THE ROLE OF THE EXCHANGE RATE IN A SOUTH AFRICAN NEW KEYNESIAN DSGE MODEL

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Abstract:

Steinbach, Mathuloe, and Smit (2009) in this *Journal* develop a DSGE model that characterizes the South African economy as largely insulated from foreign shocks. The authors, however, do not include the exchange rate as an observable variable in estimating their model and assume complete risk sharing with the foreign economy. We show how their small open economy can be closed so that the exchange rate can be used in the estimation. We then analyze the effects of exchange rate shocks to the determinants of the South African business cycle, and find that largely exogenous changes to the exchange rate contain important information about business cycle dynamics.

JEL Classifications: D58, E31, E32
Keywords: DSGE Model, Open Economy;

1. INTRODUCTION

New Keynesian dynamic stochastic general equilibrium (DSGE) models, estimated using Bayesian likelihood methods, are becoming a standard tool in macroeconomics for describing business cycle dynamics. In addition, DSGE models play an important role in the monetary policy process as central bankers employ them to investigate the relative importance of different macroeconomic shocks and the effects of monetary policy.[1] Steinbach, Mathuloe, and Smit (2009; SMS hereafter) have developed a DSGE model for South Africa based on the small open economy framework of Gali and Monacelli (2005). The results of their model suggest that external shocks play a very small role in the determination of output and inflation fluctuations, which implies that the South African economy behaves similarly to a closed economy.[2] Moreover, they find that supply and productivity shocks are the major drivers of the business cycle, and the impact of demand shocks is relatively insignificant.

These results have important implications for monetary policy, since they imply that monetary policy can disregard foreign developments, as the exchange rate (and other components of the economy that rely on the foreign sector) would not significantly impact the business cycle. Furthermore, since they find that productivity shocks are largely responsible for changes to the natural level of output, their results suggest that monetary policy that seeks to avoid fluctuations in output may be misguided. Given the importance of these policy implications, it would be worthwhile to examine the robustness of the SMS description of the South African business cycle,

* We are very grateful to Rudi Steinbach, Patience Mathuloe and Ben Smit for generously sharing the data and code that they used to estimate their model.

[1] See Blanchard (2008) and Tovar (2008) for a discussion on DSGE models and their use in central banks around the world.

[2] See Table 3C for an asymptotic forecast error variance decomposition of the SMS model, which largely replicates Table 3 in their paper.

particularly because one would expect external shocks to play a role in the South African economy given that imports account for almost 30% of GDP and the rand is relatively volatile.[3]

SMS make two strong assumptions related to the exchange rate and the openness of the economy. They assume that: 1) international asset markets are complete (i.e. there exists a complete set of contingent claims traded across borders), (2) the risk premium on domestic assets relative to foreign assets depends on the difference between foreign and domestic demand shocks. In addition, they treat the depreciation rate of the rand as an unobservable in their estimation. The two assumptions and the choice of observables are interrelated because the SMS model cannot be estimated with the exchange rate as an observable.[4] In addition, without a shock to capture country risk separate from demand shocks, the SMS model is able to generate very little volatility in the nominal exchange rate. When we added a country risk premium shock that allows deviations in uncovered interest parity (UIP) between the policy rates in the home and foreign economies (thereby getting rid of assumptions 1 and 2), we are able to estimate the model with the rate of depreciation as an observed variable, which then captures the volatility in the rand more closely.

In the next section, we describe in more detail the nature of the assumptions used in SMS, before considering the implications of altering these assumptions. Thereafter, we present comparative results between the SMS model and certain variations. Interestingly enough, we find that by generalizing the first two assumptions, whilst consistently treating depreciation as an unobserved variable, we do not affect the qualitative results. Therefore, we find that the

[3] After simultaneously estimating a DSGE model for South Africa in Alpanda, Kotzé and Woglom (2009) we found that foreign shocks and demand shocks were quite important in describing business cycle phenomena, whilst productivity shocks were relatively unimportant.

[4] The problem is not related to singularity; the SMS model has 9 shocks (including 4 foreign shocks) and only 7 observables (including the depreciation rate of currency).

assumptions used to close a New Keynesian small open economy model do not seem to affect the characterization of the dynamics of the business cycle. This finding is similar to that of Schmitt-Grohe and Uribe (2005), who arrive at a similar result for RBC models. However, by generalizing the assumptions regarding asset markets, we are able to include the rate of depreciation as an observable in the estimation. As a result, the model is better able to capture the open economy features of the South African economy and describe the volatility in the exchange rate. Furthermore, we find that this model suggests that the depreciation rate is almost exclusively determined by the country risk shock. These shocks are quantitatively important in affecting domestic variables as well, particularly for consumer prices and the nominal interest rate. We also find that the changes to the model reduce the reported impact of productivity shocks on the variances of the consumer prices and output by about a third. In addition, we also report small reductions in the role of supply shocks, and the importance of demand shocks increases quite significantly. The results from our variations on the SMS model suggest that a suitable small open economy model should account for the openness of the South African economy and the volatility of the local currency.

