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Welfare costs of external shocks in the medium-scale model with shifting moderate trend inflation

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ABSTRACT

We aim at investigating welfare costs of shocks as well as dynamics of business and financial cycle due to these shocks. By using the theoretical model and parameters calibrated jointly to match the selected moments for the U.S. data during 1954Q3–2018Q4 period, our findings emphasise interaction between trend inflation and shocks. In the one side, welfare costs of these shocks in the Rotemberg model are modest but these costs increase when central banks raise their inflation targets to the higher level. Under impacts of these shocks, the economy gets more volatile reflected by higher dynamics of business and financial cycles. On the other hand, we investigate impacts of trend inflation on impulse response of key macroeconomic as well as financial variables to these shocks. In almost cases, these variables reacts more strongly to the shocks for higher trend inflation levels. Importantly, there are long-lasting debt response and short-lived equity response to unexpected changes in financial conditions.

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1. Introduction

During the time of recession, many economists held the consensus that the Federal Reserve sets inflation targets to 2 annualised per cent and they proposed that central banks should raise these targets in response to consequences of recession. For example, Blanchard et al. (2010), Ball (2013) and Krugman (2014) argue that the inflation target should be raised to 4 or even 5 annualised per cent. Trend inflation[1] can be simply regarded as implementing inflation targets over a sufficiently long time period, and increasing inflation targets as in such proposals eventually causes time-varying trend inflation or shifting trend inflation (Nakata, 2014). Moreover, the evidence on the time-varying property of trend inflation is also indicated by Levin and Piger (2003) and Ireland (2007). In fact, Ireland (2007) reports changes in trend inflation from 1959 (1.25%) to the late 1970s (8%) and in 2004 (2.5%). Proposals to increase the inflation target as well as empirical evidence by economists raise the concerns about: how the shifting moderate trend inflation affects the economy in term of

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the welfare and properties of business cycle? And what are the central bank's policies to manage their policies more effectively? By dealing with such question, our study provides new insights on the policy front to improve the efficiency of policy implementation of central banks.

In the literature, previous papers have mostly studied optimising behavior with an assumption of positive trend inflation but they have not paid enough attention to its time-varying property. Papers,[2] such as those by Kozicki and Tinsley (2001), Ireland (2007), Cogley and Sbordone (2008) and Cogley et al. (2009), have exploited implications of shifting trend inflation in distinct aspects of macroeconomic dynamics to show necessities of the research on this field. However, there have existed gaps in the literature. First, the previous works have so far employed the small-scale models with only one form of rigidities. Many crucial features, such as capital accumulation and real rigidities, are abstracted in these small-scale models. More importantly, other forms of nominal rigidities, which potentially play a vital role in transmitting adverse effects of constant and shifting moderate shifting trend inflation into the economy in term of welfare, have not been discussed. By incorporating both price and wage rigidities, Amano et al. (2009), Ascari et al. (2018) and Ha et al. (2019) show a significant welfare consequences of constant and shifting trend inflation as opposed to the modest numbers in the model with mere price rigidities (Ascari, 2004; Ascari & Ropele, 2009; Nakata, 2014). Moreover, Ha et al. (2019) emphasise the crucial role of the staggered wage channel in term of welfare costs in their study.

Second, to our best knowledge, previous studies have not investigated interactions between financial frictions and trend inflation. Theoretically, the efficiency of resource allocations in financial sector can be impacted by a sustained increase in inflation. Huybens and Smith (1998, 1999) discuss that credit market frictions with negative repercussions for financial sector performance can be adversely affected by a rise in inflation. More specifically, the increase in inflation rate leads to reduction in both real rate of money and assets, then signifies credit market frictions. This effect results in fewer loans, less efficient resource allocations, and a decline in intermediary activity and then capital investment. Both the long-run economic performance and equity market, as a consequence, are negatively affected (Choi et al., 1996; Huybens & Smith, 1999). Boyd et al. (2001) also argue that there is a nonlinear and negative relationship between inflation and banking sector development and equity market activity. Other authors also mention that the binding credit market frictions happen only when the inflation rate exceeds the threshold level (Azariadis & Smith, 1996; Choi et al., 1996). Therefore, the sustained inflation has adverse impacts on the financial sector. In term of welfare, there are few theoretical studies on a relationship between financial frictions and welfare. Obiols-Homs (2011) exploit welfare effects of exogenous borrowing limits. He argues that tight borrowing limits might adversely affect the welfare. He also shows that the welfare is displayed by a bell shaped function of the borrowing limits.

The present study, therefore, attempts to fill these gaps in the literature by expanding the medium-scale model developed by Christiano et al. (2005), Smets and Wouters (2007) and then Ascari et al. (2018) in the following dimensions. First, we incorporate the time-varying property of trend inflation by using a highly persistent shock to trend inflation that shares the similar spirit of Kozicki and Tinsley (2001), Ireland (2007) and Cogley et al. (2009). Second, we follow Born and Pfeifer (2018) to develop the model with a Rotemberg staggered price setting a Rotemberg staggered wage setting instead of the Calvo fashion as in the literature. Third, our model also allows for a roundabout production structure referred to as 'firm networking' by Christiano et al. (2016). In this structure, outputs of firms are regarded as a factor of production of another firm. Fourth, we consider investment shocks as a vital source of business cycle fluctuation as argued by Justiniano et al. (2011) instead of monetary and productivity shocks as in existing model with trend inflation. According to Justiniano et al. (2011), the process that investment goods are transformed into installed capital ready for production is affected by the marginal efficiency of investment (M.E.I.). Moreover, they also suggest that the financial system is important in this process. In particular, the ability to access credit and the efficiency that the financial system distribute that credit can impact the creation of productive capital. These findings implies that incorporating both M.E.I. shocks and the credit channel will be important to investigate welfare consequences of shifting trend inflation.

Hence, our model also features financial frictions and financial shocks in the form of credit constraints as in Jermann and Quadrini (2012). However, we differ to what extent that these constraints are assumed to be exogenous[3] which the firm's ability to borrow is completely subject to financial market's capacity, instead of endogenous constraint discussed in the work of Kiyotaki and Moore (1997), Bernanke and Gertler (1989), Mendoza and Smith (2006) and Mendoza (2010). More importantly, the exogenous credit constraints include trend inflation, suggesting that any change in a central bank's inflation targets also leads to changes in the financial conditions. In particular, changes in inflation targets cause a nominal price adjustment cost, and then credit constraints to fluctuate. These direct effects of trend inflation on the financial sector are defined as a 'staggered credit' channel in this study. With these extensions, we investigate the relationship between shifting trend inflation and economic welfare.

By using the theoretical model and parameters calibrated jointly to match the selected moments for the U.S. data during 1954Q3–2018Q4 period, we highlighted interactions between trend inflation and these shocks. In the one side, welfare costs of these shocks are modest but these costs increase when central banks raise their inflation targets to the higher levels. Under impacts of these shocks, the economy gets more volatile reflected by higher dynamics of business and financial cycles. Regarding shocks to trend inflation, their welfare costs in the model featuring Rotemberg setting are much smaller than those of model with Calvo setting. These modest welfare costs provide evidence supporting an argument of Kurmann (2005) that the Rotemberg setting might not be appropriate for welfare analysis. Moreover, the idea of intangible costs due to sticky wages is also examined in this article. More importantly, we also showed that the substitution level between debt and equity positively associates with the welfare costs of these shocks. Our model also predicts that there is no welfare consequence of financial shocks in the frictionless economy. The other striking finding is that welfare consequences of randomness in financial conditions are more serious in the economy in which firms base more on capital rather the intermediate inputs produced by other firms to produce goods and services.

On the other hand, we investigate impacts of trend inflation on impulse response of key macroeconomic as well as financial variables to these shocks. In almost cases, these variables reacts more strongly to the shocks for higher trend inflation level. The important findings come from response of debt and equity payout to financial shocks. Although both debt and equity payout increases corresponding to these financial shocks, the debt response is long-lasting for long forecast horizons, while the short-lived response of equity lasts for two forecast horizons.

The remainder of this article is organised as follows. The extended model is presented in the subsequent section. The related work is discussed in Section 2. Section 3 and 4 explains the method to compute welfare and welfare costs. Section 5 argues the parameterisation, and we use them to show the results in Section 6. Some conclusions and discussions are provided in Section 7.

2. Literature review

This article is mostly related to two strands of the literature. The first strand consists of studies incorporating the financial shocks and frictions into an estimated D.S.G.E. model, which has increasingly important to explain sources of fluctuations. Some first work starts by Kiyotaki and Moore (1997), Bernanke et al. (1996), Mendoza and Smith (2006), Mendoza (2010) which firm's ability to borrow is subjected to an endogenous collateral constraint. In this regard, firm's ability to borrow varies with changes of profitability due to the business cycle. Moreover, firm can lose borrowing constraints by over-accumulating capital and can partly determine the maximum amount of debt to borrow. Jermann and Quadrini (2012) apply the same approach but differ to what extent that they allow firms to use debt and equity payout to finance investment, and they allow for negative values of equity payout that permit firms to not limit to reinvest profits. Further, along with study of Benk et al. (2005), they also consider the financial shock originating from the financial sector to be a vital sources of business cycles and propagating other shocks. Their results indicate that the transmission mechanism of financial shocks on dynamics of real and financial variables is similar to the typical credit channel. The important role of the financial shock originating in the financial sector on the macroeconomic fluctuation is also emphasised by Christiano et al. (2008), Kiyotaki and Moore (2008) and Gilchrist et al. (2009). More recently, Hoang (2018) investigates employment and output influences of financial shocks. He develops a New Keynesian model incorporating financial frictions in the form of credit constraints and shows that the financial shock significantly affects output and employment variation. Ge et al. (2020) develop a D.S.G.E. model to uncover the transmission of diverse financial shocks. They show that there is an interaction between financial friction tied to banks and households over time. Furthermore, the financial shocks play a critical role on the dynamics of housing and macroeconomic variables. Furthermore, Kirchner (2020) employs financial frictions to capture the nonlinearities of the Great Financial Crisis. He considers the existence of shadow banking system as a type of these friction. In general, prior scholars have paid lots of attention to financial frictions and these frictions are captured in various forms.

