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Johannes W. Fedderke

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Head: Economic Research Department
South African Reserve Bank
P O Box 427
Pretoria 0001

Tel. +27 12 313 3911

Identifying Supply and Demand Shocks in the South African Economy, 1960–2020

Johannes W. Fedderke*†

July 2021

Abstract

This paper addresses the identification of supply and demand shocks in the South African economy over the 1960–2020 period, the relative importance of the two types of shock to fluctuations of growth and inflation from their steady-state values, as well as the potential impact of the two types of shocks on the steady-state growth and inflation values.

Crucially, the paper examines the significance of three alternative identification strategies on the nature of supply and demand shocks, and their impact on the economy: zero shock covariance in the presence of long-run demand neutrality; non-zero shock covariance in the presence of long-run demand neutrality; and long-run demand non-neutrality. Interest lies in which of the identification strategies provides shock decompositions that are theoretically coherent, and congruent with the empirics of South African growth and inflation.

*Pennsylvania State University, Research Fellow: South African Reserve Bank, jwf15@psu.edu

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1. Executive summary

This paper addresses the identification of supply and demand shocks in the South African economy over the 1960–2020 period, the relative importance of the two types of shocks to fluctuations of growth and inflation from their steady-state values, as well as the potential impact of the two types of shocks on steady-state growth and inflation values.

Crucially, the paper examines the significance of three alternative identification strategies on the nature of supply and demand shocks, and their impact on the economy: zero shock covariance in the presence of long-run demand neutrality; non-zero shock covariance in the presence of long-run demand neutrality; and long-run demand non-neutrality. Interest lies in which of the identification strategies provides shock decompositions that are theoretically coherent, and congruent with the empirics of South African growth and inflation.

Results are as follows:

- The preferred identification strategy is the open economy non-zero shock covariance, and long-run demand neutrality case. It provides the most theoretically coherent results in terms of shock structure, and the implied impacts of shocks on steady-state growth and inflation values.
- Figure 5 of the paper is the preferred account of international productivity, domestic supply and domestic demand shocks for the South African economy. International productivity shocks are generally of negligible importance, with exceptions such as the 2020 COVID and 2008 sub-prime crises. Supply shocks have declined in magnitude and amplitude since the 1990s, while demand shocks remain relatively prominent. There exists a relatively strong positive correlation between supply and demand shocks in South Africa, of $\rho_{\delta\lambda} \approx 0.4$.
- The preferred decompositions of deviations of growth and inflation from their steady-state values due to international productivity, supply or demand shocks are reported in Figures 6 and 7 respectively, with post-2016Q1 numeric decompositions reported in Table 7. The implication is that deviations of growth from steady values are primarily due to domestic supply shocks, with both international productivity shocks and domestic demand shocks only rarely proving anything but insignificant. Deviations of inflation from steady-state values are primarily due to domestic demand shocks, though in this instance there are periodic episodes in which both international productivity and domestic supply shocks contribute to domestic inflation shocks.
- The impact of international productivity, domestic supply and demand shocks on steady-state growth and inflation under the preferred identification is reported in the EH column of Table 5. Negative domestic supply shocks lower steady-state growth values, and also imply a strong positive impact on domestic inflation. Positive domestic demand shocks have no long run impact on growth, and have strong positive impacts on steady-state inflation. Negative international productivity shocks lower domestic growth, and have a

relatively small positive impact on domestic inflation.

- Three policy implications follow:
  - Demand-side policy shocks (fiscal, monetary policy interventions) carry significant implications for inflationary pressure in the South African economy. Positive shocks imply strong upward pressure on inflation. Contractionary shocks carry the potential of inflation mitigation. Fiscal and monetary stimuli do not appear to carry the potential for improving South Africa's growth trajectory.
  - Supply-side shocks are the principal source of deviation of South African growth from its steady-state values. The implication is that stabilisation or stimulus of growth in South Africa is not responsive to demand-side, but is responsive to supply-side policy intervention. Growth in South Africa is firmly a supply-side question.
  - South Africa does not appear to be prone to volatility arising from international productivity shocks, with the exception of "large" crises such as the 2008 sub-prime and the 2020 COVID crises.

2. Introduction

This paper is concerned with the identification of supply and demand shocks to the South African economy, and the distinct impacts of such shocks on deviations of growth and inflation from their steady-state values. The question is of importance in determining what forms of stabilisation policy responses are appropriate in the face of shocks to the economy. In the face of shocks to output being primarily demand side in nature, fiscal and monetary policy will likely be more effective as corrective measures than if shocks have supply-side origins.

To achieve shock identification, the paper undertakes a number of distinct tasks. The paper provides a clear theoretical discussion of some alternative identification strategies that can be invoked in order to back out supply and demand shocks to the economy, and thence to establish their impacts on steady-state growth and inflation. The theoretical discussion clarifies that identification requires that some crucial choices need to be made on a number of foundational questions. Amongst other more technical requirements, these relate to whether supply and demand shocks are statistically independent, or demonstrate non-zero covariance, and whether or not demand shocks are assumed to be neutral in the long run. Of these choices, the literature has developed some understanding of the impact of varying the assumption of shock independence. Less attention has been paid to the significance of the long-run demand-neutrality assumption. For this reason, in this paper we present an extension to the literature that considers the impact of relaxing the long-run demand neutrality assumption.

As its starting point, the modelling approach employs the contribution of Blanchard and Quah (1989) and its extensions, though we also note some alternative modeling approaches.

Unsurprisingly, results demonstrate that the explicit or implicit modelling choices in the theoretical framework being employed are critical. We note at the outset that results that emerge from open economy frameworks are more plausible and robust than those that emerge from closed economy frameworks. Given that South Africa is a small open economy this is as it should be – but it also suggests that prior work on the identification of shocks to the South African economy, which has been almost exclusively conducted on a closed economy framework, requires updating.

Innovations in the paper include extending shock identification to encompass the case of demand non-neutrality, extending shock identification beyond the narrow Blanchard-Quah closed economy case to include open economy Blanchard-Quah identification, and considering both closed and open economy identification under non-zero supply and demand-shock covariance. The empirical section of this paper contains another innovation. Generally the literature on shock identification merely reports impulse response analysis of the impact of shocks under the identification strategy, derived from the estimation of a structural vector autoregression. In this paper we deviate from this reporting convention as follows. Implicit in the identifying assumptions under the range of alternative approaches covered by the paper, are explicit analytical solutions for the underlying supply and demand shocks, as well as international productivity shocks. Note that while the analysis derived solutions and empirical results for both open and closed economy solutions, the discussion is focussed on the open economy cases. This is motivated both by the fact that it is the more appropriate analytical framework for a small open economy such as South Africa, and by the fact that the open economy results are more theoretically coherent.

By way of pre-empting the inferences that emerge from the analysis that follows, results from an open economy identification under non-zero supply and demand-shock covariance, but under long-run demand neutrality, provide the most theoretically consistent and plausible results.

The paper is structured as follows. Section 3. provides a (non-exhaustive) literature review, which places its principal focus on the theoretical foundations of shock identification, though we also make some reference to prior South African results. Section 4. provides a brief conceptual discussion that clarifies the critical identification questions relevant to identifying supply and demand shocks. In addition, the section explains the implications for vector autoregressive (VAR) specifications that might be used for identification purposes. Section 5. presents the alternative identification strategies for supply and demand shocks. Section 5.1 identifies the shocks under zero supply and demand shock covariance as well as long-run demand neutrality, Section 5.2 under non-zero supply and demand-shock covariance but with long-run demand neutrality, Section 5.3 under non-zero supply and demand-shock covariance without long-run demand neutrality. Section 6. presents empirical findings for South Africa under the alternative identification strategies, with Section 6.2 noting the impact of shocks on steady-state growth and inflation, Section 6.3 the implied shock structure, and Section 6.4 the relative contribution of supply and demand shocks to growth and inflation deviations from steady-state values. Section 7. concludes by isolating the preferred identification structure to have emerged from the results of Section 6., noting the implications that follow for South African supply and demand shocks and their impacts on steady-state growth and inflation, as well as inferring relevant policy implications.

3. Literature review

In the development of the literature surrounding the identification of supply and demand shocks, and their impact on the economy, Blanchard and Quah (1989) (henceforth BQ) provides the critical point of departure. The BQ methodology can be interpreted through a Keynesian model of the economy, specified in terms of output, the price level, employment, the nominal wage, the money supply and productivity growth, from which "structural" supply and demand disturbances are inferred. In application, the BQ method employs a bivariate SVAR specification in output growth and unemployment, in which the identification structure isolates temporary and permanent shocks that are uncorrelated, and that the Keynesian theoretical framework they reference allows shocks to be interpreted as demand (the temporary shock) and supply (the permanent shock) disturbances.[1] For the US, they report that demand disturbances have a

[1] Shocks to aggregate demand in Keynesian models displace the economy from the "natural" level of output only temporarily; output itself, since it is determined by capital stock, labour and productivity (technology), can only be subject to permanent displacement due to productivity innovations. See the discussion in Shapiro and

hump-shaped impact on output and unemployment, peaking after 4 quarters and dissipating after 3 years. By contrast, positive supply shocks raise output to a 2-year peak, plateauing after 5 years, while resulting in temporary increases in unemployment which dissipate rapidly over time. The implication is thus that it is the cumulative effect of permanent shocks to productivity (supply side shocks) that is responsible for the bulk of economic fluctuations. Stock and Watson (1988) provide a similar contemporaneous analysis.

The BQ methodology has been extended in a number of distinct directions that arise from the restrictions imposed by the identification structure employed by BQ. The first is that the bivariate framework employed by BQ, in domestic output and unemployment, renders the analysis a closed economy one. While this might perhaps be justified for the USA in the late 1980s, it certainly does not transfer to other economies, most of which are more appropriately understood as small open economies relative to the world economy. An immediate and important extension of the BQ framework is therefore the provision of an open economy variant of the method. Ahmed et al. (1993), Ahmed and Park (1994) and Dungey and Pagan (2000) provide an extension of the shock decomposition literature to an open economy context. This framework has found application in the African context by Ahmad and Pentecost (2012), a study that includes South Africa as one country amongst a panel in the empirical application.

The second set of concerns relates to the stringent identifying assumptions of the BQ methodology. There are a number of these. First, BQ *impose* long-run demand neutrality by assumption, from which the finding that demand shocks have little impact on output in the long run is baked into the structure of the estimation from the outset. As such, the general finding in the literature employing the BQ identification structure on the shock decomposition, that demand shocks play a small role in explaining output variation, is unsurprising. In a broader conceptual sense, this is more than a purely technical observation, since there may be good reasons to suppose that shifts in aggregate demand and supply are correlated. This may be because either fiscal or monetary authorities, or both, may respond to output variation, thus generating an aggregate demand response to shifts in aggregate supply. Alternatively, in New Keynesian theoretical models, the presence of real rigidities may result in temporary positive demand shocks triggering a positive output rather than price response – see for instance Romer (2001) and Ball et al. (1988). Third, BQ normalise demand and supply shock variances on unity, a restriction that is justified on econometric grounds, but which is not neutral. Wagoner and Zha (2003) demonstrate that variance normalisation can impact statistical inference in structural VARs, especially on the confidence intervals of impulse responses, since the restriction impacts the shape of the likelihood function. Additionally, the normalisation restriction generates quadratic solutions to the shock decompositions, with the result of multiple rather than unique solutions, and in the absence of appropriate non-negativity conditions on the relative size of the variance-covariance structure, solutions would also be potentially periodic (cyclical) rather than asymptotic.

The literature has responded by relaxing subsets of the BQ identifying restrictions. Cover et al.

Watson (1988).

(2006) address two of the concerns arising from the BQ identification restrictions. These are the quadratic solutions arising from the normalisation restrictions on shock variances, and the zero shock covariance assumption that precludes an interaction between aggregate demand and supply. However, they retain the assumption of demand-neutrality. Enders and Hurn (2007) extend the resultant framework to the open economy case. Both Cover et al. (2006) and Enders and Hurn (2007) report results consistent with a high degree of demand and supply side shock covariance. In addition, they report that output variation is primarily due to supply shocks, though some significant impacts of demand shocks on output occur over short-run time horizons, as in the case of BQ.

It is worth noting once again that the implied demand-side shock neutrality on long-run output is effectively a product of the identifying assumptions of the underlying models. A number of papers have examined the question of demand non-neutrality. Bashar (2011) modifies the Cover et al. (2006) identifying strategy to impose a causal structure flowing from demand shocks to supply shocks (the AD shifts the AS curve, on the grounds that changes in factor input usage lead to learning, reorganisations, efficiency gains and increased R&D, thus generating endogenous technological progress). Keating (2013) and Keating and Valcarcel (2015) employ a BQ framework, but allow for demand non-neutrality by imposing sign restrictions on output (positive) and price (negative) responses to positive supply shocks.[2] Both papers confirm the general finding in the BQ-type literature that output volatility is primarily due to supply shocks in the long run, though they note long-run output effects from demand shocks prior to World War I, and for short periods post-World War II for the USA. Pagliacci (2019) similarly employs sign restrictions. In Section 5.3 of the present paper we add a consideration of demand non-neutrality, combined with the relaxation of the normalisation of shock variances, but maintaining zero shock covariance between international productivity and domestic supply shocks. In order to maintain just identification, the price of allowing long-run demand non-neutrality is that the parameters employed in the shock decomposition are rendered time-varying, rather than constant. Given that we provide explicit analytical solutions for the shock decomposition this can be accommodated. Note at the outset that demand non-neutrality does not produce coherent results, and thus does not appear to offer a promising avenue of exploration, at least not on the approach to demand non-neutrality adopted in the present analysis.

An alternative challenge to the theoretical framework implicit in the BQ methodology emerges from the approach of King et al. (1991), though the results of the latter can be said to encompass the BQ methodology and its offshoots.[3] King et al. (1991) note that the finding that the preponderance of economic fluctuations are attributable to cumulative permanent productiv-

[2] They also allow for the parameters of the underlying VAR being estimated being time-varying, by estimating the VAR over sub-samples of the data.

[3] There are also alternative methodologies, such as those proposed by Fatás and Summers (2018), which abandon in its entirety the BQ methodology. In contrast to the view that trend growth is determined by a growth model, trend growth is seen not only as itself stochastic (a view shared by BQ and related tradition), but that these stochastic disturbances to trend growth are not themselves due to both demand and supply shocks (as in BQ and related tradition), but instead are purely an expression of hysteresis. This is then explored in a series of bivariate regressions.

ity shocks, rather than demand-side shocks such as those due to monetary and fiscal policy shocks, is consistent with the balanced growth implication implicit in the empirical finding of constant "great" ratios (consumption:output; investment:output – see for instance Kosobud and Klein, 1961) in post-war developed economies. Constant great ratios in turn provide a rationale for the use of single-sector real business cycle (RBC) models in the class of Kydland and Prescott (1982). The insight of King et al. (1991) is that the implication is also that the variables implicit in the great ratios then must be subject to cointegration in the sense of Engle and Granger (1987). Utilising vector error correction cointegration estimation (Johansen, 1988), King et al. (1991) verify the presence of the relevant cointegrating relationships between the real variables that constitute the great ratios, and further confirm that productivity shocks explain up to 75% of the variation in output at business-cycle horizons (4–20 quarters), consistent with the results from RBC-consistent models and BQ identification. However, with the introduction of nominal variables into the model (money, prices and interest rates), productivity shocks explain only 35–45% of variation in output, though since nominal shocks are constrained to be long-run neutral, the remainder of the variation is attributed not to nominal shocks, but to shocks in real interest rates. We do not follow the alternative possibilities presented by King et al. (1991), since the balanced growth assumption implicit to the approach is difficult to support in the South African case – see Fedderke (2018).

The South African literature identifying supply and demand shocks is relatively limited. Du Plessis et al. (2008) provides an application of BQ identification, separating demand-side shocks into fiscal and monetary shocks as in Clarida and Galí (1994). The application is of closed- rather than open-economy BQ identification. Given that the BQ identification imposes long-run demand neutrality, it is not surprising that they report that supply shocks dominate demand shocks in South Africa. Botha and Steenkamp (2020) do not use the BQ identification, and rely on the Quarterly Projection Model of the South African Reserve Bank instead. Interestingly, use of the structural model results in a shock decomposition in which 67% of growth shocks are attributable to demand, and only 33% to supply shocks, a finding that contrasts with the BQ class of findings, both internationally and including the South African specific findings of Du Plessis et al. (2008). Kuhn (2020), employing a common factor model derived from Camacho et al. (2010), provides results consistent with those of Botha and Steenkamp (2020) in the sense that demand shocks dominate supply shocks.

4. Clarifying the role of demand and supply in identifying shock decomposition

To aid understanding of the range of alternative identification strategies discussed in the present paper, it is useful to reference a simple aggregate demand and supply interaction, in order to illustrate the feasible consequences of supply and demand shocks.