2. MODELING THE EXCHANGE RATE IN A DSGE MODEL

The assumption of complete international asset markets implies complete risk sharing between the small open economy (i.e. South Africa) and the foreign sector (i.e. OECD countries). As a consequence, the marginal utility of consumption in South Africa is proportional to the product of marginal utility of consumption in the foreign sector and the real exchange rate (Gali and Monacelli, 2005). This results in consumption, the largest component of GDP, to be largely determined by foreign output and the exchange rate.

The second assumption in SMS implies that the risk premium associated with the difference between local and foreign interest rates that are faced by households. SMS further assume that the interest rates faced by households are equal to policy interest rates plus a demand shock in the two respective economies. The application of UIP and complete risk-sharing conditions then imply that the country risk premium is captured by differences in demand shocks. This feature of relating risk premiums to demand shocks is present in the *closed economy* model of Smets and Wouters (2007), where it plays a very different role. In Smets and Wouters (2007) the demand shock links the increase in the interest rate faced by households from policy rates with an increase in the cost of capital faced by firms. As a consequence, this risk premium formulation of demand shocks captures the *financial accelerator* mechanism in Bernanke et. al (1999). In the SMS *open economy* model, there is no investment and the UIP condition rather equates expected depreciations with the difference in the foreign and domestic interest rates faced by households. Therefore, the application of the Smets and Wouters (2007) assumption in an open economy model would link foreign and domestic demand shocks with expected depreciations. This may result in a restriction of the role of demand shocks in the modelled economy.

Our first alternative specification is that of Model 1, which abandons the assumption of complete asset markets. Instead, the model is closed by assuming that domestic interest rates rise with foreign borrowing as in Scmitt-Grohe and Uribe (2005).[5] This implies that consumption is stationary and it allows for consumption to be determined by a forward looking IS curve, thus replacing the equations that relate consumption to foreign income and the real exchange rate. Our second alternative specification, Model 2, follows Model 1, but with the addition of an exogenous country risk premium shock that allows deviations in UIP to be separate from the demand shocks in

[5] The equations that differ in the SMS model and model 2 are given in the Appendix.

the respective countries. This allows for exogenous changes in the exchange rate. Model 2' is the same as Model 2, with the exception that the rate of depreciation is included as an observable variable in the subsequent estimation.

Table 1 shows how well the 4 models match the observed data.[6] The variables are consumer prices excluding mortgage interest, real GDP, the South African nominal Repo rate, and the nominal depreciation rate of the rand[7] along with the first three series for the foreign sector. The first 3 models (SMS, and Models 1 and 2) describe the data in similar ways. All of these models slightly overstate the volatility of the output and inflation, but significantly understate the volatility of the depreciation rate by more than a factor of 2. Making the rate of depreciation observable (Model 2) allows the model to capture the volatility in the exchange rate, but exacerbates the problem that overall volatility is overstated.[8]

Table 1. Standard Deviations of the Data

	Data	**SMS**	**Model 1**	**Model 2**	**Model 2'**
CPI inflation	0.66%	0.88%	0.87%	0.89%	0.92%
Output	1.31%	1.50%	1.52%	1.50%	1.67%
Interest (nom)	0.40%	0.52%	0.50%	0.54%	0.63%
Deprec. rate	5.40%	1.96%	2.23%	2.09%	5.89%
Log data density		-185.3	-174.3	-185.5	not comparable

[6] The data and the Bayesian priors used in the estimation are the same as the ones used in SMS. For the depreciation rate, we used the nominal depreciation rate of the rand against a trade-weighted basket of currencies, and HP-filtered this data similar to the other series. The risk shock was modeled as an exogenous AR(1) process similar to the other shocks, and are assumed to have similar priors. We used the mode of the posterior distributions as the parameter estimates in all our calculations and for all models.

[7] The reported results for Model 2' made use of the nominal exchange rate against the USA dollar (as measured by the log deviation from the Hodrick-Prescott trend). Other measures of the nominal exchange rate, which include the nominal effective exchange rate and the nominal exchange rate against the USA (without detrending), produced similar results.

[8] We should note that the model standard deviations are asymptotic and not sample deviations. Some of the overstatement of volatility is due to this difference.

Table 2 shows the correlations of variations in output with other endogenous variables in the model. Again the patterns for the first 3 models are similar: the correlation of output with the CPI inflation is understated, the correlation of output with the nominal interest rate has the wrong sign and is substantially understated. By adding the rate of depreciation as an observable, these problems are reduced, although the size of the correlation of output with the depreciation rate is increased, in contradiction to the data.

Table 2: Correlations with Output

	Data	**SMS**	**Model 1**	**Model 2**	**Model 2'**
CPI inflation	0.14	0.04	0.06	0.05	0.20
Interest (nom)	0.08%	-0.42%	-0.33%	-0.37%	-0.11%
Deprec. rate	-0.01%	0.05%	0.05%	0.08%	0.10%

Tables 1 and 2 suggest that the first 3 models are very similar and the only important differences arise following the inclusion of the rate of depreciation as an observed variable. In addition, Model 2' matches the data at least as well as the other 3 models; it tends to overstate correlations but it (naturally) captures more of the variation in the exchange.[9]

3. VARIANCE DECOMPOSITIONS IN SMS VS. MODEL 2'

Given these results, it would be of interest to compare the variance decompositions of the SMS Model with Model 2'. In Table 3, we list the forecast-error variance decompositions of CPI

[9] In addition the parameter estimates of the 4 models are similar. In Model 1, the elasticity of substitution between foreign and home goods is above SMS's posterior 10% confidence interval. In Model 2' the inverse of the intertemporal elasticity of substitution is below that of the other three models and the persistence parameter for demand shocks is above the corresponding 10% confidence intervals in SMS. Interestingly, in all 3 variations of the SMS model the estimated standard deviation of the demand shock is above the SMS 10% confidence interval.

inflation, output, the nominal interest rate, and the nominal depreciation rate for the two models, at 1-quarter and 4-quarter horizons; along with the asymptotic decompositions.[10]

[10] The results we present for the asymptotic variance decomposition in the SMS model are only slightly different to the ones they provide in their paper. In their estimation, SMS assumed the presence of a small measurement error in the observed domestic and foreign output, which we excluded for our estimation.

