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Hysteresis and fiscal stimulus in a recession

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ABSTRACT

The COVID-19 pandemic initiated a deep global recession, and with interest rates at very low levels, warrants consideration of the efficacy of different forms of fiscal stimulus in response. History reveals that deep recessions may cause output and total factor productivity (TFP) hysteresis, a permanent or highly persistent fall in the levels of output and TFP relative to pre-recession trends. This article analyses the output and welfare multipliers of fiscal stimulus during a recession using a macro model with TFP and output hysteresis. We find that transfer payments, public consumption and investment all have high output and welfare multipliers due to their positive effects on TFP in a recessionary environment. However, public investment has the highest output and welfare multipliers, because it has a more positive impact on labour productivity due to the increase in the public capital stock.

1. Introduction

The COVID-19 pandemic and associated lockdown measures and physical restrictions resulted in a deep global recession. The world economy is likely to recover as soon as the pandemic is over, and economic growth will likely run above recent averages for some time. However, the history of recessions suggests that they also result in output hysteresis, a permanent or highly persistent fall in the level of output relative to pre-recession trend (Ball 2014, Cerra and Saxena 2017, Cerra et. al. 2021, Martin et al. 2015; Rawdanowicz et al. 2014). The IMF (2020a) and Federal Reserve chair Powell (2020) argue that the COVID-19 recession is also likely to be associated with output hysteresis. Powell (2020) noted that "the coronavirus crisis raises longer-term concerns as well. The record shows that deeper and longer recessions can leave behind lasting damage to the productive capacity of the economy".

An important implication of hysteresis is that the welfare costs of recessions can be very large (Cerra et al. 2021; Tervala 2021). Therefore, macroeconomic policy should respond strongly to recessions. A deep recession, when interest rates are at very low levels, implies a need to closely consider the case for fiscal stimulus. The IMF (2020b) argue that accommodative fiscal policy is required to "sustain the recovery and to limit long-term scarring [hysteresis]". In addition, Powell (2020) has also called for fiscal stimulus: "Additional fiscal support could be costly, but worth it if it helps avoid long-term economic damage and leaves us with a stronger recovery."

Recent contributions to the theoretical and empirical literature on fiscal output multipliers have focussed on two related questions: (i) the relative efficacy of particular fiscal instruments (e.g. Ganelli and Tervala 2020; Sims and Wolff 2018) and (ii) the size of related output multipliers in recessions versus in normal times (e.g. Auerbach and Gorodnichenko 2012,

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Gechert and Rannenberg 2018; Ramey and Zubairy 2018). There has also been an active debate concerning the most effective fiscal instruments to stimulate the economy in the wake of a global pandemic (Coates and Helm 2020, Furman 2020, IMF 2020b, Krugman 2020, Saez and Zucman 2020). In this paper, we analyse the output and welfare consequences of a debt-financed rise in public transfers, consumption and investment in the case where COVID-19 causes a deep recession, interest rates are effectively driven to zero and are at very low levels over the simulation period, and the recession causes persistent damage to the level of potential output. The main contribution of the paper is to incorporate hysteresis via a learning-by-doing mechanism, and investigate how hysteresis effects related to the effect of recessions on human capital formation influence multiplier size.

We develop a two-region dynamic stochastic general equilibrium (DSGE) model to address the output and welfare effects of fiscal stimulus. The regions represent Australia, a small open economy, and the rest of the world. Hysteresis is an essential feature of our model. Jordà et al. (2020) found empirically that temporary demand shocks (monetary in their case) can have persistent effects on total factor productivity (TFP) and output, but not on employment. They argue these findings have important implications for how we think about standard models of business cycles, as they are unable to capture these dynamics. We assume that there is learning-by-doing in production, which generates a link between short-term fluctuations and potential output following Engler and Tervala (2018). In this framework, recessions reduce employment and the stock of human capital, resulting in a persistent reduction in TFP and potential output. Furceri at al. (2021) found that a decline in output of 10 percent is associated with a 4.2% fall in cyclically adjusted TFP. That is, the ratio of the peak fall in TFP to that of output is 0.42. In our model, the ratio is 0.45 indicating that our model generates an empirically plausible link between recessions and TFP. The degree of output hysteresis is defined as the negative effect of the drop in GDP in 2020 on potential output in 2024. In our model, the degree of hysteresis is 0.3 in the baseline case. Kienzler and Schmid (2014) argued the plausible degree of hysteresis is in the range of 0.2 to 0.3. Our model features a plausible link between recessions and potential output, unlike most models used to analyse the consequences of fiscal stimulus during recessions.

IMF (2020a) observed that the COVID-19 recession has resulted from a combination of government lockdowns and voluntary social distancing measures. In our model, the COVID-19 recession is primarily driven by a real time preference shock whereby consumers would prefer to defer consumption and labour supply until after the pandemic has passed. In addition, we assume a cost-push shock, which can be interpreted as supply chain complications and negative effects on firm productivity triggered by COVID-19 restrictions. This helps replicate the modest fall in inflation in 2020 relative to declines in output. We also assume that interest rates are driven to zero in the early stage of the recession, and increase only very gradually over the simulation period. Our policy experiment involves analysing deficit-financed increases in public transfers, consumption and investment. We assume a fiscal policy rule where the government gradually increases taxes over time in reaction to higher public debt.

Fig. 1 compares the results of our model simulation for Australian GDP to the most recent IMF forecasts (IMF, 2021), and the last IMF forecasts before the pandemic (IMF 2019). The difference between the IMF's (2019) and (2021) forecasts imply that the COVID-19 recession causes output hysteresis, which is to say that the level of GDP will not recover to a level implied by its pre-recession trend during the forecast period. Our model measures the response of variables relative to the initial steady state and the response of output should be interpreted as output's deviation from pre-recession trend. We set the

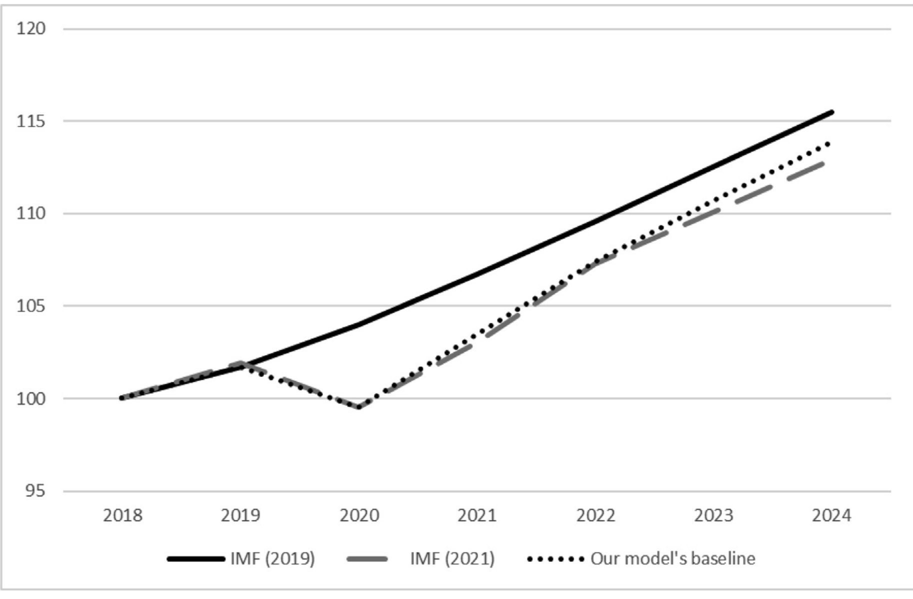

Fig. 1. Forecasted Evolution of GDP in Australia (index, 2018 = 100). Sources: IMF (2019), IMF (2019), own calculations.

sizes of the preference and cost-push shocks such that the deviation of output from pre-recession trend matches with the observation in 2020. Fig. 1 shows that the model's baseline prediction of the behaviour of GDP in 2021–2024, the grey dotted line, is roughly in line with the IMF's (2021) forecast. Actually, our model predicts that the degree of hysteresis is slightly smaller than the forecasts of IMF (2019 & 2021) imply.

Furman (2020) argued that public transfers have played an important role in supporting household consumption and the recovery. We find that the cumulative output multiplier of targeted transfers paid to liquidity constrained households over 20 periods is around one. Our result is in the middle of the meta-analysis estimates of Gechert (2015) and Gechert and Rannenberg (2018). A deficit-financed increase in transfers increases short-term output and employment, relative to the baseline case. The learning-by-doing process implies a persistent rise in TFP and output. Therefore, the output multiplier is higher than in the absence of hysteresis. However, the employment effect is short-lived consistent with Jordà et al. (2020). The consequences of fiscal policy are consistent with the empirical results in Fatás and Summers (2018) and Fatás (2019), who find permanent output effects associated with fiscal policy. Bardaka et al. (2021) find that fiscal policy affects TFP in both the short and long term.

Saez and Zucman (2020) argue that in the context of the COVID-19 pandemic governments should act as 'buyers of last resort'. Our finding is that the cumulative output multiplier of public consumption over 20 periods is 1.4, higher than that of public transfers. The output multiplier for transfers is smaller because only non-Ricardian households benefit from transfer payments, and transfer payments do not increase firm specific human capital to the same degree as public investment and consumption. A meta-survey of the literature from Gechert and Rannenberg (2018) found a cumulative output multiplier of public consumption during recessions of around 1.6. Our result is in line with this.

We show that the welfare effects of transfers are positive in the COVID-19 recession. The welfare multiplier of transfers, defined as the consumption equivalent change in the present discounted value of utility for a one unit rise in transfer spending, is 0.5. A high output multiplier implies a persistent rise in private consumption. This increases welfare. The welfare multiplier of public consumption is 0.5. A high output multiplier and the direct welfare benefits associated with public consumption increase welfare. The welfare multiplier of consumption spending is similar to that of public transfers despite the higher output multiplier, because public consumption is assumed to yield less utility than private consumption. The positive welfare multiplier is line with Watson and Tervala (2021), who analyse the welfare multiplier of public consumption using a model with TFP hysteresis in the context of the Global Financial Crisis (GFC). Rendahl (2016) found that the welfare multiplier can be positive in the presence of *employment* hysteresis. Our finding strengthens the view that the welfare multiplier of public consumption is positive in the presence of *output* hysteresis.

IMF (2020b) and Krugman (2020) argue that public investment is an effective stimulus tool in response to a pandemic-induced economic crisis. Our findings provide theoretical support for this view. A rise in public investment spending causes a similar short-term demand effect as public consumption. On one hand, the positive effect on TFP via the learning-by-doing process is somewhat weaker than in the case of a public consumption shock because of a somewhat weaker employment effect. On the other hand, a rise in the public capital stock has a stronger effect on labour productivity, which implies a higher output effect in the longer-term. In our model, the cumulative output multiplier of public investment is 2.2. This is consistent with Gechert and Rannenberg (2018) who find a cumulative output multiplier of public investment of 2.3 during recession or crisis regimes in a meta-analysis of the recent literature.