As a first logical possibility, consider circumstances in which demand is perfectly or at least highly elastic, while supply is perfectly or at least highly inelastic. Under these conditions, as Figure 1 illustrates, demand shocks (denoted λ) are neutral on output (changing from point A

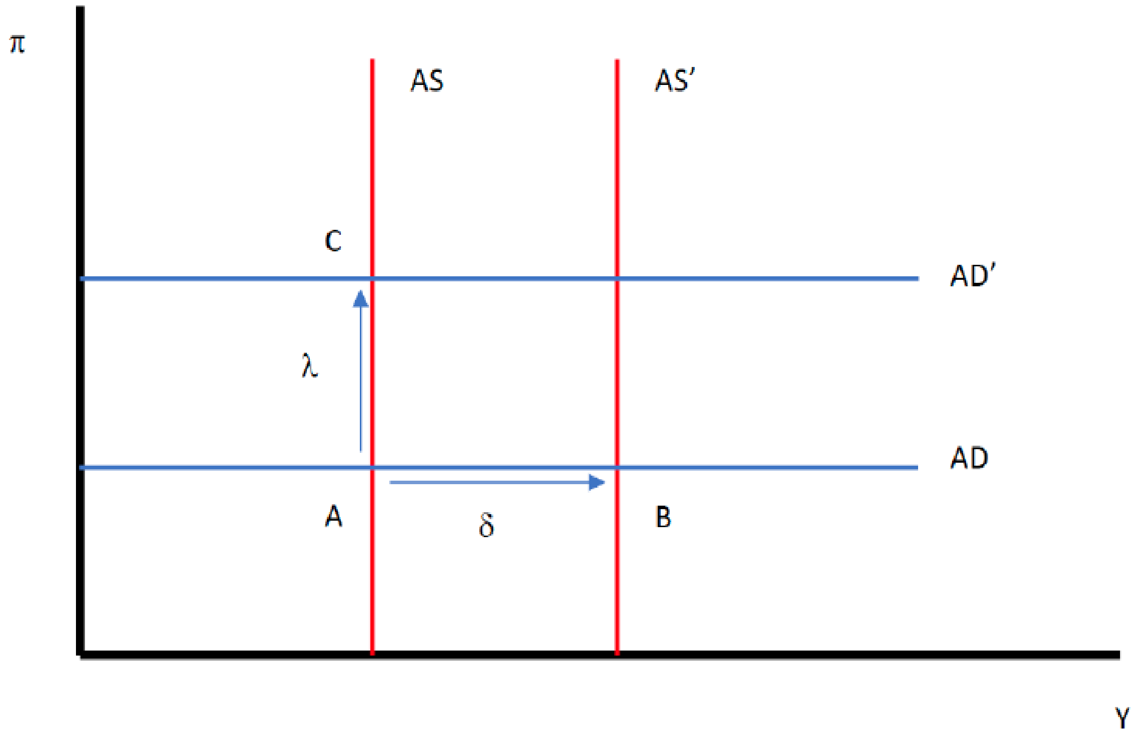

Figure 1: AD and AS interaction under zero shock covariance and demand neutrality

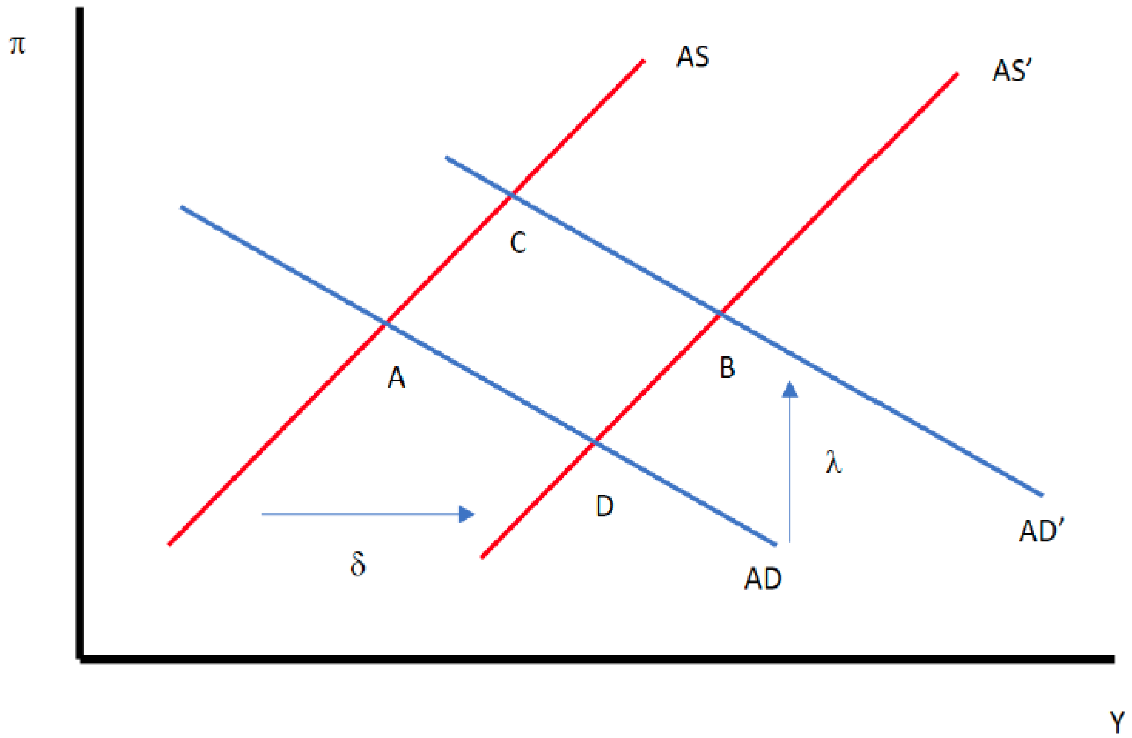

Figure 2: AD and AS interaction under non-zero shock covariance but with demand neutrality

to C in Figure 1), while supply shocks (denoted δ) are non-inflationary (changing from point A to B in Figure 1).[4] Thus supply shocks translate into pure output changes, and no inflationary pressure, while conversely, demand shocks translate into pure inflationary pressure, without any output response.

But such a conception of aggregate demand and supply invokes relatively extreme elasticity conditions – in the limit of perfect elasticity (demand) or inelasticity (supply). By way of contrast, an alternative conception of aggregate demand and supply might invoke elasticities that lie between the perfect inelasticity (0) and elasticity (∞) limit values – for instance, the circumstances as illustrated by Figure 2. Under these assumptions, both a supply shock (δ), and a demand shock (λ) would carry implications for both output and inflation (moving from A to D, and A to C respectively), in contrast to the binary outcome of supply shocks affecting only output and demand shocks impacting only inflation predicted under the extreme elasticity conditions of Figure 1.

It is also possible that under the elasticity conditions assumed for Figure 2, a supply shock (δ) might *appear* inflation neutral (changing from point A to B in Figure 2), because demand and supply shocks are not orthogonal. Instead, the supply shock (δ) with deflationary impact (changing from point A to D in Figure 2) might trigger a demand-side policy response (under an inflation targeting framework a monetary expansion), which induces the AD-AD' response (changing from point D to B in Figure 2), and hence price neutrality of the supply shock.

Comparison of the cases discussed above makes clear that any identification structure adopted will be critical to the interpretation of shocks and their impact on the economy. For instance, distinguishing between the change from A to B in Figures 1 and 2 shows that while in both there is price neutrality, this occurs for distinct reasons, and with distinct policy implications.

To clarify the methodology that will be employed in identifying demand and supply shocks for South Africa, allow y_t^f, y_t, and π_t to denote the log of real foreign output, real domestic output, and the domestic inflation rate respectively. This then provides the VAR specification given by:

$$\Delta y_t^f = \alpha_{01} + \sum_{j=1}^{k} \alpha_{11,j} \Delta y_{t-j}^f + \varepsilon_{1t} \tag{1}$$

$$\Delta y_t = \alpha_{02} + \sum_{j=1}^{k} \alpha_{21,j} \Delta y_{t-j}^f + \sum_{j=1}^{k} \alpha_{22,j} \Delta y_{t-j} + \sum_{j=1}^{k} \alpha_{23,j} \pi_{t-j} + \varepsilon_{2t} \tag{2}$$

$$\pi_t = \alpha_{03} + \sum_{j=1}^{k} \alpha_{31,j} \Delta y_{t-j}^f + \sum_{j=1}^{k} \alpha_{32,j} \Delta y_{t-j} + \sum_{j=1}^{k} \alpha_{33,j} \pi_{t-j} + \varepsilon_{3t} \tag{3}$$

in which variables are differenced as appropriate in order to ensure stationarity. The specification reflects the assumption that a small domestic economy will not impact foreign (world) output, but foreign output does impact both domestic output and inflation.

Steady-state values of international growth, domestic growth and inflation, under $\varepsilon_{1t} = \varepsilon_{2t} =$

[4] Enders and Hurn (2007) provided useful framing for the discussion of the present section.

$\varepsilon_{3t} = 0$, are then:

$$\begin{aligned}
\Delta y_t^{f,*} &= \frac{\alpha_{01}}{1-\sum_{j=1}^{k}\alpha_{11,j}} \quad (4)\\
\Delta y_t^{*} &= \frac{C_1}{C_2} \quad (5)\\
\pi_t^{*} &= \frac{C_2C_3 + C_1C_4}{C_2} \quad (6)
\end{aligned}$$

$$\begin{aligned}
C_1 &= \alpha_{02} + \left(\frac{\alpha_{01}\sum_{j=1}^{k}\alpha_{21,j}}{1-\sum_{j=1}^{k}\alpha_{11,j}}\right) + \left(\frac{\left[\alpha_{01}\sum_{j=1}^{k}\alpha_{31,j} + \alpha_{03}\left(1-\sum_{j=1}^{k}\alpha_{11,j}\right)\right]\sum_{j=1}^{k}\alpha_{23,j}}{\left(1-\sum_{j=1}^{k}\alpha_{11,j}\right)\left(1-\sum_{j=1}^{k}\alpha_{33,j}\right)}\right)\\
C_2 &= \frac{\left(1-\sum_{j=1}^{k}\alpha_{22,j}\right)\left(1-\sum_{j=1}^{k}\alpha_{33,j}\right) - \sum_{j=1}^{k}\alpha_{23,j}\sum_{j=1}^{k}\alpha_{32,j}}{1-\sum_{j=1}^{k}\alpha_{33,j}}\\
C_3 &= \left(\frac{\alpha_{01}\sum_{j=1}^{k}\alpha_{31,j} + \alpha_{03}\left(1-\sum_{j=1}^{k}\alpha_{11,j}\right)}{\left(1-\sum_{j=1}^{k}\alpha_{11,j}\right)\left(1-\sum_{j=1}^{k}\alpha_{33,j}\right)}\right)\\
C_4 &= \left(\frac{\sum_{j=1}^{k}\alpha_{32,j}}{1-\sum_{j=1}^{k}\alpha_{33,j}}\right)
\end{aligned}$$

This then implicitly defines cyclical variation for international and domestic growth, and domestic inflation:

$$\widetilde{\Delta y_t^f} = \Delta y_t^f - \Delta y_t^{f,*} \quad \widetilde{\Delta y_t} = \Delta y_t - \Delta y_t^{*} \quad \widetilde{\pi}_t = \pi_t - \pi_t^{*} \qquad (7)$$

The purpose of what follows is to attribute the two cyclical variations, $\widetilde{\Delta y_t} = \Delta y_t - \Delta y^*$, $\widetilde{\pi}_t = \pi_t - \pi^*$, to international productivity shocks, domestic supply shocks and domestic demand shocks. Section 5. will be particularly concerned with attributing the two cyclical variations, $\widetilde{\Delta y_t}$, $\widetilde{\pi}_t$, to demand and supply shocks, such that the total composite shocks defined by (7) are separated into the components that are due to distinct demand- and supply-shock components.[5]

5. Identifying supply and demand shocks in cyclical output and price fluctuations

Identification of supply and demand shocks in this paper considers three logical possibilities. The first identifies the shocks under the assumption of long-run demand neutrality, and zero supply and demand-shock covariance. This is the identification strategy due to Blanchard and Quah (1989). The second identification strategy continues to assume long-run demand neutrality, but relaxes the zero supply and demand-shock covariance condition. The third possibility considered is a relaxation of the long-run demand neutrality assumption, but assumes

[5] A companion paper, Fedderke (2021), examines the empirical implications for steady-state growth and inflation, and the implied growth and inflation gaps in South Africa, for both the closed and open economy cases.

no covariance between international productivity and domestic supply shocks.[6]

In the open economy case analysis begins with the underlying VAR, (1, 2, & 3). The ε_{1t}, ε_{2t}, ε_{3t}, residual structure is assumed to be non-orthogonal, and instead to be mutually interdependent through three structural innovations: foreign productivity shocks, v_t, domestic supply shocks, δ_t, and domestic demand shocks, λ_t, such that:

$$\begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \end{bmatrix} = G \begin{bmatrix} v_t \\ \delta_t \\ \lambda_t \end{bmatrix} \tag{8}$$

$$G = \begin{bmatrix} g_{11} & g_{12} & g_{13} \\ g_{21} & g_{22} & g_{23} \\ g_{31} & g_{32} & g_{33} \end{bmatrix} \tag{9}$$

This provides 15 unknowns, the 9 g_{ij} elements, which link the structural innovations (foreign and domestic productivity shocks, domestic demand shocks) to the VAR errors, ε_{ij}, and from the variance-covariance matrix, $\sum_s$, of the structural innovations:

$$\sum_s = \begin{bmatrix} \sigma_\upsilon^2 & \sigma_{\upsilon\delta} & \sigma_{\upsilon\lambda} \\ \sigma_{\upsilon\delta} & \sigma_\delta^2 & \sigma_{\delta\lambda} \\ \sigma_{\upsilon\lambda} & \sigma_{\delta\lambda} & \sigma_\lambda^2 \end{bmatrix} \tag{10}$$

3 variances, σ_υ^2, σ_δ^2, σ_λ^2, and 3 covariances, $\sigma_{\upsilon\delta}$, $\sigma_{\upsilon\lambda}$, $\sigma_{\delta\lambda}$.

The variance-covariance matrix of the VAR-residuals is then given by:

$$\sum_\varepsilon = \begin{bmatrix} \widehat{\sigma}_{\varepsilon_1}^2 & \widehat{\sigma}_{\varepsilon_1\varepsilon_2} & \widehat{\sigma}_{\varepsilon_1\varepsilon_3} \\ \widehat{\sigma}_{\varepsilon_1\varepsilon_2} & \widehat{\sigma}_{\varepsilon_2}^2 & \widehat{\sigma}_{\varepsilon_2\varepsilon_3} \\ \widehat{\sigma}_{\varepsilon_1\varepsilon_3} & \widehat{\sigma}_{\varepsilon_2\varepsilon_3} & \widehat{\sigma}_{\varepsilon_3}^2 \end{bmatrix} = G\Sigma_s G' \tag{11}$$

where the 3 variances, $\sigma_{\varepsilon_1}^2$, $\sigma_{\varepsilon_2}^2$, $\sigma_{\varepsilon_3}^2$, and covariances, $\sigma_{\varepsilon_1\varepsilon_2}$, $\sigma_{\varepsilon_1\varepsilon_3}$, $\sigma_{\varepsilon_2\varepsilon_3}$, are provided directly from estimation of the underlying VAR, (1, 2, & 3).

The alternative identification strategies examined below are concerned with restrictions that allow for the isolation of the elements of the G- and $\sum_s$-matrixes, and hence the v_t, δ_t and λ_t shocks from the knowns of the $\sum_\varepsilon$.

[6] Note that while the analysis derived solutions and empirical results for both open and closed economy solutions, the discussion is focussed on the open economy cases. This is motivated both by the fact that it is the more appropriate analytical framework for a small open economy such as South Africa, and by the fact that the open economy results are more theoretically coherent. Both closed and open economy cases are considered for all indentification strategies, and for all implied results, though we report only the open economy cases. Closed economy results are available on request.

5.1 Zero shock covariance and demand neutrality: The Blanchard-Quah (BQ) decomposition

In Blanchard and Quah (1989) the two critical assumptions are that shocks do not covary, and that demand shocks have no long-run impact on domestic output – the circumstances depicted under Figure 1.

Under the open economy Blanchard-Quah decomposition, in addition to the 6 restrictions provided by the $\sum_{\varepsilon}$, (equation 11), there is an assumption of a zero shock covariance (amongst foreign supply, domestic supply and domestic demand shocks), long-run demand-shock neutrality, and the normalisation of shock variances (for the three shocks). The open economy case adds a further identification restriction, which is simply the small economy assumption that any small domestic economy will not affect world output that is already implicit in the specification of (1).

This then gives the following restrictions:

$$\begin{aligned}
\textit{Normalisation} &: \quad \sigma_{\upsilon}^2 = \sigma_{\delta}^2 = \sigma_{\lambda}^2 = 1 && (12)\\
\textit{No shock covariance} &: \quad \sigma_{\upsilon\delta} = \sigma_{\upsilon\lambda} = \sigma_{\delta\lambda} = 0 && (13)\\
\textit{Small country} &: \quad g_{12} = g_{13} = 0 && (14)\\
\textit{Demand neutrality} &: \quad g_{23}\left[1 - \sum_{j=1}^{k} \alpha_{33,j}\right] + g_{33}\left[\sum_{j=1}^{k} \alpha_{23,j}\right] = 0 && (15)
\end{aligned}$$

For the demand-neutrality condition see Appendix 1.