Table 3A: 1-Quarter Ahead Variance Decompositions (in percent)

	Productivity	Demand	Supply	Monetary	Foreign	Risk
SMS						
CPI inflation	29.3	11.5	46.3	12.7	0.2	
Output	17.4	32.4	23.0	26.5	0.7	
Interest (nom)	10.5	19.2	17.6	52.4	0.3	
Deprec. rate	0.6	34.5	0.4	30.0	34.5	
Model 2'						
CPI inflation	21.1	15.0	38.6	14.3	0.3	10.6
Output	12.3	27.6	17.9	22.7	0.7	18.8
Interest (nom)	7.2	23.0	14.4	38.9	0.5	16.1
Deprec. rate	1.4	0.0	1.0	6.0	3.4	88.2

Table 3B: 4-Quarter Ahead Variance Decompositions (in percent)

	Productivity	Demand	Supply	Monetary	Foreign	Risk
SMS						
CPI inflation	26.9	16.5	36.0	20.4	0.2	
Output	40.0	12.1	36.8	10.8	0.3	
Interest (nom)	20.0	35.3	21.8	22.7	0.3	
Deprec. rate	1.6	34.9	1.6	28.8	33.1	
Model 2'						
CPI inflation	16.2	22.9	27.9	21.3	0.3	11.5
Output	29.6	18.4	32.5	12.9	0.4	6.3
Interest (nom)	8.4	45.8	11.5	14.5	0.5	19.4
Deprec. rate	1.4	0.4	1.1	5.9	3.5	87.7

Table 3C: Asymptotic Variance Decompositions (in percent)

	Productivity	**Demand**	**Supply**	**Monetary**	**Foreign**	**Risk**
SMS						
CPI inflation	27.2	15.8	37.0	19.7	0.2	
Output	49.2	8.6	34.4	7.7	0.3	
Interest (nom)	19.6	38.4	20.4	21.3	0.3	
Deprec. rate	1.9	34.7	1.8	28.7	33.0	
Model 2'						
CPI inflation	17.2	21.9	28.9	20.4	0.3	11.2
Output	33.4	15.7	31.7	11.1	0.6	7.4
Interest (nom)	7.5	46.0	10.6	12.8	0.5	22.7
Deprec. rate	1.4	0.5	1.1	5.8	3.5	87.8

We focus first on the asymptotic results in Table 3.C. There are 5 notable differences between the decompositions in Table 3.C for model 2' relative to SMS: (1) Variations in the CPI are not dominated by productivity and supply shocks; monetary and demand shocks contribute over 40% to the asymptotic variance, (2) Productivity and supply shocks are still quite important for variations in output, especially in longer horizons, especially at longer horizons, but demand and monetary shocks contribute over 25% to the total variation, (3) Monetary policy shocks are less important in explaining variation in the nominal interest rate, (4) Risk premium shocks are important for explaining variations in all three domestic variables, (5) Variations in the nominal exchange rate are determined exogenously to the domestic economy.

In evaluating differences 1 and 2, it is important to recognize the assumed properties of the variable being described by the variance decomposition. In particular the variance decomposition for output in this model has different properties than the variance decomposition in a structural VAR with long-run restrictions. In a traditional, structural VAR, the output variable is assumed to have a unit root and is subject to both permanent and temporary shocks (e.g. Shapiro and Watson, 1989, for the US, and du Plessis, Smit and Sturzenegger, 2008, for South Africa). In these models, productivity shocks are assumed to be permanent and the other shocks are temporary, such as shocks to aggregate demand. By construction, the long-run (i.e. asymptotic) variance in output is solely due to the permanent shock because of the unit root. In the SMS and similar DSGE models, all shocks including productivity shocks, are temporary. Therefore, productivity shocks can explain the long-run variation in output only if these shocks are estimated to be more volatile and persistent relative to other shocks present in the economy.[11]

Therefore, there is no a priori reason why supply and productivity shocks should explain most of the variance of output, as in the SMS model where over 80 percent of detrended or temporary deviations in output is due to productivity and supply shocks. In Model 2', this percentage falls to 65, which we believe is reasonable. Similarly, the decrease in the importance of productivity and supply shocks for the unconditional variance in inflation, from 64 percent to 46 percent, also seems reasonable.

The third difference relates to the decline in the contribution of monetary shocks in the volatility in the nominal interest rate. Monetary shocks are changes in the interest rate that cannot be explained by the variables in the model. It is undoubtedly true that some of these "shocks" are in fact a reasonable response of the Reserve Bank to information that is not captured by the variables in the model. Nevertheless, the fact that these shocks contribute only 12.8 percent to the variation in the interest rate in Model 2' suggests that the Reserve Bank is responding more systematically to the shocks hitting the economy.

