WORKING PAPER

MONEY VELOCITY, DIGITAL CURRENCY, AND INFLATION DYNAMICS

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ABSTRACT

This paper empirically investigates the impact of transaction cost-induced variations in the velocity of money on inflation dynamics in Indonesia, based on a structural New Keynesian Phillips curve (NKPC) with an explicit money velocity term. This money velocity effect arises from the role of money, both in physical and digital forms, in reducing the aggregate transaction cost and facilitating purchases of goods and services. We find a significant aggregate impact: our preferred estimates suggest that a 10% reduction in money velocity, which may be facilitated by a new digital currency (e.g. CBDC) issuance, would reduce the inflation rate by 1%, all else equal. Using the estimates and within a small-scale, structural New Keynesian model, we investigate the likely implications of a CBDC issuance on aggregate nominal and real fluctuations. A CBDC issuance that (conservatively) lowers the velocity of money by 5% is predicted to permanently raise the GDP level by 0.8% and lower the inflation rate by 0.8%. Both nominal and real interest rates are also permanently lower. Shocks to the velocity of money are an important driver of aggregate fluctuations.

Keywords: inflation dynamics, transaction cost, velocity of money, digital money, digital currency, digital payments, central bank digital currency (CBDC).

JEL Classifications: E31, E32, E42, E52, E58
1 Introduction

In August 2014 Bank Indonesia initiated a so-called National Noncash Movement (Gerakan Nasional Nontunai) to facilitate a transition from cash to non-cash transactions (digital payments) in the marketplace. Since then, there has been a tremendous growth in the use of digital payments in purchasing goods and services in Indonesia. In the first quarter of 2022 alone, the volumes of electronic money and digital banking transactions grew by 42% and 35% (year-on-year) and are predicted to reach 360 trillion and 52 trillion rupiahs, respectively, by the end of 2022.¹ While the majority of transactions in Indonesia currently are still conducted in cash, the share of non-cash transactions has steadily increased over the years.²

Similar to traditional paper money or cash, digital currency could be used to facilitate purchases of goods and services by lowering the transaction costs (Tobin (1956), Cooley and Hansen (1989), Dotsey and Ireland (1996)). The increased use of digital payments/money/currency is therefore associated with a reduction in the aggregate transaction costs (Woodford (2000), Humphrey et al. (2001)).³ Such a reduction in transaction costs in turn increases consumption activities, both in the offline and online marketplaces, and positively contributes to aggregate demand and output. Furthermore, the use of money as a means of payment induces variations in the velocity of money. In particular, a higher demand for money, both physical and digital, should decrease the velocity, all else equal. As shown by Ireland (2001) and Kim and Subramanian (2006), these movements in the velocity may amplify inflation fluctuations through a Phillips-curve relationship, affecting the transmission of monetary policy. Whether this effect is economically significant is an important empirical question, especially for central banks. This question is also relevant for the plan of various central banks to issue a central bank digital currency (CBDC), Bank Indonesia included (Bank Indonesia (2022)), as CBDC is a form of digital money or currency that is intended to be widely used as a means of payments.⁴

In this paper, we empirically investigate the impact of transaction cost-induced variations in the velocity of money on inflation dynamics in Indonesia. Given the estimates, we analyze the implications of an issuance of a new digital currency, e.g. a CBDC, on aggregate nominal and real fluctuations. To this end, we proceed in two steps. First, we derive and estimate a structural Phillips curve with an explicit money velocity term, as in Kim and Subramanian (2009). The estimations are conducted using a partial-information, generalized method of moments (GMM) method as in Gali and Gertler (1999). In the estimations, we consider several versions of the New Keynesian Phillips curve (NKPC), including a version with a backward-looking inflation component and with an open-economy dimension, relevant for Indonesia as

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¹Source: Bank Indonesia

²23% of point-in-sale transactions in Indonesia in 2020 were non-cash transactions (FIS 2020 Global Payments Report) — the share increased to 47% in 2021 (FIS 2021 Global Payments Report).

³In this paper, we use the terms digital payments, digital money, and digital currency interchangeably.

⁴See Boar et al. (2020) for a recent survey on CBDCs issuance by central banks around the world.
an open-economy emerging market country with historically moderate-to-high and highly variable inflation rates. In the second step, to facilitate our analysis on the likely implications of a new digital currency issuance, we utilize a small-scale, textbook New Keynesian model along the lines of Woodford (2003) and Gali (2015). While we only parsimoniously model the effect of a digital money issuance in this paper, the underlying mechanism is similar to that assumed in more-rigorous models (Barrdear and Kumhof (2022), Minesso et al. (2022)) — that is, a new digital money issuance such as CBDC acts as a technological innovation that reduces the aggregate transaction costs in purchasing goods and services.

We find that variations in the velocity of money have a non-trivial impact on inflation dynamics in Indonesia. In our preferred estimates, we find that a 10% increase in money velocity would increase inflation by almost 1%, all else equal. This is a non-trivial influence, even though the effect is still smaller than the effect of output gap variations, i.e. the traditional driving process of inflation fluctuations in a Phillips-curve relationship. Further to this, we show using a standard New Keynesian model that this effect translates to other nominal and real variables as well. For example, even under a low variance case, money velocity shocks are responsible for 23% of output gap variations and 14% of nominal interest rate variations, vis-à-vis other shocks in the model (technology, cost-push, and monetary-policy shocks). In our simulation of the effect of a CBDC issuance, which we treat as a near-permanent technological innovation, we find that an issuance that (conservatively) lowers the velocity of money by 5% would permanently raise the GDP level by 0.8% and lower the inflation rate by 0.8%. Both nominal and real interest rates are also predicted to be permanently lower.

Our paper contributes to the literature in two ways. There is currently an extensive literature on the estimation of the NKPC relationship using Indonesian data (Insukindro and Sahadewo (2010), Wimanda et al. (2011), Wimanda et al. (2013), Yanuarti (2007)). Such an NKPC has also been used in various structural, business-cycle models for the Indonesian economy for policy analyses and simulations (Harmanta et al. (2014), Idham et al. (2014), Lie (2019), Zams (2021), Juhro et al. (2022)). These studies, however, typically assume a cashless environment (Woodford (2003)), and hence, a constant velocity of money. Variations in the velocity therefore play no role in inflation dynamics. Our estimates and subsequent analyses show that ignoring the money velocity term may cause central banks to miss a significant source of inflation variations in their projections and an important channel in the transmission of monetary policy. This is especially true in an economic environment with a high growth rate of digital payments adoption, such as in Indonesia in the past decade or so.\(^5\)

We also contribute to the growing literature on the effect of digital money, CBDC included, on aggregate fluctuations (Berentsen (1998), Humphrey et al. (2001), Davoodalhosseini (2022), Barrdear and Kumhof (2022), Minesso et al. (2022), Williamson

\(^5\)For empirical studies on how digital money or payments and financial technologies affect the transmission of monetary policy, see Berentsen (1998), Woodford (2000), Meaning et al. (2018), and Hasan et al. (2020).
(2022)). We uniquely show that as long as the digital currency is widely used as a means of payments and reduces the transaction costs in the marketplace, the aggregate effect would transpire through a reduction in the velocity of money. As such, our paper also contributes to a growing body of research analyzing the likely economic implications of a CBDC issuance in Indonesia (Harahap et al. (2017), Syarifuddin and Bakhtiar (2021), DKEM (2021)). Our unique contribution on this front is in showing that at the aggregate level, the impact of a CBDC issuance works like a permanent positive shock to the rate of technological progress.

The paper’s organization is as follows. In Section 2, we briefly discuss the relationship between money creation, money velocity, and inflation, with a particular focus on the Indonesian economy. Section 3 derives a New Keynesian Phillips curve with an explicit money velocity term. We present and discuss our estimates of the NKPC in Section 4. Given the estimates, Section 5 investigates the impact of a digital money issuance on aggregate nominal and real variables within a small-scale New Keynesian model. Section 6 concludes.

2 Money velocity in Indonesia

The increasing risk of global stagflation arises from a complex interaction of global variables. While the global economic recovery creates new demand, the real sector is still experiencing supply chain disruption; the extreme climate changes and the Russian war have worsened the supply chain crisis in terms of rising energy and global food prices. Furthermore, the Zero Covid-19 Policy (ZCP) re-lockdown in China, responding to the latest virus variant, also decreasing the global value chain dynamic.