Then:

$$\sum_{\varepsilon} = \begin{bmatrix} \widehat{\sigma}_{\varepsilon_1}^2 & \widehat{\sigma}_{\varepsilon_1\varepsilon_2} & \widehat{\sigma}_{\varepsilon_1\varepsilon_3} \\ \widehat{\sigma}_{\varepsilon_1\varepsilon_2} & \widehat{\sigma}_{\varepsilon_2}^2 & \widehat{\sigma}_{\varepsilon_2\varepsilon_3} \\ \widehat{\sigma}_{\varepsilon_1\varepsilon_3} & \widehat{\sigma}_{\varepsilon_2\varepsilon_3} & \widehat{\sigma}_{\varepsilon_3}^2 \end{bmatrix} \tag{16}$$

$$= \begin{bmatrix} g_{11} & 0 & 0 \\ g_{21} & g_{22} & g_{33}\frac{\left[-\sum_{j=1}^{k}\alpha_{23,j}\right]}{\left[1-\sum_{j=1}^{k}\alpha_{33,j}\right]} \\ g_{31} & g_{32} & g_{33} \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} g_{11} & g_{21} & g_{31} \\ 0 & g_{22} & g_{32} \\ 0 & g_{33}\frac{\left[-\sum_{j=1}^{k}\alpha_{23,j}\right]}{\left[1-\sum_{j=1}^{k}\alpha_{33,j}\right]} & g_{33} \end{bmatrix} \tag{17}$$

which provides 15 restrictions in order to solve for the 15 unknowns of (11).

This allows for the underlying international productivity (v_t) domestic supply (δ_t), and domestic demand (λ_t) shocks to be recoverable. Specifically:

$$\widehat{v_t} = \frac{\widehat{\varepsilon_{1t}}}{\widehat{g_{11}}} \tag{18}$$

$$\widehat{\lambda_t} = \left(\frac{\widehat{g_{22}}}{\widehat{g_{22}}\widehat{g_{33}} - \widehat{g_{23}}\widehat{g_{32}}}\right)\widehat{\varepsilon_{3t}} - \left(\frac{\widehat{g_{22}}\widehat{g_{31}} - \widehat{g_{21}}\widehat{g_{32}}}{\widehat{g_{22}}\widehat{g_{33}} - \widehat{g_{23}}\widehat{g_{32}}}\right)\widehat{v_t} - \left(\frac{\widehat{g_{32}}}{\widehat{g_{22}}\widehat{g_{33}} - \widehat{g_{23}}\widehat{g_{32}}}\right)\widehat{\varepsilon_{2t}} \tag{19}$$

$$\widehat{\delta_t} = \left(\frac{1}{\widehat{g_{22}}}\right)\widehat{\varepsilon_{2t}} - \frac{\widehat{g_{21}}}{\widehat{g_{22}}}\widehat{v_t} - \left(\frac{\widehat{g_{23}}}{\widehat{g_{22}}}\right)\widehat{\lambda_t} \tag{20}$$

with the analytical solutions detailed in Appendix 2.

It is important to understand the implications of the BQ identification restrictions.

First, the demand-neutrality restrictions given by (15) *impose* the outcome that demand shocks have little impact on output in the long run. The general finding in the literature employing the BQ identification structure on the shock decomposition, that demand shocks play a small role in explaining output variation, is baked into the decomposition through the identification adopted.

Second, the assumption of no shock covariance (13) is more than a purely technical restriction. As observed under the conceptual discussion of the relationship between the AD and AS sides of the economy, there are good reasons to suppose that shifts in the two curves are correlated. This may be because either fiscal or monetary authorities, or both, may respond to output variation, thus generating an AD response to shifts in the AS. Alternatively, in New Keynesian theoretical models, the presence of real rigidities may result in temporary positive demand shocks triggering a positive output rather than price response (see for instance Romer (2001); Ball et al. (1988)). The only way to then maintain orthogonality of the structural disturbances in (8) would be to increase the dimensionality of the VAR. This might take the form of including endogenous policy instruments (e.g. the interest rate), potentially labor market conditions (for instance in a New Keynesian framework with positive supply responses to temporary real wage increases), or firm-level output responsiveness to demand fluctuations, to capture the output non-neutrality of demand shocks. The limitation of this response is that for any prospect of capturing the feasible space that a real economy presents, this structural expansion might be prodigious, thereby posing challenging identification difficulties. These are both that the *number* of identification restrictions rapidly expands, and hence that the consequent restriction requirements are likely to escape theorisation into ad hocery.

Third, the normalisation restriction under (12) is not econometrically neutral. Wagoner and Zha (2003) note that variance normalisation can impact statistical inference in structural VARs, especially on the confidence intervals of impulse responses, since the restriction impacts the shape of the likelihood function. For the open economy BQ case the potentially quadratic solutions for the g_{ij} provide at least eight feasible decompositions for our open economy case (see Appendix 2). Specifically:

$$
\begin{array}{cccccccccc}
\widehat{g_{11}} & & \widehat{g_{21}} & \widehat{g_{31}} & & \widehat{g_{22}} & \widehat{g_{32}} & & \widehat{g_{33}} & \widehat{g_{23}} \\
 & & & & & & & & & \\
\sqrt[2]{\widehat{\sigma}^2_{\varepsilon_1}} & \rightarrow & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_2}}{\widehat{g_{11}}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_3}}{\widehat{g_{11}}} & \rightarrow & +\sqrt[2]{\Phi} & \frac{\Lambda}{\widehat{g_{22}}}+\frac{\widehat{g_{22}}}{C} & \rightarrow & +\sqrt[2]{\Psi} & \widehat{g_{33}}C \\
 & & & & & & & & -\sqrt[2]{\Psi} & \widehat{g_{33}}C \\
 & & & & \rightarrow & -\sqrt[2]{\Phi} & \frac{\Lambda}{\widehat{g_{22}}}+\frac{\widehat{g_{22}}}{C} & \rightarrow & +\sqrt[2]{\Psi} & \widehat{g_{33}}C \\
 & & & & & & & & -\sqrt[2]{\Psi} & \widehat{g_{33}}C \\
-\sqrt[2]{\widehat{\sigma}^2_{\varepsilon_1}} & \rightarrow & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_2}}{\widehat{g_{11}}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_3}}{\widehat{g_{11}}} & \rightarrow & +\sqrt[2]{\Phi} & \frac{\Lambda}{\widehat{g_{22}}}+\frac{\widehat{g_{22}}}{C} & \rightarrow & +\sqrt[2]{\Psi} & \widehat{g_{33}}C \\
 & & & & & & & & -\sqrt[2]{\Psi} & \widehat{g_{33}}C \\
 & & & & \rightarrow & -\sqrt[2]{\Phi} & \frac{\Lambda}{\widehat{g_{22}}}+\frac{\widehat{g_{22}}}{C} & \rightarrow & +\sqrt[2]{\Psi} & \widehat{g_{33}}C \\
 & & & & & & & & -\sqrt[2]{\Psi} & \widehat{g_{33}}C
\end{array} \tag{21}
$$

with the Φ, Λ, Ψ and C constants as defined in Appendix 2. Note that the 8 solutions transfer to the derived shock values of (18) through (20).

Fourth, note that the normalisation restriction not only generates quadratic solutions, but as a consequence imposes a set of non-negativity conditions on the relative size of the variance-covariance structure, in order for the solutions to be in real number space. Failure of the non-negativity conditions being met, would render the g_{ij} solutions periodic (cyclical). Again this is rendered explicit in Appendix 2.

While the attraction of the BQ identification is that it is based on an extremely general specification of the association between growth and inflation, the price paid for this generality is that the identification restrictions are both non-neutral and generate a multiplicity of solutions. An alternative approach is to allow theory to provide more a priori structure on the growth-inflation interaction, rendering identification more attainable, and stronger restrictions on the nature of the solutions that are consistent with both theory and data.

5.2 Allowing shock covariance under demand neutrality (CEH, EH)

A limiting assumption under the BQ identification strategy is that supply and demand shocks do not covary – see equations (13). The discussion in section 4. has already given an indication that this is an assumption likely at odds with empirical reality. A first relaxation of the assumptions of the BQ framework, is thus to allow shock covariance.

Cover et al. (2006) (henceforth CEH) address two of the concerns arising from the BQ identification restrictions: the quadratic solutions arising from the normalisation restrictions (12), and the zero shock covariance assumption that precludes an interaction between AD & AS (13). On the other hand the assumption of demand-neutrality (15) is retained. CEH augment the VAR representation by a small structural macroeconomic model, which is central to their identification strategy. Enders and Hurn (2007) (henceforth EH) present a generalisation of the CEH closed economy model to the open economy context. As for the CEH paper, the object is to relax some of the identification restrictions in the open economy BQ framework, in order to address two of the concerns arising from the BQ identification restrictions. These are the quadratic solutions arising from the normalisation restrictions (12), and the zero shock covariance assumption that precludes an interaction between AD & AS by equation (13). The demand-neutrality (15) and small-country (14) assumptions from open economy BQ identification are retained. The objective remains to employ the VAR representation of (1, 2 & 3), in order to decompose the three underlying structural international productivity (ν_t), domestic supply (δ_t) and demand (λ_t) shocks responsible for variation in Δy_t, and π_t, by means of (8).

Identification proceeds by the use of the CEH AD-AS model adjusted for the presence of international productivity shocks, given by:

$$\begin{aligned}
\Delta y_t^s &= E_{t-1}\left(\Delta y_t^s\right) + \alpha\left(\Delta\pi_t - E_{t-1}\left(\Delta\pi_t\right)\right) + \delta_t + \gamma\nu_t,\ \alpha > 0 && (22)\\
\Delta y_t^d + \Delta\pi_t &= E_{t-1}\left(\Delta y_t^d + \Delta\pi_t\right) + \lambda_t && (23)\\
y_t^s &= y_t^d && (24)
\end{aligned}$$

where $E_{t-1}\left(\Delta y_t^s\right)$, $E_{t-1}\left(\Delta y_t^d\right)$, $E_{t-1}\left(\Delta\pi_t\right)$, are expected changes in domestic output supply, demand and domestic inflation at the end of period $t-1$ respectively, (22) is a standard Lucas (1972) aggregate supply function, in which supply responds to inflation surprises $\left(\Delta\pi_t - E_{t-1}\left(\Delta\pi_t\right)\right)$, and domestic ($\delta_t$) and international ($\nu_t$) productivity shocks, and (23) is the aggregate demand curve.

Allowing agents to form expectations in terms of the VAR implied by (22 & 23), under the equilibrium condition that $y_t^s = y_t^d$:

$$\begin{aligned}
\Delta y_t - E_{t-1}\left(\Delta y_t\right) &= \alpha\left(\Delta\pi_t - E_{t-1}\left(\Delta\pi_t\right)\right) + \delta_t + \gamma\nu_t && (25)\\
\Delta\pi_t - E_{t-1}\left(\Delta\pi_t\right) &= -\left(\Delta y_t - E_{t-1}\left(\Delta y_t\right)\right) + \lambda_t && (26)
\end{aligned}$$

hence:

$$\begin{aligned}
\Delta y_t - E_{t-1}\left(\Delta y_t\right) &= \alpha\left(-\left(\Delta y_t - E_{t-1}\left(\Delta y_t\right)\right) + \lambda_t\right) + \delta_t + \gamma\nu_t\\
\Longrightarrow (1+\alpha)\left(\Delta y_t - E_{t-1}\left(\Delta y_t\right)\right) &= \gamma\nu_t + \delta_t + \alpha\lambda_t\\
\Longrightarrow \left(\Delta y_t - E_{t-1}\left(\Delta y_t\right)\right) &= \frac{\gamma}{(1+\alpha)}\nu_t + \frac{1}{(1+\alpha)}\delta_t + \frac{\alpha}{(1+\alpha)}\lambda_t && (27)\\
\Delta\pi_t - E_{t-1}\left(\Delta\pi_t\right) &= -\left(\frac{\gamma}{(1+\alpha)}\nu_t + \frac{1}{(1+\alpha)}\delta_t + \frac{\alpha}{(1+\alpha)}\lambda_t\right) + \lambda_t\\
\Longrightarrow \left(\Delta\pi_t - E_{t-1}\left(\Delta\pi_t\right)\right) &= \frac{-\gamma}{(1+\alpha)}\nu_t + \frac{-1}{(1+\alpha)}\delta_t + \frac{1}{(1+\alpha)}\lambda_t && (28)
\end{aligned}$$

To complete the identification, EH then follow CEH in imposing two normalisations, such that shocks have one-unit impacts on supply and demand (see 25 & 26):

$$\begin{aligned}
\delta_t &\rightarrow \Delta y_t^s && (29)\\
\lambda_t &\rightarrow \Delta y_t^d
\end{aligned}$$

though note that provided that $\gamma \neq 1$, this is not true of the foreign productivity shock v_t. In addition, EH assume that the slope of the AD curve in (26) is unity:

$$E_{t-1}\left(\Delta y_t^d + \pi_t\right) \to \Delta y_t^d + \pi_t \tag{30}$$

and by imposing long-run neutrality of output with respect to the demand shock (λ_t):

$$g_{23}\left[1 - \sum_{j=1}^{k} \alpha_{33,j}\right] + g_{33}\sum_{j=1}^{k} \alpha_{23,j} = 0 \tag{31}$$

with $\widehat{\alpha}$ recoverable from the estimation of (1, 2 & 3). Instead of the variance normalisation of BQ ($\sigma_\upsilon^2 = \sigma_\delta^2 = \sigma_\lambda^2 = 1$), EH only impose:

$$g_{11} = 1 \tag{32}$$

though they retain the BQ small country assumption that domestic shocks do not impact world growth:

$$g_{12} = g_{13} = 0 \tag{33}$$

An additional small country assumption EH add is that international and domestic productivity shocks are orthogonal:

$$\sigma_{\upsilon\delta} = 0 \tag{34}$$

The six empirical restrictions ($\widehat{\sigma}^2_{\varepsilon_1}, \widehat{\sigma}^2_{\varepsilon_2}, \widehat{\sigma}^2_{\varepsilon_3}, \widehat{\sigma}_{\varepsilon_1\varepsilon_2}, \widehat{\sigma}_{\varepsilon_1\varepsilon_3}, \widehat{\sigma}_{\varepsilon_2\varepsilon_3}$), the unit-impact restrictions (29), productivity shock orthogonality (34), small country assumption (33), the AD slope (30) and long-run demand neutrality (31), and the structure of (35) identifies the system. As before, estimation of the open economy VAR (1, 2, 3) provides $\widehat{\sigma}^2_{\varepsilon_1}, \widehat{\sigma}^2_{\varepsilon_2}, \widehat{\sigma}^2_{\varepsilon_3}, \widehat{\sigma}_{\varepsilon_1\varepsilon_2}, \widehat{\sigma}_{\varepsilon_1\varepsilon_3}, \widehat{\sigma}_{\varepsilon_2\varepsilon_3}$.

In (8), (9), from (27 & 28):

$$G = \begin{bmatrix} 1 & 0 & 0 \\ \frac{\gamma}{(1+\alpha)} & \frac{1}{(1+\alpha)} & \frac{\alpha}{(1+\alpha)} \\ \frac{-\gamma}{(1+\alpha)} & \frac{-1}{(1+\alpha)} & \frac{1}{(1+\alpha)} \end{bmatrix} \tag{35}$$

purely a function of the parameters of the macroeconomic model.

Specifically, we can now obtain:

$$\begin{aligned}
\Longrightarrow \widehat{\nu_t} &= \widehat{\varepsilon_{1t}} && (36)\\
\widehat{\delta_t} &= \frac{\widehat{\varepsilon_{2t}} - \widehat{\gamma} C_2 \widehat{\nu_t}}{C_2} - \frac{C_3}{C_2}\left(\frac{\widehat{\varepsilon_{2t}} + \widehat{\varepsilon_{3t}}}{C_2 + C_3}\right) && (37)\\
\widehat{\lambda_t} &= \frac{\widehat{\varepsilon_{2t}} + \widehat{\varepsilon_{3t}}}{C_2 + C_3} && (38)\\
\widehat{\gamma} &= \frac{C_2 \widehat{\sigma}_{\varepsilon_1 \varepsilon_2} - C_3 \widehat{\sigma}_{\varepsilon_1 \varepsilon_3}}{\left(C_2 C_3 + (C_2)^2\right) \widehat{\sigma}_{\upsilon}^2} && (39)
\end{aligned}$$

and the variance-covariance structure:

$$\begin{aligned}
\widehat{\sigma}_{\upsilon}^2 &= \widehat{\sigma}_{\varepsilon_1}^2 && (40)\\
\widehat{\sigma}_{\upsilon\lambda} &= \frac{\widehat{\sigma}_{\varepsilon_1 \varepsilon_2} - \widehat{\gamma} C_2 \widehat{\sigma}_{\upsilon}^2}{C_3} && (41)\\
\widehat{\sigma}_{\delta\lambda} &= \frac{\widehat{\sigma}_{\varepsilon_3}^2 - (\widehat{\gamma} C_2)^2 \widehat{\sigma}_{\upsilon}^2 + 2\left(\widehat{\gamma}(C_2)^2\right) \widehat{\sigma}_{\upsilon\lambda} - (C_2)^2 (C_4 - C_6 C_7 - C_7)}{-(C_2)^2 (C_5 + C_6 C_8 + C_8 + 2)} && (42)\\
\widehat{\sigma}_{\delta}^2 &= C_4 - C_6 C_7 - (C_5 + C_6 C_8) \widehat{\sigma}_{\delta\lambda} && (43)\\
\widehat{\sigma}_{\lambda}^2 &= C_7 - C_8 \widehat{\sigma}_{\delta\lambda} && (44)
\end{aligned}$$

where the $C_i, i \in (2,3,4,5,6,7,8)$ are a set of constants as defined in Appendix 3.