[11] Smets and Wouters (2007) find that, in the US, productivity and supply shocks explain most (over 90%) of the long-run variance of output in a model with only temporary shocks. They also find that over 80% percent of the asymptotic variance in inflation is due to wage and price markup shocks. Shapiro and Watson (1989), in an SVAR model with long-run restrictions, find that demand shocks explain 80 percent or more of the variance in inflation.

The fourth and fifth differences are probably the most important. The SMS model describes an economy, which except for the exchange rate, is immune to international shocks. Even for the exchange rate, the SMS model ascribes most of its variation to domestic shocks. Model 2' in contrast describes an economy where foreign shocks (including the risk premium shock) are much more important, and where movements in the exchange rate are mostly determined by events exogenous to economic variables in the South African economy.

The finite horizon variance decompositions are interesting because they show that by the fourth quarter the results are very similar to the asymptotic decompositions. The one interesting difference is in the one-quarter ahead decompositions. In this case, the SMS model finds that the demand shocks are more important than in Model 2'.

4. HISTORICAL DECOMPOSITION IN THE TWO MODELS

The difference in the description of the South African economy can be seen even more dramatically in the historical decompositions of the shocks in the two models, which are depicted in Figures 1-3. The historical decomposition shows the contribution of the estimated shocks to each of the 3 domestic variables, CPI inflation, output and the nominal interest rate. These decompositions are generated by isolating the effects of a single shock (i.e., by excluding the effects of all other shocks) and then generating the paths of the respective endogenous variables. This procedure is repeated for all shocks and the sum of these paths is the model's estimate of that endogenous variable. For example, Figure 1A shows that in the fourth quarter of 2007, CPI inflation was primarily the result of cumulated positive demand and monetary policy shocks along, with a small positive cumulated supply shock and small negative cumulated external and productivity shocks.[12]

An immediate, apparent difference in the two panels of each of the figures is the importance of the risk premium shock in the B panels. Most dramatically the difference can be seen in the periods of two big depreciations in the data that include the Asian crisis, when the real value of the rand fell by over 15 percent in the third quarter of 1998, and in the fourth quarter of 2001 when the rand also fell by 14 percent (followed by a 5 percent decline in the next quarter). During the Asian crisis, the SMS model relies heavily on the cumulated effects of monetary policy shock and inflation reflects the offsetting effects of the negative monetary policy shocks and positive other domestic shocks (Figure 1A). Output is predominantly attributed to negative monetary policy shocks more than offsetting the effects of positive cumulated demand shocks (Figure 2A). The large spike in interest rates reflects the cumulated positive domestic shocks and a large positive monetary policy shock (Figure 3A).

In contrast, Model 2' relies heavily on the risk premium shock. Inflation is still influenced by a large cumulated negative interest rate shock, but this is predominantly offsetting the positive cumulated risk premium shock and the cumulated demand shocks are negatively influencing inflation (Figure 1B). A similar pattern emerges for output, where the monetary policy shocks more than offset the positive risk premium shocks and the cumulated demand shocks are again negative. Finally, the spike in interest rates is also the result of large monetary policy shocks along and risk premium shocks, and in this case demand shocks are of little importance.

[12] The early years of these plots are less reliable because there is no information about the cumulated shocks in the first observation. Instead, it is assumed that the share of each shock in explaining the first observation is the same as its share in the asymptotic variance decomposition. In spite of this caveat and the caveats in the text about comparing DSGE and structural VAR models, the early years for output in both models (Figures 2A ands 2B) are interesting. In both models, large and negative productivity shocks in the early 90s are followed by large positive productivity in the mid 90s. This pattern is similar to a finding in du Plessis, Smit and Struzenegger (2008).

The biggest difference in the historical decompositions occurs for inflation during the rand crisis at the end of 2001 (Figures 1A &B). The SMS model explains the spike in inflation primarily as the result of productivity and supply shocks, followed by positive demand shocks during 2002. Model 2' explains the spike as predominantly due to positive risk premium shock more than offsetting the effects of negative demand shocks. This pattern of shocks continues into 2002.

It is interesting to note that both models find that the South African Reserve Bank reacted quite differently to the two episodes of depreciation. Both models find large positive shocks to the interest rate in 1998 and negative monetary policy shocks in 2002 (Figure 3). Therefore the two models are consistent with the view that the South African Reserve Bank is placing less importance on the exchange rate in the inflation targeting regime (c.f. Ortiz and Sturzenegger, 2007 and Woglom, 2003).

5. MONETARY POLICY IN THE TWO MODELS

For completeness we have plotted the impulse responses of variables to a 100 basis points innovation in the Taylor rule in Figure 4. The impulse responses are very similar in both models, which is due to the fact that the parameter estimates are not all that different (see footnote 7). Therefore, in spite of the difference in explaining the business cycle in the two models, both models imply a similar transmission mechanism for monetary policy.

