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Structural versus Matching Estimation: Transmission Mechanisms in Armenia*

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Abstract

Opting for structural or reduced form estimation is often hard to justify if one wants to both learn about the structure of the economy and obtain accurate predictions. In this paper, we show that using both structural and reduced form estimates simultaneously can lead to more accurate policy predictions. Our findings are based on using new information criteria whose econometric properties allow us to pick for both methods the impulse responses that are valid and relevant for prediction. We illustrate our findings in the context of analyzing the monetary transmission mechanism for Armenia. Based on picking valid and relevant information from both structural and reduced form matching estimation, our findings suggest that the interest rate targeting and the exchange rate channel are well specified and strongly reinforce each other in promoting the recent double-digit growth Armenia experienced before the crisis.

JEL Classification: E52, E58, C36, C52, C53

Keywords: Armenia, monetary policy, structural model, GMM and MDE estimation, information criteria, valid and relevant IRFs

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1 Introduction

In the last decade, substantial advances in macroeconomic theory and practice were fueled by the widespread use of dynamic stochastic general equilibrium models (DSGE) - see *interalia* Rotemberg and Woodford (1997), Clarida, Galí, and Gertler (1999), Woodford (2003), Smets and Wouters (2005, 2007), Galí (2008).

These models, often known as new Keynesian models, have been used intensively by the main central banks for modeling macroeconomic fluctuations and for prediction. Because they are derived from microeconomic foundations and incorporate key nominal rigidities, they are capable of quantifying the key monetary transmission mechanisms and thus of guiding policy makers in implementing adequate macroeconomic and monetary policies.

The estimation of new Keynesian models can be done via direct or indirect inference. The direct inference approach is to estimate the structural model via e.g. generalized method of moments (GMM), and use the resulting estimates directly to generate impulse response functions and predict the macroeconomic reactions to various shocks. The indirect inference approach is to generate from the structural model a reduced form, determining the implied theoretical impulse response functions which are then matched to the data via e.g. minimum distance estimation (MDE). Various methods for direct and indirect inference have been implemented by *interalia* Braun (1994), Christiano, Eichenbaum, and Evans (2005), DiCecio (2005), Boivin and Giannoni (2006), Uribe and Yue (2006), Jordà and Kozicki (2007), Dupor, Han, and Tsai (2009) and Altig, Christiano, Eichenbaum, and Lindé (2011).

Misspecification in the structural model as well as using too many impulse responses can lead to biased estimates and misleading policy conclusions for both methods. Hall, Inoue, Nason, and Rossi (2012) address this concern by proposing a method to pick impulse response functions (IRFs) that are based on valid and relevant information. The picked IRFs not only provide a more reliable estimator, but also indicate valid and relevant portions of the model, where validity and relevance refers to accurate description of the transmission of shocks into the economy.

This paper is, to our knowledge, the first study to use the methods in Hall, Inoue, Nason, and Rossi (2012) in the context of both structural and reduced form estimation, with the scope of pin-pointing valid and relevant information for policy makers in terms of both economic structure and shock transmissions.

The methods proposed in Hall, Inoue, Nason, and Rossi (2012) are especially relevant for developing countries, where there is not enough data for accurate estimation of a full-scale nonlinear DSGE model. An interesting example of a developing country where such devices are valuable is Armenia. In the decade preceding the crisis, Armenia witnessed successful disinflation and double-digit economic growth. As pointed out by Mkrtchyan,

Dabla-Norris, and Stepanyan (2009), the fiscal consolidation undertaken in the late 1990s played a critical role in reducing inflation, and so did a recent much sounder monetary policy based on targeting inflation through interest rates rather than monetary aggregates.

As for most emerging economies, we find that for Armenia, the interest and exchange rate channels are the main policy transmission channels. The interest rate channel has strengthened due to the official introduction of inflation targeting in 2006, when monetary aggregates became increasingly difficult to target due to the large inflow of cash remittances from Armenians living abroad. Via an open economy New Keynesian model, our paper quantifies the inflation targeting mechanism and its effectiveness in conjunction with the large appreciation of the nominal exchange rate of dram.¹

Most papers consider structural estimation or reduced form estimation, but not both. Our main contribution is to combine the two with the scope of both learning about the structure of the economy and its responses to various shocks. We take advantage of econometrically rigorous misspecification checks to point to the valid and relevant shock transmission mechanisms.

We start by estimating a closed economy model to evaluate the monetary policy in the absence of the exchange rate channel. We then introduce a small scale New Keynesian open economy model to quantify the exchange-rate pass-through to output and prices. We estimate the model both directly (structural estimation) and indirectly (reduced form matching estimation), and use the new methods proposed by Hall, Inoue, Nason, and Rossi (2012) to check for misspecification. We find that inflation targeting, reinforced by a small exchange-rate pass-through to prices, has been very successful in Armenia in the recent decade. Our study is in line with the findings of Mkrtchyan, Dabla-Norris, and Stepanyan (2009), Bordon and Weber (2010) and El-Ganainy and Weber (2010), but due to picking valid and relevant IRFs, we are able to show that the exchange rate and interest rate shocks are well-specified in our model. Additionally, we find that even though agents are forward-looking and inflation targeting was successful in the last decade, the dynamics of output may be more subtle, possibly due to cash remittances and large monopolies in the import sector that prevent a higher exchange-rate pass-through. Inflation targeting in conjunction with forward-lookingness are extremely relevant for the macroeconomic performance of Armenia in the recent crisis period, but we find that more research is needed to uncover the true response of the economy to output and inflation shocks.

Our paper is organized as follows. Section 2 gives a brief account of the Armenian economy in recent years. Section 3 introduces the closed and open economy New Keynesian models. In Section 4 we detail the construction of our data-set. Section 5 and 6 report and interpret the estimation results for structural and IRF matching estimation, respectively. In Section 7, we check for misspecification via the methods in Hall, Inoue, Nason, and Rossi (2012), which we extend to structural estimation as well. This sections also contains the policy implications based on impulse response functions that contain valid and relevant

¹Dram is the national Armenian currency.

information. Section 8 concludes. The Appendix contains graphs of our dataset and of the valid and relevant IRFs.