As the solution illustrates, the gain of the EH identification is that we also obtain the variance-covariance structure Σ_s of the shocks in (11). Moreover, under this identification structure, the limitation arising from the BQ identification structure, viz. that the possibility of cross-correlation between demand and supply shocks is eliminated by assumption, is now no longer present. Specifically, instead of $\sigma_{\delta\lambda} = 0$ under BQ, under the EH identification typically $\sigma_{\delta\lambda} \neq 0$, allowing for cross-correlation across shocks. Thus the theoretical prior, that fiscal and monetary policies may respond to both demand and supply shocks, or the possibility of real rigidities in the economy, can now be accommodated empirically.

Moreover, the elimination of the BQ normalisation restriction, $\sigma_{\nu}^2 = \sigma_{\delta}^2 = \sigma_{\lambda}^2 = 1$, now leads to an empirical determination of shock variances, which in general will provide, $\sigma_{\nu}^2 \neq 1$, $\sigma_{\delta}^2 \neq 1$, $\sigma_{\lambda}^2 \neq 1$, such that decomposition now has unique roots, and hence a unique solution for demand and supply shocks.

What remains as a restriction, is that long-run neutrality of demand shocks continues to be imposed by the identification strategy.

5.3 Identification under zero international and domestic supply shock covariance and demand non-neutrality (DNN)

As a final consideration, we relax the assumption of long-run demand neutrality. In addition, we also relax the assumption of a one-to-one pass (AD-curve slope of unity) through of an output gap to prices. In order to achieve identification while relaxing the demand-neutrality assumption comes at a price: the parameters that identify the shock structure of the economy will no longer be constant, but become time-varying instead.[7] In what follows, we render this explicit.

Continue under the structural macroeconomic model (22, 23, 24), but replace the assumption of a one-to–one pass (AD-curve slope of unity) through of an output gap to prices, with $\beta \neq 1$, such that in contrast to (22, 23, 24), now:

$$\begin{aligned}\Delta y_t - E_{t-1}(\Delta y_t) &= \alpha(\pi_t - E_{t-1}(\pi_t)) + \delta_t + \gamma v_t & (45)\\ \pi_t - E_{t-1}(\pi_t) &= -\beta(\Delta y_t - E_{t-1}(\Delta y_t)) + \lambda_t & (46)\end{aligned}$$

such that:

$$\begin{aligned}\Delta y_t - E_{t-1}(\Delta y_t) &= \alpha(-\beta(\Delta y_t - E_{t-1}(\Delta y_t)) + \lambda_t) + \delta_t + \gamma v_t\\ &= \frac{\alpha}{1+\alpha\beta}\lambda_t + \frac{1}{1+\alpha\beta}\delta_t + \frac{\gamma}{1+\alpha\beta}v_t & (47)\\ \pi_t - E_{t-1}(\pi_t) &= -\beta(\alpha(\pi_t - E_{t-1}(\pi_t)) + \delta_t + \gamma v_t) + \lambda_t\\ &= \frac{1}{1+\alpha\beta}\lambda_t + \frac{-\beta}{1+\alpha\beta}\delta_t + \frac{-\beta\gamma}{1+\alpha\beta}v_t & (48)\end{aligned}$$

Again we proceed under the small economy assumption that any small domestic economy will not affect world output that is already implicit in the specification of (1), namely the (14) restriction that $g_{12} = g_{13} = 0$. In addition, as for the EH identification strategy, instead of the variance normalisation of BQ ($\sigma_\upsilon^2 = \sigma_\delta^2 = \sigma_\lambda^2 = 1$), we only impose $g_{11} = 1$ (as for 32). This then provides allows for the shock decomposition in (11) since now:

$$G = \begin{bmatrix} g_{11} & g_{12} & g_{13}\\ g_{21} & g_{22} & g_{23}\\ g_{31} & g_{32} & g_{33}\end{bmatrix} = \begin{bmatrix} 1 & 0 & 0\\ \frac{\gamma}{1+\alpha\beta} & \frac{1}{1+\alpha\beta} & \frac{\alpha}{1+\alpha\beta}\\ \frac{-\beta\gamma}{1+\alpha\beta} & \frac{-\beta}{1+\alpha\beta} & \frac{1}{1+\alpha\beta}\end{bmatrix} \tag{49}$$

which is purely a function of the parameters of the macroeconomic model.

In addition, as for EH we impose the additional small economy restriction that $\sigma_{\upsilon\delta} = 0$, such that domestic and international productivity shocks are orthogonal (as for 34). Thus:

$$\sum_\varepsilon = \begin{bmatrix} \widehat{\sigma}_{\varepsilon_1}^2 & \widehat{\sigma}_{\varepsilon_1\varepsilon_2} & \widehat{\sigma}_{\varepsilon_1\varepsilon_3}\\ \widehat{\sigma}_{\varepsilon_1\varepsilon_2} & \widehat{\sigma}_{\varepsilon_2}^2 & \widehat{\sigma}_{\varepsilon_2\varepsilon_3}\\ \widehat{\sigma}_{\varepsilon_1\varepsilon_3} & \widehat{\sigma}_{\varepsilon_2\varepsilon_3} & \widehat{\sigma}_{\varepsilon_3}^2\end{bmatrix} = G\begin{bmatrix} \sigma_\upsilon^2 & 0 & \sigma_{\upsilon\lambda}\\ 0 & \sigma_\delta^2 & \sigma_{\delta\lambda}\\ \sigma_{\upsilon\lambda} & \sigma_{\delta\lambda} & \sigma_\lambda^2\end{bmatrix} G' \tag{50}$$

This then implies (see Appendix 4):

[7] This arises since one of the just-identifying restrictions is lost by dropping (13). Hence the elements of the G matrix cease being constants.

$$\widehat{g_{33,t}} = \frac{B_7\widetilde{\Delta y_t} - B_3\widetilde{\pi}_t}{B_3B_8 - B_4B_7} \tag{51}$$

$$\widehat{g_{23,t}} = \frac{B_4\widetilde{\pi}_t - B_8\widetilde{\Delta y_t}}{B_4B_7 - B_3B_8} \tag{52}$$

$$\widehat{g_{22,t}} = \frac{B_7\widetilde{\Delta y_t} - B_3\widetilde{\pi}_t}{B_3B_8 - B_4B_7} \tag{53}$$

$$\widehat{g_{32,t}} = \left(\frac{\widehat{g_{33,t}} - 1}{\widehat{g_{23,t}}}\right)\widehat{g_{33,t}} \tag{54}$$

$$\widehat{g_{21,t}} = \widehat{\gamma}\widehat{g_{33,t}} \tag{55}$$

$$\widehat{g_{31,t}} = \widehat{\gamma}\widehat{g_{32,t}} \tag{56}$$

$$\widehat{g_{11,t}} = 1 \tag{57}$$

$$\widehat{g_{12,t}} = \widehat{g_{13,t}} = 0 \tag{58}$$

where B_3, B_4, B_7, B_8, are constants recoverable from the $\widehat{\alpha_{ij}}$ of (1, 2 & 3) as defined in Appendix 4, and $\widetilde{\Delta y_t}$, $\widetilde{\pi}_t$, continue to define cyclical variation in domestic growth and inflation from (7).

Given the knowns $\widehat{\sigma}^2_{\varepsilon_1}$, $\widehat{\sigma}_{\varepsilon_1\varepsilon_2}$, $\widehat{\sigma}_{\varepsilon_1\varepsilon_3}$, $\widehat{\sigma}^2_{\varepsilon_2}$, $\widehat{\sigma}_{\varepsilon_2\varepsilon_3}$, $\widehat{\sigma}^2_{\varepsilon_3}$, and $\widehat{\alpha_{01,j}}$, $\widehat{\alpha_{11,j}}$, $\widehat{\alpha_{02,j}}$, $\widehat{\alpha_{21,j}}$, $\widehat{\alpha_{22,j}}$, $\widehat{\alpha_{03,j}}$, $\widehat{\alpha_{31,j}}$, $\widehat{\alpha_{32,j}}$, $\widehat{\alpha_{33,j}}$, and $\widehat{g_{11,t}}$, $\widehat{g_{12,t}}$, $\widehat{g_{13,t}}$, $\widehat{g_{21,t}}$, $\widehat{g_{22,t}}$, $\widehat{g_{23,t}}$, $\widehat{g_{31,t}}$, $\widehat{g_{32,t}}$, $\widehat{g_{33,t}}$, this now allows for the identification of σ^2_ν, $\sigma^2_{\nu\lambda}$, σ^2_δ, $\sigma_{\delta\lambda}$, σ^2_λ, in addition to ν_t, δ_t and λ_t. Specifically, Appendix 5 shows that:

$$\widehat{\nu_t} = \widehat{\varepsilon_{1t}} \tag{59}$$

$$\widehat{\delta_t} = \frac{\widehat{\varepsilon_{3t}} - \left(\widehat{\gamma}\widehat{\beta_t}\widehat{g_{33,t}}\widehat{\nu_t} + \frac{\widehat{g_{33,t}}\left(\widehat{\varepsilon_{2t}} - \widehat{\gamma}\widehat{g_{33,t}}\widehat{\nu_t}\right)}{\widehat{g_{23,t}}}\right)}{\widehat{g_{33,t}}\left(\widehat{\beta_t} - \frac{\widehat{g_{33,t}}}{\widehat{g_{23,t}}}\right)} \tag{60}$$

$$\widehat{\lambda_t} = \frac{\widehat{\varepsilon_{2t}} - \widehat{\gamma}\widehat{g_{33,t}}\widehat{\nu_t} - \widehat{g_{33,t}}\widehat{\delta_t}}{\widehat{g_{23,t}}} \tag{61}$$

$$\widehat{\beta_t} = \frac{1 - \widehat{g_{33,t}}}{\widehat{g_{23,t}}} \tag{62}$$

and:

$$
\begin{aligned}
\widehat{\sigma_{\upsilon}^{2}} &= \widehat{\sigma}_{\varepsilon_1}^{2} && (63)\\
\widehat{\gamma} &= \frac{\widehat{g_{23,t}}\,\widehat{\sigma}_{\varepsilon_1\varepsilon_3} - \widehat{g_{33,t}}\,\widehat{\sigma}_{\varepsilon_1\varepsilon_2}}{\left(\widehat{g_{33,t}} - 2\left(\widehat{g_{33,t}}\right)^2\right)\widehat{\sigma_{\upsilon}^{2}}} && (64)\\
\widehat{\sigma_{\upsilon\lambda}} &= \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_2}}{\widehat{g_{23,t}}} - \frac{\widehat{g_{33,t}}\,\widehat{\sigma_{\upsilon}^{2}}}{\widehat{g_{23,t}}}\widehat{\gamma} && (65)\\
\widehat{\sigma_{\lambda}^{2}} &= \frac{\widehat{D_{6,t}}}{\widehat{D_{7,t}}} && (66)\\
\widehat{\sigma_{\delta}^{2}} &= \widehat{D_{4,t}} - \widehat{D_{5,t}}\,\widehat{\sigma_{\lambda}^{2}} && (67)\\
\widehat{\sigma_{\delta\lambda}} &= \left(\widehat{D_{1,t}} - \widehat{D_{2,t}}\widehat{D_{4,t}}\right) + \left(\widehat{D_{2,t}}\widehat{D_{5,t}} - \widehat{D_{3,t}}\right)\widehat{\sigma_{\lambda}^{2}} && (68)
\end{aligned}
$$

where the $\widehat{D_{i,t}}$ are a set of time varying parameters specified in Appendix 5.

It is important to note that the time-varying parameters of the shock-decomposition parameters contained in the G-matrix carry a further implication for diagnosing shock impacts. This arises from the fact that the implications of the time-varying parameters specified by (51) through (58) will differ depending on whether $\widetilde{\Delta y_t} \gtrless 0$, and $\widetilde{\pi}_t \gtrless 0$. In effect the parameters will be distinct conditional upon how the economy has been displaced from its long-run equilibrium. As Figure 3 illustrates, there are 4 logical possibilities, such that for Case I, $\widetilde{\Delta y_t} > 0$, $\widetilde{\pi}_t < 0$; for Case II, $\widetilde{\Delta y_t} > 0$, $\widetilde{\pi}_t > 0$; for Case III, $\widetilde{\Delta y_t} < 0$, $\widetilde{\pi}_t > 0$; and for Case IV, $\widetilde{\Delta y_t} < 0$, $\widetilde{\pi}_t < 0$. Shock identification will be distinct in each of the 4 cases, since the g_{ij} elements will be distinct under the four types of displacement from equilibrium.

Note that the distinction arises not with respect to implied steady-state values, but with respect to the dynamics of adjustment to steady state – i.e. it relates not to the economy's stability characteristic, but how it adjusts to steady state in response to a shock.

6. The South African empirical evidence on shock identification: 1960–2020

Our interest here is three-fold. The first requirement is to identify supply (δ) and demand (λ) shocks in the South African economy. A second requirement is to establish the implied contribution of supply and demand shocks to variation in growth and inflation. A third question is how a one-period supply or demand shock of specifiable magnitude translates into steady-state growth and inflation for the South African economy.

In pursuing these questions, we consider the answers provided by the alternative identification strategies we have reviewed, in order to draw inferences on the strategy that provides the most reliable answers, in addition to considering the inferences for the South African economy's shock structure.

In what follows, Section 6.1 considers the characteristics of the data we employ and its characteristics. Section 6.2 notes the impact of shocks on steady-state growth and inflation, Section

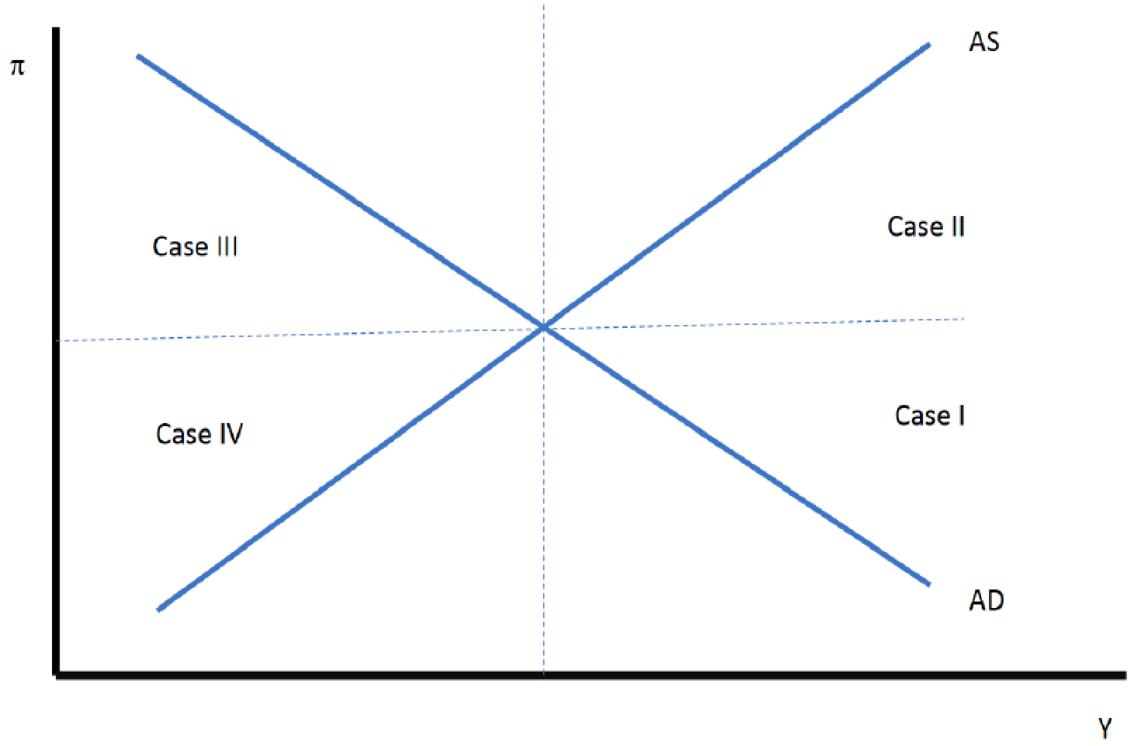

Figure 3: Four feasible cases under DNN identification

6.3 the implied supply and demand-shock structure, and Section 6.4 the relative contribution of supply and demand shocks to growth and inflation deviations from steady-state values.

6.1 Data

Our empirical application considers quarterly data over the 1960Q1 to 2020Q2 period. South African data for output (real GDP, lnY) and inflation (from the GDP deflator, π) is obtained from the South African Reserve Bank. International output data (lnY^*) employs US output derived from the St. Louis Federal Reserve.