6. CONCLUSION

Our analysis has shown that the exchange rate has important information for describing the dynamic determinants of the South African business cycle. However, given the volatility of the local currency, the practicalities of including this variable in a DSGE model are not obvious or easy. Despite these difficulties, we believe that a successful model will need to use the information in the exchange rate and allow for exogenous violations in uncovered interest rate parity.[13]

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[13] A more complete description to our approach to modeling the exchange rate in a New Keynesian DSGE model is provided in Alpanda, Kotzé and Woglom (2009).

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Appendix: Equations in the Models

SMS:

(1) $y_t * - \vartheta y_{t-1} * = \frac{\sigma}{\sigma *}\left(c_t - \vartheta c_{t-1}\right) + \frac{1-\vartheta}{\sigma *} q_t$

(2) $E[q_{t+1}] - q_t = \left(r_t + \mu_t^d - E\left[\pi_{t+1}\right]\right) - \left(r_t * + \mu_t^d * - E\left[\pi *_{t+1}\right]\right)$

Model 2':

(1) $c_t - \vartheta c_{t-1} = E[c_{t+1}] - \vartheta c_t - \frac{(1-\vartheta)}{\sigma}\left(r_t + \mu_t^d - E\left[\pi_{t+1}\right]\right)$

(2) $E[q_{t+1}] - q_t = \left(r_t - E\left[\pi_{t+1}\right]\right) - \left(r_t * - E\left[\pi *_{t+1}\right]\right) + risk_t;$

(3) $risk_t = \mu_t^{risk} + \chi assets_t$

(4) $assets_t - \frac{assets_{t-1}}{\beta} = y_t - c_t - \gamma\left(s_t + \psi_{f,t}\right);$

c and c* (=y*) is domestic and foreign consumption (= foreign output);

$\sum$ is the foreign and domestic degree of habit formation;

σ and $\sigma*$ are the domestic and foreign inverse of the intertemporal elasticity of substitution;

q is the real exchange rate;

r is the nominal interest rate;

π and $\pi*$ are domestic and foreign inflation;

μ^d and μ^d* are domestic and foreign demand shocks;

risk is the country risk premium;

χ is the elasticity of the country risk premium with respect to *assets*;

assets is the countries net foreign asset position;

μ^{risk} is a risk premium shock;

β is the rate of pure time preference;

γ is the import share in output;

s is the terms of trade;

