similar characteristics are first grouped together to provide a clearer picture of the major driving forces of India’s business cycle. The shocks to government expenditure and intertemporal preference shock are combined into the demand category, the two permanent unit root shocks (labour-augmenting growth factor \(X_t\) and IST growth factor \(Z_t\)) are classified as long-term productivity, and the stationary productivity shock \((A_t)\) is classified as short-term productivity.

As per our output gap estimate, the Indian economy has witnessed broadly two rounds of sustained expansion – 2003–2008 and late 2014 to early 2018 (Chart 11). The model identifies three main reasons for the expansion in the 2000s. The price markup (supply) shocks remained quite favourable over this period. This is corroborated by the fact that inflation remained largely stable during this period. At the same time, monetary policy shock and shock to investment adjustment cost remained accommodative to drive the upward movement in the output gap. It is interesting to note that the shock to investment adjustment cost is a good proxy for financial frictions (Wang & Wen, 2012), which contributed favourably to the output gap, reflecting the easy availability of investment finance during this period.

The period following the global financial crisis witnessed a sharp upturn in output gap, driven mainly by fiscal and monetary stimulus. However, the positive momentum did not sustain beyond 2010 and the economy started slowing down. Initially, the decline in economic activity mainly came from the roll-back of fiscal stimulus on account of a narrowing fiscal space. Later, however, a major part of this decline was contributed by a series of adverse price markup (supply) shocks. This was the time when the economy was facing the threat of stagflation – oil prices were high and the taper tantrum caused a sharp outflow of foreign capital. Double digit inflation, slowing growth hitting the government budget from the revenue side and rapid depreciation of the Indian Rupee were the main factors contributing to the situation of twin deficit.

The next phase of sustained recovery started in 2014Q4 and continued till 2017Q4. But unlike previous episodes, this time the turnaround was slow and feeble. Although the price markup (supply) shocks became favourable, the demand shocks remained weak. In addition, shocks to investment adjustment cost and monetary policy dampened the recovery process. It is important to note that this period in particular saw the emergence of stress in the banking sector. Policy initiatives like the asset quality review in 2014 led to the uncovering of deep structural problems in the banks’ balance sheets, which although beneficial in the long run, might have diminished the pace of recovery by constraining the supply of credit.

The period since 2018Q1 is characterised by a significant deceleration in economic activity, mainly contributed by weak demand conditions and unfavourable investment adjustment costs. In contrast to the earlier period, monetary policy shocks turned favourable in this period mitigating the drop in output gap. Overall, the results indicate that the economy was undergoing a slowdown even before the advent of COVID-19. The model ascribes this slowdown primarily to weak demand along with a rise in investment adjustment cost reflecting heightened stress in the investment and financial sector.

5.3. Inflation forecasting

This section focuses on the usefulness of the model-based output gaps in conducting monetary policy. Specifically, we evaluate whether the model-based output gaps are good indicators of inflationary pressures. Therefore, we assess the inflation forecast performance of various output gap estimates using the Phillips curve framework. As per the New Keynesian economic construct, output gap contains relevant information on inflationary pressures and therefore can be used for inflation forecasts.

We evaluate the predictability of inflation by comparing bivariate models of output gap and inflation with a univariate autoregressive (AR) model of inflation, following Coenen, Smets, and Vetlov (2009). The general specification of the bivariate model is as follows,

$$\pi_{t+h} = a + b(L)\pi_t + c(L).\text{OutputGap}_t + e_{t+h}$$

where \(\pi_{t+h}\) is the h-period ahead quarter-on-quarter CPI inflation, \(a\) is the constant term, and \(b(L)\) and \(c(L)\) are lag polynomials. Pa-

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\(^{18}\) The idea behind a historical decomposition is as follows. The model contains a variety of structural shocks. A historical decomposition recovers these shocks and shows the contribution of each to the evolution of output gap and other endogenous variables.
rameters are estimated by ordinary least squares on rolling sample from 1996Q3 to 2010Q1 through 1996Q3 to 2017Q1. We then calculate the root mean square forecast errors (RMSE) of the bivariate models and a univariate autoregressive model of inflation at forecast horizons (h) of one, four, and eight quarters ahead.