The variables are illustrated in levels and where appropriate in first difference format in Figure 4.

Tests for optimal degrees of augmentation in the tests for stationarity are reported in Table 1, employing the Ng and Perron (1995) and Campbell and Perron (1991) t-test statistic, the AIC information criterion, the Ng and Perron (2001) modified AIC test statistic,[8] and the Schwert (1989, 2002) test statistics.

Table 2 reports the sequence of augmented Dickey-Fuller (1979, 1981) tests (henceforth ADF) under the Perron (1988) sequence, as well as Phillips-Perron (PP) and KPSS tests (Phillips and Perron, 1988; Kwiatkowski et al., 1992). Since unit root tests suffer from poor power characteristics in the presence of structural breaks (Perron, 1989, 1994; Holden and Perman,

[8] Though note that Wu (2010) in comparing the Ng-Perron-t-test and the Ng-Perron AIC-test found the t-test to outperfom the AIC-test.

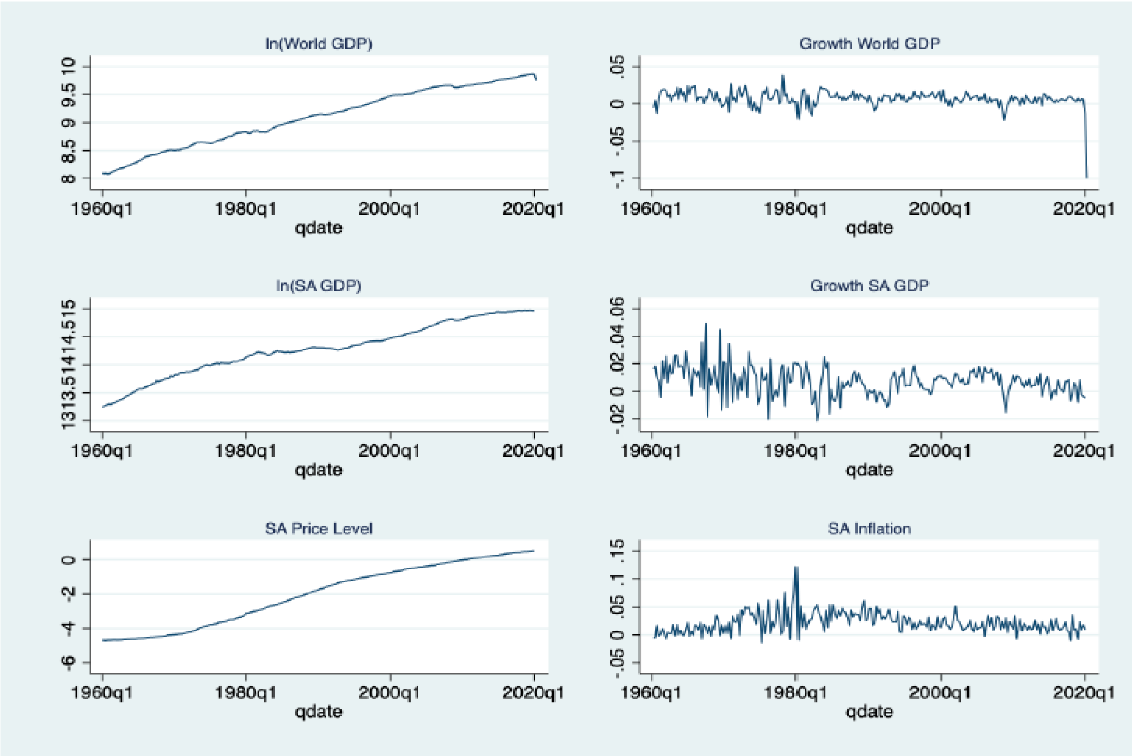

Figure 4: Variables in levels and first differences

	Lag Length				Adopted Lag Length
	NP-t	AIC	NP-AIC	S	
$\ln Y^*$	2	1	2	14	2
$\Delta \ln Y^*$	8	1	8	14	2
$\ln Y$	7	3	7	14	3
$\Delta \ln Y$	6	2	14	14	2
π	11	5	11	14	14

NP-t = Ng-Perron t; AIC = Akaike; Np-AIC = Ng-Perron AIC; S = Schwert lag-length test statistic.

Table 1: Optimal lag lengths for unit root test augmentation

	ADF						PP	KPSS
	τ_τ	Φ_3	Φ_2	τ_μ	Φ_1	τ		
lnY*	-0.025	3.35	4.97**	-2.58*	7.45**	2.617	-1.130	1.26***
ΔlnY*	-5.086***	14.19**	9.58**	-4.366***	9.71**	-3.148***	-142.016***	0.0843
lnY	-2.661	6.11	9.52**	-2.704*	11.70**	3.836	-1.514	0.671***
$\Delta \ln Y$	-6.195***	19.19**	12.82**	-5.730***	16.45**	-4.026***	-254.898***	0.291***
π	-2.156	3.43	2.29	-1.895	1.81	-0.614	-228.365***	0.342***
ADF = Augmented Dickey Fuller; PP = Phillips-Perron, KPSS = Kwiatkowski et al.; ***. **, *, denotes significance at the 1%, 5%, 10% levels respectively.								

Table 2: Univariate stationarity tests

1994), and given the likely presence of such breaks over a 60-year period at the quarterly frequency, we test for unit roots in the presence of up to two structural breaks, allowing for the structural breaks to be endogenously identified under both the Clemente et al. (1992) and Zivot and Andrews (1992) methodologies.[9] We report the results in Table 3, reporting the Clemente et al. (1992) test for a single (CMR1) and two (CMR2) structural breaks, and the Zivot and Andrews (1992) test for a single structural break (ZA), as well as the implied timing of the breaks. Final inferences on the univariate structure of the data are provided in Table 4.

The implication from the univariate time series properties of the data is that both SA and US real GDP are stationary in first differences $(\sim I(1))$, such that SA and US growth rates are stationary. Both PP and KPSS tests confirm this inference, thus lowering the chance that the integration properties of the data are a product of the specific power and size properties of the ADF tests. While the evidence confirms the presence of structural breaks in the data, this does not alter the inference that the two output series are difference stationary. By contrast, while for SA inflation ADF, PP and KPSS imply non-stationarity, once we control for the presence of structural breaks (by both the CMR and ZA methodologies), the SA inflation series proves stationary. The critical breaks are endogenously determined for the early 1970s, immediately preceding the oil price crises, and the mid-1990s, when South African monetary and fiscal policy became more firmly anti-inflationary. Thus SA inflation proves to be stationary $(\sim I(0))$, recognising the period of relative price instability stretching from the mid-1970s to the mid-1990s.

6.2 Impact of shocks on steady-state growth and inflation

We begin by considering the impact of shocks on steady-state growth and inflation in South Africa under the alternative BQ, the EH and the DNN identification strategies. We report the impacts on growth and inflation steady-state values under a range of international productivity (ν), domestic supply (δ) and demand (λ) shocks in Table 5.

For BQ identification, negative supply shocks ($\delta < 0$) marginally lower steady-state growth values, and imply a negative impact on domestic inflation. Of the two impacts, only the growth

[9] See also the discussion in Perron (1989), Holden and Perman (1994), Glynn et al. (2007).

		Statistic	Implied Breaks
$\ln Y^*$	CMR1	-2.398	1996q2
	CMR2	-2.910	1983q2, 1998q4
	ZA	-1.489	2008q1
$\Delta \ln Y^*$	CMR1	-7.951^{**}	2017q2
	CMR2	-5.526^{**}	1979q4, 2008q2
	ZA	-7.871^{***}	1983q1
$\ln Y$	CMR1	-2.684	2005q2
	CMR2	-3.209	1978q2, 2004q1
	ZA	-3.354	1984q3
$\Delta \ln Y$	CMR1	-6.106^{**}	1967q1
	CMR2	-3.846	1967q1, 1982q2
	ZA	-7.255^{***}	1993q1
π	CMR1	-1.297	1979q3
	CMR2	-6.617^{**}	1970q3, 1993q3
	ZA	-7.334^{***}	1971q2
CMR1 and CMR2 = Clemente et al. 1 and 2 break; ZA = Zivot-Andrews test statistics. ***. **, *, denotes significance at the 1%, 5%, 10% levels respectively.			

Table 3: Univariate stationarity tests

	$\sim I(d)$	Trend	Drift	Breaks
$\ln Y^*$	1	No	Yes	1983q2, 1996q2, 1998q4, 2008q1
$\Delta \ln Y^*$	0	-	-	1979q4, 1983q1, 2008q2, 2017q2
$\ln Y$	1	No	Yes	1978q2, 1984q3, 2004q1, 2005q2
$\Delta \ln Y$	0	-	-	1967q1, 1982q2, 1993q1
π	0	No	No	1970q3, 1971q2, 1979q3, 1993q3

Table 4: Inferred univariate time series structure of the data

impact is theoretically consistent. Positive demand shocks ($\lambda > 0$) have no long-run impact on growth (recall that this is an identifying restriction under the BQ methodology, and thus follows of necessity), and reports theoretically inconsistent negative impacts on steady-state inflation. Finally, negative international productivity shocks ($\nu < 0$) lowers domestic growth, though even less dramatically than domestic supply shocks do, and have insignificant impacts on domestic inflation.

Under the EH identification, negative supply shocks ($\delta < 0$) lower steady-state growth values, considerably more strongly than under the BQ identification. Negative supply shocks also imply a strong positive impact on domestic inflation. Both impacts are theoretically consistent – in contrast to the BQ identification. Positive demand shocks ($\lambda > 0$) have no long-run impact on growth (recall that this is an identifying restriction under the EH methodology, and thus follows of necessity), and reports theoretically consistent and strong positive impacts on steady-state inflation. Finally, negative international productivity shocks ($\nu < 0$) lowers domestic growth, though even less dramatically than domestic supply shocks do, and have a relatively small positive impact on domestic inflation.

For DNN identification results are not theoretically coherent. Negative supply shocks ($\delta < 0$) dramatically increase steady-state growth values, and lower steady-state domestic inflation. Both impacts are theoretically inconsistent. Similarly, positive demand shocks ($\lambda > 0$) have no long-run impact on steady-state growth or inflation. Only negative international productivity shocks ($\nu < 0$) have the theoretically consistent finding of lower domestic growth and increased inflation, though both effects prove very moderate.

Consideration of the steady-state growth and inflation impacts of supply and demand shocks, thus provides the most theoretically consistent results under the EH identification strategy. The implication is that positive supply shocks raise steady-state output, and lowers inflation. By contrast, the BQ and DNN identification strategies both imply that negative supply shocks lower prices, and in addition the DNN strategy suggests that negative supply shocks raise steady-state output. The BQ identification fails to produce fully satisfactory results, since negative supply shocks produce negligible steady-state growth costs, which are difficult to reconcile with the necessary theoretical prior for BQ identification, of highly elastic aggregate demand paired with inelastic aggregate supply. In addition, the inference of falling inflation rates in the presence of negative supply shocks is additionally theoretically incoherent. Since BQ and DNN results are difficult to support, the remainder of the discussion focusses on the EH identification strategy results. Full results for all identification strategies are available on request for derived shocks, and the proportion of growth and inflation cyclicality that is attributable to demand and supply shocks.

6.3 Supply and demand shocks under alternative identification strategies

Consider the implied shock structure for South Africa, under the EH identification strategy. Figure 5 reports the international productivity, domestic supply and domestic demand shocks

International Productivity Shock													
Shock (%):		Steady-State											
		Growth (%): Pre-Shock 0.695 Q-on-Q						Inflation (%): Pre-Shock 2.195 Q-on-Q					
		Post-Shock						Post-Shock					
		BQ		EH		DNN		BQ		EH		DNN	
Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y
-0.100	-0.401	0.692	2.797	0.592	2.389	0.671	2.711	2.193	9.065	2.210	9.137	2.197	9.082
-0.250	-1.004	0.691	2.793	0.440	1.772	0.637	2.572	2.193	9.065	2.235	9.244	2.204	9.112
-0.500	-2.015	0.689	2.785	0.187	0.750	0.582	2.348	2.193	9.065	2.278	9.428	2.215	9.159
-0.750	-3.033	0.687	2.776	-0.067	-0.268	0.526	2.121	2.193	9.065	2.320	9.608	2.226	9.206
-1.000	-4.060	0.685	2.768	-0.320	-1.268	0.470	1.893	2.193	9.065	2.362	9.788	2.238	9.257
Supply Shock													
Shock (%):		Steady-State											
		Growth (%): Pre-Shock 0.695 Q-on-Q						Inflation (%): Pre-Shock 2.195 Q-on-Q					
		Post-Shock						Post-Shock					
		BQ		EH		DNN		BQ		EH		DNN	
Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y
-0.100	-0.401	0.692	2.797	0.539	2.173	0.847	3.431	2.189	9.048	2.414	10.011	2.162	8.933
-0.250	-1.004	0.689	2.785	0.308	1.238	1.078	4.382	2.182	9.018	2.746	11.445	2.116	8.736
-0.500	-2.015	0.685	2.768	-0.077	-0.308	1.463	5.982	2.171	8.971	3.300	13.868	2.039	8.409
-0.750	-3.033	0.681	2.752	-0.461	-1.857	1.848	7.599	2.160	8.924	3.853	16.326	1.961	8.078
-1.000	-4.060	0.677	2.736	-0.846	-3.427	2.234	9.240	2.145	8.860	4.407	18.828	1.884	7.752
Demand Shock													
Shock (%):		Steady-State											
		Growth (%): Pre-Shock 0.695 Q-on-Q						Inflation (%): Pre-Shock 2.195 Q-on-Q					
		Post-Shock						Post-Shock					
		BQ		EH		DNN		BQ		EH		DNN	
Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y	Q-on-Q	Y-on-Y
0.100	0.401	0.693	2.801	0.693	2.801	0.693	2.801	2.190	9.052	2.383	9.878	2.193	9.065
0.250	1.004	0.693	2.801	0.693	2.801	0.693	2.801	2.186	9.035	2.669	11.111	2.193	9.065
0.500	2.015	0.693	2.801	0.693	2.801	0.693	2.801	2.178	9.001	3.146	13.190	2.193	9.065
0.750	3.033	0.693	2.801	0.693	2.801	0.693	2.801	2.171	8.971	3.622	15.294	2.193	9.065
1.000	4.060	0.693	2.801	0.693	2.801	0.693	2.801	2.164	8.941	4.100	17.436	2.193	9.065

Table 5: Impact on steady-state growth and inflation under specified values of permanent international productivity, and domestic supply and demand shocks under open economy BQ, EH and DNN identification

that emerge. International productivity shocks are generally of negligible importance, with the exception of the 2020 COVID shock, and to a lesser degree the 2008 sub-prime crisis. Further, while supply shocks have declined in magnitude and amplitude since the 1990s, negative demand shocks under the open economy identification remain relatively prominent. Note that the 2020 crisis is associated with negative international, supply and demand shocks.

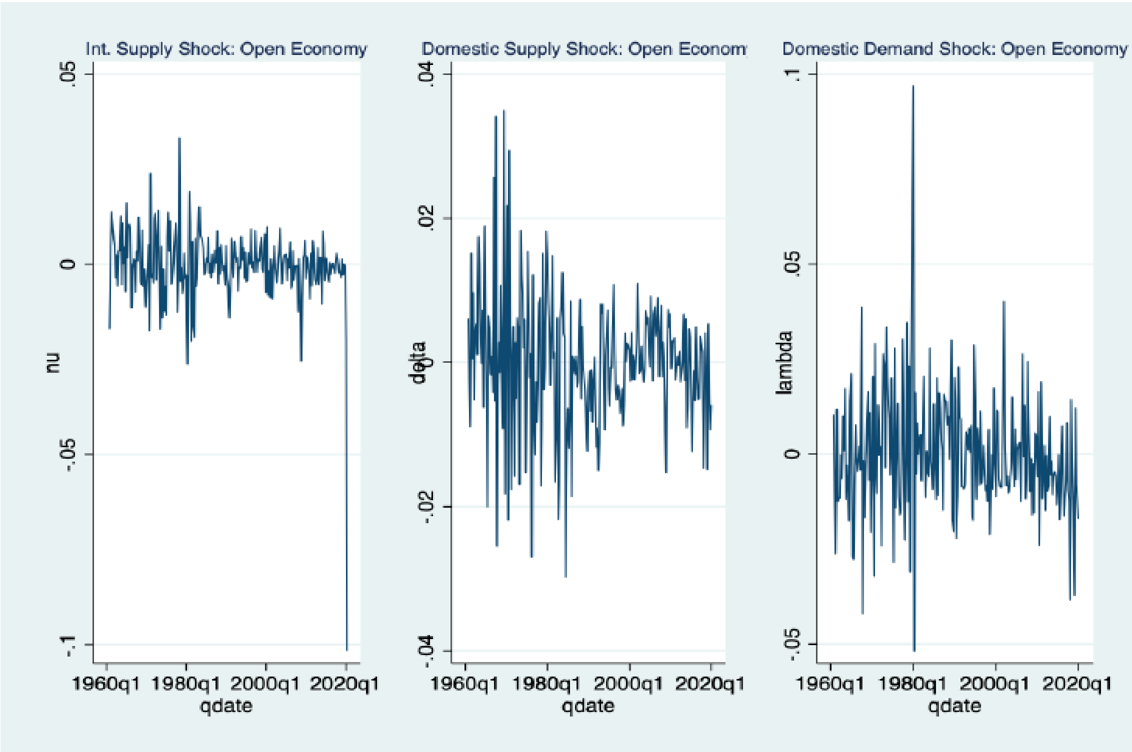

Figure 5: International productivity, domestic supply and demand shocks under EH open economy identification

Under EH identification, the correlation between demand and supply shocks is not restricted to 0, as it is under BQ identification. Table 6 reports the correlations, $\rho_{\delta\lambda}$, both for the full sample and over decadal sub-samples. Note that cross-correlations across supply and demand shocks are strong, and consistently positive under EH identification. The full sample $\rho_{\delta\lambda} \approx 0.4$ EH-value is approximately half that reported for the Australian case study reported by Enders and Hurn (2007). Nonetheless, the reported correlations provide some prima facie support for an identification strategy that does not rely on the absence of supply and demand-shock covariance.