The other strand is related to the model with shifting trend inflation. By employing the second perturbation approximation method suggested by Nakata (2014) attempts to quantify welfare consequences of shifting trend inflation. In his model, he argues that the negative impacts of exogenous variations in trend inflation are transmitted into the economy solely by the staggered price contracts. With this consideration, he shows trivial welfare costs of shifting trend inflation. In this article, we follow the similar approach as in Nakata (2014) to measure welfare consequences of shifting trend inflation. However, we add an additional channel that trend inflation distorts the relative allocation of labours across households throughout a staggered wage contract as discussed by Ascari et al. (2018), thus changes in welfare. They mostly concentrate on variations in the dynamics of the economy in response to the M.E.I. shocks due to a rise in trend inflation. In this study, they study the impulse response of key macroeconomic variables to these shocks in the model for a different level of trend inflation. Without considering two channels jointly, different conclusions could be drawn. Recently, Ha et al. have provided evidence to support the view that higher trend inflation signifies effects of policy risk on the economy. In particular, they use time-varying volatility shocks to capture monetary policy risk. These shocks then lead to fluctuations in the macroeconomy and large welfare costs, especially in the high-trend inflation economy.

3. Model

3.1. The household

Households maximise the expected discounted utility sum of future period utility

$$\sum_{t=0}^{\infty} \beta^t \left(\ln \left(C_t - \gamma C_{t-1} \right) - \frac{\omega}{1+\nu} N_{j,t}^{1+\nu} \right), \tag{1}$$

where C_t is consumption, and $N_{j,t}$ is the supply of labour. The parameters β and γ denotes the discount factor and the habit formation parameter, which are restricted as $0<\beta<1$, $0 \leq \gamma<1$ and υ is the inverse Frisch elasticity of labour supply.

The households budget constraint is given by:

$$P_t\{I_t + C_t + a(u_t)\bar{K}_t + T_t - d_t\} + \frac{B_{t+1}}{R_t} \leq W_{j,t}N_{j,t} + R_t^k u_t \bar{K}_t + \Pi_t + B_t, \tag{2}$$

where P_t is the nominal price of goods, I_t is investment, $\bar{K}_t$ is the physical capital stock, u_t is the level of capital utilisation, $W_{j,t}$ is the nominal wage received by the labour of type j, T_t is lump-sum taxes, B_t is holdings of government bonds, R_t is the gross nominal interest rate, d_t is the real dividends received from distinct intermediate-good producing firms at the end of period and Π_t is the per capita profit accruing to households from ownership of the firms.

By choosing the capital utilisation rate, u_t, installed physical capital is transformed into effective capital as given

$$K_t = u_t \bar{K}_{t-1}. \tag{3}$$

Firms then rent effective capital at the rate R_t^k. $a(u_t)\bar{K}_t$ denotes the dollar cost of capital utilisation per unit of physical capital. We make the assumption that $u_t = 1$ and a(1)=0 in the steady-state. The capital utilisation cost can be written as follows:

$$a(u_t) = \gamma_1(u_t - 1) + \frac{\gamma_2}{2}(u_t - 1)^2, \tag{4}$$

where parameters γ_1 and γ_2 are related to a resource cost of capital utilisation.

The equation representing an accumulation of physical capital is:

$$\bar{K}_{t+1} = (1 - \sigma)\bar{K}_t + \zeta_t \left\{ 1 - \frac{\kappa}{2}\left[\frac{I_t}{I_{t-1}} - 1\right]^2 \right\} I_t, \tag{5}$$

where σ and κ captures a depreciation rate and a cost to adjusting investment growth, respectively. The accumulation process described by Equation (5) is affected by the M.E.I. shock ζ_t. As in the literature, we assume that the M.E.I. shock follows a stationary AR(1) process with a mean zero normal distribution and standard deviation σ_ζ :

$$\ln(\zeta_t) = \rho_\zeta \ln(\zeta_{t-1}) + \epsilon_{\zeta,t}. \tag{6}$$

Firms are owned by a continuum of households indexed by $j \in [0, 1]$. Each household is a monopolistic supplier of specialised labour, $N_{j,t}$. A large number of competitive 'employment agencies' combines this specialised labour into a homogeneous labour input as given

$$N_t = \left[\int_0^1 N_{j,t}^{\frac{\theta_w - 1}{\theta_w}} dj\right]^{\frac{\theta_w}{\theta_w - 1}}, \tag{7}$$

where θ_w denotes the desired mark-up of the wage over the household's marginal rate of substitution. The labour demand function is obtained by solving a profit maximisation for the perfectly competitive employment agencies as given:

$$N_{j,t} = \left[\frac{W_{j,t}}{W_t}\right]^{-\theta_w} N_t, \tag{8}$$

Where employment agencies pay the wage, $W_t(j)$, to the supplier of labour of type j. The intermediate firms pay the wage, W_t to the supplier of homogeneous labour inputs that can be expressed as follows:

$$W_t = \left[\int_0^1 W_{j,t}^{1-\theta_w}\right]^{\frac{1}{1-\theta_w}}. \tag{9}$$

In term of wage setting, we follow Born and Pfeifer (2018) to set up the Rotemberg problem for households. In particular, a household j is selecting $W_{j,t}$ to maximise:

$$E_t \sum_{s=0}^{\infty} \eta_w^s \beta^s \left\{ -\omega \frac{N_{j,t+s}{}^{1+\nu}}{1+\nu} \right\}, \tag{10}$$

subject to the labour demand function:

$$N_{j,t} = \left[\frac{W_{j,t}}{W_t} \right]^{-\theta_w} N_t, \tag{11}$$

and subject to the budget constraint:

$$P_t C_{j,t} = W_{j,t} N_{j,t} - \frac{\phi_w}{2} \left[\frac{1}{\left(\pi_t{}^{\omega_w} \bar{\pi}_t{}^{1-\omega_w}\right)^{\rho_w}} \frac{W_{j,t}}{W_{j,t-1}} - 1 \right]^2 Y_t + M_t, \tag{12}$$

where ϕ_w denotes the Rotemberg wage adjustment cost parameter. The quadratic Rotemberg costs of adjusting the wage represented by the second-to-last term are proportional to the nominal output Y_t and depend on the indexed inflation rate, and especially on trend inflation level $\bar{\pi}_t$. Other terms not related to the current optimisation problem are captured by M_t. The associated F.O.C. after imposing symmetry can be written as

$$\begin{aligned} 0 = \omega \theta_w \frac{N^{1+\nu}}{w_t} + \lambda_t \Bigg\{ (1-\theta_w) N_t - \phi_w \left(\frac{\pi_t}{\left(\pi_{t-1}{}^{\omega_w} \bar{\pi}_t{}^{1-\omega_w}\right)^{\rho_w}} \frac{w_t}{w_{t-1}} - 1 \right) \frac{y_t \pi_t}{\left(\pi_t{}^{\omega_w} \bar{\pi}_t{}^{1-\omega_w}\right)^{\rho_w} w_{t-1}} \Bigg\} \\ + E_t \frac{\lambda_{t+1}}{w_t} \left\{ \phi_w \left(\frac{\pi_{t+1}}{\left(\pi_t{}^{\omega_w} \bar{\pi}_{t+1}{}^{1-\omega_w}\right)}^{\rho_w} \frac{w_{t+1}}{w_t} - 1 \right) \left(\frac{w_{t+1}}{w_t} \right) \left(\frac{\pi_{t+1} y_{t+1}}{\left(\pi_t{}^{\omega_w} \bar{\pi}_{t+1}{}^{1-\omega_w}\right)^{\rho_w}} \right) \right\} \end{aligned} \tag{13}$$

3.2. The final-goods producing firm

In each period t, perfectly competitive firms manufacture Y_t units of final consumption product by using $Y_{i,t}$ units of intermediate goods at the nominal price $P_{i,t}$ according to the constant-return-to-scale technology as follows:

$$\left[\int_0^1 Y_{i,t}^{\frac{\theta_p - 1}{\theta_p}} di \right]^{\frac{\theta_p}{\theta_p - 1}} = Y_t, \tag{14}$$

where θ_p denotes price elasticity of demand for intermediate goods. Profit maximisation and the zero profit condition imply the demand function of intermediate good i is given as:

$$Y_{i,t} = \left[\frac{P_{i,t}}{P_t}\right]^{-\theta_p} Y_t, \tag{15}$$

and that the price of the final good, P_t is a CES aggregate of the prices of the intermediate goods, $P_{i,t}$

$$P_t = \left[\int_0^1 P_{i,t}^{1-\theta_p} di\right]^{\frac{1}{1-\theta_p}}. \tag{16}$$

3.3. The intermediate-goods producing firm

Monopolistic firms produce the intermediate good i using the following production function:

$$Y_{i,t} = Z_t \Upsilon_{i,t}{}^{\varepsilon} (K_{i,t}{}^{\alpha} N_{i,t}{}^{1-\alpha})^{1-\varepsilon} - \Omega_t F, \tag{17}$$

where $K_{i,t}$ and $N_{i,t}$ denote the effective capital and labour input for the production good i. $\Upsilon_{i,t}$ is the amount of intermediate input, and $\varepsilon \in (0, 1)$ is the intermediate input share. Intermediate inputs come from aggregate gross output, Y_t. The production process requires a non-negative fixed cost, F, that is multiplied by Ω_t to keep profits zero along a balanced growth path as argued by Justiniano et al. (2010), Justiniano et al. (2011) and Ascari et al. (2018). Z_t is an exogenous stochastic process capturing the productivity effects. In particular, $\ln(Z_t)$ follows stationary AR(1) process:

$$\ln(Z_t) = \rho_Z \ln(Z_{t-1}) + \epsilon_{Z_t}, \tag{18}$$

where ϵ_{Z_t} is the serially uncorrelated innovation, which has a normal distribution with mean zero and standard deviation σ_Z.