2 Brief on Armenia

According to the CIA World Factbook, under the Soviet Union, Armenia developed a modern industrial sector, but since then has switched to placing emphasis on small-scale agriculture. It has progressed in introducing many economic reforms, including privatization, solid fiscal policies, price reforms, but its narrow export base and pervasive monopolies in main business sectors make Armenia still vulnerable to a global downturn. Nevertheless, in the decade before the crisis, it has been successful in slashing inflation to single digits and in promoting a double-digit growth, due to sounder macroeconomic policies, in conjunction with a booming construction sector and the cash remittances from abroad. The sharp trade imbalance has been financed by international aid, and Armenia, joining the World Trade organization in 2003, has made large improvements in tax and customs administration.

The central bank of Armenia, targeting first monetary aggregates and the exchange rate, has switched in the last decade to inflation targeting through interest rates, as managing the monetary aggregates has been proved ineffective due to the large inflow of cash remittances from abroad. Even though the inflation targeting was officially introduced in 2006, there is evidence that the central bank has been targeting inflation much earlier - see e.g. El-Ganainy and Weber (2010). The credibility of the monetary authority has been increasing over the recent years due to its successful policies. In this paper, we quantify the strength of the monetary transmission mechanisms through both structural and reduced form estimation. The structural models are presented in the next section.

3 Structural models

3.1 Closed Economy

To understand the dynamics of the main macroeconomic variables in Armenia, we start with a simple New Keynesian closed economy model. Since, to our knowledge, this model or similar models have not been estimated so far for Armenia, we use a closed economy model as a benchmark for comparison with an open economy model. The closed economy model also serves for quantifying monetary policy and its transmission even in the absence of an exchange rate and trade, that in conjunction render more subtle transmission mechanisms.

As is common practice in macroeconomics, the New Keynesian model we use is derived from a representative's agent intertemporal utility maximization problem, in the presence of external habit persistence, with staggered wages and hybrid monetary policy (hybrid here means both forward and backward looking). Cho and Moreno (2003) argue that such

a parsimonious model is rich enough so that the dynamic path of inflation, output gap and interest rate can be clearly explained in terms of structural parameters. We make no such claims, because as Ruge-Murcia (2007) points out, structural and matching estimation can suffer from misspecification, weak identification and/or stochastic singularity. We acknowledge that our model may be misspecified, but we start with it as a benchmark, then check which part of the model may be misspecified.

The aggregate demand equation is derived from the representative agent's intertemporal utility maximization problem, as in Fuhrer (2000):

$$y_t = \mu E_t y_{t+1} + (1 - \mu) y_{t-1} - \phi(i_t - E_t \pi_{t+1}) + \epsilon_t^y \quad (1)$$

where y_t , i_t and π_t are respectively the real output gap (measured in log deviations from its long-run trend), the nominal interest rate and the inflation, both in percentage points, at time t , E_t denotes the expectation at time t and ϵ_t^y is a mean-zero demand shock with variance σ_y^2 . In this setting, the monetary transmission parameter, ϕ , depends inversely on the elasticity of consumption across periods and the habit persistence parameter. We pick the aggregate demand equation with habit persistence, since it is a common feature of economies across the world - see Justiniano and Preston (2004), and a very likely feature of the Armenian economy - see Mkrtchyan, Dabla-Norris, and Stepanyan (2009).

As there is evidence of both forward and backward looking behavior for Armenia - see Mkrtchyan, Dabla-Norris, and Stepanyan (2009), we specify the aggregate supply equation as a hybrid New Keynesian Phillips curve, as in Gali and Gertler (1999),

$$\pi_t = \delta E_t \pi_{t+1} + (1 - \delta) \pi_{t-1} + \lambda y_t + \epsilon_t^\pi \quad (2)$$

where ϵ_t^π is an aggregate supply structural shock with mean zero and variance σ_π^2 .

To stabilize output and inflation, the central bank implements inflation and output targeting via a Taylor rule with a certain degree of monetary inertia:

$$i_t = \rho i_{t-1} + (1 - \rho)(\beta E_t \pi_{t+1} + \gamma y_t) + \epsilon_t^i \quad (3)$$

where ϵ_t^i is the monetary policy shock with mean zero and variance σ_i^2 . The coefficient ρ is the degree of interest rate smoothing, which seems to be substantive for developing countries, and we expect it will be large for Armenia as well. The parameters β and γ ($\beta, \gamma > 0$) are the relative weights on inflation and output gap. Economic theory postulates that β should be above one for a rational expectation equilibrium to exist. If inflation targeting is successful and the main focus of monetary policy, then we expect β to be large compared to γ .

Next subsection enriches the model by adding real exchange rate dynamics and the exchange rate pass-through to output and prices.

3.2 Open Economy

To enrich the closed economy model with the appropriate open economy features, we closely follow Berg, Karam, and Laxton (2006).

In the open economy model, output gap depends on aggregate demand, thus on the real interest rate and the real exchange rate, as well as past and future expected output:

$$y_t = \mu E_t y_{t+1} + (1 - \mu)y_{t-1} - \phi r_t + \kappa e_t + \epsilon_t^y \quad (4)$$

where r_t is real interest rate, e_t is the real exchange rate (measured so an increase is a depreciation, in percentage points).² Here, ϵ_t^y is a demand shock with mean zero and variance σ_y^2 . The key parameters of interest are the monetary transmission mechanism parameter ϕ , and the effect of competitiveness on home demand, κ . Comparing output gap equations for the open and closed economy models, the main difference is the presence of the real exchange rate, which measures the degree of competitiveness, positively correlated with the real GDP gap. As mentioned in Berg, Karam, and Laxton (2006), if $(\phi + \kappa)$ is small relative to $(1 - \mu)$, we expect significant lags in the transmission of monetary policy, since the inertia in output will prevent monetary policy effectiveness. On the other hand, if it is relatively high, then the monetary policy transmission mechanism is swift.

Following Berg, Karam, and Laxton (2006), we define the open economy New Keynesian Phillips curve as depending on expected and lagged inflation, the output gap and the exchange rate gap.

$$\pi_t = \delta E_t \pi_{t+1} + (1 - \delta)\pi_{t-1} + \lambda y_t + \tau(e_t - e_{t-1}) + \epsilon_t^\pi \quad (5)$$

This Phillips curve is appropriate for Armenia, as it reflects the idea that the fundamental role of monetary policy is to provide a nominal anchor for inflation, and placing weights on all other objectives cannot be consistent with its fundamental role. This is reflected in the fact that the backward- and forward-looking coefficients on inflation add up to one. The parameter τ represents the real exchange rate pass-through to prices, which we expect to be low for Armenia: the nominal exchange rate appreciated approximately 40% in 2004-2007, followed by only a 5% drop in imported good prices. This slow exchange rate pass-through is usually attributed to nominal rigidities in the imported good sector and arises from inefficient distribution networks, but also due to a large proportion of monopoly retailers that use domestic labor as an input, making prices even less responsive to exchange rate movements - see Mkrtchyan, Dabla-Norris, and Stepanyan (2009). As before, ϵ_t^π denotes an aggregate supply structural shock with mean zero and variance σ_π^2 .