6.4 The relative contribution of shocks to growth and inflation variation under alternative identification strategies

In this section we consider the contribution of supply and demand shocks to growth and inflation variation.

For the EH identification, Figure 6 decomposes the total shock to domestic growth into the relative contribution of international productivity shocks, domestic supply and domestic demand

	$\rho_{\delta\lambda}$
Period:	EH
1960-2020	0.392
1960s	0.739
1970s	0.304
1980s	0.352
1990s	0.274
2000s	0.473
2010s	0.392

Table 6: Correlation between supply and demand shocks under EH identification

	Growth Shocks			Inflation Shocks		
	Int.Prod.	Supply	Demand	Int.Prod.	Supply	Demand
2016Q1	-0.013	0.964	0.049	-0.006	0.422	0.583
2016Q2	-0.074	1.031	0.043	-0.035	0.484	0.551
2016Q3	0.038	1.327	-0.366	-0.005	-0.156	1.161
2016Q4	-0.008	1.105	-0.097	0.005	-0.730	1.725
2017Q1	0.029	1.029	-0.058	-0.057	-2.034	3.091
2017Q2	-0.106	1.206	-0.100	0.066	-0.755	1.688
2017Q3	0.054	0.811	0.135	0.012	0.180	0.808
2017Q4	0.166	0.627	0.207	0.026	0.098	0.876
2018Q1	-0.014	1.123	-0.109	0.008	-0.616	1.609
2018Q2	0.028	0.902	0.070	0.010	0.321	0.669
2018Q3	-0.081	1.064	0.016	-0.057	0.747	0.310
2018Q4	0.409	1.112	-0.520	-0.033	-0.089	1.121
2019Q1	-0.014	1.118	-0.104	0.008	-0.658	1.650
2019Q2	-0.082	1.181	-0.099	0.053	-0.754	1.702
2019Q3	0.001	1.070	-0.071	-0.001	-1.277	2.278
2019Q4	0.008	1.046	-0.054	-0.019	-2.611	3.630
2020Q1	0.331	0.750	-0.081	-0.302	-0.686	1.988

Table 7: Proportional contribution of international productivity, domestic supply and demand shocks to growth and inflation shocks in South Africa under EH identification

shocks. Figure 7 repeats for shocks to domestic inflation. Table 7 reports for the post-2016Q1 period. The implication is that deviations of growth from steady values are primarily due to domestic supply shocks, with both international productivity shocks and domestic demand shocks only rarely proving anything but insignificant. Deviations of inflation from steady-state values are primarily due to domestic demand shocks, though in this instance there are periodic episodes in which both international productivity and domestic supply shocks contribute to domestic inflation shocks.

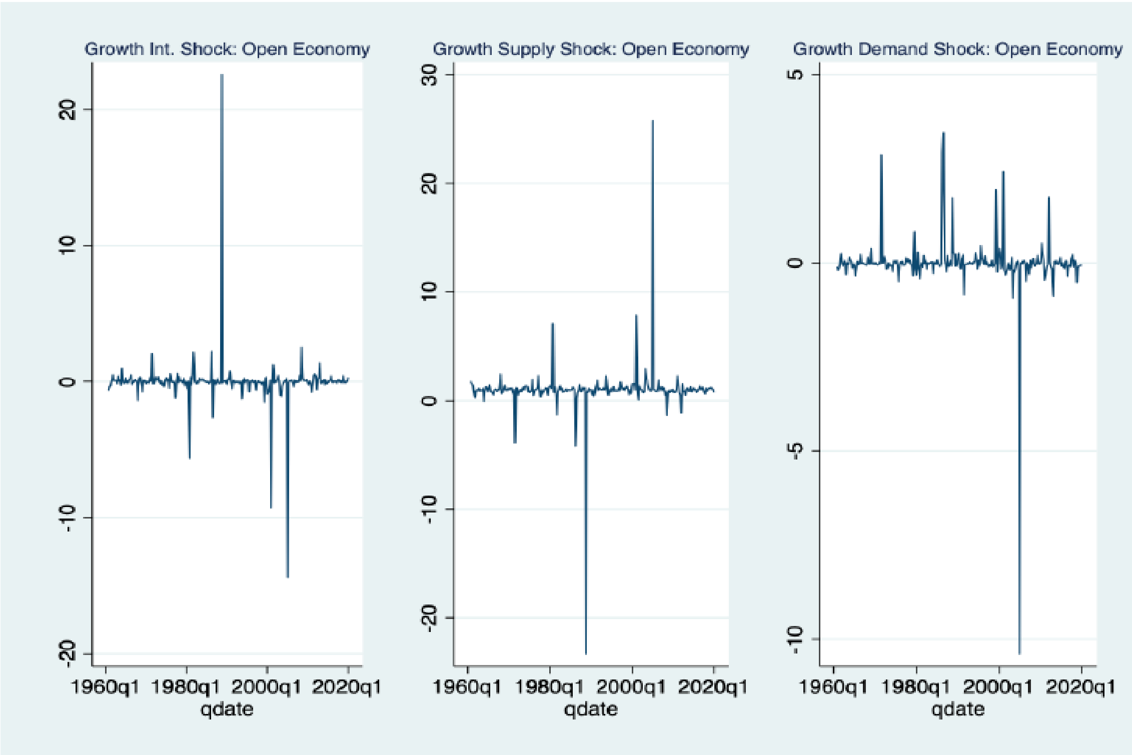

Figure 6: Decomposition of growth shocks into international productivity, domestic supply and domestic demand shocks under EH open economy identification

ftbpFU4.6423in3.3529in0ptDecomposition of growth shocks into international productivity, domestic supply and domestic demand shocks under EH open economy identificationFig14Figure

ftbpFU4.6414in3.3529in0ptDecomposition of inflation shocks into international productivity, domestic supply and domestic demand shocks under EH open economy identificationFig15Figure

7. Conclusion and evaluation

This paper addresses the identification of supply and demand shocks in the South African economy over the 1960–2020 period. It further considers the relative importance of the two types of shock to fluctuations of growth and inflation from their steady-state values, as well as the potential impact of shocks on the steady-state values themselves.

Since supply and demand shocks are not directly observable, and since observed deviations of growth and inflation from steady-state are a composite of supply, demand, and potentially

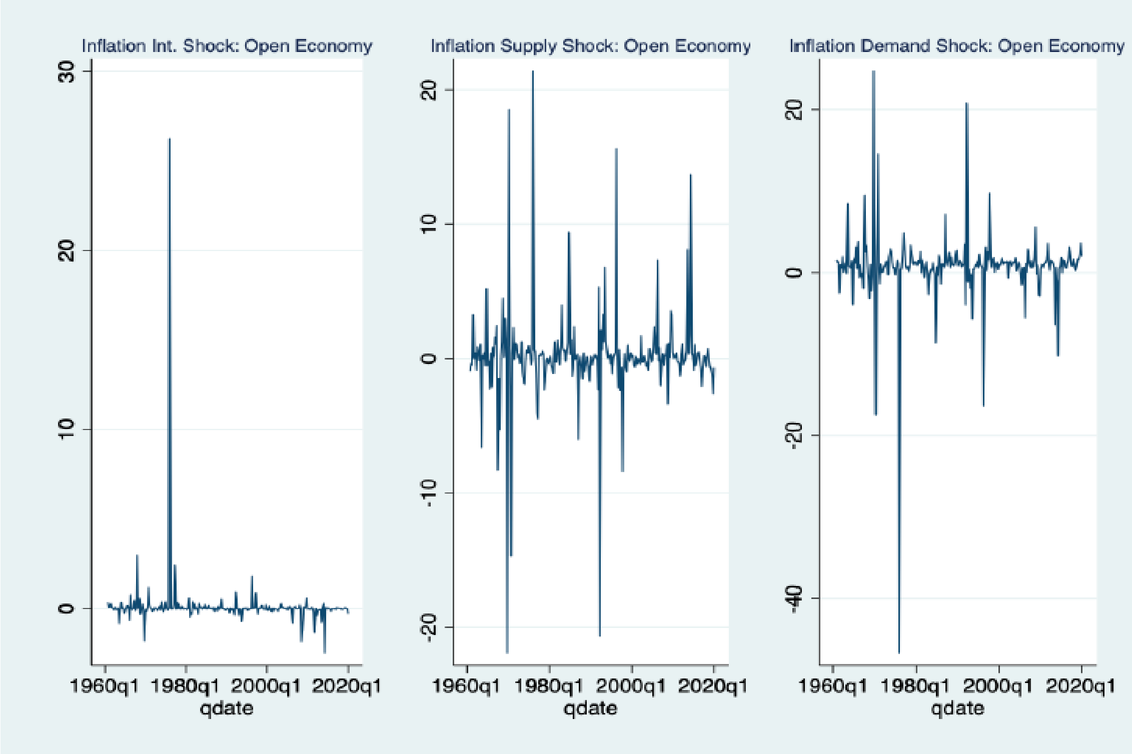

Figure 7: Decomposition of inflation shocks into international productivity, domestic supply and domestic demand shocks under EH open economy identification

international productivity shocks, the underlying shocks have to be identified. Of central concern to this paper is an examination of the significance of alternative identification strategies on the nature of supply and demand shocks, and their impact on the economy. Three alternative identification strategies are explored: zero shock covariance in the presence of long-run demand neutrality; non-zero shock covariance in the presence of long-run demand neutrality; and long-run demand non-neutrality.

The empirical results do provide an answer as to which identification strategy provides the most reliable results. The implied shock structure and its implications for steady-state values of growth and inflation also provides some policy implications.

7.1 The preferred identification strategy for the South African context

The paper considered three alternative identification strategies: the Blanchard-Quah (BQ) zero shock covariance in the presence of long-run demand neutrality; non-zero shock covariance in the presence of long-run demand neutrality associated with Enders and co-authors (CEH, EH); and the long-run demand non-neutrality case (DNN).

Use of BQ identification for South Africa faces multiple caveats.

The fact that the identification strategy provides multiple solutions for supply and demand shocks (4 for the closed economy, 8 for the open) introduces an element of uncertainty in the solution choice that is not guided by statistical criteria.[10]

Even under the 2020 and 2008 shock negativity restrictions that then produce a single preferred shock identification, the BQ identification fails to produce fully satisfactory results. Negative supply shocks produce negligible steady-state growth costs that are difficult to reconcile with the necessary theoretical prior for BQ identification, of highly elastic aggregate demand paired with inelastic aggregate supply. The inference of falling inflation rates in the presence of negative supply shocks is additionally theoretically incoherent.

These concerns attach to the BQ identification strategy over and above the concerns that arise from the assumptions that define identification for BQ. Most significant of these are the assumption of shock orthogonality, and of long-run demand shock neutrality. Under the latter of these assumptions, the empirical finding to emerge – that fluctuation of growth around its steady-state value is driven primarily by supply rather than demand shocks – is unsurprising, since it is baked into the derivation by assumption.

Use of the EH identification strategy has the significant advantage of producing unique solutions for domestic supply and demand as well as international productivity shocks. This immediately removes one of the uncertainties that attach to the interpretation of shock identification that emerges under BQ identification.

In addition, the open economy EH identification produces theoretically consistent and defensible shock decompositions. Negative supply shocks significantly lower steady-state growth and raise steady-state inflation. Positive demand shocks serve to raise steady-state inflation, while leaving steady-state growth unchanged. Finally, negative international productivity shocks lower steady-state growth and raise steady-state inflation, though less dramatically than domestic supply shocks.

The open economy EH identification thus produces results that are considerably more theoretically defensible than the BQ identification.

However, the EH identification strategy, while explicitly relaxing the assumption of shock orthogonality, continues to impose long-run demand-shock neutrality. The empirical finding that fluctuation of growth around its steady-state value is driven primarily by supply rather than demand shocks continues to be a direct result of the identifying assumptions.

Under the DNN identification strategy, the demand-neutrality assumption is relaxed. However, the results from the DNN identification either amplify the implications of the EH identification, or are amongst the least theoretically coherent to emerge from our analysis. Thus for the open economy DNN identification, negative supply shocks serve to raise steady-state growth, and lower steady-state inflation – a result that is entirely theoretically incoherent (aggregate demand would have to be positively sloped and less elastic than aggregate supply). Demand

[10] Though these results are not reported in the body of the paper, when considering BQ results in the present study the choice of solution was guided by an insistence that both demand and supply shocks for the COVID and 2008 sub-prime crises should prove negative. This does generate a unique solution, but there is no guarantee that this modelling choice is in fact reflective of reality.

shocks have no impact on either steady-state growth or inflation. Thus the consequence of relaxing demand-neutrality is to generate theoretically incoherent results, at least under the approach adopted in the present paper. Perhaps most significantly of all, the relaxation of the demand neutrality assumption does not release the demand side of the economy into an ability to generate strong growth gains for the South African economy.

The conclusion is thus that the preferred identification strategy for the South African economy emerges under the assumption of non-zero shock covariance, and long-run demand neutrality. What is more, while the implications of supply and demand shocks for steady-state growth and inflation are both theoretically coherent, and mirror one another closely, the open economy case has the added advantage of producing theoretically coherent results for international productivity shocks (negative growth, positive inflationary consequences), and of providing insight into the susceptibility of the South African economy to international shocks.

The preferred identification strategy is thus the open economy non-zero shock covariance, and long-run demand neutrality case (EH).

7.2 What does this mean for South Africa's shock structure?

Given the preference for EH identification, the implication is thus that Figure 5 of the paper is the preferred account of international productivity, domestic supply and domestic demand shocks for the South African economy. International productivity shocks are generally of negligible importance, with the exception of the 2020 COVID shock, and to a lesser degree the 2008 sub-prime crisis. Note that the 2020 crisis is associated with negative international, supply and demand shocks. Supply shocks have declined in magnitude and amplitude since the 1990s, while demand shocks remain relatively prominent. The implication is further that there exists a relatively strong positive correlation between supply and demand shocks in South Africa, with $\rho_{\delta\lambda} \approx 0.4$ over the full sample.

The preferred decompositions of deviations of growth and inflation from their steady-state values are reported in Figures 6 and 7 respectively, with post-2016Q1 numeric decompositions reported in Table 7. The implication is that deviations of growth from steady-state values are primarily due to domestic supply shocks, with both international productivity shocks and domestic demand shocks only rarely proving anything but insignificant. Deviations of inflation from steady-state values are primarily due to domestic demand shocks, though in this instance there are periodic episodes in which both international productivity and domestic supply shocks contribute to domestic inflation shocks.

The impact of international productivity, domestic supply and demand shocks on steady-state growth and inflation under the preferred identification is reported in the EH column of Table 5. Negative supply shocks ($\delta < 0$) lower steady-state growth values, and also imply a strong positive impact on domestic inflation. Positive demand shocks ($\lambda > 0$) have no long-run impact on growth, and return theoretically consistent and strong positive impacts on steady-state inflation. Finally, negative international productivity shocks ($\nu < 0$) lower domestic growth, though even less dramatically than domestic supply shocks do, and have a relatively small positive impact on domestic inflation. All implied impacts are theoretically consistent.

Note that the underlying finding that emerges for South Africa, that long-run fluctuations in output are primarily supply-side rather than demand-side in nature, is consistent with the international literature on shock decompositions.

7.3 Policy implications

Finally, given the preferred identification structure of non-zero shock covariance in the presence of long-run demand neutrality in the open economy context, we specify three policy implications implied by the findings of the present paper.

First, demand-side policy shocks (fiscal, monetary policy interventions) carry significant implications for inflationary pressure in the South African economy. Positive shocks imply strong upward pressure on inflation, but contractionary shocks also carry the potential of inflation mitigation. Unfortunately, steady-state growth does not respond to demand shocks, and hence fiscal and monetary stimuli do not appear to carry the potential for improving South Africa's growth trajectory.

Second, supply-side shocks are the principal source of deviation of South African growth from its steady-state values. The implication is that the stabilisation of growth in South Africa is less likely to respond to demand-side than to supply-side policy intervention. Deviations of growth from steady-state values is thus relatively unresponsive to standard macroeconomic policy tools in the fiscal and monetary policy tool-kit. Growth in South Africa is firmly a supply-side question.