Existing theoretical studies of public investment ignore the possibility of hysteresis. Sims and Wolff (2018) and Ganelli and Tervala (2020) found the short-term output multiplier of public investment without hysteresis is 0.9–1.5. Our baseline output multiplier is higher and consistent with empirical estimates showing high multipliers in a recessionary environment (Gechert and Rannenberg 2018). The findings give support for the views of IMF (2020b) and Powell (2020) that fiscal stimulus would help limit the long-term damage of the COVID-19 recession and support the recovery. A rise in public investment would yield substantial and long-lived benefits to output, although the employment benefits are relatively smaller and short-lived, consistent with the empirical evidence of Buchheim and Watzinger (2017).

We find that the welfare multiplier of public investment is 1.6, roughly three times larger than that of transfers and consumption. Public investment is a better tool for fiscal stimulus in a recession than transfers and public consumption spending also from welfare point of view. A rise in welfare is induced by a rise in private consumption. Sims and Wolff (2018) found the welfare multiplier of public investment without hysteresis is only 0.3. Ganelli and Tervala (2018) highlight that the key parameters are the efficiency of public investment (the fraction of public investment that translates into the effective public capital stock) and the productivity and depreciation rate of public capital. We can use the same main parameterization as in Sims and Wolff (2018). In the absence of hysteresis, we find that the welfare multiplier is 0.22, which is fully consistent with the results of Ganelli and Tervala (2020). The difference to Sims and Wolff (2018) is caused by our model's open economy dimension: a large fraction of gains leak abroad. In the presence of hysteresis, and utilising the proposed parameterization of Sims and Wolff (2018), we find that the welfare multiplier is 0.84. The differences in results relative to Sims and Wolff (2018) can be attributed to the presence of hysteresis and the fact that we use a higher value of the productivity of public capital and a lower value of the depreciation rate. Ganelli and Tervala (2020) found the welfare multiplier can be sizable even without hysteresis. However, they found that the welfare multiplier can turn negative when the efficiency of public investment and the output elasticity of public capital are both low. Our study shows that in the presence of hysteresis, the welfare multiplier of public investment is positive and higher than that of transfers and public consumption, even if investment efficiency and the output elasticity of public capital are both low.

Section 2 introduces the model and Section 3 its parameterization. Section 4 investigates the output and welfare consequences of fiscal stimulus during the COVID-19 recession. Section 5 does robustness checks. Section 6 draws conclusions from the findings.

2. Model

The world economy has two regions: home and foreign. We normalized the world population to one. A continuum of firms and households are indexed by $z \in [0,1]$. A fraction n (*1-n*) of households and firms are domestic (foreign). We discuss the features of the home economy. The equations describing the foreign economy are identical to the domestic ones, unless they are shown.

2.1. Households

Following Galí et al. (2007), a fraction λ of households are non-Ricardian, and do not smooth consumption over time. This implies that public debt matters for the efficacy of fiscal stimulus. Non-Ricardian households earn income from labour and have no residual rights to firm profits. A fraction 1-λ of households are Ricardian who smooth consumption over time and own domestic firms. We assume that transfer payments are targeted to non-Ricardian households. The 'N' ('R') subscript denotes non-Ricardian (Ricardian) households. The utility function of both types of households is given by

$$U_t = E_t \sum_{s=t}^{\infty} \beta^{s-t} \epsilon_s^P \left[logC_{i,s} - \frac{(l_{i,s}(z))^{1+\frac{1}{v}}}{1+\frac{1}{v}} + \vartheta logG_{i,s}^C \right], \tag{1}$$

where $i = N, R$, E_t denotes the expectations operator, β denotes the discount factor, ϵ_t^P is a time preference, $C_{i,t}$ denotes private consumption, $l_t(z)$ denotes the labour supply of the household z, v is the Frisch elasticity of labor supply, G_t^C denotes a public consumption index, and ϑ is the subjective weight of public consumption relative to private consumption in household utility. Aggregate private consumption (C_t) is made up of the consumption of non-Ricardian households, denoted by $C_{N,t}$, and the consumption of Ricardian households, denoted by $C_{R,t}$, as follows: $C_t = \lambda C_{N,t} + (1-\lambda)C_{R,t}$. The same logic applies to government consumption. Aggregate labour supply (l_t) is $l_t = \lambda l_{N,t} + (1-\lambda)l_{R,t}$.

The private consumption index is

$$C_{i,t} = \left[n\alpha^{\frac{1}{\rho}} \left(C_t^h \right)^{\frac{\rho-1}{1}} + (1-n\alpha)^{\frac{1}{\rho}} \left(C_t^f \right)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}$$

where $i = N, R$ and $C_{i,t}^h$ and $C_{i,t}^f$ are an indexes of domestically and foreign produced goods, $n\alpha$ is the share of domestic goods in the consumption basket ($\alpha > 1$ captures the degree of home bias in consumption and $0 < n\alpha < 1$) and $\rho > 0$ denotes the Armington elasticity, the elasticity of substitution between domestic and foreign goods. The public consumption index is similar to the private consumption one. In addition, an analogous index represents public infrastructure spending. C_t^h and C_t^f are consumption indexes defined as follows

$$C_t^h = \left[n^{-\frac{1}{\theta}} \int_0^n \left(c_t^h(z) \right)^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}}, C_t^f = \left[(1-n)^{-\frac{1}{\theta}} \int_n^1 \left(c_t^f(z) \right)^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}}$$

where $i = N, R$ and $c_t^h(z)$ and $(c_t^f(z))$ are the consumption of differentiated domestic and foreign good z, and $\theta > 1$ stands for the elasticity of substitution between two goods produced in the same region. The foreign private consumption index is

$$C_{i,t}^* = \left[n\alpha^{*\frac{1}{\rho}} \left(C_{i,t}^{*h} \right)^{\frac{\rho-1}{\rho}} + (1-n\alpha^*)^{\frac{1}{\rho}} \left(C_{i,t}^{*f} \right)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}$$

where $i = N, R$, asterisks indicate the foreign economy and $n\alpha^*$ $(0 < n\alpha^* < 1)$ denotes the share of domestic goods in foreign consumption. Home bias in consumption requires $\alpha^* < 1$.

The private demand functions (the public demand functions are identical) of the domestic and foreign goods by domestic and foreign households are

$$c_t^h(z) = \left[\frac{p_t^h(z)}{P_t^h} \right]^{-\theta} \left[\frac{P_t^h}{P_t} \right]^{-\rho} \alpha C_t, c_t^f(z) = \left[\frac{p_t^f(z)}{P_t^f} \right]^{-\theta} \left[\frac{P_t^f}{P_t} \right]^{-\rho} \left(\frac{1-n\alpha}{1-n} \right) C_t$$

$$c_t^{*h}(z) = \left[\frac{p_t^{*h}(z)}{P_t^{*h}} \right]^{-\theta} \left[\frac{P_t^{*h}}{P_t} \right]^{-\rho} \alpha^* C_t^*, c_t^{*f}(z) = \left[\frac{p_t^{*f}(z)}{P_t^{*f}} \right]^{-\theta} \left[\frac{P_t^{*f}}{P_t^*} \right]^{-\rho} \left(\frac{1-n\alpha^*}{1-n} \right) C_t^*.$$

$p_t^h(z)$ and $p_t^f(z)$ are the home region price of home and foreign goods, respectively. P_t^h and P_t^f shows the price indexes of the home and foreign consumption baskets $C_{i,t}^h$ and $C_{i,t}^f$. All price indexes are expressed in local currency terms. Foreign currency indexes are designated with an asterisk. P_t^h and P_t^f are defined as $P_t^h = \left[n^{-1}\int_0^n \left(p_t^h(z)\right)^{1-\theta}dz\right]^{\frac{1}{1-\theta}}$ and $P_t^f = \left[(1-n)^{-1}\int_n^1 \left(p_t^f(z)\right)^{1-\theta}dz\right]^{\frac{1}{1-\theta}}$. The home region price index is $P_t = \left[n\alpha\left(P_t^h\right)^{1-p} + (1-n\alpha)\left(P_t^f(\tau)\right)^{1-p}\right]^{\frac{1}{1-p}}$. The foreign region price indexes are analogous to the domestic ones.

Ricardian households smooth consumption, receive dividends from firms and pay a lump-sum tax to the government. Their nominal budget constraint is

$$\frac{D_t}{1-\lambda} = \frac{(1+i_{t-1})}{1-\lambda}D_{t-1} + w_t l_{R,t}(z) - P_t C_{R,t} + \frac{\pi_t}{1-\lambda} - P_t T_{R,t} \tag{2}$$

D_t are domestic nominal bonds, which return one domestic currency in period *t + 1*, held at the end of period t, i_t denotes the nominal interest rate on bonds between t-1 and t, w_t is the nominal wage, π_t are dividends (profits) of domestic firms, $T_{R,t}$ is a lump-sum tax levied on households. We assume that Ricardian and non-Ricardian households pay an equal share of the total tax burden. The domestic private bond is internationally traded and its global market clearing condition is $nD_t + (1-n)D_t^* = 0$. The foreign private bond (F_t^*), denominated in foreign currency, is not traded internationally. The budget constraint of the foreign Ricardian household is

$$\frac{D_t^*}{(1-\lambda^*)S_t} + \frac{F_t^*}{(1-\lambda^*)} = (1+i_{t-1})\frac{D_{t-1}^*}{(1-\lambda^*)S_t} + \frac{(1+i_{t-1}^*)}{(1-\lambda^*)S_t}F_{t-1}^* + w_t^* l_{R,t}^*(z) - P_t^* C_{R,t}^* + \frac{\pi_t^*}{(1-\lambda^*)} - P_t^* T_{R,t}^*$$

S_t stands for the nominal exchange rate, the price of the foreign currency in the domestic currency. A rise in S_t represents a depreciation of the domestic currency. We assume a risk premium $(\psi(\exp(D_t) - 1))$ over uncovered interest parity. Private foreign net debt increases the domestic interest rate, implying that that private net debt returns to the initial level in the long term. The parity condition is

$$(1+i_t) = (1+i_t^*)\frac{E_t(S_{t+1})}{S_t} + \psi(\exp(D_t) - 1)$$

The optimality conditions for consumption and labour supply of the Ricardian household are

$$\beta(1+i_t)E_t\left(\frac{\epsilon_{t+1}^P P_t C_{R,t}}{\epsilon_t^P P_t C_{R,t+1}}\right) = 1 \tag{3}$$

$$l_{R,t}(z) = \left(\frac{w_t}{C_{R,t}P_t}\right)^{v} \tag{4}$$

Non-Ricardian households do not smooth consumption over time or own firms, and receive transfer payments from government, denoted by $G_{N,t}^{Tr}$. Their budget constraint is

$$P_t C_{N,t} = w_t l_{N,t}(z) - P_t T_{N,t} + P_t\frac{G_{N,t}^{Tr}}{\lambda}. \tag{5}$$

The optimal labour supply of the non-Ricardian household is

$$l_{N,t}(z) = \left(\frac{w_t}{C_{N,t}P_t}\right)^{v} \tag{6}$$

2.2. Economic policy

There are three types of public spending: Consumption, investment and transfers to households. The government finances its spending by non-distortionary taxes. We assume that the taxes and public consumption of different types of households are identical. The budget constraint in per-capita terms can be expressed as

$$P_t T_t + B_t = P_t G_t^I + P_t G_t^C + P_t\frac{G_{N,t}^{Tr}}{\lambda} + (1+i_{t-1})B_{t-1} \tag{7}$$

where B_t denotes public debt and G^I public investment spending.