As a respond, many countries have chosen to adopt protectionism policies and stop food exports. Moreover, interest rate hikes many central banks to tackle the rising inflation led by advanced economies have driven the capital outflows from the emerging market economies, causing more pressure on the currencies of the emerging economies. This recent boom and bust cycle post pandemic have been well explained back in 1978.

In his seminal work in 1978 Milton Friedman raised issues on three recessions that had struck US economy over the preceding decade. Loose money created a boom and then inflation. An outcry against rising prices led to higher interest rates and a recession, only for rising unemployment to catch more public attention. So economic policy turned expansionary. Just as inflation began to fall, another boom kicked off. In relation with the current stagflation, the inflationary cycle began again, where the initial loose money policy happened during pandemic with low interest regime and liquidity injection to the economy, to cope with negative impact of economy lockdown.

Meanwhile, the megatrend of digitalization has created structural changes in Indonesia; and the pandemic has accelerated this phenomenon. On the one hand, the use of digital technology has provided us with many benefits, for both economic growth and inclusiveness. On the other hand, this cashless technology also contributes to the increasing volatility of money velocity, which in turn led to variability
in inflation dynamics.

However, research on the role of money velocity to inflation in Indonesia is very limited while mostly focuses on the USA, therefore no velocity of money factor in the Indonesian inflation decomposition. There is still also limited attempt to examine the determinants of velocity of money in emerging and developing economies (Akinlo, 2012; Okafor et al., 2013; Short, 2007; Altayee and Adam, 2013), therefore the intention of our study is to fill this research gap.

Our research, therefore, mainly relates to the first strand of literature on impact of velocity of money in the case of Indonesia. An analysis on the impact of velocity of money is essential to support monetary policy formulation in Indonesia. Understanding dynamics of money velocity is important because it provides information for policy makers on measuring the effectiveness of monetary policy. As mentioned before, as one of the resilient economies during this global inflation pressures, Indonesia is currently facing several challenges in the financial development such as aggressive promotion of cash-less society with QR code, e-money, online payment and the proposed Central Bank Digital Currencies. Again, these issues are expected to affect the dynamics of money velocity of money in Indonesia.

There is some evidence of cointegration movement between money velocity and industrial production, tax revenue, M2 money demand and short-term interest rates), while In the long-run, only tax revenue, short-term interest rates, and industrial production that significantly impact money velocity in Indonesia (Sharma and Syarifuddin (2019))

3 The Phillips-curve relationship: Inflation dynamics with transaction costs and money velocity

To model the aggregate effect of a digital currency issuance on inflation dynamics, we follow the tradition and basic idea behind the well-established transaction cost literature (Baumol (1952), Tobin (1956), Prescott (1987), Dotsey and Ireland (1996), Ireland (2001), Kim and Subramanian (2006)). Similar to traditional paper money or cash, digital money or currency could be used to facilitate purchases of goods and services by lowering the transaction costs, thus creating a demand for (digital) money. We do not take a stand on the form of the transaction costs — these costs could be in the form of communication and record-keeping costs in facilitating credit transactions (Dotsey and Ireland (1996)), or the credit time costs involved (Khan et al. (2003)), or something else entirely. Rather, following the setup in Kim and Subramanian (2006, 2009), we define the aggregate transaction cost \( \tau \) as

\[
\tau_t = c_t k_0 \left( \frac{M_t}{P_t c_t} \right)^{1-k_1} \exp(\varepsilon_t). \tag{1}
\]

In this setup, an increase in the volume of transaction (consumption purchase), \( c_t \), would raise the aggregate transaction cost, all else equal. As a means of payment, however, digital money can be used to facilitate transactions and reduce the transac-
tion cost \( \tau_t \). For a given volume of transactions, a higher use of (or the issuance of) digital money would increase real money balances \( M_t/P_t \), lowering the costs. \( \varepsilon_t \) can be generally treated as any other factors that affect the aggregate transaction cost, e.g. an exogenous shock to money creation, or, relevant for our paper, a new CBDC issuance by the central bank.

Since the velocity of money is \( v_t = P_t c_t / M_t \), equation (1) can be alternative written as

\[
\tau_t = c_t k_0 \varepsilon_t^{k_1 - 1} \exp(\varepsilon_t). \tag{2}
\]

Hence, there is a positive relationship between the velocity of money and the aggregate transaction cost. A lower money velocity, which could arise due to a higher use of (digital) money \( M_t \) or a lower aggregate nominal transaction value \( P_t c_t \), would decrease the cost \( \tau_t \), potentially influencing inflation dynamics and real fluctuations. The extent of this relationship is also dependent on the scale parameter \( k_0 > 0 \) and the curvature parameter \( k_1 > 0 \), which could be estimated from actual data.

**The Phillips curve relationship** As shown in the appendix, assuming the existence of transaction cost (2) and incorporating it into a standard New Keynesian model (Woodford (2003), Galí (2015)), we can obtain the following structural, log-linearized New Keynesian Phillips curve (NKPC):

\[
\hat{\pi}_t = \frac{\varrho}{1 + \varrho} \hat{\pi}_{t-1} + \frac{\beta}{1 + \varrho} E_t \hat{\pi}_{t+1} + \kappa \left[ \frac{(\sigma + \eta)}{1 + \varrho} \right] \left( \hat{y}_t - \hat{y}_f \right) + \kappa \left[ \frac{(1 - \beta \varrho)}{(1 + \varrho)(k_1 - 1)v_0} \right] \left( \hat{v}_t - \hat{v}_f \right). \tag{3}
\]

Here, \( \hat{\pi}_t, \hat{y}_t - \hat{y}_f, (\hat{v}_t - \hat{v}_f) \) denote inflation, the output gap, and the velocity gap, respectively. We define the two “gap” variables as their log deviation from the level under the flexible-price equilibrium, i.e. the natural level. \( \beta \) is the subjective discount factor, \( \varrho \) is the degree of past price indexation, \( \sigma \) is the inverse elasticity of intertemporal substitution, and \( \eta \) is the inverse Frisch labor supply elasticity. The reduced-form parameter \( \kappa \equiv (1 - \theta)(1 - \theta \beta)/\theta \) can be thought as the slope of the Phillips curve and is a compound function of \( \beta \) and the (Calvo (1983)) probability of non-optimal price adjustment \( \theta \). The parameter \( v_0 \geq 0 \) is related to the aggregate transaction cost function and is a function of the long-run level of money velocity. When there is no past indexation (\( \varrho = 0 \)), (3) is purely forward-looking as in Kim and Subramanian (2009).

Provided that \( v_0 > 0 \), it is apparent from (3) that variations in the money velocity gap \( \hat{v}_t - \hat{v}_f \) additionally affects inflation dynamics in our model. When no transaction cost is present, as in standard models, \( v_0 = 0 \) and the output gap becomes the only driving process. Whether \( v_0 > 0 \) and is economically significant in is an empirical question, which we investigate in the next section.
4 Estimates of the Phillips curve with money velocity

We estimate the velocity-enhanced NKPC relationship using a generalized method of moments (GMM) approach, which is a standard approach in the literature when estimating an NKPC relationship using a partial-information method (see e.g. the seminal paper of Gali and Gertler (1999)). We first describe the data series used and the calibration of several parameters, prior to describing the estimation procedure and results.

4.1 Data and calibration

The following Indonesian quarterly data series are used in our study: the nominal short-term interest rate (Bank Indonesia (BI) 7-day reverse repo rate), headline CPI inflation rate, real GDP (output) gap, money (M1 and M2) velocity gap, and commodity price inflation. The interest rate, inflation, and money velocity data are sourced from Bank Indonesia’s Indonesian Economic and Financial Statistics (SEKI). GDP data are sourced from OECD Main Economic Indicators. Commodity price inflation data, which are used as part of the instrument sets in the GMM estimation, are taken from the IMF’s primary commodity price index. To obtain GDP and money velocity gaps, we extract the gap components from the respective raw data using the Hodrick-Prescott (HP) filter. Our benchmark estimation period is from 2005.Q3 to 2022.Q1, where the starting period coincides with the start of the full-fledged implementation of the inflation targeting framework (ITF) by Bank Indonesia.