ψ is deviations from the law of one price

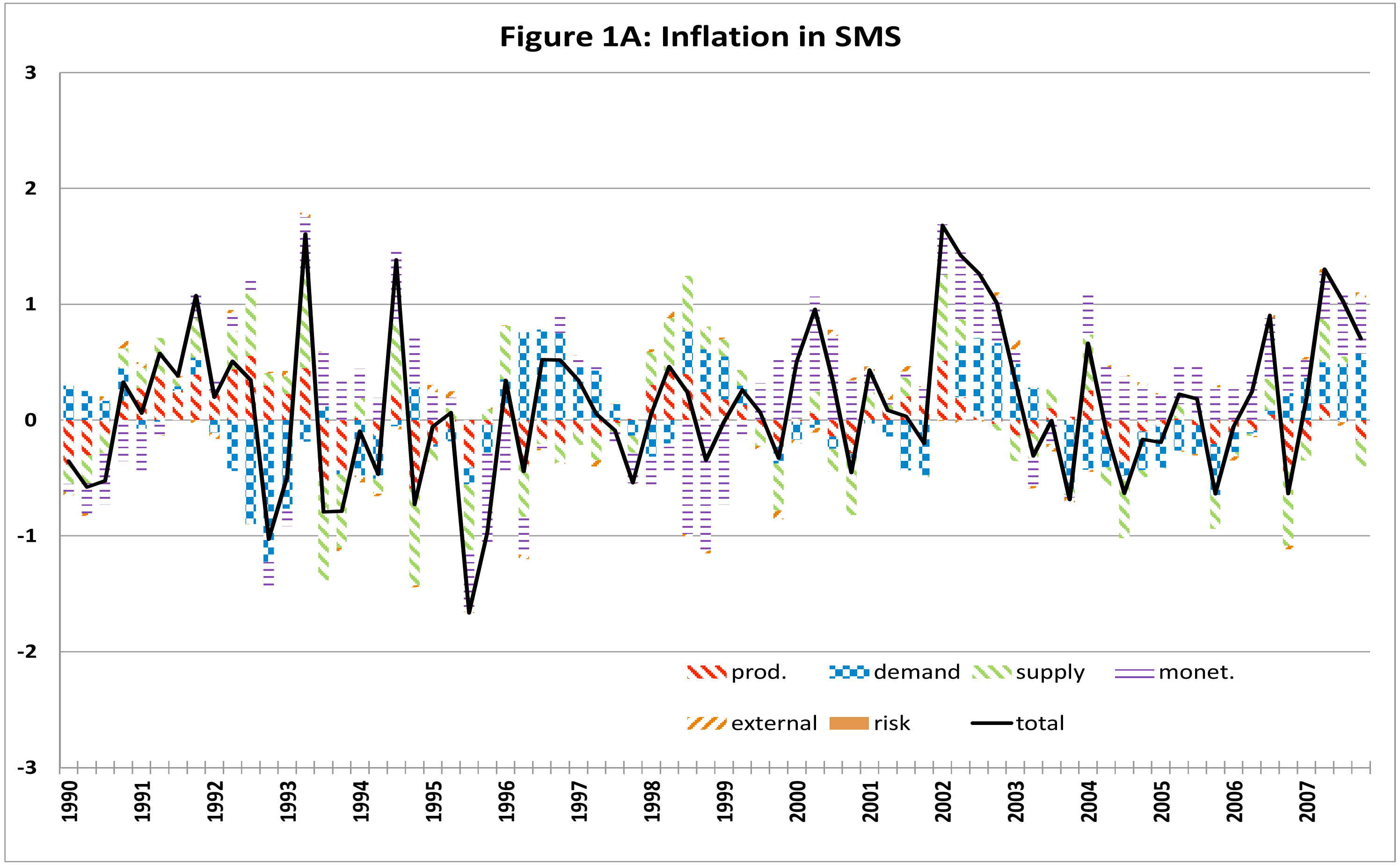


Figure 1A: Inflation in SMS
3
2
1
0
-1
-2
-3
prod.
demand
supply
monet.