Galí et al. (2007) assume a log-linear fiscal policy rule, which taxes responds to changes in public debt and government spending. Our conjecture is that fiscal stimulus during the Covid-19 recession is entirely deficit financed in the short term, and the repayment period will be long. Taxes react to public debt in the previous period:

$$\widehat{T}_t = \Phi\widehat{B}_{t-1}$$

where Φ denotes the elasticity of taxes with respect to public debt.

Public spending is assumed to follow an AR(1) process

$$\widehat{G}_t^i = \rho^i \widehat{G}_{t-1}^i + \widehat{\varepsilon}_t^i$$

where i = I, C, Tr and $\rho^i \in [0,1]$, $\widehat{\varepsilon}_t^i$ represents an unexpected change in public spending and the hat operator denotes percentage deviation from the initial steady state (denoted by the subscript zero, for example: $\widehat{x}_t = dx_t/x_0$). Variables whose initial value is zero are normalized by the initial level of GDP.

Empirical studies provide evidence that the efficiency of public investment spending varies across countries and regions, and can be inefficient in many cases (Caselli 2005, Dabla-Norris et al. 2012, Gupta et al. 2014, IMF 2015). Inefficiency can be caused by corruption, poor project selection and unnecessarily high investment costs (Berg et al., 2019). Following Prichett (2000) and Ganelli and Tervala (2020), we assume that only a fraction of the cost of public investment translates into the *effective* stock of public capital:

$$K_{t+1}^G = (1-\delta^K)K_t^G + \zeta G_t^I.$$

δ^K denotes the depreciation rate of public capital and ζ ($0<\zeta \le 1$) is the efficiency of public investment. DSGE models typically assume the perfect efficiency of public investment ($\zeta = 1$).

Garga and Singh (2020) found that optimal monetary policy involves setting interest rates to eliminate output hysteresis. In our modelling framework, central banks aim to eliminate output hysteresis by targeting the gap between actual output and its initial trend level prior to the recession. We assume that the central bank follows a log–linear Taylor-type rule

$$\widehat{i}_t = (1-a_s)\left(a_p \Delta \widehat{P}_t + a_y \widehat{y}_t\right) + a_s \widehat{i}_{t-1} + \varepsilon_t^{MP}$$

$a_s < 0$ denotes the degree of interest rate smoothing, $a_p < 0$ measures the reaction to inflation, Δ is the first difference operator, $a_y < 0$ measures the reaction to the deviation of output from the pre-recession level and ε_t^{MP} represents an unexpected change in monetary policy. A key distinction relative to the standard Taylor rule is that the central bank reacts to the deviation of output from the initial level, not to the output gap.

2.3. Firms and technology

A common assumption in studies with public capital is constant returns to scale in private factors of production, and increasing returns to scale in all factors due to the positive externality of public capital (Iwata 2013). Following Ganelli and Tervala (2020), we treat private capital as in fixed supply of one unit as a simplification. Some empirical studies find that public investment does not crowd out private investment, which provides a rationalisation for this simplification (e.g. Auerbach et al. 2019).

IMF (2020a) argue that the COVID-19 recession may reduce "the level of potential output, thus leading to permanent losses even after the pandemic is over". A key feature of our production technology is that productivity is endogenous, such that a recession can have a persistent or permanent effect on potential output. Cerra et al. (2021) highlight that several models with endogenous productivity have been developed to match the empirical evidence that business cycles and productivity are strongly correlated. They argue that these models can be grouped into learning-by-doing models, "AK" models and R&D models. Following Chang et al. (2002) and Engler and Tervala (2018), we assume endogenous productivity through learning-by-doing. Firms produce a differentiated good and the production function is

$$y_t(z) = a_t l_t(z)\left(K_t^G\right)^{\varnothing} \tag{8}$$

where $y_t(z)$ is the firm's output, a_t is the level of TFP and $\varnothing$ is the output elasticity of public capital (often referred as the productivity of public capital). The level of TFP accumulates over time based on the level of previous employment in a log-linear process

$$\widehat{a}_t = \phi \widehat{a}_{t-1} + \mu \widehat{l}_{t-1}$$

where ϕ is the persistence of TFP and μ measures the elasticity of TFP with respect to past employment. For instance, a fall in employment, caused a recession, reduces the level of TFP in the next period. If $0 < \phi < 1$, a level of employment has a persistent effect on TFP that erodes over time. If $\phi = 1$, the effect is permanent. Chang et al. (2002) estimate the parameters ϕ and μ for the US, finding empirical support for a learning-by-doing process of the nature specified here. Watson and Tervala (2021) present empirical evidence indicating the model implied human capital formulation process is supported in the Australian context. Anzoategui and Kim (2021) provide further empirical support for the implied behaviour of TFP specified here, whereby demand shocks affect TFP with a delay, and can have a highly persistent rather than a permanent effect on TFP.

The firm maximizes profits

$$\pi_t(z) = p_t^h(z) y_t(z) - w_t l_t(z) \tag{9}$$

subject to the production function (8) and the demand for its goods

$$y_t(z) = \left[\frac{p_t^h(z)}{P_t^h}\right]^{-\theta}\left[\frac{P_t^h}{P_t}\right]^{-\rho} n\alpha\left(C_t + G_t^A\right) + \left[\frac{p_t^h(z)}{S_t P_t^{*h}}\right]^{-\theta}\left[\frac{S_t P_t^{*h}}{S_t P_t^*}\right]^{-\rho}(1-n)\alpha^*\left(C_t^* + G_t^{*A}\right) \tag{10}$$

Here G_t^A denotes aggregate public spending ($G_t^A = G_t^I + G_t^C$). We can use equation (10) to express the firm's profits as

$$\pi_t(z) = \left[p_t^h(z) - \frac{w_t}{a_t\left(K_t^G\right)^{\varnothing}}\right]\times$$

$$\left\{\left[\frac{p_t^h(z)}{P_t^h}\right]^{-\theta}\left[\frac{P_t^h}{P_t}\right]^{-\rho} n\alpha\left(C_t + G_t^A\right) + \left[\frac{p_t^h(z)}{S_t P_t^{*h}}\right]^{-\theta}\left[\frac{S_t P_t^{*h}}{S_t P_t^*}\right]^{-\rho}(1-n)\alpha^*\left(C_t^* + G_t^{*A}\right)\right\}$$

Under flexible prices, profit maximisation with respect to $p_t^h(z)$ implies that price is a constant mark-up over marginal costs

$$p_t^h(z) = \frac{\theta}{\theta - 1}\frac{w_t}{a_t\left(K_t^G\right)^{\varnothing}} \tag{11}$$

We assume staggered-price setting following Calvo (1983), whereby a firm changes price with a probability of $1-\gamma$ in any period. The firm maximizes

$$\max_{p_t^h(z)} V_t(z) = E_t\sum_{s=t}^{\infty}\gamma^{s-t}\varsigma_{t,s}\pi_s(z)$$

where $\varsigma_{t,s}$ is the stochastic discount factor between periods t and s. The optimal price is

$$p_t^h(z) = \left(\frac{\theta}{\theta-1}\right)\frac{E_t\sum_{s=t}^{\infty}\gamma^{s-t}\varsigma_{t,s}Q_s\frac{w_s}{a_t\left(K_s^G\right)^{\varnothing}}}{E_t\sum_{s=t}^{\infty}\gamma^{s-t}\varsigma_{t,s}Q_s}$$

$$\text{where}Q_t = \left[\frac{1}{P_t^h}\right]^{-\theta}\left[\frac{P_t^h}{P_t}\right]^{-\rho} n\alpha\left(C_t + G_t^A\right) + \left[\frac{1}{S_t P_t^{*h}}\right]^{-\theta}\left[\frac{S_t P_t^{*h}}{S_t P_t^*}\right]^{-\rho}(1-n)\alpha^*\left(C_t^* + G_t^{*A}\right)$$

We log-linearize it and add a cost-push shock, denoted by u_t, to yield a variant of the familiar New Keynesian Phillips curve

$$\widehat{p}_t^h(z) = \beta\gamma E_t\widehat{p}_{t+1}^h(z) + (1-\beta\gamma)\left(\widehat{w}_t - \widehat{a}_t - \varnothing\widehat{K}_t^G\right) + \widehat{u}_t$$

The cost-push shock follows an AR(1) process $\widehat{u}_t = \rho^u\widehat{u}_{t-1} + \widehat{\varepsilon}_t^u$. The change in the optimal price depends on the changes in current and future marginal costs and cost-push shocks. An increase in the level of public capital or TFP reduces the optimal price, whereas a positive cost-push shock increases it. IMF (2020a) illustrates that the fall in inflation was relatively modest and temporary in advanced economics. The positive cost-push shock can be interpreted as supply chain complications triggered by COVID-19 physical restrictions. It can help resolve the 'missing deflation puzzle', as the model may have only modest deflation despite a large drop in output. Eggertsson et al. (2020) adopt a similar approach in the context of the GFC.

2.4. COVID-19 shock

We treat the COVID-19 pandemic as exogenous, and our model does not feature a trade-off between health and the economy, consistent with the evidence (Aghion et al. 2021; Our World in Data 2020). The size of the COVID-19 recession has been driven by a combination of government restrictions and voluntary social distancing measures that have been adopted in response to the pandemic (IMF 2020a). Smets and Wouters (2003) show that preference shocks are an important source of business cycle dynamics. We assume that a preference shift captures the combined consequences of voluntary social distancing and government restrictions on inter-temporal consumption and labour supply decisions:

$$\widehat{\epsilon}_{t+1}^P = \left(1-\delta^P\right)\widehat{\epsilon}_t^P + \rho^P\widehat{\epsilon}_{t-1}^P + \widehat{\varepsilon}_t^P \tag{12}$$

where $0 < \delta^P < 1$ is the deprecation rate of a preference shift, which captures the gradual lifting of restrictions and pandemic-induced changes in consumption behaviour and labour supply, $0 < \rho^P < 1$ denotes the persistence of the preference shock, and $\widehat{\varepsilon}_t^P$ is a preference shock, which represents the effects of pandemic-induced shifts in consumption and labour supply and restrictions set out by the government. A key difference to Smets and Wouters (2003) is that a shift in preferences does not follow an AR(1) process, and the preference process can be thought of as implying that there is a habitual dimension to intertemporal preference formation. Equation (12) captures the idea that COVID–19 spread gradually and restrictions were implemented and subsequently removed gradually, with intertemporal substitution gradually returning to normal over time.