The third equation specifies the exchange rate path. Unlike in Berg, Karam, and Laxton (2006), the real exchange rate dynamics is a linear expected exchange rate rule, known as “partially uncovered interest parity” - see Plasmans, Verkooijen, and Daniëls

²Some symbols are the same as in the previous sub-section, although the models are different. We slightly abuse notation to facilitate comparison of the closed and open economy model estimates.

(1998) and De Grauwe and Vansteenkiste (2007). Unlike Mkrtchyan, Dabla-Norris, and Stepanyan (2009), we do not impose uncovered interest parity (UIP), as it would require perfect capital mobility and complete financial markets, features that are unlikely to hold for developing countries like Armenia. We assume that the real exchange rate depends on the expected and lagged real exchange rate as well as the differences between home and foreign real interest rate gap:

$$e_t = \varphi E_t e_{t+1} + (1 - \varphi)e_{t-1} - \eta(r_t - r_t^*) + \epsilon_t^e \quad (6)$$

where r_t^* is the international real interest rate and ϵ_t^e is an real exchange rate structural shock with mean zero and variance σ_e^2 . This way, the expected real exchange rate gap is partly covered by the previous gap and partly by the exchange rate difference. Despite the widespread use of UIP, estimates for η are not one as UIP predicts, but usually small and quantitatively similar for OECD countries - Plasmans, Verkooijen, and Daniëls (1998) and ASEAN countries - Boldea, Engwerda, Michalak, Plasmans, and Salmah (2010). We show in Section 7 that the exchange rate dynamics is well-specified across all models and identification strategies we use.

We close the model by specifying a monetary policy rule for Armenia, which targets inflation as well as output. Even though the inflation targeting regime was introduced in 2006, implying as in Bordon and Weber (2010) a possible parameter change in β , there is strong evidence that there was inflation targeting before. Our short data horizon does not allow us to reliably identify potential change-points in the interest rate rule, so we stick to a stable-parameter interest rate rule:

$$i_t = \rho i_{t-1} + (1 - \rho)(\beta E_t \pi_{t+1} + \gamma y_t) + \epsilon_t^i \quad (7)$$

with ϵ_t^i an interest rate shock with mean zero and variance σ_i^2 .

The next section details the construction of our dataset and its main features. We then use this dataset to compare estimates for the closed and open economy models.

4 Data

Our dataset comprises monthly data on Armenian key macroeconomic indicators, from January 2001 to December of 2008, and it is computed using information provided publicly by the Central Bank of Armenia (CBA) and National Statistical Agency of Armenia (NSA).³ We construct two monthly real GDP series that are not publicly available but can be proxied using the data at hand. To our knowledge, this is the first study that constructs and uses monthly data for Armenia, thus suffering from less severe small sample problems compared to e.g. Mkrtchyan, Dabla-Norris, and Stepanyan (2009).

³The data is available at www.cba.am and www.armstat.am, respectively.

To construct proxies for the monthly real gross domestic product (GDP), we use information about monthly nominal GDP, nominal value added GDP levels for the main sectors of the economy (industry, agriculture, construction and services), the price indexes for these branches and the cumulative monthly real growth rates of GDP with respect to the same month of the previous year, all published by NSA. Based on this data, it is possible to compute two measures (proxies) for the monthly real GDP.

For the first measure, we proceed as follows. We compute the basic price indexes for each sector, then calculate the yearly average price indexes for each sector. We readjust the original price indexes to the average yearly base, and divide the monthly nominal GDP by these prices. The first measure of real GDP is then obtained by adding these quantities together and multiplying the above result with the respective monthly growth rates of real GDP in each area compared to previous year.

What this achieves is setting the common base year to 2001 for the newly computed monthly real GDP measure. However, this measure may only be imperfectly capturing the quarterly movements, as the published quarterly real GDP is not taken into account. It is difficult to match the published movements exactly, but using the quarterly published data along with quarterly growth we can bring the real GDP measure to the 2005 base year. This is our second measure, real GDP 2. The two measures are not too different, as can be seen from Figure 1 in the Appendix. But 2005 is a more stable year, and it corresponds better to the inflation measure which is also measured with respect to 2005 as the base year. Plots of the two real GDP measures are in the Appendix, Figure 1.

Regarding the Consumer Price Index (CPI), data are disseminated by NSA as a modified Laspeyres index with 2005 as a base year. The index is the weighted average monthly change in prices of 470 commodities. It is calculated for Yerevan and other 11 most densely populated regions. We seasonally adjust the natural logarithm of the reported monthly CPI, as well as the monthly real GDP measures above, using the TRAMO/SEATS software. The plots in Figure 1 indicate that inflation has been kept down to single digits quite successfully during the recent decade.

The Central Bank of Armenia main policy instruments is the repo (repurchase agreement) interest rate. Real exchange rates (in dollars per Armenian dram) and nominal interest rate data are published by the Central Bank of Armenia. Plots of the interest rate and real exchange rate gap data can be found in Figure 1.

All time-series except inflation are in percentage deviation from their gaps, and so have been de-trended using the Hodrick-Prescott filter. Using the above described data set, we quantify the monetary transmission mechanisms in the next sections.

5 Structural Estimation by GMM

Based on the two output gap measures, we estimate the closed economy model in (1)-(3) and the open economy model in (4)-(7) via iterated GMM.

Table 1: GMM estimates for the closed/open economy models

| | Real GDP 1 | Real GDP 2 | Real GDP 1 | Real GDP 2 |
|-----------|------------------------|------------|------------------------|------------|
| | Output equation (1) | | Output equation (4) | |
| μ | 0.5323*** | 0.4977*** | 0.5483*** | 0.5677*** |
| ϕ | 0.0094* | 0.0430*** | 0.0162*** | 0.0432*** |
| κ | | | 0.0002 | 0.0012* |
| | Phillips curve (2) | | Phillips curve (5) | |
| δ | 0.5124*** | 0.4973*** | 0.5678*** | 0.5661*** |
| λ | 0.0054 | 0.0014 | 0.0073 | 0.0044 |
| τ | | | 0.0319*** | 0.0331*** |
| | | | Exchange rate rule (6) | |
| ϕ | | | 0.5597*** | 0.5359*** |
| η | | | 0.1879*** | 0.1416*** |
| | Interest rate rule (3) | | Interest rate rule (7) | |
| ρ | 0.7698*** | 0.7925*** | 0.6444*** | 0.7870*** |
| β | 2.0500*** | 2.0200*** | 2.2341*** | 2.0544*** |
| γ | 0.0022 | 0.0070 | 0.0836*** | 0.0165*** |

Note: The superscripts *, ** and *** are used to indicate significance at the 10%, 5% and 1% level, respectively.