The results suggest that bivariate models outperform the univariate AR model in the case of gap from short-run efficient output (\(Y_{pgap}\)) across different horizons (Table 3). However, the bivariate model which includes the HP-filtered output gap performs worse than the AR model in the short to medium run, while the output gap based on long-run efficient output performs better than the AR model only in one quarter ahead forecast horizon.

In particular, \(Y_{pgap}\) (Model 1) beats all other measures of output gap at all forecast horizons, which justifies its theoretical construct. It also outperforms the univariate AR model. The gap from long-run efficient output (\(Y_{pgap}\), Model 1) comes second in terms of forecasting performance, particularly in the short to medium term. It outperforms AR model at one and four quarter ahead forecast horizons. The gap from the short-run efficient output in Model 2 performs better than the model with HP-filtered output gap at one and four quarter ahead forecast horizons, but performs worse than the AR model at all forecast horizons. The possible reason for this can be the misspecification that may have crept into, due to the inclusion of IST growth exogenously. The general superiority of our model-based gap measures over conventional counterparts like the HP-filtered gap stems from the fact that the latter are calculated without using the information on actual inflation.

6. Conclusion

In order to build a strong and sustainable recovery post the COVID-19 pandemic, we need to draw important observations from the growth experience of the past. In this context, the paper undertakes a historical exploration of India’s potential output and output gap estimates from the late-1990s till the advent of COVID emergency. In this regard, the objective of this paper is not confined to providing a specific number for the estimates of potential growth and output gap. Rather, it is to address a broader debate on finding out the possible drivers of fluctuations in output over the years. To this end, the paper employs a Bayesian-DGSE framework which not only allows for the dissection of economic activity into potential output and business cycle, but also decomposes the latter into a variety of economic frictions.

We find that the long-run efficient output is a better estimate of potential output as it conforms well with the traditional policymakers’ view which suggests that potential output is a long-run concept, driven mainly by permanent technological changes. According to this estimate, potential growth in India witnessed a sustained increase from 2002 to 2007, and remained subdued thereafter. A decomposition of potential growth into contributions from neutral, IST and population growth indicates that the contribution of population growth has been decreasing over the whole sample period. We also find that the sudden uptick (2002 onwards) in potential growth is mainly driven by neutral growth. On the other hand, IST growth appears to be following neutral growth. Moreover, IST growth has been moderating since 2013, which possibly reflects the deteriorating investment dynamics in the country. Since mid-2016, a combined deceleration in neutral and IST growth has steadily brought down the potential growth.

Similarly, we find a sharp downturn since 2018 in all measures of the output gap. By carrying out the historical decomposition of \(Y_{ngap}\) (Model 2), we find that weak demand and unfavourable investment-adjustment shocks are the main reasons pulling the business cycle down in the recent period. We also undertake an inflation forecasting exercise and find that the \(Y_{ngap}\) from Model 1 is a superior predictor of inflation than HP-filtered output gap and the baseline AR model at all horizons of 1, 4, and 8 quarters. To sum up, the high growth years of 2000s were accompanied by a combined pick up in potential growth and the business cycle. The growth deceleration thereafter (2011 to 2014) was mainly a cyclical slowdown, followed by a modest rise in growth from 2014 to 2018, again driven by an uptick in the cycle. On the other hand, the recent slowdown (since 2018) has been characterized by a combined downfall in the potential growth and business cycle. The policy agenda for post-COVID reconstruction should, therefore, include a mix of counter-cyclical stimulus as well as structural reforms.