We develop the model consisting of an intermediate-goods producing firm (i) with financial constraints. In particular, both equity and debt can be employed by firms as financial resources in this model. However, the debt is preferred to the equity as argued in the pecking order theory suggested by Myers (1984). Firms' equity payouts, (d_t), which are subject to a quadratic adjustment cost, are not perfectly substituted by debts, (b_t). Accordingly, the actual cost, $\Phi(d_{i,t})$ given the equity payout, $d_{i,t}$, is expressed as a sum of $d_{i,t}$ and the quadratic adjustment cost as given

$$\Phi(d_{i,t}) = d_{i,t} + \frac{\eta}{2}(d_{i,t} - d_i)^2, \tag{19}$$

where $\eta \geq 0$ captures the degree of rigidities representing the substitution level between equity and debt. Equity payouts can take either negative or positive values. Negative equity payouts imply an issuance of equity. As argued by Jermann and Quadrini (2012), firms enjoy tax benefits from the government from issuing one-period bonds. In particular, holders receive payments, $b_{i,t}$, from the type-i firm. This firm, then, makes decision on new debts, ($b_{i,t+1}$) at the beginning of each period t to receive $\left(\frac{b_{i,t+1}}{R_t}\right)$ from purchasers and $\left(\frac{b_{i,t+1}}{R_t^e} - \frac{b_{i,t+1}}{R_t}\right)$ from the government, where $R_t^e = R_t - \tau(R_t - 1)$ is the effective gross interest rate for the firms. τ is interpreted the tax benefit when issuing debt and $R_t^e = R_t$ when there is no tax benefit ($\tau = 0$).

Moreover, the intermediate goods are traded in the monopolistically competitive market, thus they are differentiated and are not perfect substitutions for another to produce the final goods. Therefore, the intermediate-goods producing firms set their own prices such that their demands are met at their predetermined price. And the firms' objectives are the same as households since they are owned by households. To pursue these objectives, the type-i firm makes a decision on the selling price, $(p_{i,t})$, labour demand, $(N_{i,t})$, equity payout, $(d_{i,t})$, and new debts, $(b_{i,t+1})$, subject to a quadratic adjustment cost at the beginning of period. The nominal price adjustment cost is presented as:

$$\chi(P_{i,t}, P_{i,t-1}) = \frac{\phi_p}{2}\left[\frac{P_{i,t}}{(\pi_{t-1}^{\omega_p}\bar{\pi}_t^{1-\omega_p})^{\rho}P_{i,t-1}} - 1\right]^2 Y_t, \tag{20}$$

where ϕ_p denotes the degree of price adjustment cost and $\bar{\pi}_t$ is trend inflation interpreted as central bank's implicit inflation target and private sector's long-run inflation expectation. We also assume that firms finance the total cost, including the wage bills, $(W_t N_t)$, the amount of intermediate input, $P_t \Upsilon_{i,t}$, the actual cost of equity payout, $(\Phi(d_{i,t}))$, matured intertemporal debts, $(b_{i,t})$, and the cost of nominal price adjustment, $(\chi(P_{i,t}, P_{i,t-1}))$ at the beginning of each period. Therefore, the exogenous credit constraint faced by firms can be written as:

$$f_t \geq \frac{W_t N_{i,t} + R_t^K K_t + P_t \Upsilon_{i,t} + b_{i,t} - \frac{b_{i,t+1}}{R_t^e}}{P_t} + \Phi(d_{i,t}) + \chi(P_{i,t}, P_{i,t-1}) + \frac{b_{i,t+1}}{P_t R_t}, \tag{21}$$

where f_t denotes the financial market condition. Notice that f_t behaves in the model as a shock due to randomness in the financial market's condition. These financial shocks follow a stationary stochastic process:

$$\ln(f_t) = (1-\rho_f)\ln(f) + \rho_f \ln(f_{t-1}) + \epsilon_{f_t}, \tag{22}$$

where $\rho_f \in [0,1)$, and f capture the shock persistence value and the steady-state value of the financial shock, respectively. ϵ_{f_t} is the serially uncorrelated innovation, which has a normal distribution with zero mean and standard deviation σ_f.

Moreover, we expand the model with an assumption that trend inflation $(\overline{\pi_t})$ participates in the model as a shock rather than a simple steady-state value. The evolution of trend inflation can be described as an AR(1) process to model the sustained rise in inflation as follow

$$\ln(\overline{\pi_t}) = (1-\rho_{\bar{\pi}})\ln(\bar{\pi}^*) + \rho_{\bar{\pi}}\ln(\bar{\pi}_{t-1}) + \epsilon_{\bar{\pi}_t}, \tag{23}$$

where $\rho_{\bar{\pi}} \in [0,1)$, and $\bar{\pi}^*$ are the shock persistence value and trend inflation, respectively. $\epsilon_{\bar{\pi}_t}$ is a standard normal and independent of time. Equation (20) indicates that as long as there are changes in the inflation targets, the nominal price adjustment cost, and then the credit constraint fluctuates accordingly.

3.4. Authority's policy

3.4.1. Monetary policy

We modify the standard Taylor rule (1993) as below:

$$\frac{R_t}{\bar{R}_t} = (R_{t-1}\bar{R})^{\rho_R}\left[(\frac{\pi_t}{\bar{\pi}_t})^{\phi_\pi}(y_t\bar{y})^{\phi_y}\right]^{1-\rho_R} \exp\left(\epsilon_{R_t}\right), \tag{24}$$

where $y_t = \frac{Y_t}{Z_t}$, $\bar{R}, \bar{y}$ are the steady state of R_t and Y_t, respectively. The parameter ρ_R illustrates the degree of interest rate smoothing, and ϕ_π and ϕ_y are respectively Taylor coefficient on inflation and output gap. ϵ_{R_t} is an i.i.d monetary policy shock.

3.4.2. Fiscal policy

The government finances its expenditures, (G_t), purchased final goods at the nominal price, (P_t), and to subsidise the intermediate-goods producing firm by using a lump-sum tax collected from the household. Hence the government's budget constraint is written as:

$$P_tG_t + b_{t+1}\left(\frac{1}{R_t^e} - \frac{1}{R_t}\right) = T_t. \tag{25}$$

Let g_t denote the government spending growth, and then the government spending is a fraction of aggregate output:

$$G_t = \left(1 - \frac{1}{g_t}\right)Y_t, \tag{26}$$

where the logarithm of g_t participates in the model as an AR(1) process:

$$\ln\left(g_{t+1}\right) = (1-\rho_g)\ln\left(\bar{g}\right) + \rho_g \ln\left(g_t\right) + \epsilon_{g_t}, \tag{27}$$

where $(1-1\bar{g})$ is the value of government spending relative to output in the steady state, ρ_g is the government shock persistence. $\epsilon_{g,t}$ is the government spending shock with zero mean and standard deviation σ_g.

3.5. Market clearing condition

The market clearing condition in the labour market can be expressed as:

$$N_t = \int N_t(i)di. \tag{28}$$

The condition in model is given:

$$Y_t = C_t + \frac{\phi_p}{2}\left[\frac{P_{i,t}}{(\pi_{t-1}^{\omega_p}\bar{\pi}_t^{1-\omega_p})^{\rho_p}P_{i,t-1}} - 1\right]^2 Y_t + I_t + a(u_t)\bar{K}_t + G_t, \tag{29}$$

where the second term is the aggregate price adjustment cost. Finally, the zero net supply of bond is described as:

$$B_t = 0. \tag{30}$$

4. Welfare and welfare cost computation

In the similar spirit in the literature, we employ the second-order Taylor expansion of the household's utility function around the deterministic steady-state to decompose the welfare into the different components as given:

$$\begin{aligned} E\left[\sum_{t=0}^{\infty}\beta^t u(x_t)\right] &\approx \sum_{t=0}^{\infty}\beta^t u(\bar{x}) + \sum_{t=0}^{\infty}\beta^t Mu(\bar{x})E[x_t - \bar{x}] + \sum_{t=0}^{\infty}\beta^t Nu(\bar{x})E[(x_t - \bar{x})\otimes(x_t - \bar{x})] \\ &= U_d + U_l + U_v, \end{aligned}$$

where $x_t = [C_t, C_{t-1}, H_t]$; and $Mu(\bar{x})$ and $Nu(\bar{x})$ are vector which contain the first and second derivative of u(.) evaluated at $\bar{x}$ which are the deterministic steady state of x_t. Therefore, the welfare can be decomposed into three components: the deterministic component, $U_d = \sum_{t=0}^{\infty}\beta^t u(\bar{x})$, the level component, $U_l = \sum_{t=0}^{\infty}\beta^t Mu(\bar{x})E[x_t - \bar{x}]$, and the volatility component, $U_v = \sum_{t=0}^{\infty}\beta^t Nu(\bar{x})E[(x_t - \bar{x})\otimes(x_t - \bar{x})]$. U_d depends on the deterministic steady-state $(\bar{x})$, U_l depends on the mean of x_t, and U_v depends on the volatility of x_t.