A possible pitfall of using GMM with lags of variables as instruments is that they may be weak - see e.g. Fuhrer and Rudebusch (2004) for concerns about the output equation, and Ma (2002) and Mavroeidis (2004) for concerns about the Phillips curve. We assess various instruments sets via Cragg and Donald's (1993) statistic using Stock and Yogo's (2005) critical values. We chose the set of instruments which is strongest according to Stock and Yogo's (2005) test: $z'_t = (y_{t-1}, y_{t-2}, y_{t-3}, \pi_{t-1}, \pi_{t-2}, \pi_{t-3}, i_{t-1}, i_{t-2})$ for the closed economy and $(y_{t-1}, y_{t-2}, y_{t-3}, \pi_{t-1}, \pi_{t-2}, \pi_{t-3}, e_{t-1}, e_{t-2}, i_{t-1}, i_{t-2})$ for the open economy model.⁴

The results in Table 1 are very consistent across the two different measures of real GDP and the closed and open economy model.

Some of the parameter estimates are closely in line with those of other developed or developing countries, others reveal unique features of the Armenian economy. Since the estimate of ϕ is strongly significant, we find that the interest rate in Armenia does influence output directly. The estimate is not large, but much larger than usually found for US - see Cho and Moreno (2003), indicating that even if the objective of monetary policy is mostly

⁴ Results with various instrument combinations are available upon request from the authors.

Table 2: Weak Instrument Diagnostics for the closed/open economy models

| Closed Economy Model | | | | |
|----------------------------|---------------------------|---------------------|---------------------------|---------------------|
| | F statistic real GDP 1 | Reject 10% level | F statistic real GDP 2 | Reject 10% level |
| Output equation (1) | 24.6 | Yes | 29.3 | Yes |
| Phillips curve (2) | 8.56 | No | 8.50 | No |
| Interest rate equation (3) | 4.20 | No | 4.24 | No |
| System (1)-(3) | 7.84 | Yes | 8.43 | Yes |
| Open Economy Model | | | | |
| | F statistic real GDP 1 | Reject 10% level | F statistic real GDP 2 | Reject 10% level |
| Output equation (4) | 22.5 | Yes | 19.6 | Yes |
| Phillips curve (5) | 16.5 | Yes | 16.3 | Yes |
| Exchange rate rule (6) | 6.33 | No | 11.0 | Yes |
| Interest rate equation (7) | 0.62 | No | 0.41 | No |
| System (4)-(7) | 14.9 | Yes | 13.4 | Yes |

inflation targeting, as seen from the interest rate equation estimates, there is potential for the monetary policy to stabilize output as well.

For the output equation, we find that the intertemporal elasticity of substitution in consumption, according to the estimates based on real GDP 2, is - see Cho and Moreno (2003) for formula derivation - $1/\sigma = \phi/\mu \sim 0.05/0.5 = 0.1$. This implies that Armenian consumers are impatient, in line with the majority of population having small wages - see Guvenen (2006). Also, habit persistence h , defined as $1/\phi = \sigma(1+h) - h$ - see Cho and Moreno (2003), is approximately $h \sim 1.11$. This implies that people's consumption choices are strongly enrooted in habit, unlike findings for some EU members - see e.g. Flavin and Nakagawa (2008).

The estimate of λ indicates a flat Phillips curve. This flatness is a well-known finding for many economies, whether the model estimated is a closed or open economy model - see e.g. Gali and Gertler (1999) for US, Mihailov, Rumler, and Scharler (2011) for Poland, Hungary, Slovakia, Latvia, Lithuania, Cyprus, Malta, Czech Republic, Slovenia, Bulgaria, where some estimates are even negative. Gali and Gertler (1999) argue that output gap is not proportional to real marginal cost, but real marginal cost better accounts for direct productivity gains on inflation, and so it should replace output gap in the Phillips curve. On the other hand, real marginal cost is also unobserved, and other authors, e.g. Rudd and Whelan (2005) argue that the current practice of replacing marginal cost with average unit labor cost has little theoretical foundations. We do not use marginal cost proxies here

due to data limitations.

El-Ganainy and Weber (2010) estimate a slightly different specification for the open-economy Phillips curve for Armenia, and find that output gap is significant; their results might be influenced by the less efficient single equation estimation and by the use of data from the recent financial crisis. They also find that inflation is mostly backward looking, while we find that the success story of Armenia in reducing inflation to single digits is attributable to inflation targeting combined with forward-looking behavior. Our results show that the backward looking component is almost equally important. Similar findings can be found in Berg, Karam, and Laxton (2006) for Canada, and Zhang, Osborn, and Kim (2008) for US. Mkrtchyan, Dabla-Norris, and Stepanyan (2009) calibrate the forward-looking parameter to 0.65, assuming slightly less inflation inertia but the IRFs are qualitatively comparable to ours, reinforcing the effectiveness of inflation targeting through forward-lookingness.

As for the interest rate, we notice that despite the inflation targeting, it exhibits high inertia. This is not surprising, as policy makers maintain credibility by not spooking the markets with large interest rate swings. We find that the objective of price stability precedes that of output stability. As compared to the closed economy model, output stability becomes more important and is also significant. This is important as the Armenian central bank is forced to dampen the effect of large cash remittances from abroad, which are part of the measured GDP.

As for competitiveness, the parameter κ is close to zero, even though significant for real GDP 2. This implies that the direct competitiveness has a small impact on output. On the other hand, the estimates for τ are significant and slightly larger, indicating that the exchange rate pass-through to prices does happen but is incomplete. This is in line with the fact that during 2004-2007, the nominal exchange rate appreciated by more than 40% but was accompanied by a less than 5% decline in imported good prices; thus, most importing Armenian firms take into account domestic unit labor costs in their pricing decisions. According to Karam and Pagan (2008), Canada exhibits an incomplete pass-through of almost the same magnitude.