Finally, we admit that there is enough scope to improve and expand this model to include more information about the variables and channels which affect both potential growth and the business cycle in India. For example, inclusion of informal (labour and production) sector is desirable as a large fraction of the labour force is informally employed. Castillo and Montoro (2010) showed that inclusion of informal sector in the model makes demand shocks more expansionary plus it weakens the interest rate channel of the monetary policy. Another area for further development can be the inclusion of sophisticated fiscal block along with credit-constrained consumers. The presence of credit constrained consumers raises the marginal propensity to consume in case of fiscally induced changes in the disposable income, thereby capturing the stabilisation role of fiscal policy more effectively. However, we leave these to future research efforts in this area.

Declarations of interest

None.

Data availability

Data will be made available on request.
Appendix A. Responses to structural shocks

See Chart A1, Chart A2, Chart A3, Chart A4, Chart A5, Chart A6.

Chart A1. Response of output, consumption, investment and employment to productivity shock.

Chart A2. Response to preference shock.
Chart A3. Response to fiscal shock.

Chart A4. Response to price markup shock.
Chart A5. Response to investment adjustment cost shock.

Chart A6. Response to monetary policy shock.
Appendix B. Estimated parameters under different model specifications

see Table B1,

Table B1
Comparison of Parameters Estimated using Models 1, 2 and 3.

| Parameter | Posterior mean |
|-----------|----------------|
|           | Model 1 (Uses $Y_{ngap}$ in Taylor rule) | Model 2 (Uses $Y_{pgap}$ in Taylor rule) | Model 3 (Uses $Y_{ngap}$ in Taylor rule) + IST shocks |
| $\vartheta$ | 0.6266 | 0.6253 | 0.6584 |
| $\phi$ | 2.7013 | 3.1324 | 2.1865 |
| $\alpha$ | 0.3592 | 0.3144 | 0.3376 |
| $h$ | 0.1330 | 0.1286 | 0.1444 |
| $\kappa$ | 14.0613 | 9.7292 | 25.9463 |
| $\phi_u$ | 0.5843 | 0.7127 | 1.5653 |
| $\phi_\pi$ | 1.5462 | 1.5669 | 1.5510 |
| $\phi_y$ | 0.6769 | 0.2707 | 0.6726 |
| $\phi_{\delta}$ | 0.0108 | 0.0126 | 0.0114 |
| $\beta_{\text{index}}$ | 0.2017 | 0.2572 | 0.2101 |
| $\rho_a$ | 0.3369 | 0.2622 | 0.3233 |
| $\rho_{\mu}$ | 0.9791 | 0.9790 | 0.9798 |
| $\rho_{\text{gz}}$ | NA | NA | 0.9783 |
| $\rho_{\text{pref}}$ | 0.5066 | 0.5622 | 0.3886 |
| $\rho_{\text{mc}}$ | 0.8087 | 0.8024 | 0.8130 |
| $\rho_{\gamma}$ | 0.3127 | 0.3475 | 0.4224 |
| $\rho_{\gamma}$ | 0.9275 | 0.9356 | 0.9375 |
| $\rho_{\text{adj}}$ | 0.2186 | 0.1755 | 0.3325 |
| $\rho_{\text{mp}}$ | 0.0102 | 0.0145 | 0.0107 |
| $\rho_{\text{mp}}$ | 0.0047 | 0.0047 | 0.0046 |
| $\rho_{\text{i}}$ | 0.001 | 0.0011 | 0.001 |
| $\rho_{\text{mc}}$ | NA | NA | 0.0003 |
| $\rho_{\gamma}$ | 0.1065 | 0.1061 | 0.1066 |
| $\rho_{\gamma}$ | 0.0094 | 0.0084 | 0.0089 |
| $\rho_{\text{adj}}$ | 0.0383 | 0.0394 | 0.0409 |
| $\rho_{\text{pref}}$ | 0.0269 | 0.0260 | 0.0252 |

Appendix C. Additional variance decomposition results

Table C1, Table C2.