2.5. Initial equilibrium and consumption

The consolidated budget constraint of the home economy, taking into account the government's budget constraint, the production function and the profits, is

$$D_t - (1+i_t)D_{t-1} - B_t + (1+i_t)B_{t-1} = p_t^h(z)y_t(z) - P_tC_t - P_tG_t^I - P_tG_t^C$$

Recall that D_t measures private *assets*, B_t measures public *debt*. For future reference, we define the trade balance as the right hand side of the above equation.

We log-linearize the model, for simplicity's sake, around a symmetric steady state where initial net foreign assets and public debts are both zero ($D_0 = B_0 = 0$). Then the above equation becomes $y_0 = C_0 + G_0^C + G_0^I$. This and equation (4) or (5) and equations (8) and (11) imply that the initial level of employment is

$$l_0 = l_{N,0}(z) = l_{R,0}(z) = \left[\left(\frac{\theta-1}{\theta}\right)\left(\frac{y_0}{C_0}\right)\right]^{\frac{1}{1+1/v}} \tag{13}$$

The log-linearized Euler condition for Ricardian households can be expressed as

$$\widehat{C}_{R,t} = E_t\left(\widehat{C}_{R,t+1}\right) - \left[\widehat{i}_t - E_t\left(\Delta\widehat{P}_{t+1}\right) + E_t\left(\Delta\widehat{\epsilon}_{t+1}^P\right)\right. \tag{14}$$

The corresponding equation for non-Ricardian households can be expressed as

$$\widehat{C}_{N,t} = \left(\frac{w_0 l_{N,0}}{P_0 C_{N,0}}\right)\left(\widehat{w}_t - \widehat{P}_t + \widehat{l}_{N,t}\right) - \left(\frac{y_0}{C_{N,0}}\right)\left(\widehat{T}_{N,t} + \frac{\widehat{G}_{N,t}^{Tr}}{\lambda}\right) \tag{15}$$

We assume than initial consumption of different types of households is identical and then

$$\frac{w_0 l_{N,0}}{P_0 C_{N,0}} = \left[\left(\frac{\theta-1}{\theta}\right)\left(\frac{y_0}{C_0}\right)\right]^{\frac{1}{1+\frac{1}{v}}}\left\{\left[\left(\frac{\theta-1}{\theta}\right)\left(\frac{y_0}{C_0}\right)\right]^{\frac{1}{1+\frac{1}{v}}}\right\}^{v} \equiv \chi \tag{16}$$

The log-linearized versions of aggregate consumption and labour supply, the optimal labour supply of non-Ricardian households (6) and optimal aggregate labour supply are

$$\widehat{C}_t = \lambda\widehat{C}_{N,t} + (1-\lambda)\widehat{C}_{R,t}, \tag{17}$$

$$\widehat{l}_t = \lambda\widehat{l}_{N,t} + (1-\lambda)\widehat{l}_{R,t}, \tag{18}$$

$$v^{-1}\widehat{l}_{R,t} = \widehat{w}_t - \widehat{C}_{N,t} - \widehat{P}_t \tag{19}$$

$$v^{-1}\widehat{l}_t = \widehat{w}_t - \widehat{C}_t - \widehat{P}_t \tag{20}$$

We can substitute equations (18), (19) and (20) into (15) to yield

$$\widehat{C}_{N,t} = \frac{\chi(1+v)}{1+\chi v}\widehat{C}_t + \frac{\chi(1+v^{-1})}{1+\chi v}\widehat{l}_t - \frac{1}{1+\chi v}\widehat{T}_{N,t} + \frac{1}{\lambda(1+\chi v)}\widehat{G}_{N,t}^{Tr} \tag{21}$$

We apply the lag operator $\left(1-L^{-1}\right)$ to (17) to give us

$$\widehat{C}_t - E_t\left(\widehat{C}_{t+1}\right) = \lambda\left[\widehat{C}_{N,t} - E_t\left(\widehat{C}_{N,t+1}\right)\right] + (1-\lambda)\left[\widehat{C}_{R,t} - E_t\left(\widehat{C}_{R,t+1}\right)\right]$$

Then we substitute (14) and (21) into the above equation to yield an Euler-like equation for aggregate consumption

$$\widehat{C}_t = E_t\left(\widehat{C}_{t+1}\right) - \sigma\left[\widehat{i}_t - E_t\left(\Delta\widehat{P}_{t+1}\right) + E_t\left(\Delta\widehat{\epsilon}_{t+1}^P\right)\right] - \Gamma E_t\left(\Delta\widehat{l}_{t+1}\right) + \kappa E_t\left(\Delta\widehat{T}_{N,t+1}\right) - -\Omega E_t\left(\Delta\widehat{G}_{N,t+1}^{Tr}\right) \tag{22}$$

where

$$\sigma = (1-\lambda)\left(1-\lambda\frac{\chi(1+\nu)}{(1+\chi\nu)}\right)^{-1}, \Gamma = \lambda\left(\frac{\chi(1+\nu)}{(1+\chi\nu)}\right)\left(1-\lambda\frac{\chi(1+\nu)}{(1+\chi\nu)}\right)^{-1}, \kappa = \frac{\lambda}{1+\chi\nu}\left(1-\lambda\frac{\chi(1+\nu)}{(1+\chi\nu)}\right)^{-1},$$
$$\Omega = \frac{1}{1+\chi\nu}\left(1-\lambda\frac{\chi(1+\nu)}{(1+\chi\nu)}\right)^{-1}.$$

Equation (22) is the only log-linear equilibrium condition of aggregate variables that depends on the fraction of non-Ricardian households. The presence of non-Ricardian households implies that consumption depends in part on changes in current transfers and taxes.

3. Parameterization

The home region represents Australia and the foreign region the rest of the world (ROW). Australia's share of the world GDP in 2017–19 averaged 1.6% (World Bank 2020). The relative size of the home economy (n) is set at 0.016. Australia's import to GDP ratio in 2017–19 averaged 21% (World Bank 2020). We set α at 0.79/0.016. The import to GDP ratio is then $(1-n\alpha) = 0.21$. We set $\alpha^* = (1-n\alpha)/n$, so that the implied share of Australian goods in the ROW's consumption basket $(n\alpha^*)$ is roughly 0.3%.

The discount factor (β) is set at 0.995. This implies a 2% annual real interest rate. Fiorito and Zanella (2012) found that the Frisch elasticity of labour supply at an extensive margin is in the range 0.8–1.4. We set the Frisch elasticity (ν) at 1.1. The baseline value of the weight of public consumption relative to private consumption (ϑ) is 0.5, but we vary it in the range of 0–1. It influences only the welfare multipliers of public consumption, but not the response of the economy. The Calvo parameter (γ) is set at 0.75, a common assumption in the literature. The elasticity of substitution between two goods produced in the same region (θ) is set at six, a common assumption in the literature. The *meta*-analysis of Bajzik et al. (2020) shows that the Armington elasticity, using quarterly data, is two. Therefore, it (ρ) is set at two.

The interest rate smoothing parameter (a_s) is set at 0.85. This is the conventional value, according to Federal Reserve Bank of Atlanta (2020). Jääskelä and Nimark (2011) and Rees et al. (2016) found almost identical estimates for Australia (0.86 and 0.87, respectively). The coefficients on inflation $(a_p = 1.5)$ and output $(a_y = 0.5/4)$ are common assumptions in the literature. The risk premium parameter (ψ) in the UIP is set at 0.001, an empirical estimate by Jääskelä and Nimark (2011) for Australia. This implies that an increase in net external debt of 1 percent of GDP increases the interest rate by one basis point.

Cogan et al. (2010) estimated that the share of non-Ricardian households is 0.29. Albonico et al. (2019) found that the share is 0.32. We set the share (λ) at 0.3 which is a commonly observed value internationally based on Kaplan et al. (2014). The elasticity of taxes with respect to public debt (Φ) is set at 0.043, based on the estimate of Cogan et al. (2010). A rise in public debt of 1 percent of GDP increases taxes by 0.043%.

Australia's public investment to GDP ratio in 2015 was 2.6% (IMF 2017). We set the ratio at this value. For simplicity's sake, we log-linearize the model around a steady state in which public consumption and transfers are zero. Thus, the initial private consumption to output ratio is (C_0/y_0) 97.4%. The meta-analysis of Bom and Ligthart (2014) found that the short-term output elasticity of public capital at the central government level is 0.083. Therefore, it $(\varnothing)$ is chosen to be 0.083. IMF (2015) found an average inefficiency in public investment processes of 13% in advanced economies. Therefore, the efficiency of public investment (ζ) is set at 0.87, following Ganelli and Tervala (2020). IMF (2015) estimated that the annual depreciation rate of public capital was 4.6% in advanced economies. We choose the quarterly depreciation rate (δ^K) to be 1.25%, implying an annual depreciation rate of 5%.

The persistence of TFP (ϕ) is set to 0.96 following Reifschneider et al. (2015). They use this value in the calibration of hysteresis effects in the context of the GFC. The value implies that the changes in TFP are persistent, but not permanent. The value is within the range of estimates for Australia suggested by Watson and Tervala (2021). We set the elasticity of TFP with respect to past employment (μ) at at 0.13. This is within the range of estimates found by Chang et al. (2002) for the US and Watson and Tervala (2021) for Australia. With these parameter values, the model generates a link between recessions and TFP, which is consistent with the empirical findings of Furceri et al. (2021).

We set the sizes of the shocks and their persistence such that the model generates a plausible recession. The data of Fig. 1 shows that the deviation of GDP from the pre-recession trend was −4.3% in Australia for 2020. We calibrate parameters such that deviation in GDP from its initial steady state is −4.3% both in Australia and the ROW. In 2020, deflation was short lived. Inflation in Australia in 2020 was 0.7 percentage points lower than in 2019 (IMF 2021). The size of the recession takes into account globally accommodative fiscal policy in 2020. Our paper's findings can be interpreted as addressing the consequences of additional fiscal stimulus above that already provided in 2020. The size of the monetary policy shock (ε_t^{MP}) is set such that they cause a fall in interest rates by 200 basis points in both regions. This reflects the behaviour of the main central banks that drove policy rates to zero in the early stages of the recession. However, the preference shock affects monetary policy through the Taylor rule too. The size of the preference shock $(\widehat{\varepsilon}_t^P)$ is set at −5.4% in both regions. Persistence (ρ^P) is set at 0.8. The depreciation rate of the preference shift (δ^P) is set at 0.5. We set the persistence of the shocks and the depreciation rate such that the shift in preferences causes a hump-shaped recession. The size of the cost-push shock $(\widehat{\varepsilon}_t^u)$ is set at 1.4, and persistence (ρ^u) is assumed to be 0.8, which helps generate realistic inflation dynamics based on Australian data at the beginning of the pandemic.

Our policy experiment is a rise in public spending with persistence of 0.75 ($\rho^i = 0.75$, i = C, I, Tr), based on the empirical results of Iwata (2013). We assume that a rise in public spending is always 1 percent of initial quarterly GDP.