Figure 1 plots the constructed M1-based and M2-based money velocity data, along with the headline CPI inflation rate. As shown in the top panel, both measures of money velocity vary over the sample, with M1-based velocity being the more volatile one. The bottom panel plots the M1-based velocity and the headline CPI inflation rate. Although not readily visible, the two series are positively correlated, as suggested by the theoretical model. While the correlation coefficient is moderate (0.37), it is the case that inflation dynamics are also driven by other factors such as inflation expectations and output gap variations. To assess and isolate the significance of the variations in velocity gap on inflation dynamics, one need to conduct a full econometric exercise.

4.1.1 Calibration of elasticity parameters

The parameters \( \sigma, \eta, \) and \( k_1 \) in (3) are not identified, and hence, need to be calibrated. We set \( \sigma = 1, \eta = 1 \) as is standard in the literature (see e.g. Juhro et al. (2022)). The interest rate elasticity parameter is set to \( k_1 = 12.3 \), following our Newey-West OLS estimate of the model-implied money demand function. The appendix provides more details on the money demand function and the estimate of the parameter \( k_1 \).
Figure 1: Velocity of money and inflation in Indonesia
4.2 Reduced-form estimations

We first present the GMM estimates of the reduced-form coefficients $\gamma_b$, $\gamma_f$, $\lambda_y$ and $\lambda_v$, based on the NKPC

$$\hat{\pi}_t = \gamma_b \hat{\pi}_{t-1} + \gamma_f E_t \hat{\pi}_{t+1} + \lambda_y \left( \hat{y}_t - \hat{y}_t^f \right) + \lambda_v \left( \hat{v}_t - \hat{v}_t^f \right). \quad (4)$$

The orthogonality (moment) condition under the GMM approach is given by

$$0 = E_t \left[ \left\{ \hat{\pi}_t - \gamma_b \hat{\pi}_{t-1} - \gamma_f E_t \hat{\pi}_{t+1} - \lambda_y \left( \hat{y}_t - \hat{y}_t^f \right) - \lambda_v \left( \hat{v}_t - \hat{v}_t^f \right) \right\} \cdot Z_t \right], \quad (5)$$

where $Z_t$ is the a vector of variables dated $t$ or earlier, i.e. the set of instruments. An orthogonality condition such as (5) forms the basis of the GMM approach: time-$t$ (or later) expectation error should be orthogonal to the information set at time $t$. All variables in the instrument sets contain relevant information for inflation forecasts. We use two sets of instruments in our estimations, both in the reduced-form estimations and in the structural estimations below, as part of our robustness check. The first set (henceforth, IS 1) comprises of four lags of inflation, four lags of real GDP gap, two lags of BI 7-day repo rate, and two lags of M1 velocity. The second, larger set (henceforth, IS 2) includes four lags of inflation, four lags of GDP gap, six lags of BI 7-day repo rate, six lags of M1 velocity gap, and four lags of commodity price index.

Table 1 reports the reduced-form estimates for several NKPC specifications. In the standard NKPC with no money velocity term ($\lambda_v$ set to 0), all three coefficients are statistically significant, i.e. they have small standard errors. Moreover, the coefficients have the right signs. Lagged inflation is slightly more important than one-period ahead inflation expectation ($\gamma_b > \gamma_f$) in determining current inflation, irrespective of the instruments used in the GMM estimation. The point estimates of $\lambda_y$, 0.09 based on IS 1 and 0.10 based on IS 2, show that output gap is a relevant determinant of inflation fluctuations in Indonesia. These estimates are in line with other estimates of the NKPC slope using Indonesian data (see e.g. Insukindro and Sahadewo (2010), Wimanda et al. (2013), and Zams (2021)). \(^7\) The last column in Table 1 reports the J-statistic from Sargan-Hansen test (J-test), which show that we cannot reject the null of over-identifying restrictions against model misspecification.

The estimates for the NKPC with money velocity are reported in the middle panel. We find that once the velocity term is present, the forward-looking inflation term is much more important than the backward-looking term. Based on the first instrument set for example, $\gamma_f = 0.82$ with a low standard error, while $\gamma_b = 0.03$ and is not statistically different than zero. This finding that a purely forward-looking NKPC fits the Indonesian data better (rather than a hybrid one) is consistent with the findings from the full-information (Bayesian) DSGE-model estimates in Lie (2019), Zams (2021), and Juhro et al. (2022). Importantly, we find that the estimates of $\lambda_v$ are positive and both economically and statistically significant. $\lambda_v = 0.054$ (from IS 1 estimate) means

\(^7\)In their linear reduced-form Phillips curve specification, for example, Wimanda et al. (2013) find that the point estimate of the output gap coefficient is 0.12.
Table 1: NKPC with money velocity - Reduced-form estimation

<table>
<thead>
<tr>
<th></th>
<th>$\gamma_b$</th>
<th>$\gamma_f$</th>
<th>$\lambda_y$</th>
<th>$\lambda_v$</th>
<th>J-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No velocity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrument set 1 (IS 1)</td>
<td>0.484</td>
<td>0.464</td>
<td>0.085</td>
<td>–</td>
<td>11.59</td>
</tr>
<tr>
<td></td>
<td>(0.098)</td>
<td>(0.085)</td>
<td>(0.026)</td>
<td></td>
<td>[0.17]</td>
</tr>
<tr>
<td>Instrument set 2 (IS 2)</td>
<td>0.458</td>
<td>0.349</td>
<td>0.096</td>
<td>–</td>
<td>14.54</td>
</tr>
<tr>
<td></td>
<td>(0.070)</td>
<td>(0.063)</td>
<td>(0.022)</td>
<td></td>
<td>[0.80]</td>
</tr>
<tr>
<td><strong>With velocity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IS 1</td>
<td>0.029</td>
<td>0.815</td>
<td>-0.045</td>
<td>0.054</td>
<td>11.83</td>
</tr>
<tr>
<td></td>
<td>(0.065)</td>
<td>(0.081)</td>
<td>(0.044)</td>
<td>(0.022)</td>
<td>[0.22]</td>
</tr>
<tr>
<td>IS 2</td>
<td>0.147</td>
<td>0.642</td>
<td>0.022</td>
<td>0.031</td>
<td>14.45</td>
</tr>
<tr>
<td></td>
<td>(0.024)</td>
<td>(0.034)</td>
<td>(0.030)</td>
<td>(0.012)</td>
<td>[0.76]</td>
</tr>
<tr>
<td><strong>With velocity, purely forward-looking, no output gap</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IS 1</td>
<td>–</td>
<td>0.779</td>
<td>–</td>
<td>0.045</td>
<td>12.51</td>
</tr>
<tr>
<td></td>
<td>(0.043)</td>
<td>(0.012)</td>
<td></td>
<td>(0.033)</td>
<td></td>
</tr>
<tr>
<td>IS 2</td>
<td>–</td>
<td>0.738</td>
<td>–</td>
<td>0.048</td>
<td>14.42</td>
</tr>
<tr>
<td></td>
<td>(0.027)</td>
<td>(0.008)</td>
<td></td>
<td>(0.085)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: (1) This table reports the GMM estimates of the reduced-form coefficients of the NKPC in Eq. (4), based on the orthogonality condition in Eq. (6); (2) the instrument set IS 1 includes four lags of inflation, four lags of real GDP gap, two lags of BI rate (7-day repo rate), and two lags of M1 velocity gap; (3) the instrument set IS 2 includes all the variables in IS 1 plus two additional lags of BI rate, two additional lags of M1 velocity gap, and four lags of commodity price inflation; (4) numbers in parentheses are standard errors, except for the J-statistic (probability value is reported instead); (5) sample period: 2005.Q3-2022.Q1.

that a 10% increase in the velocity of money would increase the (quarterly) inflation rate by 0.54%. We also find that, somewhat surprisingly, once we account for money velocity in the NKPC, output gap is no longer a relevant determinant of inflation variation: irrespective of the instrument set used, the estimates of $\lambda_y$ are not statistically significant from zero (at 5% level).