Third, South Africa does not appear to be prone to volatility arising from international productivity shocks. Big crises such as the 2008 sub-prime and the 2020 COVID crises do transfer into appreciable shocks to South African growth and inflation, but generally South Africa appears relatively immune to international shock transmission.

8. Appendix 1: Demand-shock neutrality

From (8), in the presence of a demand shock and absence of a supply shock, $\lambda = 1$, $\delta = 0$, $\nu = 0$, for $t = t_s$, where t_s denotes the time period in which the shock occurs, specifies $\varepsilon_{1t} = 0$, $\varepsilon_{2t} = g_{23}$, $\varepsilon_{3t} = g_{33}$. From (5), long-run ($\pi_{t-j} = \pi^*$) demand-shock neutrality requires:

$$\begin{aligned}
\Delta y_t^* - \frac{C_1}{C_4} &= \frac{C_2}{C_4}\varepsilon_{1t} + \frac{1}{C_4}\varepsilon_{2t} + \frac{C_3}{C_4}\varepsilon_{3t} = 0 \\
&= \frac{1}{C_4}g_{23} + \frac{C_3}{C_4}g_{33} = 0 \\
\Longrightarrow g_{23} &= -C_3 g_{33} \\
&= \frac{-\sum_{j=1}^{k}\alpha_{23,j}}{1-\sum_{j=1}^{k}\alpha_{33,j}}g_{33}
\end{aligned}$$

$$
\begin{aligned}
C_1 &= \alpha_{02} + \left(\frac{\alpha_{01} \sum_{j=1}^{k} \alpha_{21,j}}{1 - \sum_{j=1}^{k} \alpha_{11,j}} \right) + \left(\frac{\left[\alpha_{01} \sum_{j=1}^{k} \alpha_{31,j} + \alpha_{03} \left(1 - \sum_{j=1}^{k} \alpha_{11,j} \right) \right] \sum_{j=1}^{k} \alpha_{23,j}}{\left(1 - \sum_{j=1}^{k} \alpha_{11,j} \right) \left(1 - \sum_{j=1}^{k} \alpha_{33,j} \right)} \right) \\
C_2 &= \left(\frac{\sum_{j=1}^{k} \alpha_{21,j} \left(1 - \sum_{j=1}^{k} \alpha_{33,j} \right) + \sum_{j=1}^{k} \alpha_{23,j} \sum_{j=1}^{k} \alpha_{31,j}}{\left(1 - \sum_{j=1}^{k} \alpha_{11,j} \right) \left(1 - \sum_{j=1}^{k} \alpha_{33,j} \right)} \right) \\
C_3 &= \left(\frac{\sum_{j=1}^{k} \alpha_{23,j}}{1 - \sum_{j=1}^{k} \alpha_{33,j}} \right) \\
C_4 &= 1 - \sum_{j=1}^{k} \alpha_{22,j} - \frac{\sum_{j=1}^{k} \alpha_{23,j} \sum_{j=1}^{k} \alpha_{32,j}}{1 - \sum_{j=1}^{k} \alpha_{33,j}} \\
&= \frac{\left(1 - \sum_{j=1}^{k} \alpha_{22,j} \right) \left(1 - \sum_{j=1}^{k} \alpha_{33,j} \right) - \sum_{j=1}^{k} \alpha_{23,j} \sum_{j=1}^{k} \alpha_{32,j}}{1 - \sum_{j=1}^{k} \alpha_{33,j}}
\end{aligned}
$$

9. Appendix 2: Blanchard-Quah identification

$$
\begin{aligned}
\widehat{g_{11}} &= \pm \sqrt[2]{\widehat{\sigma}^2_{\varepsilon_1}} \\
\widehat{g_{21}} &= \frac{\widehat{\sigma}_{\varepsilon_1 \varepsilon_2}}{\widehat{g_{11}}} \\
\widehat{g_{31}} &= \frac{\widehat{\sigma}_{\varepsilon_1 \varepsilon_3}}{\widehat{g_{11}}}
\end{aligned}
$$

$$
C = \frac{\left[- \sum_{j=1}^{k} \alpha_{23,j} \right]}{\left[1 - \sum_{j=1}^{k} \alpha_{33,j} \right]}
$$

$$
\widehat{g_{22}} = \pm \sqrt[2]{\frac{\left(\widehat{\sigma}_{\varepsilon_2 \varepsilon_3} - \widehat{g_{21}} \widehat{g_{31}} - \frac{\widehat{\sigma}^2_{\varepsilon_2}}{C} + \frac{(\widehat{g_{21}})^2}{C} \right)^2}{\widehat{\sigma}^2_{\varepsilon_3} - (\widehat{g_{31}})^2 - 2 \frac{\left(\widehat{\sigma}_{\varepsilon_2 \varepsilon_3} - \widehat{g_{21}} \widehat{g_{31}} - \frac{\widehat{\sigma}^2_{\varepsilon_2}}{C} + \frac{(\widehat{g_{21}})^2}{C} \right)}{C} - \left(\frac{\widehat{\sigma}^2_{\varepsilon_2}}{C^2} - \frac{(\widehat{g_{21}})^2}{C^2} \right)}}
$$

$$
\Longrightarrow \widehat{g_{32}} = \frac{1}{\widehat{g_{22}}} \left(\widehat{\sigma}_{\varepsilon_2 \varepsilon_3} - \widehat{g_{21}} \widehat{g_{31}} - \frac{\widehat{\sigma}^2_{\varepsilon_2}}{C} + \frac{(\widehat{g_{21}})^2}{C} \right) + \frac{\widehat{g_{22}}}{C}
$$

$$\widehat{(g_{33})} = \pm \sqrt[2]{\frac{\widehat{\sigma}^2_{\varepsilon_2}}{C^2} - \frac{(\widehat{g_{21}})^2}{C^2} - \frac{\widehat{(g_{22})}^2}{C^2}}$$

Hence we have eight potential solutions to the decomposition:

$$\begin{array}{llllllll}
 & \widehat{g_{11}} & \widehat{g_{21}} & \widehat{g_{31}} & \widehat{g_{22}} & \widehat{g_{32}} & \widehat{g_{33}} & \widehat{g_{23}} \\
Sol\ 1: & \sqrt[2]{\widehat{\sigma}^2_{\varepsilon_1}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_2}}{\widehat{g_{11}}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_3}}{\widehat{g_{11}}} & +\sqrt[2]{\Phi} & \frac{\Lambda}{\widehat{g_{22}}} + \frac{\widehat{g_{22}}}{C} & +\sqrt[2]{\Psi} & \widehat{g_{33}}C \\
Sol\ 2: & -\sqrt[2]{\widehat{\sigma}^2_{\varepsilon_1}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_2}}{\widehat{g_{11}}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_3}}{\widehat{g_{11}}} & +\sqrt[2]{\Phi} & \frac{\Lambda}{\widehat{g_{22}}} + \frac{\widehat{g_{22}}}{C} & +\sqrt[2]{\Psi} & \widehat{g_{33}}C \\
Sol\ 3: & \sqrt[2]{\widehat{\sigma}^2_{\varepsilon_1}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_2}}{\widehat{g_{11}}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_3}}{\widehat{g_{11}}} & -\sqrt[2]{\Phi} & \frac{\Lambda}{\widehat{g_{22}}} + \frac{\widehat{g_{22}}}{C} & +\sqrt[2]{\Psi} & \widehat{g_{33}}C \\
Sol\ 4: & -\sqrt[2]{\widehat{\sigma}^2_{\varepsilon_1}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_2}}{\widehat{g_{11}}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_3}}{\widehat{g_{11}}} & -\sqrt[2]{\Phi} & \frac{\Lambda}{\widehat{g_{22}}} + \frac{\widehat{g_{22}}}{C} & +\sqrt[2]{\Psi} & \widehat{g_{33}}C \\
Sol\ 5: & \sqrt[2]{\widehat{\sigma}^2_{\varepsilon_1}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_2}}{\widehat{g_{11}}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_3}}{\widehat{g_{11}}} & +\sqrt[2]{\Phi} & \frac{\Lambda}{\widehat{g_{22}}} + \frac{\widehat{g_{22}}}{C} & -\sqrt[2]{\Psi} & \widehat{g_{33}}C \\
Sol\ 6: & -\sqrt[2]{\widehat{\sigma}^2_{\varepsilon_1}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_2}}{\widehat{g_{11}}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_3}}{\widehat{g_{11}}} & +\sqrt[2]{\Phi} & \frac{\Lambda}{\widehat{g_{22}}} + \frac{\widehat{g_{22}}}{C} & -\sqrt[2]{\Psi} & \widehat{g_{33}}C \\
Sol\ 7: & \sqrt[2]{\widehat{\sigma}^2_{\varepsilon_1}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_2}}{\widehat{g_{11}}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_3}}{\widehat{g_{11}}} & -\sqrt[2]{\Phi} & \frac{\Lambda}{\widehat{g_{22}}} + \frac{\widehat{g_{22}}}{C} & -\sqrt[2]{\Psi} & \widehat{g_{33}}C \\
Sol\ 8: & -\sqrt[2]{\widehat{\sigma}^2_{\varepsilon_1}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_2}}{\widehat{g_{11}}} & \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_3}}{\widehat{g_{11}}} & -\sqrt[2]{\Phi} & \frac{\Lambda}{\widehat{g_{22}}} + \frac{\widehat{g_{22}}}{C} & -\sqrt[2]{\Psi} & \widehat{g_{33}}C
\end{array}$$

$$\Phi = \frac{\left(\widehat{\sigma}_{\varepsilon_2\varepsilon_3} - \widehat{g_{21}}\widehat{g_{31}} - \frac{\widehat{\sigma}^2_{\varepsilon_2}}{C} + \frac{(\widehat{g_{21}})^2}{C}\right)^2}{\widehat{\sigma}^2_{\varepsilon_3} - (\widehat{g_{31}})^2 - 2\frac{\left(\widehat{\sigma}_{\varepsilon_2\varepsilon_3} - \widehat{g_{21}}\widehat{g_{31}} - \frac{\widehat{\sigma}^2_{\varepsilon_2}}{C} + \frac{(\widehat{g_{21}})^2}{C}\right)}{C} - \left(\frac{\widehat{\sigma}^2_{\varepsilon_2}}{C^2} - \frac{(\widehat{g_{21}})^2}{C^2}\right)}$$

$$\Lambda = \widehat{\sigma}_{\varepsilon_2\varepsilon_3} - \widehat{g_{21}}\widehat{g_{31}} - \frac{\widehat{\sigma}^2_{\varepsilon_2}}{C} + \frac{(\widehat{g_{21}})^2}{C}$$

$$\Psi = \frac{\widehat{\sigma}^2_{\varepsilon_2}}{C^2} - \frac{(\widehat{g_{21}})^2}{C^2} - \frac{\widehat{(g_{22})}^2}{C^2}$$

Note also that since:

$$\begin{aligned}
\widehat{g_{22}} &= \pm\sqrt[2]{\Phi} \in R\ iff\ \Phi > 0 \\
\widehat{g_{33}} &= \pm\sqrt[2]{\Psi} \in R\ iff\ \Psi > 0
\end{aligned}$$

where R denotes real number space, failure to satisfy the non-negativity condition would issue in solutions subject to periodicity.

Finally, from (8, 14):

$$\widehat{v}_t = \frac{\widehat{\varepsilon_{1t}}}{\widehat{g_{11}}}$$

$$\widehat{\lambda}_t = \left(\frac{\widehat{g_{22}}}{\widehat{g_{22}}\widehat{g_{33}} - \widehat{g_{23}}\widehat{g_{32}}}\right)\widehat{\varepsilon_{3t}} - \left(\frac{\widehat{g_{22}}\widehat{g_{31}} - \widehat{g_{21}}\widehat{g_{32}}}{\widehat{g_{22}}\widehat{g_{33}} - \widehat{g_{23}}\widehat{g_{32}}}\right)\widehat{v}_t - \left(\frac{\widehat{g_{32}}}{\widehat{g_{22}}\widehat{g_{33}} - \widehat{g_{23}}\widehat{g_{32}}}\right)\widehat{\varepsilon_{2t}}$$

$$\widehat{\delta}_t = \left(\frac{1}{\widehat{g_{22}}}\right)\widehat{\varepsilon_{2t}} - \frac{\widehat{g_{21}}}{\widehat{g_{22}}}\widehat{v}_t - \left(\frac{\widehat{g_{23}}}{\widehat{g_{22}}}\right)\widehat{\lambda}_t$$

10. Appendix 3: Shock covariance under demand neutrality

From (31), and substituting from (35):

$$\begin{aligned}
g_{23}\left[1 - \sum_{j=1}^{k}\alpha_{33,j}\right] + g_{33}\sum_{j=1}^{k}\alpha_{23,j} &= 0 \\
g_{23} &= g_{33}\frac{\left[-\sum_{j=1}^{k}\alpha_{23,j}\right]}{\left[1 - \sum_{j=1}^{k}\alpha_{33,j}\right]} \\
\Longrightarrow \widehat{\alpha} &= \frac{\left[-\sum_{j=1}^{k}\alpha_{23,j}\right]}{\left[1 - \sum_{j=1}^{k}\alpha_{33,j}\right]} \\
let\ C_1 &= 1 + \widehat{\alpha} \\
C_2 &= \frac{1}{1 + \widehat{\alpha}} \\
C_3 &= \frac{\widehat{\alpha}}{1 + \widehat{\alpha}}
\end{aligned}$$

Then:

$$\widehat{\sigma}_{\upsilon}^2 = \widehat{\sigma}_{\varepsilon_1}^2$$

$$\widehat{\gamma} = \frac{C_2\widehat{\sigma}_{\varepsilon_1\varepsilon_2} - C_3\widehat{\sigma}_{\varepsilon_1\varepsilon_3}}{\left(C_2C_3 + (C_2)^2\right)\widehat{\sigma}_{\upsilon}^2}$$

$$\widehat{\sigma}_{\upsilon\lambda} = \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_2} - \widehat{\gamma}C_2\widehat{\sigma}_{\upsilon}^2}{C_3}$$

$$
\begin{aligned}
C_4 &= \frac{\widehat{\sigma}^2_{\varepsilon_2} - (\widehat{\gamma}C_2)^2\,\widehat{\sigma}^2_{\upsilon} - 2\,(\widehat{\gamma}C_2C_3)\,\widehat{\sigma}_{\upsilon\lambda}}{(C_2)^2} \\
C_5 &= \frac{2\,(C_2C_3)}{(C_2)^2} \\
C_6 &= \frac{(C_3)^2}{(C_2)^2}
\end{aligned}
$$

$$
\begin{aligned}
C_7 &= \frac{\widehat{\sigma}_{\varepsilon_2\varepsilon_3} + (\widehat{\gamma}C_2)^2\,\widehat{\sigma}^2_{\upsilon} + (C_2)^2\,C_4}{C_2C_3 + (C_2)^2\,C_6} \\
C_8 &= \frac{(C_2)^2 - C_2C_3 + (C_2)^2\,C_5}{C_2C_3 + (C_2)^2\,C_6}
\end{aligned}
$$

$$
\begin{aligned}
\widehat{\sigma}_{\delta\lambda} &= \frac{\widehat{\sigma}^2_{\varepsilon_3} - (\widehat{\gamma}C_2)^2\,\widehat{\sigma}^2_{\upsilon} + 2\left(\widehat{\gamma}(C_2)^2\right)\widehat{\sigma}_{\upsilon\lambda} - (C_2)^2\,(C_4 - C_6C_7 - C_7)}{-(C_2)^2\,(C_5 + C_6C_8 + C_8 + 2)} \\
\widehat{\sigma}^2_{\lambda} &= C_7 - C_8\widehat{\sigma}_{\delta\lambda} \\
\widehat{\sigma}^2_{\delta} &= C_4 - C_6C_7 - (C_5 + C_6C_8)\,\widehat{\sigma}_{\delta\lambda}
\end{aligned}
$$

Hence:

$$
\begin{aligned}
\widehat{v_t} &= \widehat{\varepsilon_{1t}} \\
\widehat{\lambda_t} &= \frac{\widehat{\varepsilon_{2t}} + \widehat{\varepsilon_{3t}}}{C_2 + C_3} \\
\widehat{\delta_t} &= \frac{\widehat{\varepsilon_{2t}} - \widehat{\gamma}C_2\widehat{v_t}}{C_2} - \frac{C_3}{C_2}\left(\frac{\widehat{\varepsilon_{2t}} + \widehat{\varepsilon_{3t}}}{C_2 + C_3}\right)
\end{aligned}
$$