4. Macroeconomic effects of fiscal stimulus

4.1. Fiscal multipliers

The cumulative output multiplier (CUM) is the difference between the cumulative change in output in the fiscal stimulus case (denoted by superscript Fs) and the baseline case (denoted by superscript Bl) divided by the cumulative change of public spending as a percentage of GDP:

$$CUM = \frac{\sum_h \widehat{Y}^{Fs}_{t+h} - \sum_h \widehat{Y}^{Bl}_{t+h}}{\sum_h \widehat{G}^i_{t+h}}$$

where i = I, C, Tr. We report CUM over 20 quarters (5 years). In this model, fiscal policy has a long-lasting effect on output and we calculate also the present value output multiplier (PVM) using 40 periods. The main difference is that changes are discounted at the steady state interest rate:

$$PVM = \frac{\sum_{s=t}^h \beta^{s-t} \widehat{Y}^{Fs}_{t+h} - \sum_{s=t}^h \beta^{s-t} \widehat{Y}^{Bl}_{t+h}}{\sum_{s=t}^h \beta^{s-t} \widehat{G}^i_{t+h}}$$

where i = I, C, Tr.

The welfare multiplier of fiscal policy is the consumption equivalent change in the present discounted value of utility for a one unit rise in public spending, following the idea of Rendahl (2016) and Engler and Tervala (2018). Aggregate consumption and labour supply in the baseline case are denoted by $\left\{C_s^{Bl}, G_s^{Bl}, l_s^{Bl}(z)\right\}_{s=t}^{\infty}$. The present value (PV) of aggregate welfare is then

$$U_\epsilon^{Bl} = E_t \sum_{s=t}^{\infty} \beta^{s-t} \epsilon_s^{PS} \left[logC_s^{Bl} - \frac{\left(l_s^{Bl}\right)^{1+\frac{1}{v}}}{1+\frac{1}{v}} + \vartheta logG_s^{Bl,C} \right]. \tag{23}$$

Let us define U^{Bl} as the PV of aggregate welfare in the absence of a preference shock

$$U^{Bl} = E_t \sum_{s=t}^{\infty} \beta^{s-t} \left[logC_s^{Bl} - \frac{\left(l_s^{Bl}\right)^{1+\frac{1}{v}}}{1+\frac{1}{v}} + \vartheta logG_s^{Bl,C} \right]. \tag{24}$$

The welfare effect of fiscal stimulus relative to the no fiscal stimulus case is denoted by λ. It measures the proportion of initial private consumption that the household would be willing to pay for fiscal stimulus. The PV of welfare in the fiscal stimulus case is

$$U_\epsilon^{FS} = E_t \sum_{s=t}^{\infty} \beta^{s-t} \epsilon_s^{PS} \left[log\left((1+\lambda)C_s^{Fs}\right) - \frac{\left(l_s^{Fs}\right)^{1+\frac{1}{v}}}{1+\frac{1}{v}} + \vartheta logG_s^{Fs,C} \right].$$

We can divide this equation by the time preference and use the definition of (24) and the similar definition in the fiscal stimulus case to yield

$$U^{Fs} = \frac{1}{1-\beta} \log(1+\lambda) + U^{Bl}$$

Then we multiply the above equation by 100 to express the welfare effect as a percentage of initial private consumption, and solve for λ to yield

$$\lambda = 100 \times \left[\exp(1-\beta)\left(U^{Fs} - U^{Bl}\right) - 1 \right] \tag{25}$$

Then we substitute the first-order Taylor expansion of (24) and an analogous equation in the baseline case to equation (25) to yield

$$\lambda = 100 \times \left[\exp(1-\beta)\left(\left(\sum_{s=t}^{\infty} \beta^{s-t} \left(\widehat{C}_s^{Fs} - (l_0(z))^{1+\frac{1}{v}} \widehat{l}_s^{Fs}(z) + \vartheta \widehat{G}_s^{Fs,C} \right) \right. \right. \right.$$
$$\left. - \left(\sum_{s=t}^{\infty} \beta^{s-t} \left(\widehat{C}_s^{Bl} - (l_0(z))^{1+\frac{1}{v}} \widehat{l}_s^{Bl}(z) + \vartheta \widehat{G}_s^{Bl,C} \right) - 1 \right] \tag{26}$$

Equation (26) defines the welfare *effect* of fiscal stimulus as the percentage equivalent of initial private consumption. The final step is to divide the welfare effect by public spending discounted the same way. The welfare *multiplier*, the consumption equivalent change in welfare for a one unit change in public spending, is then defined as

$$WM = \frac{\lambda}{\sum_{s=t}^{\infty} \beta^{s-t} \widehat{G}_s^i} \tag{27}$$

where i = I, C, Tr. The welfare multiplier is calculated over 2000 quarters as an approximate to its infinite discounted present value.

4.2. COVID-19 recession

We begin by discussing the consequences of hysteresis in the baseline case without additional fiscal stimulus. The solid lines of Fig. 2 show the responses of the selected variables in the presence of hysteresis (μ = 0.13); the dashed lines depict the case without hysteresis (μ = 0). Figures show each variable's percentage deviation from initial steady state, noting that inflation is expressed in annualized terms.

In the baseline case, regions face the same shocks and the economies behave identically. In this paper, a negative preference shock represents a reduction in the willingness and opportunities for consumption and labour supply caused by COVID-19. It is the main driver of the recession and deflation. A short-lived and hump-shaped shift in preferences causes a hump-shaped recession. A cost-push shock deepens the recession and causes a temporary rise in inflation. The inflationary effect is dominated by the preference shock due to the small size of the cost-push shock. A monetary shock tends to increase output and inflation, but it is dominated by other shocks.

In the absence of hysteresis, the recession is deep, but output returns quickly to the pre-recession level during the recovery (Fig. 2(a)). The behaviour of output is consistent with most DGSE models. However, it is inconsistent with the empirical evidence showing that recessions commonly have an enduring negative effect on the level of output (Ball 2014, Cerra and Saxena 2017, Cerra et al. 2021, Martin et al. 2015, Rawdanowicz et al. 2014). In addition, the behaviour of TFP, shown at Fig. 2(d), is inconsistent with the empirical observation that deep recessions are associated with a strong deterioration in the level of TFP (Furceri at al. 2021).

In the presence of hysteresis, a fall in the level of employment (Fig. 2(c)) has a persistent, negative effect on TFP via the learning-by-doing process. Anzoategui and Kim (2021) found that shocks affect TFP with a delay. Our result is consistent with this empirical evidence. Furceri at al. (2021) found that a decline in output of 10 percent is associated with a 4.2% fall in cyclically adjusted TFP. That is, the ratio of the peak fall in TFP to that of output is 0.42. In our model, the size of the shocks are set such that the change in output in the first year is −4.3%, and the deterioration of the TFP in the second year is roughly −1.9%. Consequently, the ratio of the peak fall in TFP to the peak fall in output is 0.45. This is consistent with the empirical evidence. Furceri at al. (2021) also found that the ratio of the TFP fall to the peak fall in output is roughly 0.3 in the sixth year.

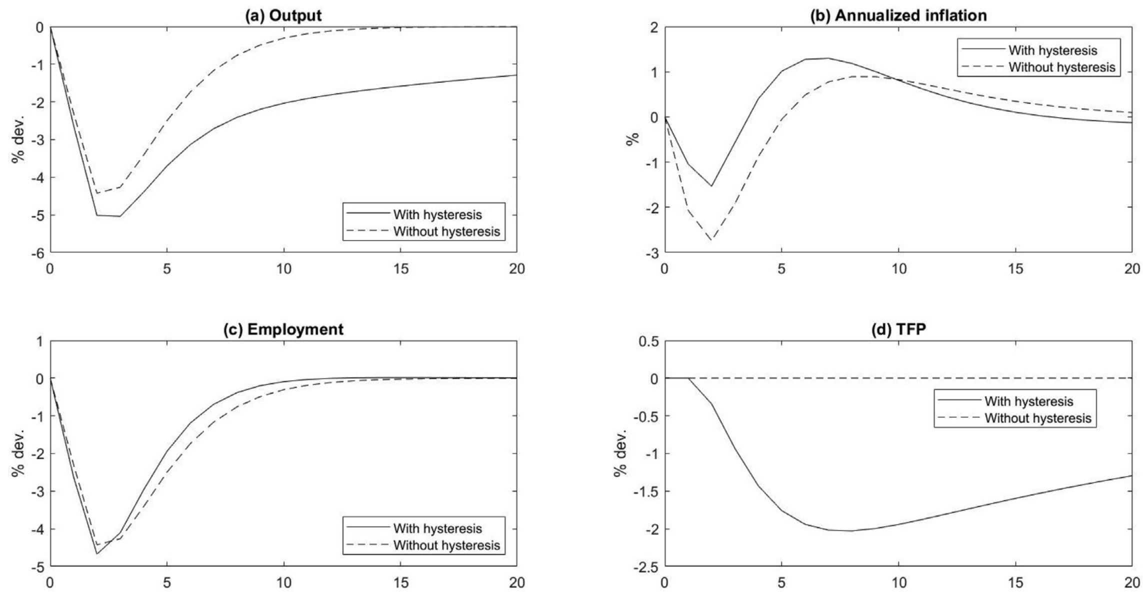

Fig. 2. Covid-19 recession in the baseline case.

In our model, this ratio is 0.27. The learning-by-doing process generates an empirically plausible link between recessions and TFP.

In our model, TFP hysteresis causes output hysteresis. We measure the degree of output hysteresis as the ratio of the fifth-year change in output to the first-year change in output. In the fifth year, output is at the potential level (in the absence of hysteresis, output has returned to its initial level). The ratio measures the negative effect of the recession on potential output. In our model, the degree of hysteresis is 0.32. Kienzler and Schmid (2014) found that the plausible degree of hysteresis is in the range of 0.2 to 0.3. Rawdanowicz et al. (2014) estimated that the median and average degree of hysteresis was roughly 0.5 in a sample of 32 countries following the GFC. The model generates an empirically realistic relationship between recessions and long-term output. Fig. 1 demonstrates that in the presence of hysteresis the model's baseline prediction on the behaviour of GDP in 2021–2024 is in line with the IMF's (2021) forecast. Our model's prediction, which reflects empirical evidence on the consequences of recessions for potential output, is that economic growth will be slightly better than IMF (2021) forecasts, and that the degree of hysteresis will be slightly smaller than the difference between IMF pre and post-pandemic forecasts would imply.

Fig. 2(b) illustrates that the recession is associated with a milder deflation in the presence of hysteresis. The 'missing deflation puzzle' refers to the observation that GDP fell substantially during the GFC, but the decline in inflation was modest (see e.g. Lindé and Trabandt, 2019). In the short term, a reduction of TFP and a positive cost-push shock increases the representative firm's optimal price. These effects are more than offset by the deflationary pressure of the recession. However, they improve the model's ability to account for the 'missing deflation puzzle'.

4.3. Public transfers

Furman (2020) and Furman et al. (2020) argue that public transfers played a major role in supporting US household incomes and consumption during the pandemic recovery. For example, the US government sent stimulus checks, via the Economic Impact Payment program, to households. In our model, the home economy conducts a rise in public transfers targeted to non-Ricardian households, of 1% of initial GDP, in period 1.