The irrelevance of lagged inflation (based on IS 1) and the output gap prompts us to estimate an NKPC specification with only forward-looking inflation and money velocity terms (bottom panel of Table 1). This specification mirrors the standard purely forward-looking NKPC (see e.g. Yun (1996), Rotemberg and Woodford (1997), Woodford (2003), and Gali (2015)), albeit with money velocity as the driving process, instead of the output gap or real marginal cost. We find strong evidence of the importance of the forward-looking inflation and money velocity terms in driving inflation fluctuations. Here in particular, the estimates of $\lambda_v$ have the right sign and both economically and statistically significant, in line with the previous estimates under the hybrid NKPC and with the output gap term included.
Table 2: NKPC with money velocity - Structural estimation

<table>
<thead>
<tr>
<th></th>
<th>$\beta$</th>
<th>$\varrho$</th>
<th>$\theta$</th>
<th>$v_0$</th>
<th>Implied $\lambda_y$</th>
<th>Implied $\lambda_v$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unrestricted</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrument set 1 (IS 1)</td>
<td>1.057</td>
<td>-0.255</td>
<td>0.629</td>
<td>0.055</td>
<td>0.540</td>
<td>0.168</td>
</tr>
<tr>
<td></td>
<td>(0.056)</td>
<td>(0.098)</td>
<td>(0.092)</td>
<td>(0.040)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrument set 2 (IS 2)</td>
<td>1.019</td>
<td>-0.187</td>
<td>0.614</td>
<td>0.027</td>
<td>0.580</td>
<td>0.089</td>
</tr>
<tr>
<td></td>
<td>(0.054)</td>
<td>(0.087)</td>
<td>(0.067)</td>
<td>(0.015)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Restricted $\beta$</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IS 1</td>
<td>0.9942</td>
<td>-0.247</td>
<td>0.646</td>
<td>0.050</td>
<td>0.521</td>
<td>0.148</td>
</tr>
<tr>
<td></td>
<td>(0.098)</td>
<td>(0.083)</td>
<td>(0.033)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IS 2</td>
<td>0.9942</td>
<td>-0.184</td>
<td>0.614</td>
<td>0.025</td>
<td>0.600</td>
<td>0.086</td>
</tr>
<tr>
<td></td>
<td>(0.087)</td>
<td>(0.053)</td>
<td>(0.011)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Restricted $\beta$, purely forward-looking</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IS 1</td>
<td>0.9942</td>
<td>0</td>
<td>0.592</td>
<td>0.029</td>
<td>0.567</td>
<td>0.094</td>
</tr>
<tr>
<td></td>
<td>(0.063)</td>
<td></td>
<td>(0.013)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IS 2</td>
<td>0.9942</td>
<td>0</td>
<td>0.578</td>
<td>0.017</td>
<td>0.620</td>
<td>0.060</td>
</tr>
<tr>
<td></td>
<td>(0.038)</td>
<td></td>
<td>(0.006)</td>
<td></td>
<td></td>
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</tbody>
</table>

**Notes:** (1) This table reports the GMM estimates of the structural parameters of the NKPC in Eq. (3), based on the orthogonality condition in Eq. (6); (2) numbers in parentheses are standard errors; (3) $\lambda_y = \frac{\kappa}{1+\beta\varrho}$, $\lambda_v = \frac{\kappa v_0 (k_1-1)}{(1+\beta\varrho)}$, $\kappa \equiv (1-\theta)(1-\theta\beta)/\theta$, and in all cases, $\sigma = \eta = 1$, $k_1 = 12.3$; (4) the instrument set IS 1 includes four lags of inflation, four lags of real GDP gap, two lags of BI rate (7-day repo rate), and two lags of M1 velocity gap; (5) the instrument set IS 2 includes all the variables in IS 1 plus two additional lags of BI rate, two additional lags of M1 velocity gap, and four lags of commodity price inflation; (6) sample period: 2005.Q3-2022.Q1.

### 4.2.1 Structural estimations

We now estimate directly the structural parameters $\beta$, $\varrho$, $\theta$, and $v_0$, based on the orthogonality condition

$$0 = E_t \left[ \begin{array}{l}
\theta (1+\beta \varrho) \hat{\pi}_t - \theta \varrho \hat{\pi}_{t-1} - \theta \beta \hat{\pi}_{t+1} \\
-(1-\theta)(1-\theta\beta) \{ (\sigma + \eta) (\hat{y}_t - \hat{y}_t^f) \} \\
+ v_0 (k_1-1) (\hat{v}_t - \hat{v}_t^f) \end{array} \right] \cdot Z_t . \right.$$  

(6)

As in the reduced-form estimations, we report estimates for the two aforementioned instrument sets.

Table 2 presents the structural estimation results. As in the reduced-form estimations, we report the estimates for two different instrument sets, IS 1 and IS 2. In addition to the unrestricted, benchmark specification—where we estimate the parameters $\beta$, $\varrho$, $\theta$, and $v_0 = V_0/(1+V_0)$—we also report the estimates under restricted $\beta$ (as in Gali and Gertler (1999)), both under the hybrid NKPC (unrestricted $\varrho$) and purely forward-looking NKPC (restricted $\varrho = 0$). The purely forward-looking case is motivated by the previous reduced-form estimation results. We calibrate $\sigma = 1$ and $\eta = 1$ since
these parameters are not identified — these values are standard in the literature, used e.g. in the estimated DSGE model for Indonesia in Juhro et al. (2022). The last two columns in the table report the implied coefficients of the output gap ($\lambda_y$) and the velocity of money ($\lambda_v$), given the calibration and the point estimates of the structural parameters.\(^8\)

Our estimates in the unrestricted case show that the impact of the velocity of money on inflation dynamics, represented by the parameter $v_0$, is positive (as predicted by the theoretical model) and have low standard errors. This is true irrespective of the instrument set used, although the point estimate is somewhat lower under IS 2 (0.03 vs. 0.06 under IS 1). The point estimates of the Calvo parameter $\theta$ across the two instrument sets range from 0.61 to 0.63, which are in line with the estimates reported in various studies using Indonesian data.\(^9\) The estimates of $\beta$ and $\varphi$, however, are incongruent with the underlying theory. $\beta$ are estimated to be above unity (although still close to 1). The estimates for $\varphi$ are negative and have low standard errors. Notwithstanding these estimates, we find that the implied coefficient on the money velocity term is significant: $\lambda_v = \{0.17, 0.09\}$. While the impact of money velocity is not as large as the output gap impact ($\lambda_y$), it is not insignificant and is larger than that based on the reduced-form estimation.

We next restrict $\beta$ to be consistent with the underlying theory, i.e. we set $\beta = 0.9942$, per the estimate in Juhro et al. (2022). Overall, the estimates are consistent with those in the unrestricted case. The estimated values of $v_0$ and the implied coefficients on the velocity term are positive and significant. In the bottom panel of Table 2, we also report the estimates when we restrict $\varphi = 0$, rendering the Phillips curve purely forward-looking. The estimated values of $\theta$ and $v_0$ and the implied $\lambda_v$ coefficients are now slightly smaller compared to their counterparts in the previous two cases in the table. Despite this, we still find strong evidence of a positive and significant contribution of money velocity on inflation dynamics.

### 4.3 Robustness

This section presents the results from three robustness exercises. First, we extend the sample period to include the formative period of the implementation of inflation targeting framework (ITF) in Indonesia, going back from the 1st quarter of 2001. Second, instead of M1, we measure the velocity gap using broad money (M2). The third robustness exercise involves the use of an alternative moment condition in the structural estimation:

$$0 = E_t \left[ \left\{ \begin{array}{c} \hat{\pi}_t - \frac{\varphi}{1+\varphi \theta} \hat{\pi}_{t-1} - \frac{\beta}{1+\beta \varphi} \hat{\pi}_{t+1} \\ \frac{(1-\theta)(1+\beta \varphi)}{\sigma + \eta} \left\{ \begin{array}{c} \hat{y}_t - \hat{y}_f \\ \hat{v}_t - \hat{v}_f \\ \end{array} \right\} \right\} \cdot Z_t \right]. \quad (7)$$

\(^8\)The J-test results (not reported in the table) indicate that for all cases, we cannot reject the over-identifying restrictions.

\(^9\)See e.g. Hermawan and Munro (2008), Harmanta et al. (2014), Dutu (2016) Lie (2019), and Juhro et al. (2022).
The results from these robustness exercises are reported in Table 3.