The present study defines the welfare cost as compensating variation in consumption that enhances the welfare of a typical household in one economy to make them as well-off as others in another economy. Mathematically, wc can be represented as:

$$E\left[\sum_{t=0}^{\infty}\beta^t u\left(\left(1+\frac{wc}{100}\right)C_{A,t}, \left(1+\frac{wc}{100}\right)C_{A,t-1}, H_{A,t}\right)\right] = E\left[\sum_{t=0}^{\infty}\beta^t u(C_{B,t}, C_{B,t-1}, H_{B,t})\right], \tag{31}$$

where $C_{A,t}, H_{A,t}$ are consumption and labour supply in the economy with $\sigma_{\bar{\pi}} > 0$ and $C_{B,t}, H_{B,t}$, are in economy with $\sigma_{\bar{\pi}} = 0$.

5. Calibration

Table A1 reports parameter values used to investigate cyclical and welfare implications of constant and shifting trend inflation in the following step. The set of model parameters is separated into two subsets. The first subset include parameters that take conventional values in the literature or we can directly compute them without solving the model. The conventional values includes the discount factor ($\beta = 0.99$), the inverse Frisch elasticity ($\upsilon = 1$), labour supply disutility ($\omega = 1$). We follow Ascari et al. (2018) to set the value for the share of capital services (α) to $\frac{1}{3}$. The cost share of intermediate input, ϵ, is set at 0.55 which multiplies the weighted average revenue share of intermediate input in the private sector of U.S. in 2002 that is 51% by the markup. We follow Christiano et al. (2005), Justiniano et al. (2010) and Ascari et al. (2018) to set the value of the depreciation rate on physical capital (σ) and the investment adjustment cost (κ) to 0.025 and 3, respectively. Based on estimation of Justiniano et al. (2010, 2011), γ_1 is the steady state utilisation that takes value of 1 and γ_5 is five time γ_1.

In this article, we permit imperfect indexation and shifting trend inflation in the model as in Cogley et al. (2009). Hence, the degree of price (ρ_p) and wage (ρ_w) indexation that take value of 0.00 and the weight on lagged inflation (ω_p and ω_w) that take value of 1.00. Regarding the financial sector, we also follow Jermann and Quadrini (2012), to set the tax advantage, τ, and the substitution level between equity and debt, η, to 0.35 and 0.42, respectively. As in Justiniano and Primiceri (2008), we set the values for parameters related to persistence level and standard deviation of some structural shocks, such as the government expenditure shock ($\rho_g = 0.98, \sigma_g = \frac{0.25}{100}$). Furthermore, some parameter values are calibrated using the standard calibration technique based on the steady-state values. In particular, the steady-state inflation ($\bar{\pi}^*$), the steady-state share of government expenditure ($1-1\bar{g}$), the steady-state debt–output ratio are respectively 1.006, $\frac{1}{1-0.34}$, and 0.41.

The second subset includes the remaining parameters that are calibrated jointly to match selected moments for the U.S. during 1954Q3–2018Q4 period. There are six moments, including the consumption volatility (σ_C), the volatility of output (σ_Y), the volatility of labour (σ_N), the volatility of debt (σ_b), a correlation between output and consumption ($\rho(Y, C)$), and a correlation between output and labour ($\rho(Y, N)$). These moments are important for the subsequent welfare analysis because they closely reflect the dynamic behavior of consumption, labour supply and debt. We adapt the moment matching approach as Ha et al. (2019) to pin down the values for remaining parameters in the second subset. In particular, the persistence level and volatility level of other structural shocks are reported in detail in Table A1. We concentrate more likely to the M.E.I. shocks, financial shocks, and shocks to trend inflation. The coefficients representing the persistence level and volatility level of M.E.I. shocks are respectively 0.90 and 0.013 that are slightly higher than Justiniano et al. (2011). Since there is less compelling evidence on the persistence of the M.E.I. shocks (Ascari et al., 2018), we will adjust these parameter values pertaining M.E.I. shocks to assess sensitivity of our results. Regarding financial shocks, the AR(1) and standard deviation coefficient are 0.93 and 0.036 that are quite similar to the result adapting Bayesian method by Hoang (2018). We also obtain the parameters pertaining to shifting trend inflation shocks ($\rho_{\bar{\pi}} = 0.995$ and $\sigma_{\bar{\pi}} = \frac{0.1}{100}$) that aligned with those of Cogley et al. (2009). Three parameter in Taylor rule such that ρ_R, ϕ_π and ϕ_y are calibrated at 0.83, 1.06 and 0.09.

Regarding Rotemberg price and wage setting, we follow Ascari et al. (2018) and Ha et al. (2019) to set the similar values to parameters of these settings. Accordingly,

Table 1. Moments.

	σ_C	σ_Y	σ_N	σ_b	$\rho(Y, C)$	$\rho(Y, N)$
Data	0.007	0.011	0.02	0.028	0.84	0.86
Calibration	0.004	0.013	0.05	0.024	0.82	0.86

Note: Moments in the second row are obtained from HP-filtered U.S. data (1984Q1–2018Q4). The last row is the moments from simulations for the calibrated model.
Source: Authors' calculations.

both price and wage elasticity of substitution, θ_p and θ_w, are calibrated at 2.80 and both degree of price and wage adjustment costs are calibrated at 3.7. Our article is the first that incorporates both Rotemberg price and wage setting in addition to many other features to the model with shifting trend inflation. To investigate impacts of parameters related to these settings, we also use an alternative set of parameter values and then perform the same exercise to observe changes in the further analysis.

Table 1 represents moments generated by the calibrated model and moments computed from the HP-filtered U.S. data during 1954Q3–2018Q4 period. By comparing the second row and third row of Table 1, we emphasise that the key features of data are captured remarkably well by the calibrated model. Our model does a very good job for matching the selected moments. Hence, the proposed model can be served as a pertinent laboratory to explore cyclical and welfare implications of constant and shifting trend inflation.

6. Results

This section represent welfare costs of structural shocks, including shocks to trend inflation, M.E.I. shocks, and financial shocks. We firstly show these costs and dynamics of business cycles due to these shocks. We also conduct the further sensitivity analysis to observe their responses to changes in relevant parameters.

6.1. Welfare costs of shocks to trend inflation

6.1.1. Results

In our model incorporating Rotemberg price and wage setting, trend inflation acts as a shock that impacts the welfare, business and financial cycles of an economy. Table 2 reports the welfare costs as well as changes in business and financial cycle when central banks set the inflation target level to 2 annualised per cent and 4 annualised per cent, respectively. In the case that central banks set their inflation target to 2%, the persistent trend inflation shocks create an insignificant welfare cost, which is 0.05%. This reduction in welfare mainly comes from a reduction of volatility component, while we observe a modest change in the level component and the unchanged deterministic steady-state component. When the central banks raise their inflation target from 2% to 4%, these costs increase slightly. Our results are aligned with Nakata (2014) that also use the Rotemberg setting to measure welfare costs of shifting trend inflation. By comparing the results of welfare costs of shifting trend inflation in the model using the Calvo price setting such as Ha et al. (2019) and the Rotemberg price setting as in this study, the costs in the former is higher than those in the latter.[4] This smaller costs of shifting trend inflation in the model featuring

Table 2. Welfare costs of shocks to trend inflation: Rotemberg setting.

	$\bar{\pi}^* = 1.02^{0.25}$		$\bar{\pi}^* = 1.04^{0.25}$	
	$\sigma_{\bar{\pi}} = 0$	$\sigma_{\bar{\pi}} > 0$	$\sigma_{\bar{\pi}} = 0$	$\sigma_{\bar{\pi}} > 0$
Welfare cost		0.050%		0.051%
Welfare	−495.74	−495.86	−496.55	−496.67
U_d	−466.49	−466.49	−466.99	−466.99
U_l	−27.47	−27.48	−27.76	−27.77
U_v	−1.77	−1.88	−1.79	−1.91
Business cycles				
E(C)(*)	−0.011	−0.011	−0.011	−0.011
E(H)(*)	0.011	0.011	0.011	0.011
$100\sigma_C$	0.10	0.10	0.10	0.10
$100\sigma_H$	11.1	11.1	11.1	11.1
Financial cycles				
E(b)(*)	0.0207	0.0207	0.0208	0.0208
E(d)(*)	0.0004	0.0003	−0.0014	−0.0015
$100\sigma_b$	0.96	0.97	0.96	0.96
$100\sigma_d$	1.73	1.73	1.74	1.74

Note: b and d denote debt and equity payout. (*) expressed as percentage deviation from the deterministic steady-state. U_d, U_l and U_v are the deterministic steady-state, level and volatility component, respectively.
Source: Authors' calculations.