Fig. 3 shows the response of output, while Figs. 3 and 4 show the responses of selected variables. The home economy has virtually no impact on the ROW and we focus exclusively on domestic variables. The solid lines illustrate the baseline case, the dashed lines depict the case where transfers are increased and the dotted (dash-dotted) lines depict the case where consumption (investment) is increased. Labour productivity, shown in Fig. 4(d), is $(y_t(z)/l_t(z))\, a_t\left(K_t^G\right)^{\varnothing}$. The real exchange rate, shown in Fig. 5(e), is defined as $RER = S_t P_t^*/P_t$. Thus, a rise in it is a real depreciation of the domestic currency. Changes in public spending, public debt and the trade balance, shown in Fig. 5, are shown as percentage deviations from initial GDP. Changes in public spending, public debt and taxes are identical in all cases with fiscal stimulus. Thus, panel (a), (b) and (c) of Fig. 5 show only one case.

A rise in transfers, shown in Fig. 5(a), increases disposable income in the short term. The presence of non-Ricardian households implies that current consumption depends on changes in current transfers. A rise in transfers leads to a rise in private consumption in the short term. A rise in private consumption stimulates output (see Fig. 3) and employment (Fig. 4(a)), relative to the baseline case. An increase in short-term employment has a positive effect on TFP, shown in Fig. 4(c). This has a positive effect on potential output and the output multiplier. Table 1 shows that the cumulative output multiplier over 20

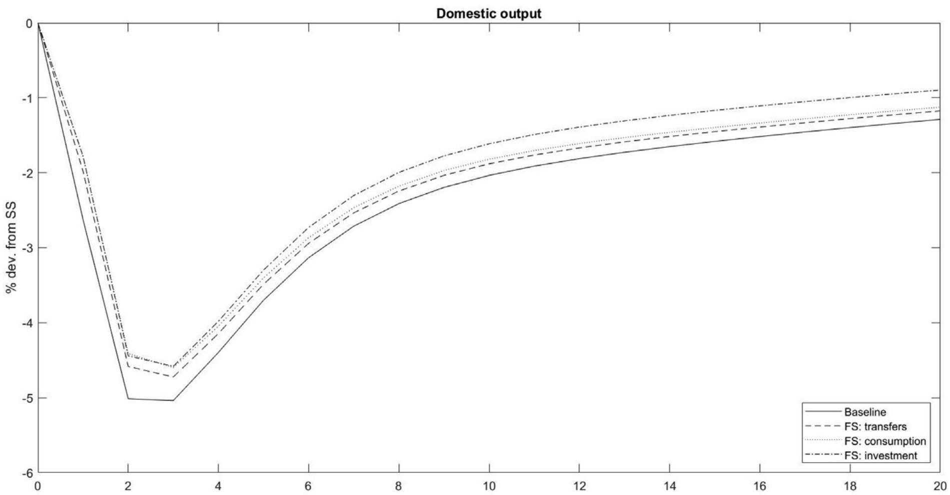

Fig. 3. Output Effects of Fiscal Stimulus.

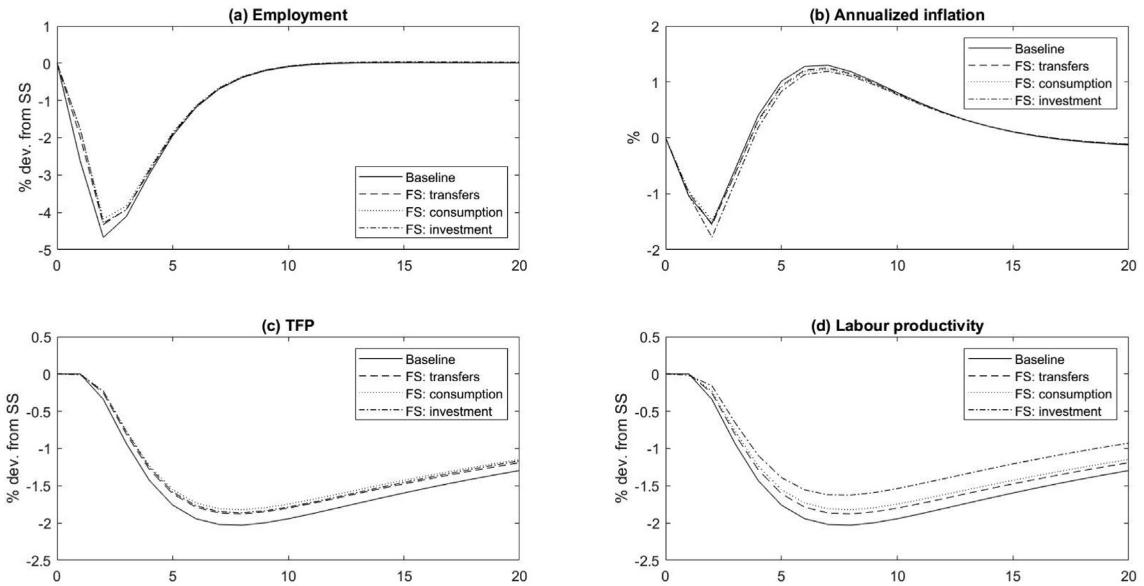

Fig. 4. Effects of Fiscal Stimulus, Part I.

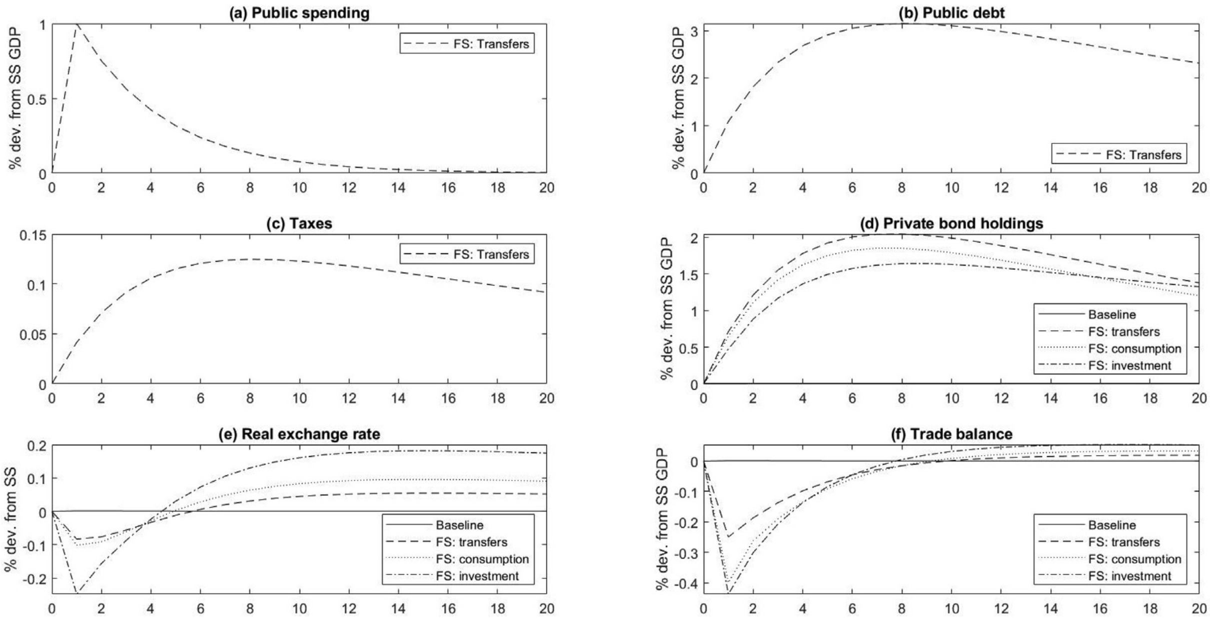

Fig. 5. Effects of Fiscal Stimulus, Part II.

Table 1
Output and Welfare Multipliers of Fiscal Stimulus.

Fiscal Stimulus	Output, CUM, 20 periods	Output, NPV, 40 periods	Welfare
Public transfers	1.0	1.4	0.49
Public consumption	1.4	1.9	0.48
Public Investment	2.2	3.6	1.6

periods is 1.0. Li and Spencer (2016) found a cumulative output multiplier of 0.75 for transfers in the absence of hysteresis. We find a larger multiplier because hysteresis increases the multiplier (see Engler and Tervala 2018). A meta-analysis from Gechert (2015) discovered that the cumulative output multiplier during the zero lower bound episodes for transfers is 0.6. A meta-analysis of Gechert and Rannenberg (2018) found the cumulative output multiplier for transfers of 1.3. Our result sits within the range of these estimates.

The NPV output multiplier (1.4) is higher than the cumulative multiplier. Fig. 3 illustrates that the output effect of fiscal stimulus lasts much longer than the fiscal demand shock, shown in Fig. 5(a). The persistent effects of fiscal stimulus on TFP and on labour productivity imply that the long-term level of output is higher than in the baseline case. However, employment returns to its pre-recession level relatively quickly. Fatás and Summers (2018) and Fatás (2019) found empirical support for the permanent output effects of fiscal policy. Bardaka et al. (2021) found empirically that fiscal consolidation has a negative effect on TFP both in the short and long-term. Galí et al. (2007) found empirically that public spending shocks affect employment in the short-term, but that employment returns roughly to its pre-shock level in the long-term. Our results are consistent with all of these empirical observations. In relation to other demand shocks, Jordà et al. (2020) found that monetary shocks typically reduce output and TFP in the long-term, but not employment.

A rise in public consumption is deficit financed. Fig. 5(b) demonstrates that public debt increases in the short term. The parameterization of the fiscal policy rule implies public debt of 1% of GDP today is followed by a rise in taxes of 0.043% in the next period. When a public spending shock vanishes and taxes, shown in Fig. 5(c), are increased, the stock of public debt begins to fall. Taxes are reduced as the debt burden falls. A hump-shaped response of taxes to a deficit-financed rise in public spending is consistent with the empirical evidence of Galí at al. (2007).

Table 1 shows that the welfare multiplier of transfers is 0.49. This means that households would be willing to sacrifice 0.49 dollars worth of consumption for a one-dollar rise in transfers. It is worth emphasizing that the welfare multiplier measures the change in welfare relative to the baseline case. The welfare multiplier depends on private consumption, employment and the direct welfare gain of public consumption (now unaffected). First, a rise in employment decreases welfare. Second, an increase in TFP, caused by the rise in employment, implies a long-lived increase in private consumption. It is somewhat smaller than the increase in output because of higher taxes and a fall in the domestic terms of trade. The result that a rise in public spending increases private consumption is consistent with empirical studies (Galí et al. 2007; and Laumer 2020). The second effect dominates and the welfare multiplier of transfers is positive. This is a new finding, as there are no studies with an analysis of the welfare multipliers of transfers in the presence of hysteresis. However, our results are consistent with Engler and Tervala (2018) and Watson and Tervala (2021) who find that the welfare multiplier of public consumption is positive in the presence of hysteresis.