external
risk
total
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007

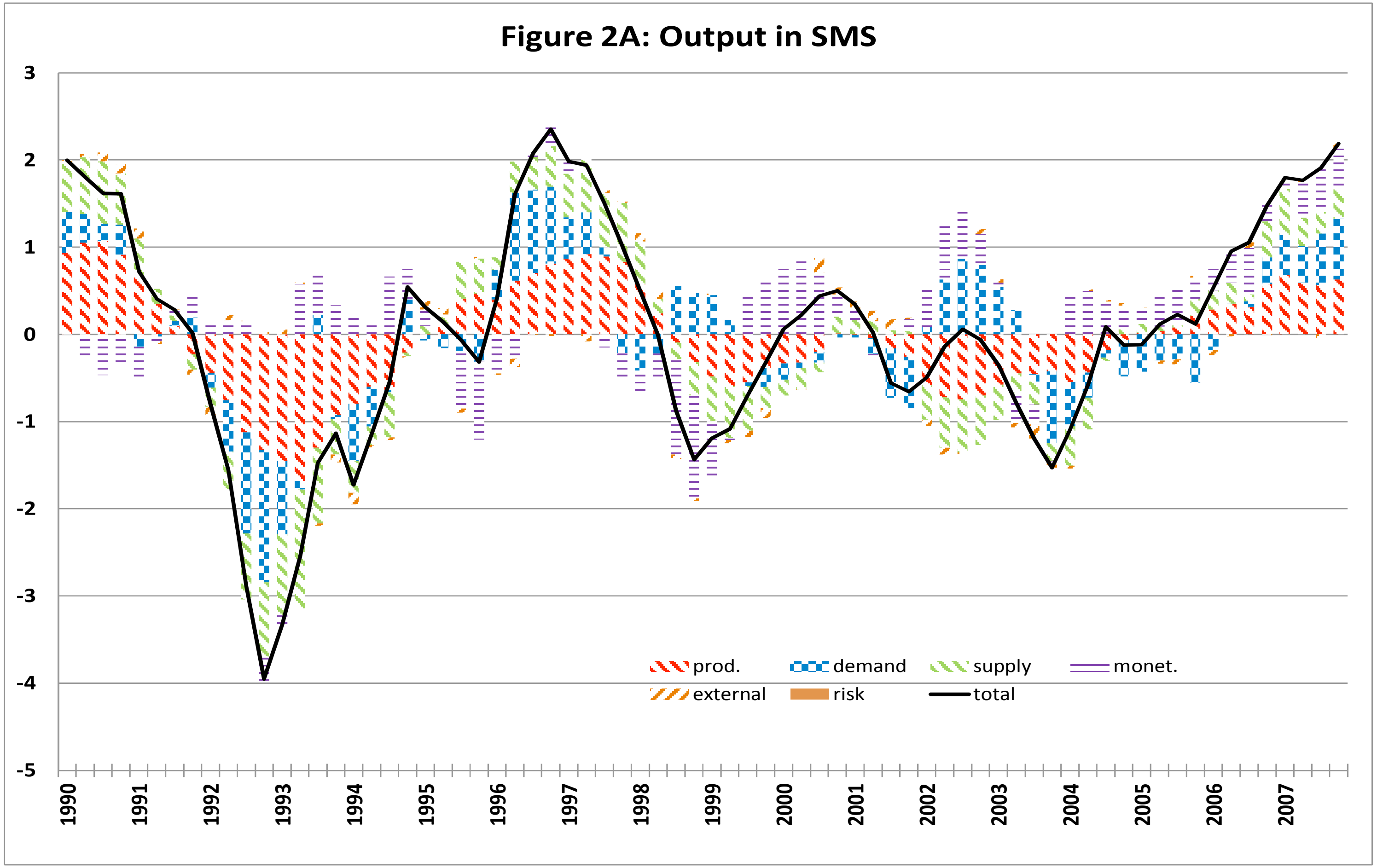
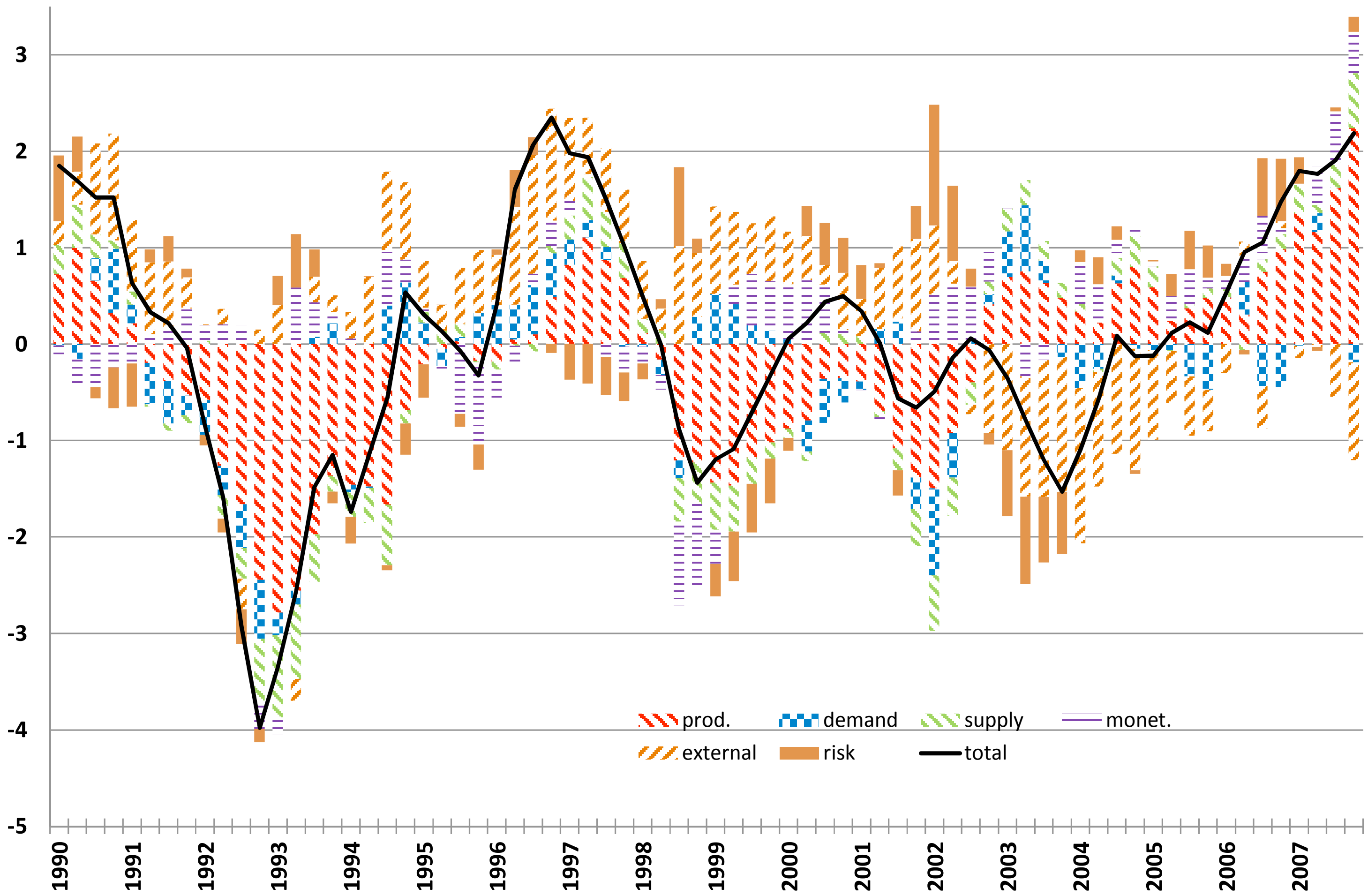