Rotemberg setting comes from the situation which one believes that the inefficient allocations of resources because of price dispersion rather than the physical adjustment costs of changing prices causes the welfare costs (Kurmann, 2005). We recommend that the Rotemberg setting might not be appropriate for welfare analysis pertaining shocks to trend inflation. In this study, we provide more evidence to advocate this discussion in term of welfare costs of shifting trend inflation.

The insignificant welfare costs shape business cycle and financial dynamics. The shocks to trend inflation cause a very small change in the average level and volatility level of consumption, working hours, debt and equity payout. The detailed results of computation indicate a reduction in both consumption and leisure that provide evidence on the source of welfare costs from the view of business cycle. Regarding the financial cycles, we observe a rise in the debt level, while the equity payout tends to diminish. Due to the shocks, the economy gets more volatile which is reflected by a rise in the standard deviation of all variables. Our findings provide explanations for the sources of welfare reduction due to the shocks to trend inflation from the view of business cycles and financial cycles.

6.1.2. Sensitivity analysis

In the following exercise, we investigate how welfare costs response to changes in relevant parameter. Figures A1, A2, and A4 depict these results. In the traditional analysis, we consider changes in parameters that are directly related to these shocks, including the level of trend inflation, the persistence and volatility level of shocks as in Figure A1. The increase in these parameters are positively associated with welfare costs of shocks to trend inflation. Specifically, the higher level of trend inflation leads to a higher cost of shifting trend inflation. More importantly, an increase in the persistence level and volatility level of shocks cause these costs to rise nonlinearly. That implies a given amount of increase in these parameters produce more serious welfare consequences to the economy.

Figure A2 illustrate the results examining the sensitivity of welfare consequence to changes in parameters governing pricing environment and wage environment (the right figures of Figure A2). The left figures of Figure A2 show how welfare costs behave corresponding to an increase of the price elasticity of demand for intermediate goods, the degree of price indexation and the rigidities of price adjustment. The larger welfare costs are attributed to an increase in the price elasticity of demand for intermediate goods and he rigidities of price adjustment as well as a reduction in the degree of price indexation. Intuitively, a higher level of substitution elasticity cause price to increase since there are more inefficient allocations among firms. Price indexation plays a crucial role in explaining welfare costs of shifting trend inflation. For a given trend inflation level, the adjustment costs (represented by Equation (20)) fall with respect to an increase in the price indexation. As a consequence, there is a lower costs of adjusting price (Ascari & Ropele, 2009). By allowing the price indexation, the effects of an increase trend inflation on the costs of adjusting prices, which lead to the rising wedge between consumption and output, can be mitigated. In a particular case of full indexation ($\rho_p = 0$). Therefore, the higher level of price indexation leads to reduction of welfare consequences. Regarding the price rigidity (φ_p), Rotemberg (1987) argues that the negative effects of prices changes on the customer-firm relationship can be accounted by the adjustment costs. Since trend inflation causes the adjustment costs to be higher. It implies that the source of inefficiency in the high-trend-inflation economy is the physical costs. If the firms revises their prices (φ_p increases), the welfare costs also increase.

The right figures of Figure A2 represent movements in welfare consequences with respect to changes in parameter controlling the wage environment. The explanation for the price elasticity of demand for intermediate goods can be applied to the degree of substitutability between diverse genres of labours (θ_w). In this study, we also observe the same effects of change in degree of wage indexation and rigidities of wage adjustment on welfare costs of shifting trend inflation. In this model, the introduction of sticky wage is considered as an intangible costs to changing nominal wage in term of lost income (De Paoli et al., 2010). When households bargain the wage, they experience the reduction of income since the time lost which cannot be used to supply labour. This costs are explained by a lower income in the budget constraint. The intangible costs causes households to make decisions based on lower income. Since experience the lower income, they are more likely to invest less in the other assets like bond, debt. As a consequence, both debt and equity diminish corresponding to a rise in trend inflation. Figure A3 depicts trends of steady-state variables when there is an increase in trend inflation level that support our discussion.

In other exercise, we also investigate how welfare costs of shifting trend inflation are sensitive to substitutability between debt and equity. Shocks to trend inflation affect the output and employment. In the case that firm cannot lower their debt, they must cut their employment. We contend that welfare costs of shifting trend inflation depend on the ability that firm can substitute debt by equity payout. Our model predicts that if debt are not perfectly substituted by equity payout ($\eta>0$), shifting trend inflation cause changes in financial conditions. As a consequence, consumption[5] and employment, and then welfare are affected.

6.2. Welfare costs of M.E.I. shocks

6.2.1. Results

This section discusses impacts of trend inflation on welfare costs of M.E.I. shocks. Although the interaction between trend inflation and M.E.I. shock is previously examined by Ascari et al. (2018), they focus only on the impulse response of macroeconomic variables to M.E.I. shocks. To our knowledge, there is no paper investigating this relationship in term of welfare consequences. Therefore, this article fill this gap in the literature. What is more, Justiniano et al. (2010, 2011) consider M.E.I. shocks as the important sources of business cycle dynamics, M.E.I. shocks might be also the shocks to the functioning of financial sectors. Therefore, we also reports dynamics of business and financial cycles under impacts of M.E.I. shocks.

Table 3 reports welfare costs of M.E.I. shock as well as changes in business and financial cycle when central banks sets the inflation target to 2 annualised per cent and 4 annualised per cent. We firstly focus on the 2%-trend-inflation economy. The welfare costs of M.E.I. shock in this economy is 0.102%, which mainly come from reduction in the level and volatility component, while the deterministic steady-state component is unchanged. Accordingly, these shocks lower the average levels of consumption and working hours, while driving their volatility up. Regarding dynamics of financial markets, we observe the opposite trends happening for the debt and equity payout. While a rise in the average levels of debt and a fall in those of equity payout are observed, the financial markets get more volatile reflected by an increase in their standard deviation. M.E.I. shocks are basically aggregate demand shocks that increase current demand for goods relative to supply. When the central banks raise their inflation targets to 4%, the more significant impacts of these shock on the properties of business and financial cycles, thus causing more welfare costs (0.107%). As argued by Ascari et al. (2018), a higher trend inflation level leads to a flatten Phillips curve, therefore positive M.E.I. shocks impacts more significantly on these variables.

Table 3. Welfare costs of M.E.I. shocks.

	$\bar{\pi}^* = 1.02^{0.25}$		$\bar{\pi}^* = 1.04^{0.25}$	
	$\sigma_{\bar{\pi}} = 0$	$\sigma_{\bar{\pi}} > 0$	$\sigma_{\bar{\pi}} = 0$	$\sigma_{\bar{\pi}} > 0$
Welfare cost		0.102%		0.107%
Welfare	−495.62	−495.86	−496.42	−496.67
U_d	−466.49	−466.49	−466.99	−466.99
U_l	−27.32	−27.48	−27.60	−27.76
U_v	−1.79	−1.88	−1.82	−1.91
Business cycles				
E(C)(*)	−0.0118	−0.0119	−0.0119	−0.0119
E(H)(*)	0.0117	0.0116	0.0108	0.0108
$100\sigma_C$	0.12	0.12	0.12	0.12
$100\sigma_H$	11.17	11.19	11.03	11.05
Financial cycles				
E(b)(*)	0.0206	0.0207	0.0206	0.0208
E(d)(*)	0.0003	0.0003	−0.0014	−0.0015
$100\sigma_b$	0.96	0.97	0.96	0.96
$100\sigma_d$	1.73	1.73	1.74	1.74

Note: b and d denote debt and equity payout. (*) expressed as percentage deviation from the deterministic steady-state. U_d, U_l and U_v are the deterministic steady-state, level and volatility component, respectively.
Source: Authors' calculations.

6.2.2. Sensitivity analysis

To explore more about welfare costs of M.E.I. shocks, we perform the further analysis that observe dynamics of these costs due to changes in relevant parameters as in Figure A5. Firstly, we support our aforementioned argument by illustrating changes in welfare with respect to changes in trend inflation levels. We confirm that the higher level of trend inflation leads to a more significant welfare cost. Additionally, we also adjust the persistence and volatility level of M.E.I. shocks to observe the sensitivity of these shocks. The more persistent and volatile shocks produce more welfare costs. The more striking results are all relationship are non-linear. That implies a given amount of increase in the level of persistence and volatility leads to greater welfare consequences.

6.3. Welfare costs of financial shocks

6.3.1. Results

This section illustrates welfare costs of financial shocks corresponding to the cases that central banks set 2 annualised per cent and 4 annualised per cent trend inflation. Table 4 reports the results. Unexpected changes in financial conditions produce modest welfare costs (0.0086%) in our model. The diminish in welfare stems from a reduction in the level and volatility component. Dynamics of cycles, especially in financial markets. Table 4 represent changes in mean values and standard deviation of debt and equity payout. Due to the financial shocks, the mean value of debt and equity payout increases, while the standard deviation of these financial variables increase considerably. The results suggest that if there are unexpected changes in financial condition, the financial markets get much more volatile. Raising inflation targets then slightly magnifies impacts of shocks on the economy to produce slightly higher welfare consequences.

Table 4. Welfare costs of financial shocks.