11. Appendix 4: Demand non-neutrality

For steady-state:

$$
\Delta y_t^{f,*} = \frac{1}{C_0}\alpha_{01} + \frac{1}{C_0}\varepsilon_{1t}
$$

$$
\Delta y_t^{*} = \frac{C_1}{C_4} + \frac{C_2}{C_4}\varepsilon_{1t} + \frac{1}{C_4}\varepsilon_{2t} + \frac{C_3}{C_4}\varepsilon_{3t}
$$

$$
\pi_t^{*} = \left(\frac{C_4C_5 + C_1C_6}{C_4}\right) + \left(\frac{C_4C_7 + C_2C_6}{C_4}\right)\varepsilon_{1t} + \left(\frac{C_6}{C_4}\right)\varepsilon_{2t} + \left(\frac{C_4C_8 + C_3C_6}{C_4}\right)\varepsilon_{3t}
$$

$$
\begin{aligned}
C_0 &= \frac{1}{1-\sum_{j=1}^{k}\alpha_{11,j}} \\
C_1 &= \alpha_{02} + \left(\frac{\alpha_{01}\sum_{j=1}^{k}\alpha_{21,j}}{1-\sum_{j=1}^{k}\alpha_{11,j}}\right) + \left(\frac{\left[\alpha_{01}\sum_{j=1}^{k}\alpha_{31,j}+\alpha_{03}\left(1-\sum_{j=1}^{k}\alpha_{11,j}\right)\right]\sum_{j=1}^{k}\alpha_{23,j}}{\left(1-\sum_{j=1}^{k}\alpha_{11,j}\right)\left(1-\sum_{j=1}^{k}\alpha_{33,j}\right)}\right) \\
C_2 &= \left(\frac{\sum_{j=1}^{k}\alpha_{21,j}\left(1-\sum_{j=1}^{k}\alpha_{33,j}\right)+\sum_{j=1}^{k}\alpha_{23,j}\sum_{j=1}^{k}\alpha_{31,j}}{\left(1-\sum_{j=1}^{k}\alpha_{11,j}\right)\left(1-\sum_{j=1}^{k}\alpha_{33,j}\right)}\right) \\
C_3 &= \left(\frac{\sum_{j=1}^{k}\alpha_{23,j}}{1-\sum_{j=1}^{k}\alpha_{33,j}}\right) \\
C_4 &= \frac{\left(1-\sum_{j=1}^{k}\alpha_{22,j}\right)\left(1-\sum_{j=1}^{k}\alpha_{33,j}\right)-\sum_{j=1}^{k}\alpha_{23,j}\sum_{j=1}^{k}\alpha_{32,j}}{1-\sum_{j=1}^{k}\alpha_{33,j}} \\
C_5 &= \left(\frac{\alpha_{01}\sum_{j=1}^{k}\alpha_{31,j}+\alpha_{03}\left(1-\sum_{j=1}^{k}\alpha_{11,j}\right)}{\left(1-\sum_{j=1}^{k}\alpha_{11,j}\right)\left(1-\sum_{j=1}^{k}\alpha_{33,j}\right)}\right) \\
C_6 &= \left(\frac{\sum_{j=1}^{k}\alpha_{32,j}}{1-\sum_{j=1}^{k}\alpha_{33,j}}\right) \\
C_7 &= \left(\frac{\sum_{j=1}^{k}\alpha_{31,j}}{\left(1-\sum_{j=1}^{k}\alpha_{11,j}\right)\left(1-\sum_{j=1}^{k}\alpha_{33,j}\right)}\right) \\
C_8 &= \left(\frac{1}{1-\sum_{j=1}^{k}\alpha_{33,j}}\right)
\end{aligned}
$$

$$
\begin{aligned}
\Longrightarrow \Delta y_t^{f,*} &= \frac{1}{C_0}\alpha_{01} + \frac{1}{C_0}\varepsilon_{1t} \\
\Delta y_t^{*} &= B_1 + B_2\varepsilon_{1t} + B_3\varepsilon_{2t} + B_4\varepsilon_{3t} \\
\pi_t^{*} &= B_5 + B_6\varepsilon_{1t} + B_7\varepsilon_{2t} + B_8\varepsilon_{3t}
\end{aligned}
$$

$$
B_1 = \tfrac{C_1}{C_4} \qquad B_2 = \tfrac{C_2}{C_4}
$$

$$
B_3 = \tfrac{1}{C_4} \qquad B_4 = \tfrac{C_3}{C_4}
$$

$$
B_5 = \tfrac{C_4C_5+C_1C_6}{C_4} \qquad B_6 = \tfrac{C_4C_7+C_2C_6}{C_4}
$$

$$
B_7 = \tfrac{C_6}{C_4} \qquad B_8 = \tfrac{C_4C_8+C_3C_6}{C_4}
$$

with implied cyclical variation (Appendix 2.2):

$$
\widetilde{\Delta y_t^f} = \Delta y_t^f - \frac{1}{C_0}\alpha_{01} = \frac{1}{C_0}\varepsilon_{1t}
$$

$$\widetilde{\Delta y_t} = \Delta y_t - B_1 = B_2\varepsilon_{1t} + B_3\varepsilon_{2t} + B_4\varepsilon_{3t}$$

$$\widetilde{\pi_t} = \pi_t - B_5 = B_6\varepsilon_{1t} + B_7\varepsilon_{2t} + B_8\varepsilon_{3t}$$

Now, given a domestic demand shock, $\nu_t = 0$, $\delta_t = 0$, $\lambda_t = 1$, (derivation under $\nu_t = 0$, $\delta_t = 1$, $\lambda_t = 0$, is symmetrical):

$$\begin{aligned}
\widetilde{\Delta y_t^f} &= 0 \\
\widetilde{\Delta y_t} &= B_3 g_{23,t} + B_4 g_{33,t} \\
\widetilde{\pi_t} &= B_7 g_{23,t} + B_8 g_{33,t}
\end{aligned}$$

$$\begin{aligned}
\Longrightarrow g_{23,t} &= \frac{\widetilde{\Delta y_t} - B_4 g_{33,t}}{B_3} \\
g_{23,t} &= \frac{\widetilde{\pi_t} - B_8 g_{33,t}}{B_7} \\
\Longrightarrow \frac{\widetilde{\Delta y_t} - B_4 g_{33,t}}{B_3} &= \frac{\widetilde{\pi_t} - B_8 g_{33,t}}{B_7} \\
\widehat{g_{33,t}} &= \frac{B_7\widetilde{\Delta y_t} - B_3\widetilde{\pi_t}}{B_3B_8 - B_4B_7}
\end{aligned}$$

$$\begin{aligned}
\Longrightarrow g_{33,t} &= \frac{\widetilde{\Delta y_t} - B_3 g_{23,t}}{B_4} \\
g_{33,t} &= \frac{\widetilde{\pi_t} - B_7 g_{23,t}}{B_8} \\
\Longrightarrow \frac{\widetilde{\Delta y_t} - B_3 g_{23,t}}{B_4} &= \frac{\widetilde{\pi_t} - B_7 g_{23,t}}{B_8} \\
\widehat{g_{23,t}} &= \frac{B_4\widetilde{\pi_t} - B_8\widetilde{\Delta y_t}}{B_4B_7 - B_3B_8}
\end{aligned}$$

From (49), $g_{22} = g_{33}$, thus:

$$\widehat{g_{22,t}} = \frac{B_7\widetilde{\Delta y_t} - B_3\widetilde{\pi_t}}{B_3B_8 - B_4B_7}$$

moreover, $g_{23} = \alpha g_{33}$, so that:

$$\widehat{\alpha}_t = \frac{\widehat{g_{23,t}}}{\widehat{g_{33,t}}}$$

from $\frac{1}{1+\alpha\beta} = g_{33}$:

$$\begin{aligned}
\frac{1}{1 + \left(\frac{\widehat{g_{23,t}}}{\widehat{g_{33,t}}}\right)\beta} &= \widehat{g_{33,t}} \\
\widehat{\beta}_t &= \frac{1 - \widehat{g_{33,t}}}{\widehat{g_{23,t}}}
\end{aligned}$$

since $g_{32} = \frac{-\beta}{1+\alpha\beta}$:

$$\widehat{g_{32,t}} = \left(\frac{\widehat{g_{33,t}} - 1}{\widehat{g_{23,t}}}\right)\widehat{g_{33,t}}$$

and finally, since $g_{21} = \frac{\gamma}{1+\alpha\beta}$, $g_{31} = \frac{-\beta\gamma}{1+\alpha\beta}$:

$$\begin{aligned} g_{21,t} &= \gamma\widehat{g_{33,t}} \\ g_{31,t} &= \gamma\widehat{g_{32,t}} \end{aligned}$$

Thus:

$$\begin{aligned} G &= \begin{bmatrix} 1 & 0 & 0 \\ \gamma\widehat{g_{33,t}} & \widehat{g_{22,t}} & \widehat{g_{23,t}} \\ \gamma\widehat{g_{32,t}} & \widehat{g_{32,t}} & \widehat{g_{33,t}} \end{bmatrix} \\ &= \begin{bmatrix} 1 & 0 & 0 \\ \gamma\widehat{g_{33,t}} & \widehat{g_{33,t}} & \widehat{g_{23,t}} \\ \gamma\widehat{\beta}_t\widehat{g_{33,t}} & \widehat{\beta}_t\widehat{g_{33,t}} & \widehat{g_{33,t}} \end{bmatrix} \end{aligned}$$

12. Appendix 5: Demand non-neutrality identification

From:

$$\begin{aligned} \sum_{\varepsilon} &= \begin{bmatrix} \widehat{\sigma}^2_{\varepsilon_1} & \widehat{\sigma}_{\varepsilon_1\varepsilon_2} & \widehat{\sigma}_{\varepsilon_1\varepsilon_3} \\ \widehat{\sigma}_{\varepsilon_1\varepsilon_2} & \widehat{\sigma}^2_{\varepsilon_2} & \widehat{\sigma}_{\varepsilon_2\varepsilon_3} \\ \widehat{\sigma}_{\varepsilon_1\varepsilon_3} & \widehat{\sigma}_{\varepsilon_2\varepsilon_3} & \widehat{\sigma}^2_{\varepsilon_3} \end{bmatrix} \\ &= \begin{bmatrix} 1 & 0 & 0 \\ \gamma\widehat{g_{33,t}} & \widehat{g_{33,t}} & \widehat{g_{23,t}} \\ \gamma\widehat{\beta}_t\widehat{g_{33,t}} & \widehat{\beta}_t\widehat{g_{33,t}} & \widehat{g_{33,t}} \end{bmatrix} \begin{bmatrix} \sigma^2_{\upsilon} & 0 & \sigma_{\upsilon\lambda} \\ 0 & \sigma^2_{\delta} & \sigma_{\delta\lambda} \\ \sigma_{\upsilon\lambda} & \sigma_{\delta\lambda} & \sigma^2_{\lambda} \end{bmatrix} \begin{bmatrix} 1 & \gamma\widehat{g_{33,t}} & \gamma\widehat{\beta}_t\widehat{g_{33,t}} \\ 0 & \widehat{g_{33,t}} & \widehat{\beta}_t\widehat{g_{33,t}} \\ 0 & \widehat{g_{23,t}} & \widehat{g_{33,t}} \end{bmatrix} \end{aligned}$$

$$\widehat{\sigma}^2_{\varepsilon_1} = \widehat{\sigma^2_{\upsilon}}$$

$$\widehat{\gamma} = \frac{\widehat{g_{23,t}}\widehat{\sigma}_{\varepsilon_1\varepsilon_3} - \widehat{g_{33,t}}\widehat{\sigma}_{\varepsilon_1\varepsilon_2}}{\left(\widehat{g_{33,t}} - 2\left(\widehat{g_{33,t}}\right)^2\right)\widehat{\sigma^2_{\upsilon}}}$$

$$\widehat{\sigma_{\upsilon\lambda}} = \frac{\widehat{\sigma}_{\varepsilon_1\varepsilon_2}}{\widehat{g_{23,t}}} - \frac{\widehat{g_{33,t}}\widehat{\sigma^2_{\upsilon}}}{\widehat{g_{23,t}}}\widehat{\gamma}$$

$$
\begin{aligned}
let\ \widehat{D_{1,t}} &= \frac{\widehat{\sigma}^2_{\varepsilon_2} - \widehat{\gamma}^2 \left(\widehat{g_{33,t}}\right)^2 \widehat{\sigma^2_{\upsilon}} - 2\widehat{\gamma}\widehat{g_{23,t}}\widehat{g_{33,t}}\widehat{\sigma_{\upsilon\lambda}}}{2\left(\widehat{g_{23,t}}\widehat{g_{33,t}}\right)} \\
\widehat{D_{2,t}} &= \frac{\widehat{g_{33,t}}}{2\widehat{g_{23,t}}} \\
\widehat{D_{3,t}} &= \frac{\widehat{g_{23,t}}}{2\widehat{g_{33,t}}}
\end{aligned}
$$

$$
\begin{aligned}
\widehat{D_{4,t}} &= \left(\frac{\widehat{\sigma}_{\varepsilon_2\varepsilon_3} - \widehat{\gamma}^2 \widehat{\beta}_t \left(\widehat{g_{33,t}}\right)^2 \widehat{\sigma^2_{\upsilon}} - \widehat{\gamma}\left(\widehat{\beta}_t\widehat{g_{23,t}}\widehat{g_{33,t}} + \left(\widehat{g_{33,t}}\right)^2\right)\widehat{\sigma_{\upsilon\lambda}} - \left(\widehat{\beta}_t\widehat{g_{23,t}}\widehat{g_{33,t}} + \left(\widehat{g_{33,t}}\right)^2\right)\widehat{D_{1,t}}}{\widehat{\beta}_t \left(\widehat{g_{33,t}}\right)^2 + \left(\widehat{\beta}_t\widehat{g_{23,t}}\widehat{g_{33,t}} + \left(\widehat{g_{33,t}}\right)^2\right)\widehat{D_{2,t}}} \right) \\
\widehat{D_{5,t}} &= \left(\frac{\left(\widehat{g_{23,t}}\widehat{g_{33,t}}\right) + \left(\widehat{\beta}_t\widehat{g_{23,t}}\widehat{g_{33,t}} + \left(\widehat{g_{33,t}}\right)^2\right)\widehat{D_{3,t}}}{\widehat{\beta}_t \left(\widehat{g_{33,t}}\right)^2 + \left(\widehat{\beta}_t\widehat{g_{23,t}}\widehat{g_{33,t}} + \left(\widehat{g_{33,t}}\right)^2\right)\widehat{D_{2,t}}} \right)
\end{aligned}
$$

$$
\begin{aligned}
\widehat{D_{6,t}} &= \widehat{\gamma}^2\widehat{\beta}_t^2 \left(\widehat{g_{33,t}}\right)^2 \widehat{\sigma^2_{\upsilon}} + 2\widehat{\gamma}\widehat{\beta}\left(\widehat{g_{33,t}}\right)^2 \widehat{\sigma_{\upsilon\lambda}} + \widehat{\beta}_t^2\left(\widehat{g_{33,t}}\right)\widehat{D_{4,t}} + 2\widehat{\beta}\left(\widehat{g_{33,t}}\right)^2\left(\widehat{D_{1,t}} - \widehat{D_{2,t}}\widehat{D_{4,t}}\right) \\
\widehat{D_{7,t}} &= \left(\left(\widehat{g_{33,t}}\right)^2 + 2\widehat{\beta}\left(\widehat{g_{33,t}}\right)^2\left(\widehat{D_{2,t}}\widehat{D_{5,t}} - \widehat{D_{3,t}}\right) - \widehat{\beta}_t^2\left(\widehat{g_{33,t}}\right)\widehat{D_{5,t}}\right)
\end{aligned}
$$

$$
\begin{aligned}
\widehat{\sigma^2_{\lambda}} &= \frac{\widehat{D_{6,t}}}{\widehat{D_{7,t}}} \\
\widehat{\sigma^2_{\delta}} &= \widehat{D_{4,t}} - \widehat{D_{5,t}}\widehat{\sigma^2_{\lambda}} \\
\widehat{\sigma_{\delta\lambda}} &= \left(\widehat{D_{1,t}} - \widehat{D_{2,t}}\widehat{D_{4,t}}\right) + \left(\widehat{D_{2,t}}\widehat{D_{5,t}} - \widehat{D_{3,t}}\right)\widehat{\sigma^2_{\lambda}}
\end{aligned}
$$

Given:

$$
\begin{bmatrix} \widehat{\varepsilon_{1t}} \\ \widehat{\varepsilon_{2t}} \\ \widehat{\varepsilon_{3t}} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ \widehat{\gamma}\widehat{g_{33,t}} & \widehat{g_{33,t}} & \widehat{g_{23,t}} \\ \widehat{\gamma}\widehat{\beta}_t\widehat{g_{33,t}} & \widehat{\beta}_t\widehat{g_{33,t}} & \widehat{g_{33,t}} \end{bmatrix} \begin{bmatrix} \nu_t \\ \delta_t \\ \lambda_t \end{bmatrix}
$$

$$\widehat{\nu}_t = \widehat{\varepsilon_{1t}}$$

$$\widehat{\delta}_t = \left(\frac{\widehat{g_{23,t}}}{\widehat{g_{33,t}}\left(1 - 2\widehat{g_{33,t}}\right)}\right)\widehat{\varepsilon_{3t}} - \left(\frac{1}{1 - 2\widehat{g_{33,t}}}\right)\widehat{\varepsilon_{2t}} - \left(\frac{\widehat{\gamma}}{1 - 2\widehat{g_{33,t}}}\right)\widehat{\varepsilon_{1t}}$$

$$\widehat{\lambda}_t = \frac{\widehat{\varepsilon_{2t}} - \widehat{\gamma}\widehat{g_{33,t}}\widehat{\nu}_t - \widehat{g_{33,t}}\widehat{\delta}_t}{\widehat{g_{23,t}}}$$

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