Under long sample (2001.Q1-2022.Q1), we still find the impact of money velocity is positive in all considered specifications. The estimates of the velocity coefficient \( \lambda_v \) range from 0.023 to 0.096. Except for the reduced-form estimate under IS 1, the estimates (\( v_0 \) in the structural estimation case) are statistically significant. When we use M2 instead of M1 to construct the velocity gap, the estimates (\( v_0 \) in the structural estimation case) turns out to be negative, which is inconsistent with underlying theory. It remains the case, however, that the reduced-form estimates show positive and significant \( \lambda_v \) values. In fact, the impact of the velocity term appears to be larger, e.g. \( \lambda_v = 0.42 \) in the IS 1 case. Our structural estimation based on the alternative moment condition produces an implausibly-large value of \( v_0 \) irrespective of the instrument set used (the estimates, however, have very large standard errors). This large value appears to be caused by a large estimate of the Calvo parameter (\( \theta \approx 1 \)) — hence, it appears that the moment condition (7) fails to identify this parameter. Interestingly, it is still the case that the implied \( \lambda_v \) values are still positive and in line with the values previously reported in Table 2.

5 Implications of a digital currency issuance on inflation dynamics and real fluctuations

Having established the econometric evidence that money velocity variations have statistically and economically significant effect on inflation dynamics, we now assess the likely implications on real aggregate fluctuations. To this end, we utilize a structural, small-scale New Keynesian model, along the line of the textbook model in Woodford (2003) or Gali (2015). This standard model consists of three (log-linearized) equations, which jointly determine the fluctuations in the output gap \( \hat{x}_t \equiv \hat{y}_t - \hat{y}_f^t \), inflation \( \hat{\pi}_t \), and the nominal interest rate \( \hat{R}_t \):

\[
\begin{align*}
\hat{x}_t &= E_t \hat{x}_{t+1} - \frac{1}{\sigma} \left( \hat{R}_t - E_t \hat{\pi}_{t+1} \right) + \hat{\varepsilon}_{x,t}, \\
\hat{\pi}_t &= \beta E_t \hat{\pi}_{t+1} + \frac{(1-\theta)(1-\theta\beta)}{\theta} (\sigma + \eta) \hat{x}_t + v_0(k_1 - 1) \left( \hat{v}_t - \hat{v}_f^t \right) + \hat{\varepsilon}_{m,t}, \\
\hat{R}_t &= \rho R \hat{R}_{t-1} + (1 - \rho R) [\phi_\pi \hat{\pi}_t + \phi_x \hat{x}_t] + \hat{\varepsilon}_{r,t}.
\end{align*}
\]

The first equation is a standard forward-looking IS curve, the second equation is a (forward-looking) Phillips curve, and the third equation is a standard, Taylor-type monetary policy rule. \( \hat{\varepsilon}_{x,t} \) is a supply shock, which can be thought as a function of productivity or technology shock. \( \hat{\varepsilon}_{m,t} \) is a cost-push or mark-up shock. \( \hat{\varepsilon}_{r,t} \) is an exogenous, unsystematic monetary-policy shock. These exogenous shocks follow

\[
\begin{align*}
\hat{\varepsilon}_{x,t} &= \rho_x \hat{\varepsilon}_{x,t-1} + \eta_{x,t}, \\
\hat{\varepsilon}_{m,t} &= \rho_m \hat{\varepsilon}_{m,t-1} + \eta_{m,t}, \\
\hat{\varepsilon}_{r,t} &= \rho_r \hat{\varepsilon}_{r,t-1} + \eta_{r,t}.
\end{align*}
\]
Table 3: Sensitivity analysis (Robustness)


<table>
<thead>
<tr>
<th></th>
<th>Reduced-form</th>
<th>Structural</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\gamma_f$</td>
<td>$\lambda_y$</td>
</tr>
<tr>
<td>IS 1</td>
<td>0.935</td>
<td>0.085</td>
</tr>
<tr>
<td></td>
<td>(0.040)</td>
<td>(0.084)</td>
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<tr>
<td>IS 2</td>
<td>1.019</td>
<td>-0.169</td>
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<tr>
<td></td>
<td>(0.033)</td>
<td>(0.043)</td>
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<tbody>
<tr>
<td></td>
<td>$\gamma_f$</td>
<td>$\lambda_y$</td>
</tr>
<tr>
<td>IS 1</td>
<td>0.816</td>
<td>-0.740</td>
</tr>
<tr>
<td></td>
<td>(0.078)</td>
<td>(0.152)</td>
</tr>
<tr>
<td>IS 2</td>
<td>0.796</td>
<td>-0.246</td>
</tr>
<tr>
<td></td>
<td>(0.026)</td>
<td>(0.064)</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Reduced-form</th>
<th>Structural</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\gamma_f$</td>
<td>$\lambda_y$</td>
</tr>
<tr>
<td>IS 1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IS 2</td>
<td>-</td>
<td>-</td>
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<td></td>
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</tbody>
</table>

Notes: (1) Numbers in parantheses are standard errors; (2) In the structural estimation, $\lambda_y = \frac{\alpha(\sigma+\eta)}{1+\beta\eta}$, $\lambda_v = \frac{\alpha_0(k_1-1)}{1+\beta\eta}$, $\kappa \equiv (1-\theta)(1-\theta\beta)/\theta$, and in all cases, we set $\sigma = \eta = 1$, $k_1 = 12.3$, $\beta = 0.9942$, $\varrho = 0$; (3) the instrument set IS 1 includes four lags of inflation, four lags of real GDP gap, two lags of BI rate (7-day repo rate), and two lags of M1 velocity gap; (4) the instrument set IS 2 includes all the variables in IS 1 plus two additional lags of BI rate, two additional lags of M1 velocity gap, and four lags of commodity price inflation; (5) the alternative moment (orthogonality) condition is given in Eq. (7); (6) for M2 and alternative moment condition estimate, the sample period is 2005.Q3-2022.Q1.
where $\eta_{x,t} \sim i.i.d. N(0, \sigma_x^2)$, $\eta_{m,t} \sim i.i.d. N(0, \sigma_m^2)$, $\eta_{r,t} \sim i.i.d. N(0, \sigma_r^2)$.

For the purpose of our simulation below, the money velocity gap $(\hat{v}_t - \hat{v}_t^f)$ is simply assumed to negatively correlate with the aggregate transaction cost $\hat{\varepsilon}_{v,t}$ in the following fashion:

$$\left( \hat{v}_t - \hat{v}_t^f \right) = -\psi \hat{\varepsilon}_{v,t}. \tag{8}$$

$\psi$ is a scale parameter that governs the extent of the relationship between the transaction cost and the velocity of money. The transaction cost is assumed to be exogenous in our simulation and is assumed to followed an AR(1) process,

$$\hat{\varepsilon}_{v,t} = \rho_v \hat{\varepsilon}_{v,t-1} + \eta_{v,t}, \tag{9}$$

$\eta_{v,t} \sim i.i.d. N(0, \sigma_v^2)$.

We note that the simple, reduced-form relationship (8) is consistent with the underlying theory presented in Section 3 and elaborated in the appendix. That is, money, physical or digital, could be used to reduce the transaction cost involved in purchasing goods and services. The presence of a digital currency that is widely acceptable as a means of payments decreases the aggregate transaction cost, which in turn should decrease the aggregate velocity of money, all else equal.\(^10\) Based on this hypothesis, a positive $\eta_{v,t}$ shock in (9) can thus be thought as representing an issuance of a new digital currency e.g. a CBDC issuance by the central bank.\(^11\)

**Calibration of parameters** We calibrate $\sigma = \eta = 1$ and $k_1 = 12.3$ as in our estimation exercise. For the Phillips curve parameters, we set $\beta = 0.9942$, $\theta = 0.592$, and $\nu_0 = 0.029$, based on the structural estimation in the previous section under restricted $\beta$ with instrument set 1 (see Table 2). The Taylor-rule parameters are set to $\rho_R = 0.75$, $\phi_\pi = 1.5$, and $\phi_x = 0.5/4$. For the standard deviations of exogenous shocks, we set $\sigma_x = 0.25$, $\sigma_m = 1$, $\sigma_r = 0.25$. For the money velocity-related parameters, we set $\rho_z = 0.995$ so that we can treat a CBDC issuance as a (near) permanent technology shock, following the literature on trend inflation (see e.g. Cogley and Sargent (2005), Justiniano and Primiceri (2008), and Barnes et al. (2011)). These calibrations are ad-hoc, as matching features of the data is not our primary aim in the current exercise. Our purpose in this section is to show that the presence of digital currency could have non-trivial implications for aggregate nominal and real variables, through its influence on the aggregate money velocity.