There is widespread empirical evidence that the uncovered interest parity (UIP) doesn't hold - see the comprehensive surveys of Froot and Thaler (1990), Lewis (1995) and Engel (1996). We reconfirm this finding for Armenia, where the expected exchange rate differentials seems to be partially uncovered by the interest rate differentials and predominantly by their previous values.

Overall, we find that inflation targeting is effective in bringing expectations of inflations close to their target and in stabilizing inflation. The exchange rate pass-through to output and prices is incomplete, but the exchange rate rule acts to reinforce inflation targeting as a monetary policy decision. These findings are consistent across the two measures of real GDP. The monetary transmission mechanism, while slow, seems to work well for Armenia. The results in Table 2 also indicate that while individual tests can suggest weak identification given our instrument set, the more rigorous overall test for both the closed

and open economy model indicate strong identification.

However, our results are based on a parsimonious model. In the next sections, we perform IRF matching estimation to provide misspecification checks via picking valid and relevant impulse response functions.

6 IRF Matching Estimation

6.1 Estimation of key structural parameters by matching IRFs

Impulse response matching estimation is frequently used in different forms and with different methods of estimation - see Ruge-Murcia (2007) for a detailed account. Here, we consider one of the most popular matching estimation procedures, the vector autoregression (VAR)-based IRF matching. The parameter estimates are obtained by minimizing the distance between the sample IRFs obtained by fitting a VAR(1) to the actual data and the theoretical IRFs generated by the New Keynesian model. We use a VAR(1) instead of a larger order because this arises as the rational expectations solution of our model.

In two recent papers, Dridi, Guay, and Renault (2007) and Hall, Inoue, Nason, and Rossi (2012) present a comprehensive statistical framework for estimating parameters of a structural model by matching moments using a binding function obtained from a reduced form model. Using their terminology here, the New Keynesian model is the structural model, the VAR(1) is the reduced form model, and the IRFs are the binding functions. They allow for model misspecification and group parameters into three categories: focus parameters (those we are interested in), estimated nuisance parameters and calibrated nuisance parameters. Since the structural model may be misspecified, an important question is whether it partially or fully encompasses the reduced form model, meaning that even in the presence of misspecification, the minimum distance estimation based on the binding function nevertheless yields consistent estimators of the focus parameters.

This paper focuses on the monetary transmission mechanism for Armenia as an open economy. We thus take the open economy model, and define the focus parameters to be $(\phi, \kappa, \lambda, \beta, \gamma)$, describing the influence of interest rates and exchange rates on output, the slope of the Phillips curve whose structural estimate might suffer from misspecification bias, and the relative weights monetary policy sets on price and output stability. We consider η as a nuisance parameter, that we have to estimate to confirm the UIP violation; the rest of the parameters we regard as calibrated nuisance parameters and set them equal to their structural estimates. We also set the variance of MDE errors as it is implied by the structural estimates $\sigma_y^2, \sigma_\pi^2, \sigma_e^2$ and σ_i^2 .

By matching all the impulse response functions at a horizon of 20 months using minimum distance estimation, we obtain the estimates for the focus and estimated nuisance parameters; the results are in Table 3 below.

One of the most striking results in Table 3 is that ϕ is much larger for the reduced form

Table 3: VAR and MDE estimates for the open economy model

| | GMM_1 | GMM_2 | MDE_1 | MDE_2 |
|------------------------|-----------|-----------|-----------|-----------|
| Output equation (4) | | | | |
| ϕ | 0.0162 | 0.0432*** | 0.1345*** | 0.0545 |
| κ | 0.0002 | 0.0012* | 0.0510*** | 0.0112 |
| Phillips curve (5) | | | | |
| λ | 0.0073 | 0.0044 | 0.0450 | 0.0350*** |
| Exchange rate rule (6) | | | | |
| η | 0.1879*** | 0.1416*** | 0.1100*** | 0.1000*** |
| Interest rate rule (7) | | | | |
| β | 2.2341*** | 2.0544*** | 1.8250*** | 2.2500*** |
| γ | 0.0836*** | 0.0165*** | 0.1500*** | 0.0450 |

Note: the * and *** superscripts are used as in Table 1, while the subscripts $_{1,2}$ indicate estimation using real GDP 1 or 2.

estimates, indicating that monetary policy may have a (much) larger influence on output than the initial structural model estimates indicates. We also note that the Phillips curve seems to be less flat if we match impulse response functions, and the trade-off between inflation and output even becomes significant under MDE_2 . Inflation targeting is consistently the primary objective of monetary policy. While MDE_1 estimates imply a higher weight on output stability, under MDE_2 , output stability seems to be a significant monetary policy goal.

Most results are qualitatively the same across different estimates, but their quantitative differences indicate that the output and inflation responses may be misspecified, and finding such misspecifications is important for accurate policy recommendation. Having potential misspecification implies that the parameters we fixed may be biased, and this, while it will affect the impulse response matching estimation as a whole, it will not affect “right” - meaning valid and relevant - impulse response functions.

The next subsection explains the notion of valid and relevant IRFs, uses the methods in Hall, Inoue, Nason, and Rossi (2012) to pick those among all IRFs, and discusses the implications of these choices for monetary policy.

7 Selecting valid and relevant IRFs

The motivation for checking for misspecification via selection of valid and relevant IRFs in MDE is best seen by drawing a parallel to moment selection in GMM. When we perform GMM estimation, we implicitly assume we have “right” moments: those that are valid, meaning that the population moment condition holds, and relevant, meaning that they add new information, thus contributing to more efficient estimators. Otherwise, one can pick the valid and relevant moments via moment selection criteria - see Hall, Inoue, Jana, and Shin (2007).

Similarly, Hall, Inoue, Nason, and Rossi (2012) propose information criteria for picking valid and relevant IRFs to estimate the focus and nuisance parameters. They pick IRFs that are valid, meaning correct even though the calibrated (fixed) nuisance parameters are misspecified, and relevant, meaning that they increase the efficiency of the focus parameter estimators.

In this paper, we do not attempt to pick IRFs across horizons as we assume that the central bank has a certain fixed horizon length $H = 20$ for prediction. This is reasonable for a developing country like Armenia. We focus on picking the valid and relevant IRFs to various shocks. In the open economy model (4)-(6), we have four equations, thus four shocks, which can be taken one, two, three at a time or all four together. For each of these, we calculate the valid impulse response selection criterion (VIRSC) and the relevant impulse response selection criterion (RIRSC).