	$\bar{\pi}^* = 1.02^{0.25}$		$\bar{\pi}^* = 1.04^{0.25}$	
	$\sigma_{\bar{\pi}} = 0$	$\sigma_{\bar{\pi}} > 0$	$\sigma_{\bar{\pi}} = 0$	$\sigma_{\bar{\pi}} > 0$
Welfare cost		0.0086%		0.0088%
Welfare	−495.84	−495.86	−496.65	−496.67
U_d	−466.49	−466.49	−466.99	−466.99
U_l	−27.46	−27.48	−27.74	−27.76
U_v	−1.88	−1.89	−1.90	−1.91
Business cycles				
E(C)(*)	−0.0119	−0.0119	−0.0119	−0.0119
E(H)(*)	0.0116	0.0116	0.0108	0.0108
$100\sigma_C$	0.12	0.12	0.12	0.12
$100\sigma_H$	11.19	11.19	11.04	11.05
Financial cycles				
E(b)(*)	0.0205	0.0207	0.0206	0.0208
E(d)(*)	0.0003	0.0003	−0.0015	−0.0015
$100\sigma_b$	0.33	0.97	0.33	0.96
$100\sigma_d$	1.50	1.73	1.52	1.74

Note: b and d denote debt and equity payout. (*) expressed as percentage deviation from the deterministic steady-state. U_d, U_l and U_v are the deterministic steady-state, level and volatility component, respectively.
Source: Authors' calculations.

6.3.2. Sensitivity analysis

Similarly to other shocks, we also provide results on sensitivity analysis which illustrates how welfare costs of financial shocks behave with respect to changes in relevant parameters. Figure A6 depicts the traditional work that is about effects of trend inflation, the persistence and volatility level of financial shocks. It can be seen that an increase in these parameters cause welfare costs of financial shocks to non-linearly rise. In other words, the consequences of unexpected changes in financial condition become more severe if these parameters take higher values.

Subsequently, we also reports the response of these costs to changes in capital share (α), intermediate input share (ϵ), tax benefit (τ) and rigidities of equity payout adjustment (η) as in Figure A7. The top panel of Figure A7 uncovers a striking finding that an improvement of welfare costs of financial shocks are attributed to an increase in capital share and a decrease in intermediate input share. In other words, the welfare consequences of randomness in financial conditions are more serious in the economy in which firms base more on capital rather the intermediate inputs produced by other firms to produce goods and services. Furthermore, we also positive impacts of tax benefit on the welfare consequences of financial shocks as shown on the bottom left panel of Figure A7. The higher tax benefit means that firm enjoy more benefits from government when issuing one-period bond or debt that reduce welfare consequences of unexpected changes in financial conditions. Finally, the substitution level between debt and equity positively associates with the welfare costs of financial shocks. Intuitively, financial frictions are greatly determined by this substitution level. Our model anticipates that there is no welfare consequence in the frictionless economy ($\eta = 0$) since debt adjustments triggered by financial shocks can be quickly accommodated by the equity of firms. Firms readjust fund resources slowly because the substitution between debt and equity are more costly (η increases). As a result, the financial shocks distort the economy more remarkably. This findings are consistent with Jermann and Quadrini (2012). In our study, we provide more intuitions in term of welfare analysis. More importantly, our result indicates that this relationship is nonlinear that implies that a given amount of increase in substitution level between debt and equity leads to more serious problems, especially when η takes the high values.

7. Cyclical effects of trend inflation

This section investigates on impacts of trend inflation on impulse response of key macroeconomic as well as financial variables to shocks to trend inflation, M.E.I. shocks, and financial shocks. Figures 1–3 plot response of output, inflation, debt, and equity to these three shocks in the economy setting three diverse levels of trend inflation. The solid black lines, the blue dashed lines, and dotted red lines corresponds to the case of 0%, 2% and 4% trend inflation, respectively.

The responses of variables to shifting trend inflation are shown in Figure 1. The shocks to trend inflation distort the macroeconomy by negatively affecting the output and positively affecting inflation. The lower level of output and the higher level of inflation are results of these shocks. These results are consistent with Ha et al.

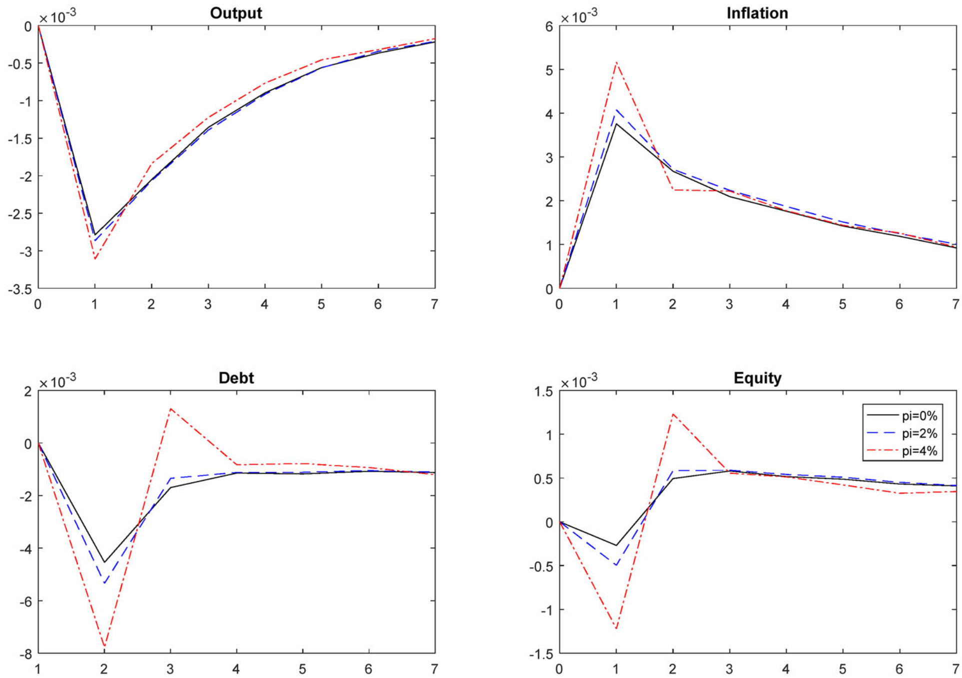

Figure 1. Trend inflation and impulse responses to shocks to trend inflation.
Source: Authors' calculations.

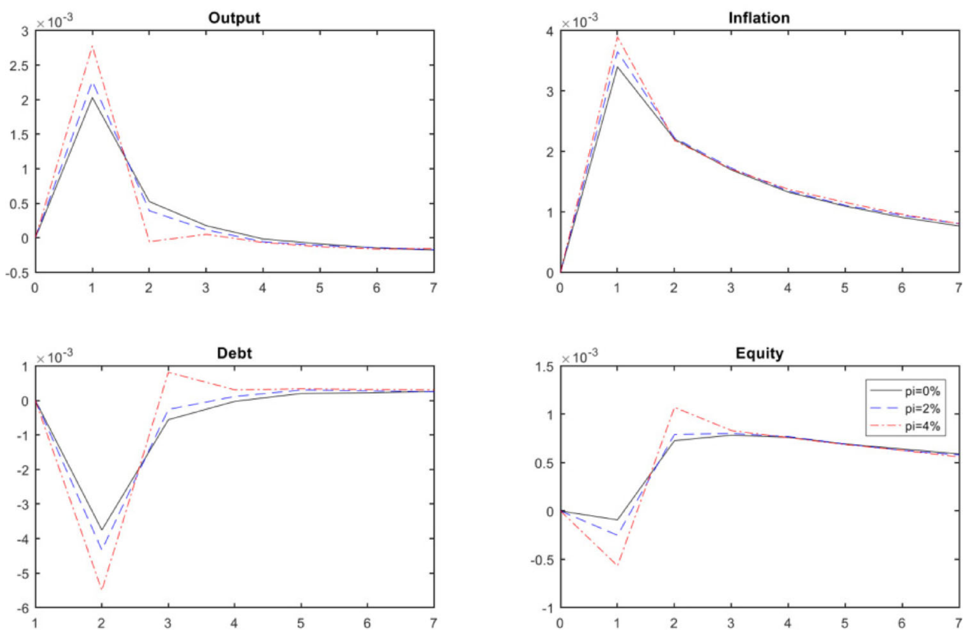

Figure 2. Trend inflation and impulse responses to M.E.I. shocks.
Source: Authors' calculations.

(2020a). Regarding the financial markets, these shocks lead to an immediate increase following a reduction of debt and a fall in equity payout. We also observe an effect of trend inflation on the response of these variables to shocks to trend inflation.

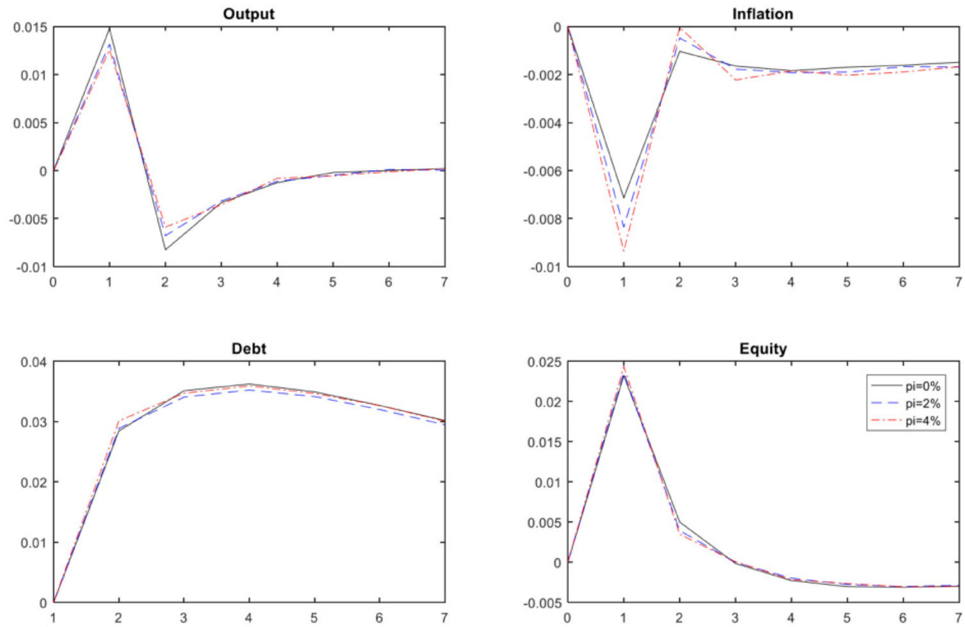

Figure 3. Trend inflation and impulse responses to financial shocks.
Source: Authors' calculations.