\(^10\)An alternative hypothesis is that the presence of a digital currency increases the velocity of money (see e.g. Berentsen (1998)). This hypothesis, however, relies on the assumptions that the digital currency replaces central bank currency and reduces the monetary base, which need not be the case.

\(^11\)While it is possible to endogenously model the effect of a CBDC issuance (Barrdear and Kumhof (2022), Davooldhosseini (2022), Minesso et al. (2022)), we leave such a modelling for future research. Here, we simply treat the CBDC as affecting (reducing) the aggregate transaction costs, which is consistent with the implications of the endogeneous models in the aforementioned studies.
Table 4: Variance decompositions for different variances of money velocity shock

<table>
<thead>
<tr>
<th></th>
<th>Productivity</th>
<th>Cost-push</th>
<th>Monetary policy</th>
<th>Money velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>No money-velocity shock ($\sigma_v = 0$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>72.95</td>
<td>20.01</td>
<td>7.04</td>
<td>0</td>
</tr>
<tr>
<td>Output gap</td>
<td>0.04</td>
<td>73.95</td>
<td>26.01</td>
<td>0</td>
</tr>
<tr>
<td>Inflation</td>
<td>0.47</td>
<td>73.53</td>
<td>26.00</td>
<td>0</td>
</tr>
<tr>
<td>Nominal int. rate</td>
<td>6.05</td>
<td>69.34</td>
<td>24.61</td>
<td>0</td>
</tr>
<tr>
<td>Low variance ($\sigma_v = 0.25$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>67.62</td>
<td>18.55</td>
<td>6.52</td>
<td>7.31</td>
</tr>
<tr>
<td>Output gap</td>
<td>0.03</td>
<td>57.27</td>
<td>20.14</td>
<td>22.56</td>
</tr>
<tr>
<td>Inflation</td>
<td>0.46</td>
<td>71.76</td>
<td>25.38</td>
<td>2.41</td>
</tr>
<tr>
<td>Nominal int. rate</td>
<td>5.20</td>
<td>59.57</td>
<td>21.14</td>
<td>14.09</td>
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<tr>
<td>Medium variance ($\sigma_v = 0.50$)</td>
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<td></td>
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<tr>
<td>Output</td>
<td>55.47</td>
<td>15.21</td>
<td>5.35</td>
<td>23.97</td>
</tr>
<tr>
<td>Output gap</td>
<td>0.02</td>
<td>34.15</td>
<td>12.01</td>
<td>53.81</td>
</tr>
<tr>
<td>Inflation</td>
<td>0.43</td>
<td>66.92</td>
<td>23.67</td>
<td>8.99</td>
</tr>
<tr>
<td>Nominal int. rate</td>
<td>3.66</td>
<td>41.87</td>
<td>14.86</td>
<td>39.61</td>
</tr>
<tr>
<td>High variance ($\sigma_v = 1$)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>32.27</td>
<td>8.85</td>
<td>3.11</td>
<td>55.77</td>
</tr>
<tr>
<td>Output gap</td>
<td>0.01</td>
<td>13.06</td>
<td>4.59</td>
<td>82.33</td>
</tr>
<tr>
<td>Inflation</td>
<td>0.34</td>
<td>52.71</td>
<td>18.64</td>
<td>28.31</td>
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<tr>
<td>Nominal int. rate</td>
<td>1.67</td>
<td>19.14</td>
<td>6.79</td>
<td>72.40</td>
</tr>
</tbody>
</table>

Notes: (1) Entries above are unconditional variance decompositions (in %), based on the small-scale structural New Keynesian model; (2) the standard deviations of the others shocks (productivity, cost-push, and monetary-policy) are kept at $\sigma_x = 0.25$, $\sigma_m = 1$, and $\sigma_r = 0.25$, respectively.
Variance decompositions  We first assess the importance of money-velocity shocks on the model variables by computing the unconditional variance decomposition. Table 4 reports the decompositions for output, output gap, inflation, and nominal interest rate, for various values of the standard deviation of money-velocity shock, \( \sigma_v \). When \( \sigma_v = 0 \), the velocity of money is constant and the shock does not contribute to the variations of all the variables. Output fluctuations are largely driven by productivity and cost-push shocks. Monetary-policy and cost-push shocks are the dominant drivers of the fluctuations in inflation, the output gap, and the nominal interest rate. Despite our ad-hoc calibration, these decompositions are not inconsistent with those produced by a larger-scale, estimated structural model for Indonesia such as in Lie (2019) and Juhro et al. (2022).12

When \( \sigma_v > 0 \), we find that money-velocity shocks could be an important driver for aggregate nominal and real fluctuations. Here, when \( \sigma_v = 0.25 \) (the “low variance” case) and is equal to \( \sigma_x \) and \( \sigma_r \), these shocks contribute to 2.4% of inflation variations and 7.3% of output variations. The impact on output gap and nominal interest rate variations are even larger, at 22.6% and 14.1%, respectively. As expected, the contribution of money-velocity shocks are even larger when \( \sigma_v \) is higher. In the “high variance” case (\( \sigma_v = 1 \)), these shocks are now responsible for 28.3% of inflation variations and 82.3% of output gap variations. The contributions of the other three shocks decline as \( \sigma_v \) gets higher. Our finding in Table 4 has various policy implications. If, for example, the central bank uses the above (or similar) model to forecast inflation and the output gap, ignoring variations in the money-velocity gap would affect the accuracy of the forecasts. The degree of the inaccuracy may be non-trivial, even in the (more realistic) low-variance case.

Impact of a CBDC issuance  Next, we use our estimates and the model to assess the impact of a CBDC issuance by the central bank, which we modelled as a 5% near-permanent decrease in the velocity of money.13 The impulse responses are plotted in Figure 2. Qualitatively, this CBDC shock, which affects the aggregate fluctuations by permanently lowering the transaction costs and the velocity of money, has a similar implication to that arising from a permanent increase in technological progress or innovation. Quantitatively, our calibration implies that that such a CBDC issuance would decrease the long-run inflation rate by around 0.8% per annum. The level of output would have permanently increased by 0.8%. Lower long-run inflation means that the nominal interest rate would be lower (by 0.8% as well). The model also predicts a permanently lower real interest rate, though the effect is minimal.

We note that despite our ad-hoc modelling of the impact of a CBDC issuance, the impact in Figure 2 is consistent with that arising from more-rigorous models

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12 Lie (2019), for example, finds that technology and monetary-policy shocks are the main drivers for output and inflation fluctuation in Indonesia.
13 As CBDC is a relatively new subject (see Boar et al. (2020) for a recent survey on CBDCs issuance by central banks around the world), we have no prior empirical material regarding the impact of a CBDC issuance on money velocity to draw upon. The 5% aggregate money velocity decrease is simply a conservative estimate of the impact.
Notes: (1) The figure plots the impulse response to a CBDC issuance shock, modeled as a 5% near-permanent decrease in the velocity of money; (2) responses are based on the small-scale structural New Keynesian model.

Figure 2: Impulse responses to a 5% decrease in money velocity (CBDC shock)
(Barrdear and Kumhof (2022). Mineso et al. (2022)). Barrdear and Kumhof (2022) for example find that a CBDC issuance is associated with a permanent decrease in transaction costs, which in turn would permanently raise GDP and lower the real interest rates.14

6 Conclusion and policy implications

Do variations in the velocity of money have a non-trivial impact on inflation fluctuations in Indonesia? We answer this question empirically within a structural New Keynesian Phillips curve (NKPC) with an explicit money velocity term. This money velocity effect arises from the role of money, both in physical and digital forms, in reducing the aggregate transaction cost and facilitating purchases of goods and services. We find a significant aggregate impact: our preferred estimates suggest that a 10% reduction in money velocity, which may be facilitated by a new digital currency (e.g. CBDC) issuance, would reduce the inflation rate by 1%, all else equal. Using the estimates and within a small-scale, structural New Keynesian model, we investigate the likely implications of a CBDC issuance on aggregate nominal and real fluctuations. We show that a CBDC issuance would permanently increase output and lower inflation and the nominal and real interest rates. Shocks to the velocity of money are an important driver of aggregate fluctuations.