4.4. Public consumption

Saez and Zucman (2020) argue that in the context of the COVID-19 pandemic the government should act as buyer of last resort, stepping in to replace lost private demand. In our model, this policy prescription can simply be interpreted as a rise in public consumption. The home economy implements a fiscal expansion, of 1% of initial GDP, in period 1.

A rise in domestic public consumption increases output (Fig. 3) and employment (Fig. 4a)), relative to the baseline case and the case where transfers were increased. A key difference compared to the case of public transfers relates to the direct employment benefits of public consumption, in addition to the indirect benefits related to higher levels of private consumption which are similar in magnitude to the direct benefits of a public transfer of comparable size. This higher level of short-term employment, relative to the case of transfers, has a positive effect on TFP via the learning-by-doing mechanism. This has a positive effect on potential output and the output multiplier. Table 1 shows that the cumulative output multiplier over 20 periods is 1.4. Watson and Tervala (2021) found a cumulative output multiplier of 1.2 in the presence of hysteresis. We find a slightly larger multiplier because fiscal policy is now deficit financed rather than balanced budget, the cumulative time period includes an extra year, and the degree of hysteresis is slightly higher. A meta-analysis of the literature from Gechert and Rannenberg (2018) found that the cumulative output multiplier during recession or crisis regimes for government consumption is typically around 1.6. Our finding is very close to this value.

Fig. 5(e) shows that the shock results in an appreciation of the real exchange rate in the short term. This is driven by an appreciation of the nominal exchange rate. A real appreciation turns into a real depreciation in the medium term. First, a rise in the relative supply of domestic goods implies that the relative price falls. Second, higher TFP implies that the relative price of domestic goods fall. Iwata (2013) finds empirical evidence that a public consumption shock causes a statistically significant depreciation of the real exchange rate in the medium term. Fig. 5(f) illustrates that the home region runs a trade balance deficit in the short term, but it soon turns into a surplus. Improved economic performance and the import component of public spending induce a trade deficit of 0.36% of initial GDP in the first year. Iwata (2013) found that a public consumption shock causes a trade balance deficit that turns into a surplus in the seventh quarter. Abbas et al. (2011) found that a strengthening in the fiscal balance by 1% of output causes an improvement of the current account of 0.3% of GDP. Our findings are in line with these observations.

The welfare multiplier of public consumption is 0.48. It depends on private consumption, employment and the direct welfare gain of public consumption. First, an increase in employment, relative to the baseline case, reduces utility. Second, a rise in private consumption increases utility. Third, the direct welfare gain of public consumption increases utility. The second and third effect dominate, and the welfare multiplier is positive. Our results indicate that the welfare multiplier of transfer payments is slightly higher than that of public consumption even if the output multiplier of transfers is smaller. The direct welfare of public consumption depends on ϑ. If it is set at zero, implying that public consumption yields no utility, the welfare multiplier drops to 0.29. It increases to 0.68, if ϑ is set at one, implying that public consumption yields as high utility as private consumption. Our results are consistent with Engler and Tervala (2018) and Watson and Tervala (2021), who found that the welfare multipliers are positive in the presence of hysteresis.

4.5. Public investment

The IMF (2020b) argued that "Countries with fiscal space and major scarring [hysteresis] from the crisis should provide temporary stimulus, including through public investment". Krugman (2020) argued that that there are strong reasons to "undertake large, deficit-financed public investment on a continuing basis". He firstly argued that output multipliers are likely to be high in a liquidity trap ("around 1.5"). Second, public investment will increase potential output in the long-term if investment is productive. Third, recessions depress future output, and limiting hysteresis effects would be beneficial. We study a temporary stimulus, 1% of initial GDP, that begins in period 1.

Fig. 2 indicates that the output effect of public investment is very similar to the case of public consumption in the short-term. They have an identical, temporary demand effect, which increases output and employment, relative to the baseline case. Public investment efficiency is set at 0.87, which implies a one-dollar rise in public investment spending leads to a rise in the *effective* stock of public capital of 0.87 dollars. The temporary increase in public investment results in a larger increase in labour productivity and aggregate supply in the medium and long-term relative to a temporary shock to public consumption, resulting in lower optimal prices, and a larger output response over this timeframe compared to the shock to public consumption.

A higher level of output relative to the public consumption case implies a rise in private consumption. Labour supply depends negatively on private consumption. The positive wealth effect, relative to the public consumption case, on labour supply implies that the rise in employment, relative to the baseline case, is smaller. The learning-by-doing process then implies that the rise in TFP, relative to no fiscal stimulus case, is smaller in the case of public investment than in the case of public consumption. Fig. 4(c) demonstrates this effect. However, a rise in the public capital stock has a positive effect on labour productivity $(y_t(z)/l_t(z) = a_t\left(K_t^G\right)^{\varnothing}$. Fig. 4(d) demonstrates an investment shock has a stronger effect on labour productivity, despite a smaller TFP effect. As mentioned in section 4.3, empirical studies have pointed out that fiscal policy has effects on output and TFP, both in the short and long term. Buchheim and Watzinger (2017) found that the effects of infrastructure investment programmes on employment can be strong in the short term, but return to zero relatively quickly after the end of the programme. Fig. 4(a) shows that our model reflects this empirical evidence: The positive employment effect is relatively temporary.

Table 1 shows that the cumulative output multiplier over 20 periods is 2.2. Ganelli and Tervala (2020) suggest that the cumulative multiplier of a balanced-budget rise in public investment without hysteresis can be greater than one, and specifically around 1.5. In our framework, the multiplier is higher due to hysteresis. The survey article of Gechert and Rannenberg (2018) found that the cumulative output multiplier of public investment is 2.3 during recession or crisis regimes. Therefore, our result is in line with empirical evidence.

The NPV output multiplier over 40 periods is 3.6. First, the persistent effects on TFP and labour productivity imply that the level of output is higher than in the baseline case both in the short and long term. Second, a rise in the stock of public capital is long-lived due to the small depreciation rate. These factors imply that the output effect is long-lived and strong. Leduc and Wilson (2013) found empirical evidence that the long-term output multiplier of highways is in the range of 3 to 7. Ganelli and Tervala (2020) showed the output multiplier of public investment depends greatly on the efficiency of public investment, the output elasticity of public capital, and the depreciation rate of public capital. The efficiency of highway investment may be high, as well as its output elasticity given that highway investment is highly complementary to private sector activity. Bom and Ligthart (2014) found that the output elasticity of core public capital, which includes roads, is higher than the average productivity that we use in our simulations. In addition, the depreciation rate of highways is likely be smaller than the average of public capital. Therefore, it is understandable that that our estimates are towards the lower range or their estimates.

IMF (2020b) and Powell (2020) argued that fiscal stimulus can limit the long-term damage of the COVID-19 recession and support the recovery. Fig. 3 illustrates that our study backs up this view. A temporary rise in public investment would yield substantial and long-lived benefits to the economy, although the positive employment effect is weak and short-lived. The main benefits of a public investment shock in a recessionary environment are to alleviate the damage of a recession on TFP and to increase labour productivity by increasing the stock of public capital. In this context, cost per job calculations (e.g. Buchheim and Watzinger, 2017; Chodorow-Reich, 2019; and Agrawala et al., 2020) may give a misleading picture of the effectiveness of public investment, as the enduring benefits most likely relate to productivity and output, not employment.

Fig. 5(e) shows that the short-term appreciation of the real exchange rate is stronger than in case of other shocks. This is caused by stronger nominal appreciation. In addition, the long–term appreciation of the real exchange rate is stronger. A rise in investment spending causes a stronger rise (fall) in the relative supply (price) of domestic goods. In addition, a rise in public capital causes a fall in the optimal price of domestic goods. According to an empirical work of Iwata (2013), public investments induce a statistically significant real depreciation of the exchange rate in the medium term. Fig. 5(f) shows that the response of the trade balance is almost identical to the case of a public consumption shock. This is in line with the empirical results of Iwata (2013).

Table 1 indicates that the welfare multiplier of public investment is 1.6, roughly three times that of public transfers and consumption (0.48–0.49). This can be attributed to the fact that the increase in public investment is also associated with an increase in private consumption, which directly raises household welfare. Ganelli and Tervala (2020) found that the welfare multiplier can be above zero if public investment efficiency is sufficiently high, public capital's depreciation rate is sufficiently low, and the output elasticity of public capital is sufficiently high. They find that the multiplier is sizable, when these parameters are set to match the empirical estimates for advanced economies. According to their study, when the output elasticity is 3, the welfare multiplier is -0.11 (0.015) when efficiency is 0.57 (0.73). In our recessionary environment with hysteresis, the welfare multiplier is as high as 0.53, when $\zeta = 0.57$ and $\varnothing = 0.02$. Public investment in these circumstances is not only welfare improving, but the welfare multiplier is higher than that of public consumption and transfers. Our main parameterization is identical to Ganelli and Tervala (2020), so the differences can be attributed to the presence of hysteresis in our model.

Sims and Wolff (2018) found that the welfare multiplier of public investment around their non-stochastic steady state is 0.33, one fifth of our result. Our main innovation is incorporating a realistic hysteresis mechanism into our model, but our parameterization differs too. Ganelli and Tervala (2018) highlight that the key parameters are the efficiency, productivity and depreciation rate of public capital. We can use the same main parameterization as in Sims and Wolff (2018), by setting the efficiency of investment at one, the productivity of capital at 0.05 and the quarterly depreciation rate at 0.025%. In the absence of hysteresis ($\phi = \mu = 0$), we find that the welfare multiplier is 0.22. This is smaller than in the closed-economy model of Sims and Wolff (2018). Ganelli and Tervala (2020) discuss that in a large-open economy setting the welfare multiplier is smaller than in a closed economy setting, since a fraction of the benefits of higher public investment leaks abroad. They find that the sum of the domestic and foreign welfare multiplier is also 0.3, when the parameterization of Sims and Wolff (2018) is used. However, their domestic multiplier is 0.21. So our results are fully consistent with Sims and Wolff (2018) and Ganelli and Tervala (2020). In the presence of hysteresis, but using the main parameterization of Sims and Wolff (2018), we find that the welfare multiplier is 0.84. So the drivers of the differences in results relative to Sims and Wolff (2018) can be attributed to the presence of hysteresis, a higher value of the productivity of public capital, and a lower value of the depreciation rate.

5. Sensitivity analysis

This section evaluates the robustness of the output and welfare multipliers to modifications in parameter values. Hysteresis is a vital feature of the model. In row 2 (3) of Table 2, we lower (raise) the elasticity of TFP with respect to employment to 0.11 (0.15). A smaller parameter value implies that a change in employment has a weaker effect on TFP, and the degree of hysteresis becomes smaller. This reduces the multipliers of fiscal policy. This is consistent with Engler and Tervala (2018) and Watson and Tervala (2021), who analyse the effects of public consumption. However, the changes are small.