To define VIRSC and RIRSC, we need to introduce some notation. Let $n_Y = 4$ be the number of shocks (equations) in the open economy model. Define $\alpha = g(\theta, \eta, \psi)$ to be the $n_Y^2 H \times 1$ vector of theoretical impulse response functions obtained from this model, and $\hat{\alpha}$ the VAR(1) estimates of the impulse response functions, using OLS. In both the theoretical and the estimated impulse responses, the nuisance parameters that are not estimated are fixed at their estimated structural values, $\psi = \bar{\psi}$.

To check for misspecification, we allow for the possibility that not all $n_Y^2 H \times 1$ IRFs are valid and relevant for MDE estimation. For selecting the valid and relevant IRFs, as in Hall, Inoue, Nason, and Rossi (2012), let c , an $n_Y \times 1$ selection vector, index the IRFs that are included for MDE for each horizon. Denote $\alpha(c) = g(\theta, \eta, \bar{\psi}, c)$ the selected theoretical IRFs, and $\hat{\alpha}(c)$ their estimated counterparts. Then, if the n^{th} element of c equals one, and the rest are zero, this implies that only the n^{th} element of $\alpha(c)$, respectively $\hat{\alpha}(c)$, is included in the MDE.

Using this notation and letting T be the sample size, the MDE estimator for selected IRFs can be defined as:

$$(\hat{\theta}(c), \hat{\eta}(c)) = \operatorname{argmin}_{\theta, \eta} Q_T(\theta, \eta, c)$$

where:

$$Q_T(\theta, \eta, c) = [\hat{\alpha}(c) - g(\theta, \eta, \bar{\psi})]' \hat{\Omega}_T(c) [\hat{\alpha}(c) - g(\theta, \eta, \bar{\psi})]$$

with $\hat{\Omega}_T(c)$ being an estimate of the inverse of the covariance matrix of the IRFs that were selected through c .

We select the valid impulse response functions by minimizing:

$$VIRSC_T(\hat{\theta}(c), \hat{\eta}(c), c) = Q_T(\hat{\theta}(c), \hat{\eta}(c), c) - |c| \ln(T)$$

over all c . This information criterion picks the minimum number of valid impulse response functions needed to minimize the MDE objective function.

The relevant impulse response functions are selected by minimizing:

$$RIRSC_T(\hat{\theta}(c), \hat{\eta}(c), c) = \ln(\det(\hat{W}_T(\hat{\theta}(c), \hat{\eta}(c), c))) + |c| \ln(\sqrt{T}/\sqrt{T})$$

where $(\hat{W}_T(\hat{\theta}(c), \hat{\eta}(c), c))$ is the 5×5 left upper corner sub-matrix of the estimate of the long-run covariance matrix of the selected theoretical IRFs (long-run variance of the focus parameters), \ln denotes the natural logarithm and $\det(A)$ stands for the determinant of the matrix A . This criterion picks the upper left 5×5 matrix relevant for our focus parameters; we want to minimize a penalized version of its determinant to pick the smallest and thus the most efficient covariance matrix with the minimum number of shocks.

The penalty of both information criteria c are imposed as suggested in Hall, Inoue, Nason, and Rossi (2012) to yield consistent estimators of c for respectively the valid and the relevant impulse response functions.

Subject to the existence of a minimizing selection vector for both criteria, one notices that their asymptotic properties in terms of picking the valid, respectively the relevant information criteria, depend only on having consistent estimates of the parameters θ, η and their asymptotic variance. In other words, they do not depend on the method used for estimating θ, η , and one can also use these criteria by plugging in GMM estimates for θ, η instead of their MDE counterparts. The asymptotic properties of c are the same, as we have a linear model, so all the smoothness assumptions in Hall, Inoue, Nason, and Rossi (2012) are satisfied.

We thus report the information criteria for both GMM and MDE estimates. Table 4 and 5 report the VIRSC, respectively RIRSC for different selection vectors c . Table 6 reports the corresponding selected IRFs group-wise for responses to one, two, three shocks and overall.

The main message of Table 6 is that the selected IRFs, similar across different output gap measures and different estimates, are the responses to exchange rate or interest rate shocks. This implies that the impulse responses to an exchange rate or interest rate shock and their transmission into the economy are both valid and relevant despite the fixed parameters ϕ which may or may not be misspecified. Since we have found that both GMM and MDE qualitatively and quantitatively agree as to the strength of the interest targeting policy in Armenia and its high effectiveness in the last decade, our findings imply that the monetary policy is quite effective when reinforced by the exchange rate channel. Since the exchange rate shock responses are picked as valid or relevant or both, the exchange rate

Table 4: VIRSC values for GMM and MDE generated IRFs

| c | GMM_1 | GMM_2 | MDE_1 | MDE_2 |
|------------|---------|---------|---------|---------|
| 1, 0, 0, 0 | 0.449 | 64.301 | 1.209 | 66.293 |
| 0, 1, 0, 0 | 0.067 | 16.412 | 0.560 | 21.122 |
| 0, 0, 1, 0 | -0.003 | 0.044 | 0.034 | 0.057 |
| 0, 0, 0, 1 | -0.002 | 0.374 | 0.001 | 0.689 |
| 1, 1, 0, 0 | 0.204 | 0.927 | 11.112 | 2.857 |
| 1, 0, 1, 0 | 0.289 | 31.297 | 0.365 | 34.640 |
| 1, 0, 0, 1 | 0.303 | 17.680 | 2.415 | 14.745 |
| 0, 1, 1, 0 | 0.011 | 37.824 | 0.036 | 42.313 |
| 0, 1, 0, 1 | 0.463 | 60.981 | 1.031 | 85.308 |
| 0, 0, 1, 1 | 0.059 | 2.655 | 0.030 | 3.257 |
| 1, 1, 1, 0 | 0.204 | 0.195 | 4.211 | 0.570 |
| 1, 1, 0, 1 | 0.050 | 0.139 | 15.989 | 2.986 |
| 1, 0, 1, 1 | 0.419 | 6.529 | 0.966 | 5.610 |
| 0, 1, 1, 1 | 0.082 | 113.587 | 0.157 | 143.219 |
| 1, 1, 1, 1 | 0.049 | 0.096 | 7.051 | 0.975 |

channel reinforces the interest rate channel in the transmission mechanism. On the other hand, we see that the responses to inflation are almost never valid or relevant, implying that the expectations are not entirely anchored as described by a Phillips curve even though the interest rate and exchange rate shocks may influence inflation as described, through indirect channels. The exclusion of the responses to inflation shocks from the valid and relevant IRFs is a robust finding across the GMM and MDE estimates, suggesting that the misspecification may come from the estimates of ρ which are being kept fixed, rather than the rest of the structural model. This is useful for policy makers as it may imply that even though their policies are effective, more credibility may be needed to modify the forward-lookingness of economic agents.