Our finding of a significant effect of money velocity within a Phillips curve relationship in Indonesia has an important implication for Bank Indonesia’s monetary policy conduct, especially in an environment with ubiquitous use of digital money as a medium of exchange. In such an environment, controlling the variations in the velocity of money, e.g. through the use of central bank accounts or the adjustment on the interest rate on the CBDC (should it become available in the future), should be an integral part of Bank Indonesia’s policy strategies in managing business cycle fluctuations. It also implies that when a structural model is used in Bank Indonesia’s policy projections and forecasts, the Phillips curve relationship should preferably include a money velocity term. Ignoring the term may result in inaccurate policy prescriptions and forecasts. Our result regarding the likely impact of a CBDC issuance should be taken with a degree of caution, given the use of a calibrated, small-scale model and parsimonious modelling of the impact. However, as long as the CBDC is widely used as a means of payment in the marketplace (and hence, leads to a reduction in the aggregate transaction cost), our predictions as to the qualitative effect are likely to hold. Future research should utilize a larger-scale, structural model to more accurately quantify the likely impact of a CBDC issuance on aggregate fluctuations and Bank Indonesia’s monetary policy conduct.

14Specifically, Barrdear and Kumhof (2022) find that a CBDC issuance equivalent in value to 30% of GDP would permanently raise the level of GDP by 3%.
References


Appendix

In this appendix we derive the New Keynesian Phillips curve (NKPC) with money velocity used in our estimation. Our approach closely follows the transaction cost assumption in Kim and Subramanian (2006) and Kim and Subramanian (2009). Here, households face a transaction cost when purchasing goods. Money, however, can be used to facilitate transactions and reduce the transaction costs. Under this scenario, an increase in the use of money will decrease the velocity of money, *ceteris paribus*. Hence, the aggregate transaction cost is a positive function of the money velocity. While money can be used to facilitate transactions and reduce the transaction cost, there is an opportunity cost of holding and using money, however (i.e. the interest rate). This means that households face a tradeoff between using money or credit.

**Households’ problem**

In each period, the representative household chooses the optimal amounts of consumption $c_t$, labor $N_t$, nominal one-period bond holding $B_t$, and nominal money holding $M_t$ to maximize the lifetime utility function

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left[ \frac{c_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\eta}}{1+\eta} \right],$$

subject to the nominal budget constraint

$$P_t c_t + M_t + B_t + P_t \tau_t \leq W_t N_t + M_{t-1} + (1 + i_{t-1}) B_{t-1} + \Pi^n_t + T R^n_t.$$  \hspace{1cm} (A.1)

Here, $W_t$ is the nominal wage, $i_t$ is the (net) nominal interest rate on the bond, $\Pi^n_t$ is the dividend received by households from their ownerships of firms, $T R^n_t$ is the nominal tax or transfer from the government, and $P_t$ is the aggregate price level. $\beta$ is the subjective discount factor, $\sigma$ is the inverse of elasticity of intertemporal substitution, $\eta$ is the inverse Frisch labor supply elasticity, and $\chi$ is a scale parameter.

$\tau_t$ is the associated (real) transaction cost incurred by households whenever they use credit when purchasing goods. The transaction cost $\tau_t$ is defined as

$$\tau_t = e^{\varepsilon_t} \varepsilon_t k_0 v_t^{k_1-1},$$

where $v_t \equiv \frac{P_t c_t}{M_t}$ is the velocity of money, $\varepsilon_t$ is an exogenous money demand shock, $k_0$ is a scale parameter, and $k_1$ is a parameter that affects the curvature of the implied money demand function (together with $k_0$).

The nominal budget constraint (A.1) can be converted into a real one by dividing
both sides by \( P_t \):
\[
c_t + m_t + b_t + e^e_t c_t k_0 v_t^{k_1 - 1} \leq w_t N_t + \frac{m_{t-1}}{\pi_t} + (1 + i_t) \frac{b_{t-1}}{\pi_t} + \Pi_t + TR_t, \tag{A.2}
\]
where \( m_t \equiv M_t / P_t \), \( b_t \equiv B_t / P_t \), \( w_t \equiv W_t / P_t \), \( \Pi_t \equiv \Pi_t^\eta / P_t \), \( TR_t \equiv TR_t^\eta / P_t \), and \( \pi_t \equiv P_t / P_{t-1} \) denote real money holding, real bond holding, real wage, real dividend, real transfer, and gross price inflation, respectively. Denoting \( \lambda_t \) as the Lagrange multiplier, the first-order conditions (FOCs) of households’ problem with respect to \( c_t, N_t, b_t, \) and \( m_t \) are given by
\[
0 = c_t - \sigma - \lambda_t \left( 1 + e^e_t k_0 v_t^{k_1 - 1} \right), \tag{A.3}
0 = -\chi N_t \eta + \lambda_t w_t, \tag{A.4}
0 = \beta E_t \lambda_{t+1} \frac{(1 + i_t)}{\pi_{t+1}} - \lambda_t, \tag{A.5}
0 = \beta E_t \lambda_{t+1} \frac{1}{\pi_{t+1}} - \lambda_t + \lambda_t e^e_t k_0 (k_1 - 1) v_t^{k_1}. \tag{A.6}
\]

**Money demand function**

The money demand function is implicit in equation (A.6). Combining (A.5) and (A.6) yields
\[
e^e_t k_0 (k_1 - 1) v_t^{k_1} = 1 - R_t^{-1}, \tag{A.7}
\]
where \( R_t = 1 + i_t \) is the gross nominal interest rate. Rearranging the above, we obtain
\[
q_t^{-k_1} = \frac{1}{e^e_t k_0 (k_1 - 1)} \left( \frac{i_t}{1 + i_t} \right), \tag{A.8}
\]
where
\[
q_t \equiv v_t^{-1} \equiv \frac{M_t}{P_tC_t}
\]
is the inverse money velocity. (A.8) is the associated money demand function, which could also be written in a log form,
\[
\log(q_t) = \gamma_0 + \gamma_1 \log \left( \frac{i_t}{1 + i_t} \right) + \eta_t, \tag{A.9}
\]
where
\[
\gamma_0 \equiv \frac{1}{k_1} \log \left( k_0 (k_1 - 1) \right),
\gamma_1 \equiv \frac{1}{k_1},
\eta_t \equiv \frac{1}{k_1} e^e_t.
\]

Given \( q_t \left( \frac{M_t}{P_tC_t} \right) \) and \( i_t \) data (see the main text), we estimate (A.9) and obtain the interest elasticity of money demand \( \frac{1}{k_1} \). We use the Newey-West OLS method to estimate the relationship (A.9). For our benchmark estimation using the data from
2005.Q3-2022.Q1, we obtain $k_1 = 12.3$.

**The log-linearized IS curve**

We next linearize the first-order conditions (A.3)-(A.6). Combining the resulting linearized equations yields the IS curve equation,

$$\sigma (E_t \hat{c}_{t+1} - \hat{c}_t) = \hat{R}_t - E_t \hat{\pi}_{t+1}$$

(A.10)

where $V_0 \equiv e^{\varepsilon} k_0 k_1 v^{k_1-1} = k_0 k_1 v^{k_1-1}$ ($\varepsilon = 0$ at the steady state). If there is no transaction cost, $V_0 = 0$ and all goods are purchased using credit — here, we have the standard, cashless-model IS curve equation, i.e. the last two terms in the RHS of (A.10) are absent. All the hatted variables are in terms of log deviations from the steady state values, except for $\hat{\varepsilon}_t \equiv \varepsilon_t - \varepsilon$, which is in level deviation.

Based on the FOCs, we also have the following log-linearized equations for real wage and money velocity:

$$\hat{w}_t = \sigma \hat{c}_t + \eta \hat{N}_t$$

(A.11)

$$\hat{v}_t = \left[ \frac{1}{k_1 (R - 1)} \right] \hat{R}_t - \left[ \frac{1}{k_1} \right] \hat{\varepsilon}_t.$$  

(A.12)

**Firms’ problem and the NKPC**

Monopolistically-competitive goods-producing firms (or retailers) problem is standard. We use a Calvo price assumption with a backward-looking indexation following the setup in Christiano et al. (2005). Under this setup, we have the following hybrid NKPC (see e.g. Christiano et al. (2005) and Barnes et al. (2011)):

$$\hat{\pi}_t = \frac{\theta}{1 + \beta \theta} \hat{\pi}_{t-1} + \frac{\beta}{1 + \beta \theta} E_t \hat{\pi}_{t+1} + \frac{\kappa}{1 + \beta \theta} \hat{m}_c t,$$

(A.13)

where $\hat{m}_c t$ is the real marginal cost and $\kappa \equiv (1 - \theta)(1 - \theta \beta)/\theta$. $\theta$ is the probability of non-optimal price adjustment.