Specifically, there is slightly higher responses of output, while those effects of shocks on inflation, debt and equity response are stronger when central banks set a higher level of inflation target. The effects of trend inflation on almost variables' response are relatively remarkable.

We focus more on the Figure 2 depicting response of variables to M.E.I. shocks. Visually, we also observe interactions of trend inflation and impulse responses to M.E.I. shock. Both output and inflation respond in the same way to the M.E.I. shocks.[6] The similar can be found in Justiniano et al. (2010, 2011) and Ascari et al. (2018). The difference is that output response experience the immediate impacts that last for two-period forecast horizons, while the inflation response tends to last for longer forecast horizon as shown in the tope panel of Figure 2. Under impacts of M.E.I. shocks, output reacts more strongly to the M.E.I. shocks for higher trend inflation level, whereas it is quite unnoticeable for inflation response.

This article also provides more empirical evidence on response of financial variables to M.E.I. shocks in the model featuring diverse levels of trend inflation. Both debt and equity payout decline with respect to M.E.I. shocks but the effect on debt is stronger than those on equity payout. Moreover, the equity response is just immediate that revert to increase after that. For higher levels of trend inflation, the debt and equity response are significantly greater. In general, the higher levels of trend inflation magnify impacts of shocks on the macroeconomic and financial variable considerably.

Our main concern is also about the response of macroeconomic and financial variables to financial shocks as well as interaction between trend inflation and these responses. Figure 3 demonstrates response of these variables to financial shocks. A rise in output and a fall in inflation stem from unexpected changes in financial conditions. Both responses are short-lived that last for one or two forecast horizons. There is not much an impact of trend inflation on responses of output but quite significant an effect of those on response of inflation to financial shocks. The important findings come from response of debt and equity payout to financial shocks. Although both debt and equity payout increases corresponding to these financial shocks, the debt response is long-lasting for long forecast horizons, while the short-lived response of equity last for two forecast horizons. What is more, these financial variables reacts almost the same for higher levels of trend inflation. We still find the interaction between trend inflation and impulse response of these variables to financial shocks but the relationship seems to be negligible.

8. Conclusion

This study developed the medium scale D.S.G.E. model featuring the time-varying trend inflation, the Rotemberg price and wage setting, the roundabout production, the M.E.I. shocks, and the financial frictions in the form of credit constraint. This article aimed at investigating welfare costs of three shocks, including shocks to trend inflation, M.E.I. shocks, financial shocks as well as business and financial cycle dynamics due to these shocks. Our findings emphasised interaction between trend inflation and these shocks. In the one side, welfare costs of these shocks are modest but these costs tend to increase when central banks raise their inflation targets to the higher levels. Under impacts of these shocks, the economy gets more volatile reflected by higher dynamics of business and financial cycles. Regarding shocks to trend inflation, their welfare costs in the model featuring Rotemberg setting are much smaller than those of model with Calvo setting. These modest welfare costs provide evidence supporting an argument of Kurmann (2005) that the Rotemberg setting might not be appropriate for welfare analysis. Moreover, the idea of intangible costs due to sticky wages is also examined in this article. More importantly, we also showed that the substitution level between debt and equity positively associates with the welfare costs of these shocks. Our model also predicts that there is no welfare consequence of financial shocks in the frictionless economy. The other striking finding is that welfare consequences of randomness in financial conditions are more serious in the economy in which firms base more on capital rather the intermediate inputs produced by other firms to produce goods and services.

In the other side, we investigate impacts of trend inflation on impulse response of key macroeconomic as well as financial variables to these shocks. In almost cases, these variables reacts more strongly to the shocks for higher trend inflation levels. The important findings come from response of debt and equity payout to financial shocks. Although both debt and equity payout increases corresponding to these financial shocks, the debt response is long-lasting for long forecast horizons, while the short-lived response of equity lasts for two forecast horizons.

Notes

1. In the literature, we formally define trend inflation as central bank's implicit inflation target and private sector's long-run inflation expectation.

2. To model a sustained increase of inflation, they use a highly persistent shock to trend inflation, regarded as the central bank's slowly-moving implicit inflation targets.
3. The endogenous constraint in these studies, however, still needs to be discussed. First, Jermann and Quadrini (2012) show that the value of capital, the discounted value of the interperiod debt and financial shocks determine the value of the intraperiod loan firms. Therefore, the credit constraint can be loosed or tightened by financial shocks or others that affect the value of capital, the discounted value of the interperiod debt. Further, Kocherlakota (2000) suggests that the effects of financial shocks could be potentially magnified when considering an endogenous credit constraint, whereas the exogenous credit constraint does not.
4. Ha et al. (2019) develop the model featuring the Calvo price and wage setting to measure the welfare costs of shifting trend inflation. They show that the welfare costs are roughly 0.6%
5. Hoang (2018) also provides a similar argument over this issue.
6. The M.E.I. shocks are an demand shocks that drive present demand for goods relative to supply, then raising output and inflation in the similar direction (Justiniano et al., 2010).

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix

A. Variable and parameter

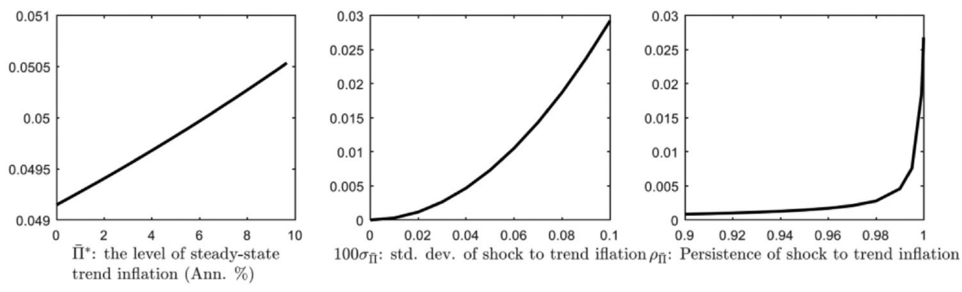

Figure A1. Welfare costs of shifting trend inflation: trend inflation level and properties of shock.

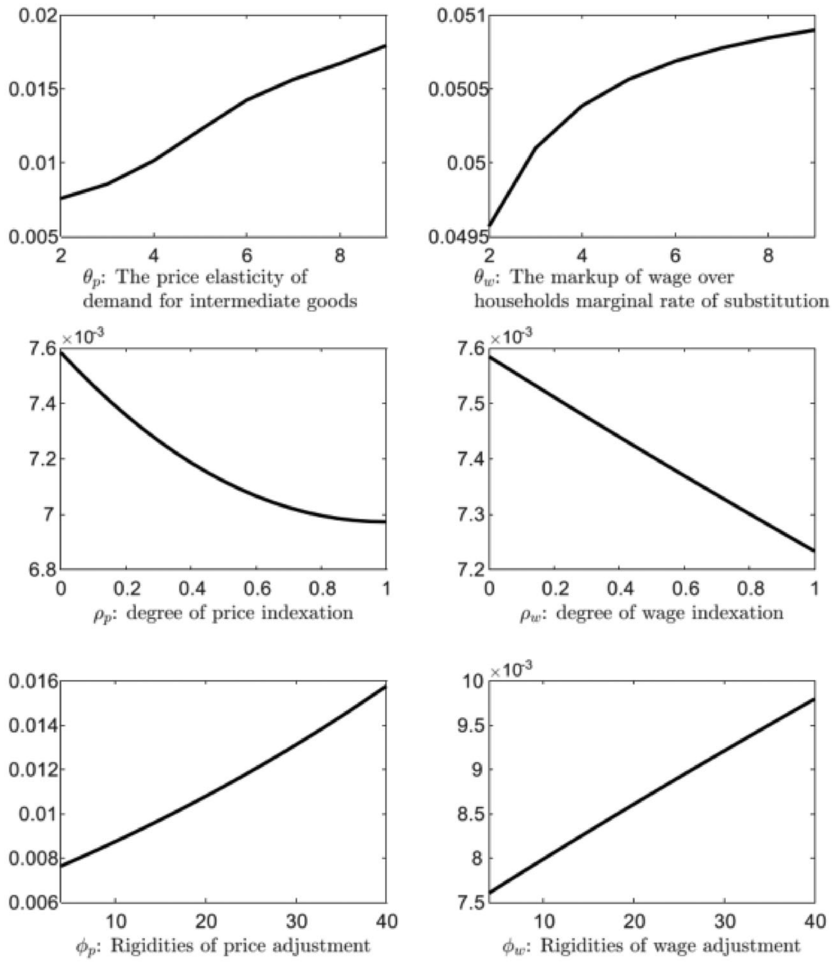

Figure A2. Welfare costs of shifting trend inflation: parameters controlling price and wage environment.