Figure 2A: Output in SMS
3
2
1
0
-1
-2
-3
-4
-5
prod.
demand
supply
monet.
external
risk
total
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007

Figure 2B: Output in Model 2'



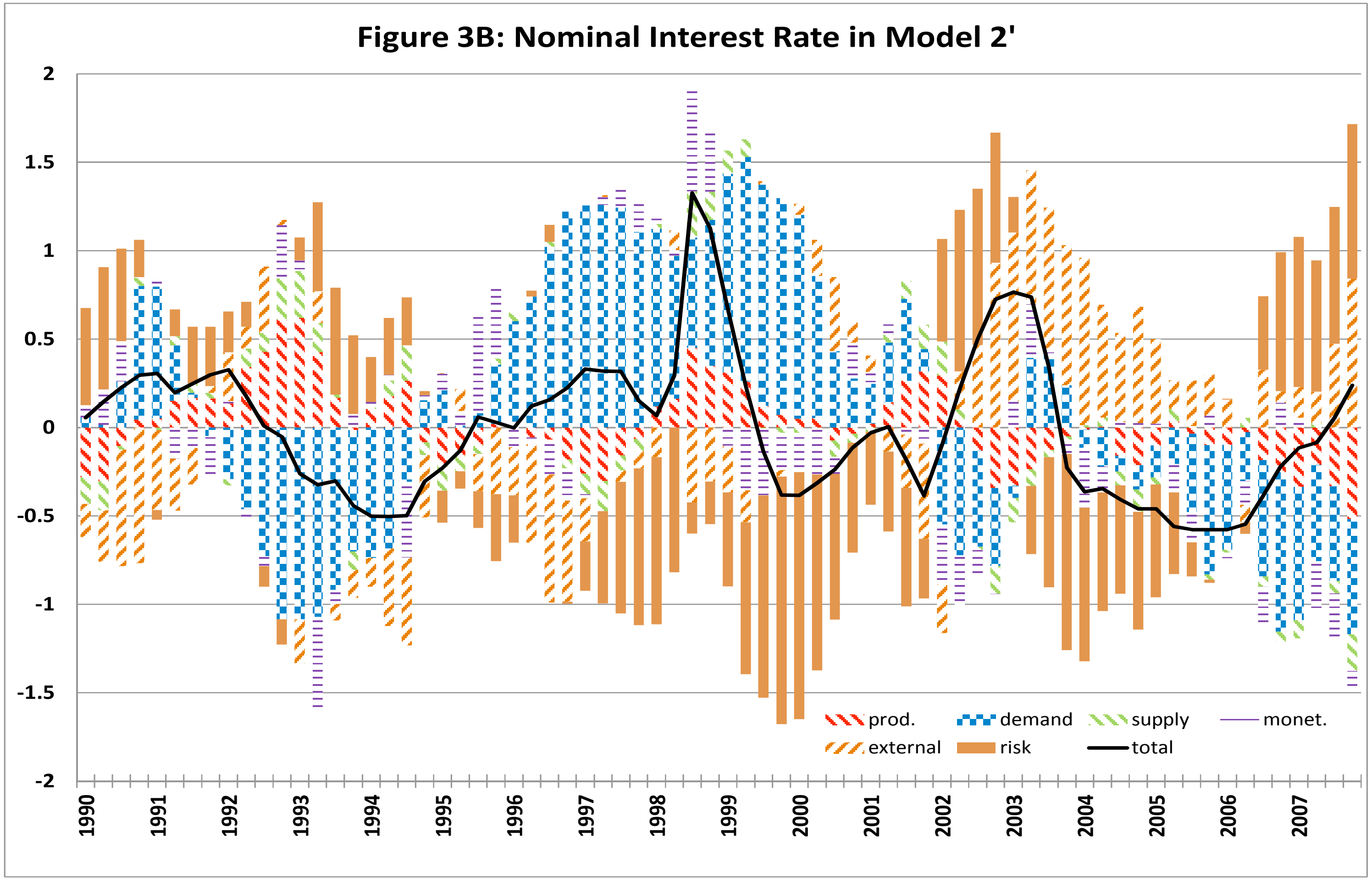


Figure 3B: Nominal Interest Rate in Model 2'
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
prod.
demand
supply
monet.
external
risk
total
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007

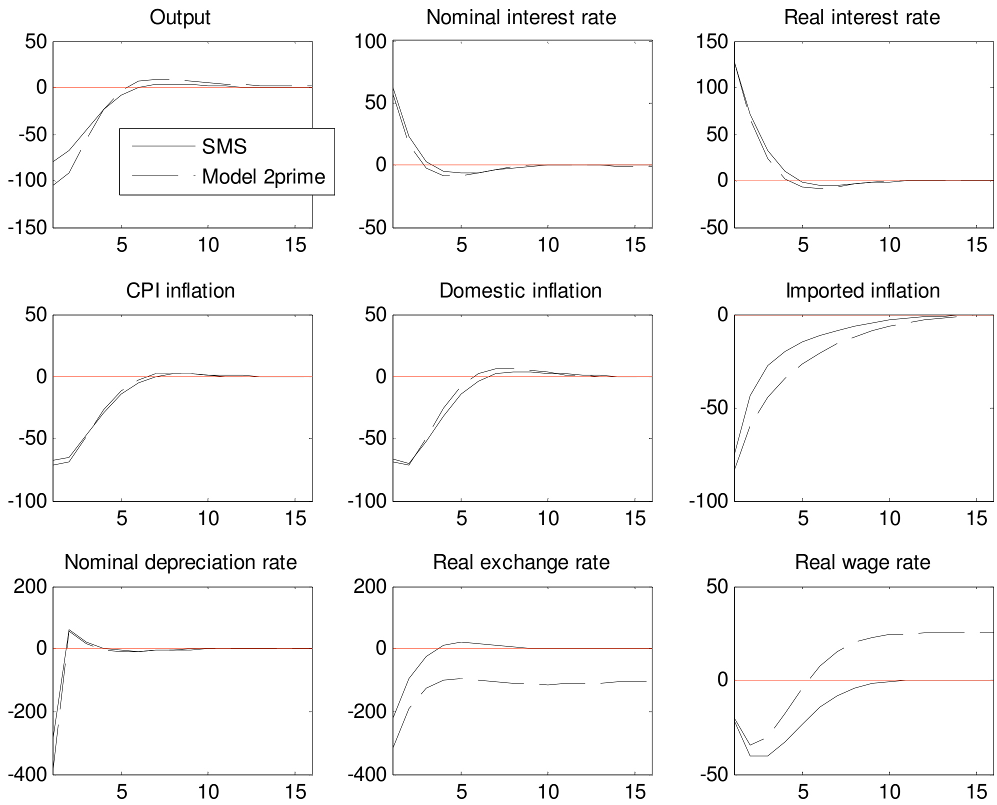


Figure 4: Impulse responses to 100 basis points innovation in the Taylor rule