After some algebra, we can write the NKPC in terms of output gap and money velocity gap:

$$\hat{\pi}_t = \frac{\theta}{1 + \beta \theta} \hat{\pi}_{t-1} + \frac{\beta}{1 + \beta \theta} E_t \hat{\pi}_{t+1}$$

(A.14)
\[ \begin{align*}
&+ \left[ \frac{\kappa(\sigma + \eta)}{1 + \beta \varrho} \right] \left( \tilde{y}_t - \tilde{y}^f_t \right) \\
&+ \left[ \frac{\kappa V_0(k_1 - 1)}{(1 + \beta \varrho)(1 + V_0)} \right] \left( \tilde{v}_t - \tilde{v}^f_t \right). 
\end{align*} \]

\( \tilde{y}^f_t \) and \( \tilde{v}^f_t \) are the level of output and money velocity at the flexible-price equilibrium, i.e. the natural output level and the natural money velocity. In order to obtain (A.14), we assume that the production function is linear in labor \( y_t = a_t N_t \), so that the real marginal cost is \( mc_t = \tilde{w}_t - \tilde{a}_t \).

Equation (A.14) is our benchmark NKPC to be estimated. \( \left( \tilde{y}_t - \tilde{y}^f_t \right) \) and \( \left( \tilde{v}_t - \tilde{v}^f_t \right) \) data can be obtained by filtering GDP and money velocity using either HP filter or Band-Pass (BP) filter. We can structurally estimate \( \varrho, \beta, \theta \), and \( v_0 \equiv V_0 \frac{1}{1 + V_0} \), given the values of parameters \( \sigma, \eta \), and \( k_1 \). We set \( \sigma = \eta = 1 \), following Juhro et al. (2022).

**NKPC as a function of nominal interest rate**  
Note that we can also write the NKPC in (A.14) as a function of interest rate \( \tilde{R}_t \) instead of money velocity \( \tilde{v}_t - \tilde{v}^f_t \).

First, notice that under the natural equilibrium, \( \tilde{v}^f_t = 0 \). It follows then equation (A.12) also describes the money velocity gap. The NKPC can thus be alternatively written as

\[ \hat{\pi}_t = \frac{\varrho}{1 + \beta \varrho} \hat{\pi}_{t-1} + \frac{\beta}{1 + \beta \varrho} E_t \hat{\pi}_{t+1} \]

\[ + \left[ \frac{\kappa(\sigma + \eta)}{1 + \beta \varrho} \right] \left( \tilde{y}_t - \tilde{y}^f_t \right) \]

\[ + \left[ \frac{\kappa V_0(k_1 - 1)}{(1 + \beta \varrho)(1 + V_0)} \right] \left( \frac{1}{k_1 (R - 1)} \right) \tilde{R}_t \]

\[ - \left[ \frac{\kappa V_0(k_1 - 1)}{(1 + \beta \varrho)(1 + V_0)} \right] \left( \frac{1}{k_1} \right) \hat{\varepsilon}_t. \]

Or, after some rearranging of the coefficients,

\[ \hat{\pi}_t = \frac{\varrho}{1 + \beta \varrho} \hat{\pi}_{t-1} + \frac{\beta}{1 + \beta \varrho} E_t \hat{\pi}_{t+1} \]

\[ + \left[ \frac{\kappa(\sigma + \eta)}{1 + \beta \varrho} \right] \left( \tilde{y}_t - \tilde{y}^f_t \right) \]

\[ + \left[ \frac{(k_1 - 1)}{k_1 (R - 1)} \frac{\kappa V_0}{(1 + \beta \varrho)(1 + V_0)} \right] \tilde{R}_t \]

\[ - \left[ \frac{(k_1 - 1)}{k_1} \frac{\kappa V_0}{(1 + \beta \varrho)(1 + V_0)} \right] \hat{\varepsilon}_t. \]

(A.15)

**Extension with an open-economy dimension**

In this extension, we include an open-economy dimension in our NKPC. To derive the open-economy NKPC, we follow the standard small open-economy model of Gali
Specifically, we use the simplified version of their model, used e.g. in the small open-economy DSGE models in Lubik and Schorfheide (2007), Justiniano and Preston (2010), Jääskelä and Nimark (2011), and Lie (2019). We further adopt the simplifying approach in Kuttner and Robinson (2010) and Lie and Yadav (2017) by assuming that the domestic goods and the imported goods sectors have the same Calvo price-stickiness and indexation parameters. This assumption results in a single-equation Phillips curve (instead of 2 equations, each involving domestic inflation and import-good inflation).

The resulting NKPC as a function of domestic real marginal cost \( \bar{mc}^d_t \) and the import-goods real marginal cost \( \bar{mc}^m_t \) is

\[
\hat{\pi}_t = \frac{\varrho}{1 + \beta \varrho} \hat{\pi}_{t-1} + \frac{\beta}{1 + \beta \varrho} E_t \hat{\pi}_{t+1} + \frac{\kappa}{1 + \beta \varrho} \left( (1 - \alpha) \bar{mc}^d_t + \alpha \bar{mc}^m_t \right).
\] (A.16)

Here, \( \alpha \) is the share of imported-goods in the aggregate consumption basket. For estimation, \( \bar{mc}^m_t \) can be proxied using real import price \( \hat{p}^m_t - \hat{p}_t \) where \( \hat{p}^m_t \) is the import price index and \( \hat{p}_t \) is the CPI. As in the closed-economy version, we can write NKPC (A.16) in terms of output gap and money velocity gap. In an open-economy setting, the domestic real marginal cost \( \bar{mc}^d_t \) is also a function of terms of trade gap, LoP gap, and the foreign output gap. This is because the domestic output gap is also a function of those additional variables. In particular, the NKPC becomes

\[
\hat{\pi}_t = \frac{\varrho}{1 + \beta \varrho} \hat{\pi}_{t-1} + \frac{\beta}{1 + \beta \varrho} E_t \hat{\pi}_{t+1} + \frac{\kappa}{1 + \beta \varrho} \left( (1 - \alpha) \left( \frac{\sigma}{1 - \alpha} + \eta \right) \right) \left( \hat{y}_t - \hat{y}_t^* \right) \\
+ \frac{\kappa}{1 + \beta \varrho} \left( \frac{V_0}{1 + V_0} \right) \left( (1 - \alpha) (k_1 - 1) \right) \left( \hat{v}_t - \hat{v}_f^* \right) \\
- \frac{\kappa}{1 + \beta \varrho} \sigma \alpha \left( \tau (2 - \alpha) \left( \hat{S}_t - \hat{S}_f^* \right) + \tau \left( \hat{\Psi}_{F,t} - \hat{\Psi}_{F,t}^* \right) + \left( \hat{y}_t^* - \hat{y}_f^* \right) \right) \\
+ \left( \frac{\kappa}{1 + \beta \varrho} \alpha \right) \bar{mc}^m_t,
\] (A.17)

where \( \left( \hat{S}_t - \hat{S}_f^* \right) \), \( \left( \hat{\Psi}_{F,t} - \hat{\Psi}_{F,t}^* \right) \), and \( \left( \hat{y}_t^* - \hat{y}_f^* \right) \) denote the terms of trade gap, the law-of-one-price (LoP) gap, and the foreign output gap, respectively. Also, note that \( \hat{\Psi}_{F,t} = \bar{mc}^m_t \) (since the LoP gap is essentially the imported-good marginal cost). \( \tau \) is the elasticity of substitution between the domestic goods and imported goods in the consumption basket.

When estimating (A.17), we can therefore construct a new composite variable,

\[
\Phi_t \equiv \tau (2 - \alpha) \left( \hat{S}_t - \hat{S}_f^* \right) + \tau \left( \hat{\Psi}_{F,t} - \hat{\Psi}_{F,t}^* \right) + \left( \hat{y}_t^* - \hat{y}_f^* \right),
\]

using the filtered terms-of-trade, real import price, and foreign output gap data. \( \alpha \) and \( \tau \) can be calibrated based on previous estimates in the literature (e.g. using the posterior mean estimates in Lie (2019) in the context of the Indonesian economy).