Moreover, picking the overall valid and relevant IRFs allows the monetary policy makers to be better informed about the policy transmission mechanism and its duration. The Appendix contains the IRFs of all variables to a positive shock in the interest rate and the exchange rate, based on our four estimates (GMM and MDE with each two different output gap measures).

Figure 2 shows that an increase in the interest rate reduces output through intertemporal substitution. The real exchange rate drop (appreciation) implies less domestic demand, reducing equilibrium prices and inflation. The monetary policy makers respond to the lower demand and production by reducing the interest rate, which then increases consumption

Table 5: RIRSC values for GMM and MDE generated IRFs

| c | GMM_1 | GMM_2 | MDE_1 | MDE_2 |
|------------|---------|---------|---------|---------|
| 1, 0, 0, 0 | -14.0 | -19.7 | -12.2 | -9.3 |
| 0, 1, 0, 0 | -4.0 | -6.8 | -8.2 | -9.2 |
| 0, 0, 1, 0 | -21.8 | -20.1 | -16.3 | -14.3 |
| 0, 0, 0, 1 | -10.6 | -8.8 | -11.9 | -12.7 |
| 1, 1, 0, 0 | 0.5 | -4.7 | -6.4 | -6.5 |
| 1, 0, 1, 0 | -14.7 | -22.2 | -13.1 | -10.3 |
| 1, 0, 0, 1 | -3.5 | -4.5 | -10.6 | -7.4 |
| 0, 1, 1, 0 | -6.1 | -6.2 | -8.5 | -9.4 |
| 0, 1, 0, 1 | -2.2 | -5.1 | -7.6 | -6.7 |
| 0, 0, 1, 1 | -15.6 | -9.2 | -14.2 | -9.4 |
| 1, 1, 1, 0 | 0.1 | -6.8 | -6.1 | -8.9 |
| 1, 1, 0, 1 | 1.7 | -1.4 | -8.7 | -6.1 |
| 1, 0, 1, 1 | -4.2 | -5.6 | -11.3 | -9.6 |
| 0, 1, 1, 1 | -3.4 | -2.8 | -8.3 | -6.2 |
| 1, 1, 1, 1 | 1.5 | -2.5 | -8.3 | -10.3 |

Table 6: Valid and relevant shocks

| Number of shocks | valid/relevant | GMM_1 | GMM_2 | MDE_1 | MDE_2 |
|------------------|----------------|-------------|-------------|-----------|-------------|
| 1 | valid | e | e | i | e |
| | relevant | e | e | i | e |
| 2 | valid | π, e | i, e | i, e | y, π |
| | relevant | i, e | y, e | i, e | y, e |
| 3 | valid | y, π, i | y, π, e | y, i, e | y, π, i |
| | relevant | y, i, e | y, π, e | y, i, e | y, π, e |
| all | valid | e | e | i | e |
| | relevant | e | y, e | e | e |

Note: The symbols y, π, e, i indicate that the IRFs of all variables that have been picked w.r.t. to a shock to y, π, e and i , respectively.

and output, depreciating the real exchange rate. The real exchange rate partial uncovered parity implies further depreciation of the real exchange rate, which returns to the equilibrium but slower than the other real variables. Our findings are qualitatively similar to those in Mkrtchyan, Dabla-Norris, and Stepanyan (2009), Figure 8, pp. 29. We find that for the MDE estimates, the return to the equilibrium is much faster for output and prices than suggested by the GMM estimates. These differences are best explained by realizing that the pass-through of the exchange rate to prices is much slower for the GMM estimates.

In addition to Mkrtchyan, Dabla-Norris, and Stepanyan (2009)'s IRFs, we report the IRFs from a shock in the real exchange rate - see Figure 3. We find that a depreciation in the exchange rate has a small but steady impact in changing domestic demand, output and prices. The monetary authority responds to the output increase by increasing the interest rate, which in turn reduces output, causing it to gradually return to equilibrium.

8 Conclusions

Opting for structural or reduced form estimation is often hard to justify in the light of potential misspecification. Since both estimations are based on a larger structural model that is unknown, both models can be misspecified, and either can be worse in terms of policy recommendation depending on data at hand - see Ruge-Murcia (2007). In this paper, we do not pick one path, but show that marrying the two can lead to important conclusions about the type of misspecification. To that end, we use Hall, Inoue, Nason, and Rossi's (2012) method for picking valid and relevant impulse response functions. We extend its use of their method to structural parameter estimates, and point to the location of the misspecification for a dataset pertaining to Armenia.

Our small-scale model for Armenia does not include the large cash remittances from abroad and the impressive boom in the construction sector, because such features are uncommon for developed countries and thus not part of any standard model. Instead of attempting to model such features which would be subject to small-sample estimation issues, we show by means of picking relevant and valid information that a Phillips curve and the open-economy aggregate demand equation may both be misspecified, especially with regard to modeling expectations. But more importantly, we show that, despite the misspecification, the interest rate targeting works through the direct transmission channel, and the exchange rate mechanism, suffering from partial uncovered interest parity, still influences aggregate demand through a small but significant partial pass-through to output and prices.

Picking valid and relevant information is thus useful in highlighting the monetary policy aspects of the Armenian economy that have been solid over the previous decade. We postulate that such methods are useful for policy makers in different countries, because they can pin-point to the source of the misspecification and thus make more accurate policy recommendations, while using information from both structural and reduced form

models when both are identified.