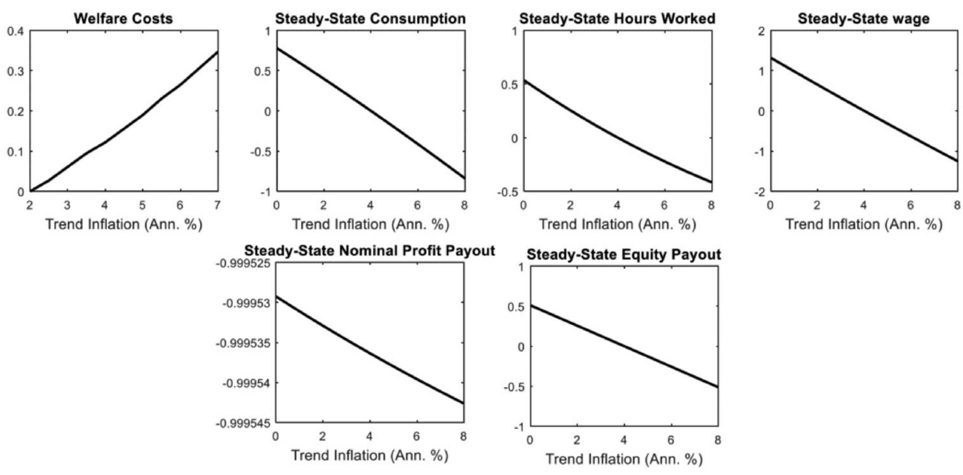

Figure A3. Trend inflation versus steady-state variables.

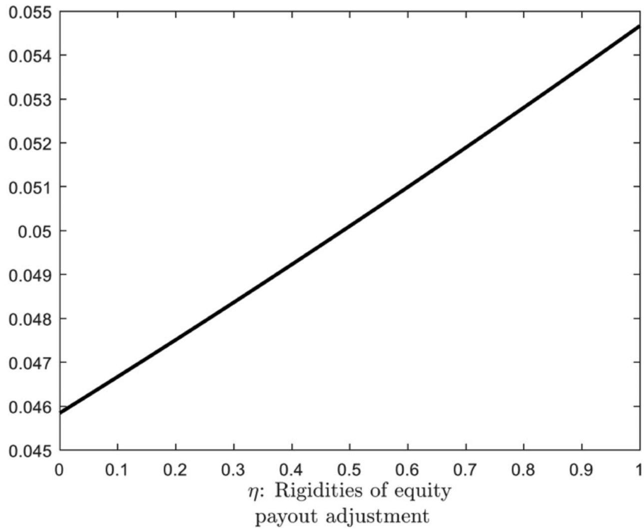

Figure A4. Welfare costs of shifting trend inflation: rigidities of equity payout adjustment.

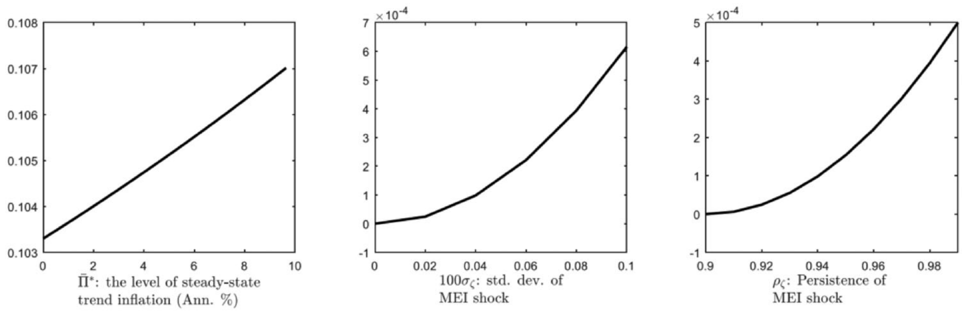

Figure A5. Welfare costs of MEI shocks: trend inflation level and properties of shock.

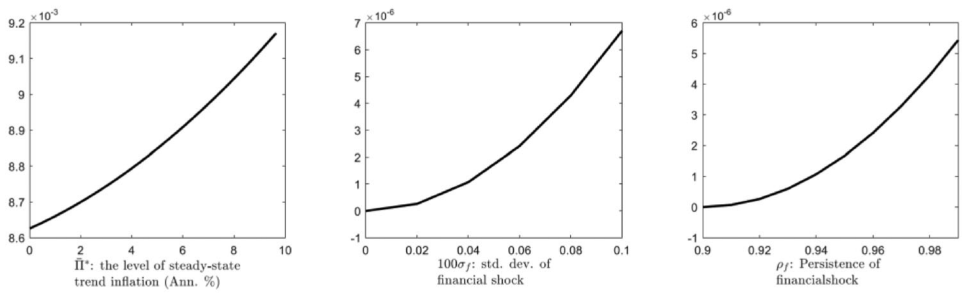

Figure A6. Welfare costs of fiscal shocks: trend inflation level and properties of shock.

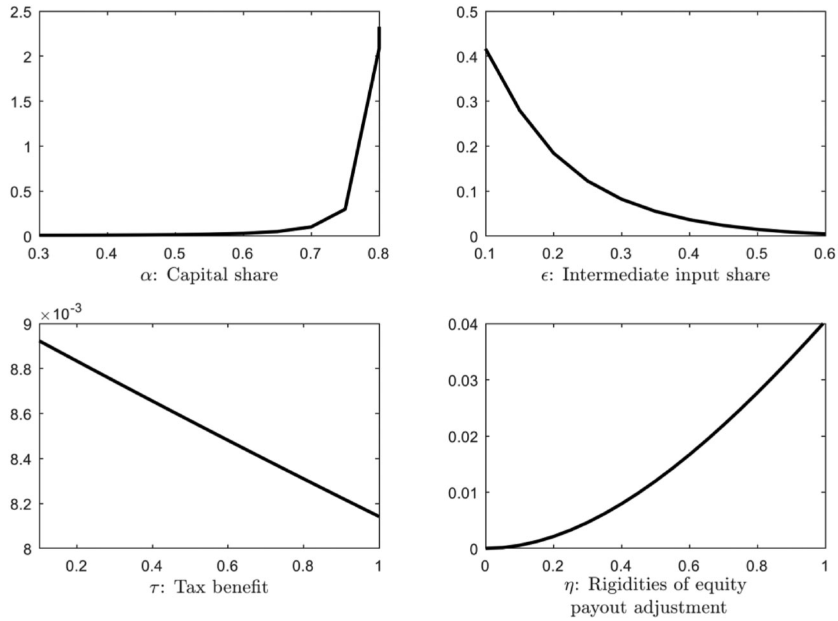

Figure A7. Welfare costs of fiscal shocks: others.

Table A1. Calibration.

Parameter	Description	Calibrated value
β	Discount factor	0.99
h	Consumption habit	0.71
ω	Labour supply disutility	1.00
υ	Inverse Frisch elasticity of labour supply	1.00
η	Substitution level between equity and debt	0.42
τ	Tax advantage	0.35
boy	Debt–output ratio	0.41
$1-\bar{g}^{-1}$	Steady state share of Government expenditure	$1/(1-0.3410)$
σ	Depreciation rate on physical capital	0.025
κ	Investment adjustment cost	3.00
α	Share of capital services	0.33
ϵ	Cost share of intermediate inputs	0.55
γ_1	Steady state utilisation	1
γ_2	$\gamma_2 = 5 * \gamma_1$	5
ρ_Z	AR(1) coefficient for technology shock	0.65
ρ_g	AR(1) coefficient for government spending shock	0.98
ρ_f	AR(1) coefficient for financial shock	0.93
ρ_ζ	AR(1) coefficient for MEI shock	0.90
$100\sigma_Z$	Standard deviation of technology shock	1.10
$100\sigma_g$	Standard deviation of government spending shock	0.25
$100\sigma_f$	Standard deviation of financial shock	3.60
$100\sigma_\zeta$	Standard deviation of MEI shock	1.30
Rotemberg price setting		
θ_P	Price elasticity	2.80
ϕ_P	Degree of price adjustment cost	3.70
ρ_P	Degree of price indexation	0.00
ω_P	Weight on lagged inflation	1.00
Rotemberg wage setting		
θ_W	Wage elasticity	2.80
ϕ_W	Degree of wage adjustment cost	3.70
ρ_W	Degree of wage indexation	0.00
ω_W	Weight on lagged inflation	1.00
Monetary policy		
ϕ_π	Taylor coefficient on the inflation gap	1.06
ϕ_y	Taylor coefficient on the output gap	0.09
ρ_R	AR(1) coefficient for monetary shock	0.83
$100\sigma_R$	Standard deviation of monetary shock	0.25
Shifting trend inflation		
$\bar{\pi}^*$	Steady-state level of trend inflation	$[1.00^{0.25}\ldots 1.06^{0.25}]$
$\rho_{\bar{\pi}}$	Persistence level of shocks to trend inflation	$[0.99\ldots\mathbf{0.995}\ldots 0.9999]$
$100\sigma_{\bar{\pi}}$	Standard deviation level of shocks to trend inflation	[0.1,**0.075**,0.05,0.025,0]