In row 4 (5), we set the persistence of TFP at 0.99 (0.93). These values are within the range of estimates by Watson and Tervala (2021). A reduction in the persistence of TFP lowers the welfare multiplier of transfers and consumption, since the positive TFP effect becomes shorter-lived. These results are consistent with Engler and Tervala (2018). The case of public investment is different. On one hand, a high persistence means that the changes are long-lived. On the other hand, TFP is unresponsive to a small increase in short-term employment.

Table 2
Sensitivity of the output and welfare multipliers.

		Transfers		Consumption		Investment	
Row	Parameter	Output, CUM	Welfare	Output, CUM	Welfare	Output, CUM	Welfare
1	Baseline	1.0	0.49	1.4	0.48	2.2	1.6
2	$\mu = 0.11$ ($\mu = 0.13$)	0.92	0.44	1.4	0.44	2.2	1.6
3	$\mu = 0.15$ ($\mu = 0.13$)	1.2	0.53	1.6	0.61	2.4	1.7
4	$\phi = 0.99$ ($\phi = 0.96$)	1.0	0.84	1.5	1.1	2.4	1.7
5	$\phi = 0.93$ ($\phi = 0.96$)	0.91	0.34	1.4	0.32	2.2	1.6
6	$\varnothing = 0.03$ ($\varnothing = 0.083$)	Unchanged	Unchanged	Unchanged	Unchanged	1.8	0.80
7	$\varnothing = 0.05$ ($\varnothing = 0.083$)	Unchanged	Unchanged	Unchanged	Unchanged	2.0	1.1
8	$\varnothing = 0.13$ ($\varnothing = 0.083$)	Unchanged	Unchanged	Unchanged	Unchanged	2.8	2.5
9	$\zeta = 0.73$ ($\zeta = 0.87$)	Unchanged	Unchanged	Unchanged	Unchanged	2.1	1.5
10	$\zeta = 1$ ($\zeta = 0.87$)	Unchanged	Unchanged	Unchanged	Unchanged	2.5	1.9
11	$\delta^K = 0.025$ $\delta^K = 0.0125$)	Unchanged	Unchanged	Unchanged	Unchanged	2.3	1.1
12	$\Phi = 0.1$ ($\Phi = 0.043$)	1.1	0.50	1.6	0.52	2.4	1.7
13	$\Phi = 0.02$ ($\Phi = 0.043$)	0.89	0.48	1.4	0.51	2.2	1.7
14	$\rho^C = \rho^I = 0.93 (\rho^C = \rho^I = 0.75)$	0.7	0.45	1.1	0.46	1.6	1.8
15	$\lambda = 0.25$ ($\lambda = 0.3$)	0.92	0.48	1.5	0.47	2.3	1.8
16	$\lambda = 0.5$ ($\lambda = 0.3$)	1.9	0.70	2.0	0.57	2.7	1.5
17	$v = 0.8$ ($v = 1.1$)	1.1	0.55	1.5	0.50	2.3	1.7
18	$v = 1.4$ ($v = 1.1$)	0.83	0.43	1.5	0.53	2.3	1.7
19	$\gamma = 0.5$ ($\gamma = 0.75$)	0.83	0.53	1.2	0.49	2.3	1.9
20	$\rho = 1.3$ ($\rho = 2$)	1.1	0.45	1.5	0.46	2.4	1.6

Sims and Wolff (2018) argue that the output elasticity of public capital is poorly identified and there is no consensus on its value in the empirical literature. In addition, the previous literature (Sims and Wolff 2018; Ganelli and Tervala 2020) shows that the multipliers are sensitive to it. In row 6, it is reduced 3%. This is a relevant value for developing countries, according to Ganelli and Tervala (2020). In row 7, it is set at 5%, as based on the calibration exercise of Sims and Wolff (2018) for the US. In row 8, it is increased to 13%. This is the estimate of the short-term output elasticity of core public capital (roads, railways, airports, and utilities) at the national level by Bom and Ligthart (2014). A low output elasticity implies a smaller increase in potential output. This is consistent with Ganelli and Tervala (2020) and Sims and Wolff (2018), who study the effects of public investment without hysteresis. In the presence of hysteresis, the output multiplier is still higher than the baseline multipliers of Ganelli and Tervala (2020) and Sims and Wolff (2018), although the output elasticity of 0.03 is less than half of that suggested by the meta-analysis of Bom and Ligthart (2014). A higher output elasticity (13%) increases the output multiplier to 2.8. Abiad et al. (2016) found that a rise in public investment of 1% of GDP increases the level of output by almost 3%, if the rise is deficit financed or implemented at a time of economic slack.

The stock of public capital depends on public investment efficiency and the depreciation rate. In row 9, we decrease efficiency from 0.87 to 0.73, which is IMF's (2015) estimate for emerging economics. In row 10, we set the public investment efficiency at 1, which implies that all public investment spending translates into *effective* public capital. A lower (higher) value of efficiency reduces (increases) multipliers. This is consistent with Ganelli and Tervala (2020). In row 11, we set the quarterly depreciation rate of public capital at 2.5%, which implies an annual depreciation rate of 10%. Sims and Wolff (2018) use this value. The higher the depreciation rate of public capital, the smaller the welfare multiplier. This is consistent with Ganelli and Tervala (2020). In any case, the welfare multiplier is more than double to that of public transfers and consumption.

The consequences of fiscal policy may depend on the type and timing of taxation. In our framework, fiscal stimulus is entirely debt financed in the short-term, but lump sum taxes are increased gradually in response to the increase in public debt. In row 12, we increase the elasticity of lump sum taxes with respect public debt to 0.1, following Lieberknecht and Wieland (2019). Now the government pays the debt back faster. In row 13, we assume that the tax elasticity is set at 0.02. The multipliers are not sensitive to it. A high elasticity implies a stronger rise in taxes in the short-term. This implies a negative wealth effect and a small increase in labour supply. This increases the short–term output multiplier. On the other hand, a low elasticity implies that the effect is weaker but longer. Thus, the welfare multiplier is nearly unchanged. These findings are novel, since Rendahl (2016), Engler and Tervala (2018), and Watson and Tervala (2021) analysed a balanced-budget rise in public consumption.

In row 14, we increase the persistence of fiscal shocks to 0.93, based on Sims and Wolff (2018). A higher degree of persistence reduces the short-term output multipliers of transfers and consumption. More highly persistent fiscal stimulus continues to increase demand after the deepest fall in output and employment. This is consistent with Engler and Tervala (2018), who find a similar result in case of public consumption. However, the welfare multipliers of transfers and consumption are virtually unaffected. On the other hand, the increase in the public capital stock is more persistent and the welfare multiplier of public investment increases.

Galí et al. (2007) show that the introduction of non-Ricardian households to a DSGE model implies that it can account for the empirically observed short-term rise in private consumption in response to increases in government spending. In row 15, we reduce the share from 30% to 25%, following Li and Spencer (2016). This mechanically reduces the output multiplier of transfers as the direct effect of transfer payments on current consumption is related to the share of non-Ricardian households. On the other hand, a smaller share of non-Ricardian households increase the short-term output multiplier of consumption and investment, as a larger share of households increase short-term consumption as a response to an increase in medium-term income. However, the welfare effects, which are expressed in net present value terms, are less affected. Row 16 increases the share of non-Ricardian households to 0.5, following Galí et al. (2007). The most significant effect is to increase the output multiplier on transfers to 1.9, which is closer to the range of estimates for transfer multipliers in recessionary conditions in Gechert and Rannenberg (2018).

In row 17 (18), the Frisch elasticity of labour supply is reduced (increased) to 0.8 (1.4). The results are practically unchanged. Engler and Tervala (2018) found that a low Frisch elasticity leads to a considerable fall in the output and welfare multipliers. The difference is caused by the funding of spending. In their balanced budget framework, a rise in public spending leads to a short-term fall in private consumption due to the negative wealth effect of taxes. This effect is muted when the fiscal shock is financed initially by public debt and a rise in taxation is comparatively small in the short term.

The baseline value of the Calvo parameter is 0.75. This is close to the value found by Justiano Preston (2010) for Australia (0.79). Li and Spencer (2016) estimated that it is as low as 0.38 and Jääskelä and Nimark (2011) 0.62–0.69 for Australia. In row 19, the Calvo parameter is set at 0.5, and the results are insensitive to this parameter choice. In row 20, the Armington elasticity is reduced to 1.3, based on the estimate of Jääskelä and Nimark (2011) for Australia. The results do not respond to this change either.

Our model is relatively stylised and parsimonious, and may miss some intricate features of the COVID-19 environment. First, COVID-19 lockdowns have caused supply constraints and supply chain disruption may lead to a lower fiscal multiplier (Guerrierri et al. 2020). Notwithstanding that we account for a supply-side effect, a cost-push shock, in our simulations, our model is linear in the shocks, and there is no mechanism whereby supply shocks constrain the effectiveness of fiscal policy in our model. However, in the emerging empirical literature concerning fiscal multipliers during the pandemic (Granja et al. 2020; Faulkender et al. 2020), fiscal multipliers appear consistent with what would be expected from similar programs operating in more 'normal' recessionary conditions. Second, the level and nature of uncertainty during the COVID-19 recession may be very different from typical recessions. Output multipliers are higher in times of high uncertainty (Bachmann and Sims 2012; Berg 2019). Third, Australia has a very low level of public debt by international standards. Our model's results may apply only to countries with small public debt, as the effects of fiscal stimulus may depend on fiscal space (Ilzetzki et al. 2013 and Huidrom et al. 2019). Four, "AK" and R&D models can also explain output hysteresis after recessions (Cerra et al. 2021). In these models, physical capital is endogenous and reacts to potential output. In our learning-by-doing model, capital is determined by past employment, which determines the level of human capital in the current period, and exogenous government investment. The learning-by-doing model has similar implications to models where the hysteresis operates via physical capital formation (e.g. Jordà et al., 2020). We view the results as complimentary and mutually reinforcing, and provide theoretical motivation for empirical results where fiscal policy is found to be effective even in small open economies where fiscal policy might otherwise be assumed to strongly crowd out private activity (e.g. Auerbach and Gorodnichenko 2013; Riera-Crichton et al. 2015).

6. Conclusions

The IMF (2020b) and Powell (2020) have argued that fiscal policy should take a more active role in stimulating aggregate demand to reduce the damage of the COVID-19 recession on potential output and to support the recovery. It is sometimes said that fiscal stimulus should be timely, temporary and targeted. In our framework, timely fiscal stimulus, implemented in a recessionary environment, helps to limit the negative consequences of recessions on TFP and potential output. Temporary fiscal stimulus has high output and welfare multipliers, with public investment possessing larger output and welfare multipliers than transfers and public consumption. Public investment spending is the most effective when it is directed efficiently towards expanding the public capital stock for which the output elasticity is high. Our policy conclusion is that a well-spent, timely, and temporary rise in public investment spending should help limit the long-term damage of the recession on potential output, and strengthen the recovery most effectively.

CRediT authorship contribution statement

Juha Tervala: Conceptualization, Methodology, Software, Validation, Formal analysis, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Timothy Watson:** Conceptualization, Methodology, Software, Validation, Formal analysis, Resources, Data curation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

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