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9 Appendix

Figure 1: Monthly Armenian Data

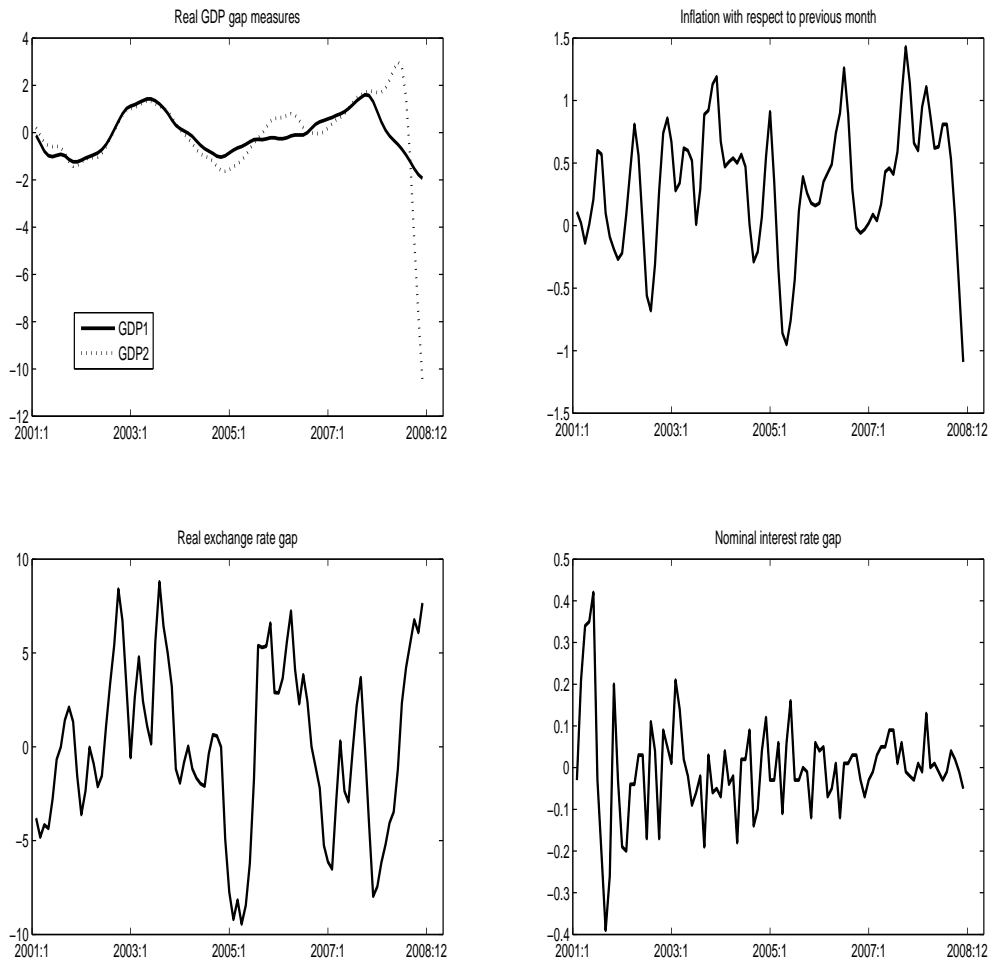


Figure 2: IRFs for an interest rate shock

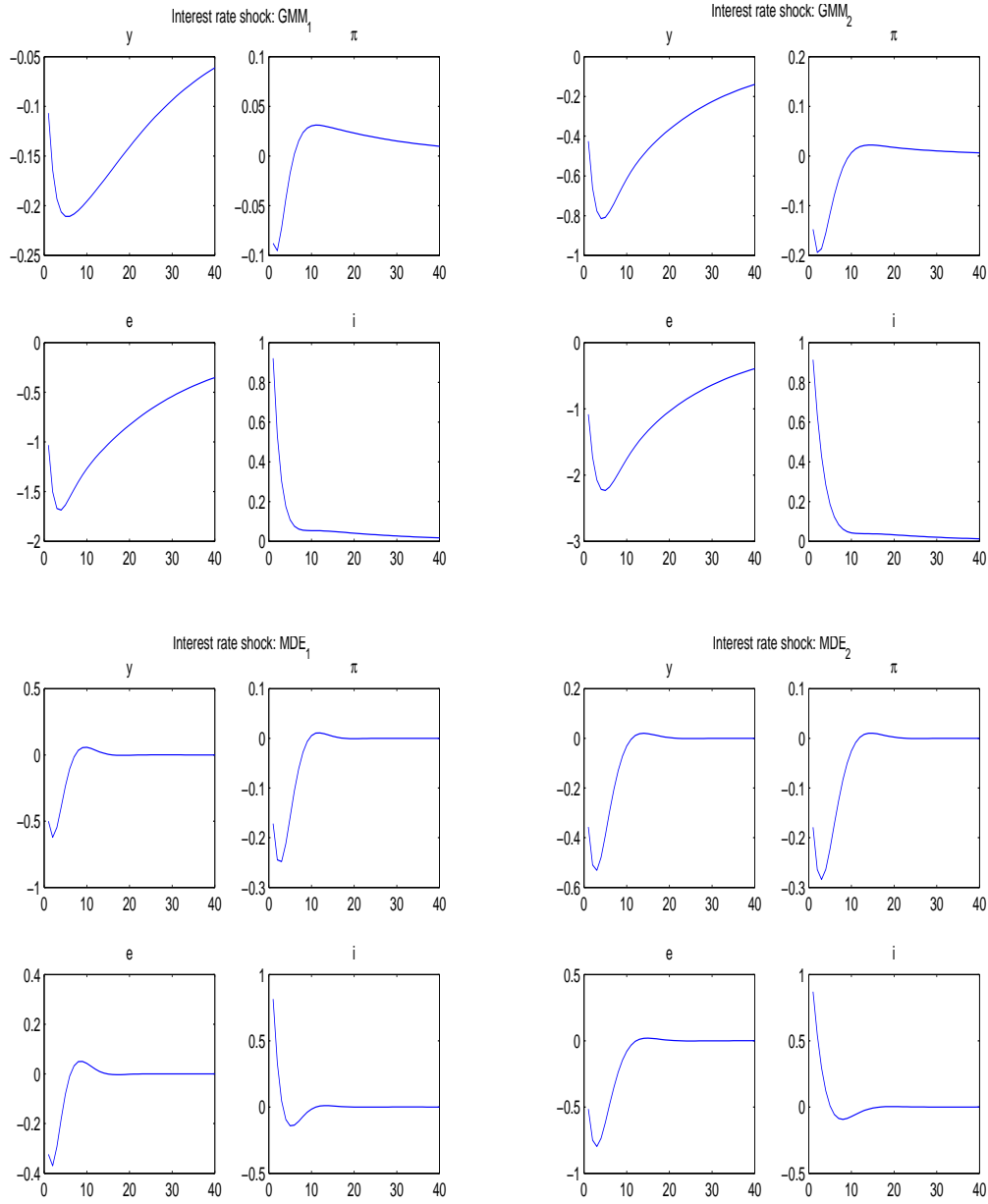


Figure 3: IRFs for an exchange rate shock