Table C1
Variance decomposition from Model 2.

| T = 1 | Output growth | Inflation | Capacity Utilization | $Y_{ngap}$ | $Y_{pgap}$ |
|-------|---------------|-----------|----------------------|------------|------------|
| Short-term Productivity Shock | 5.72 | 25.45 | 33.97 | 50.87 | 5.77 |
| Monetary Policy Shock | 9.52 | 27.98 | 4.88 | 17.5 | 9.6 |
| Government Expenditure Shock | 28.56 | 0.14 | 9.82 | 0.65 | 28.8 |
| Long-term Productivity Shock | 1 | 1.64 | 1.29 | 0.28 | 0.15 |
| Price Markup (Supply) Shock | 6.39 | 29.4 | 3.17 | 11.75 | 6.45 |
| Investment Adjustment Cost Shock | 17.23 | 0.02 | 9.65 | 0.19 | 17.38 |
| Intertemporal Preference Shock | 31.58 | 15.37 | 37.22 | 18.76 | 31.85 |
| T = 100 | | | | | |
| Short-term Productivity Shock | 4.97 | 20.59 | 2.44 | 41.17 | 5.88 |
| Monetary Policy Shock | 9.51 | 29.69 | 0.44 | 16.83 | 4.91 |
| Government Expenditure Shock | 22.79 | 3.02 | 6.79 | 0.85 | 33.02 |
| Long-term Productivity Shock | 11.02 | 6.49 | 83.72 | 0.36 | 0.1 |
| Price Markup (Supply) Shock | 5.68 | 24.2 | 0.63 | 23.8 | 6.94 |
| Investment Adjustment Cost Shock | 12.97 | 2.14 | 2.37 | 0.3 | 32.33 |
| Intertemporal Preference Shock | 33.05 | 13.87 | 3.61 | 16.69 | 16.82 |
Appendix D. Diagnostic plots

See Chart D1, Chart D2, Chart D3, Chart D4, Chart D5, Chart D6, Chart D7.

### Table C2

Variance decomposition from Model 3.

|                      | Output growth | Inflation | Capacity Utilization | Yngap | Ypgap |
|----------------------|---------------|-----------|----------------------|-------|-------|
| **T = 1**            |               |           |                      |       |       |
| Short-term Productivity Shock | 4.1          | 5.54      | 16.5                 | 25.74 | 4.1   |
| Monetary Policy Shock  | 7.14          | 18.13     | 4.22                 | 18.95 | 7.14  |
| Government Expenditure Shock | 35.15      | 4.92      | 14.15                | 4.78  | 35.16 |
| Long-term Productivity Shock | 0.17        | 0.69      | 0.38                 | 0.29  | 0.11  |
| Price Markup (Supply) Shock | 4.51         | 55.17     | 2.37                 | 11.95 | 4.51  |
| Long-term IST shock    | 0             | 0.17      | 0.1                  | 0.07  | 0.03  |
| Investment Adjustment Cost Shock | 19.25   | 4.67      | 13.65                | 1.64  | 19.25 |
| Intertemporal Preference Shock | 29.69   | 10.7      | 48.62                | 36.59 | 29.7  |
| **T = 100**           |               |           |                      |       |       |
| Short-term Productivity Shock | 3.62        | 4.97      | 2.99                 | 18.6  | 2.39  |
| Monetary Policy Shock  | 7.17          | 20.19     | 0.99                 | 16.88 | 2.38  |
| Government Expenditure Shock | 29.13       | 6.59      | 9.21                 | 3.9   | 24.38 |
| Long-term Productivity Shock | 6.07         | 2.58      | 49.8                 | 0.44  | 0.06  |
| Price Markup (Supply) Shock | 4.49         | 47.44     | 1.75                 | 30.06 | 4.23  |
| Long-term IST shock    | 0.14          | 0.59      | 12.51                | 0.11  | 0.01  |
| Investment Adjustment Cost Shock | 14.67      | 8.01      | 12.88                | 2.39  | 57.81 |
| Intertemporal Preference Shock | 34.72    | 9.63      | 9.86                 | 27.63 | 8.74  |
Chart D2. Mode check plots.

Chart D3. Mode check plots.
Chart D4. Multivariate convergence plots.

Chart D5. Prior and posterior plots.
Chart D6. Prior and posterior plots.

Chart D7. Prior and posterior plots.
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