Online Appendix

MONETARY POLICY, FINANCIAL FRICTIONS AND STRUCTURAL CHANGES IN UGANDA: A MARKOV-SWITCHING DSGE APPROACH

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1 Observed variables

1.1 Unit Root tests

The data for the ten observed variables comprises quarterly measures for the Ugandan economy and its main trading partners over the period 2000Q1 to 2018Q3. The domestic data was sourced from the Bank of Uganda (BoU) and the Uganda Bureau of Statistics (UBOS), while the foreign data was sourced from the Organisation for Economic Co-operation and Development (OECD) and the International Monetary Fund (IMF).

To ensure that the variables are stationary, we initially performed various unit root test on the levels of the variables. These results suggested that four of the variables are non-stationary in levels and include measures of domestic real GDP, terms of trade, nominal exchange rate, and foreign real GDP. Table 1 contains the results for the Dickey *&* Fuller (1981), Kwiatkowski *et al.* (1992), Phillips *&* Perron (1988), and Zivot *&* Andrews (1992) test statistics for the variables that are deemed to be non-stationary in levels.

Variables	Transformation	ADF-stat	KPSS-stat	PP-stat	ZA-stat
Uganda					
Domestic real GDP	y_t	1.7484	1.9938***	1.9026	-3.3346
Terms of trade	s_t	-2.0344	1.3423***	-1.9187	-4.6791*
Nominal exchange rate	q_t	0.0756	1.7089***	0.3661	-3.3429
Foreign economy					
Foreign real GDP	y_t^*	1.6246	1.9525***	2.0994	-4.5282

Table 1: Unit-root tests for non-stationary observed variables in levels

Notes: This table provides specific details relating to the variable transformation and the unit-root test statistics. The column labelled ADF-stat contains the Augmented Dickey-Fuller test statistics for the null hypothesis of non-stationarity, where we include a constant in the regression. The column labelled KPSS-stat contains the Kwiatkowski-Phillips-Schmidt-Shin test statistic for the null hypothesis of stationarity. The column labelled PP-stat contains the Phillips-Perron test statistic for the null hypothesis of non-stationarity. The column labelled ZA-stat contains the Zivot-Andrews test statistic for the null hypothesis of non-stationarity. *,**, and *** indicates that we are able to reject the null hypothesis at 10%, 5%, and 1% significance levels, respectively.

After following the literature for small-open economy models, which include influential studies such as Justiniano *&* Preston (2010), we calculate the growth rates of these variables. Following, this transformation these variables are found to be stationary, as is evident from

the results in Table 2.

In addition, we also find that the measures for the domestic nominal interest rate, domestic inflation rate, non-performing loans, and foreign inflation rate are all stationary in levels. These results are included in Table 2. In each of these cases we note that where the Augmented Dickey-Fuller and Phillips-Perron tests results suggest that we are able to reject the null hypothesis of non-stationarity for each variable (at either the 1% or 5% levels). In addition, the results suggest that we are unable to reject the Kwiatkowski-Phillips-Schmidt-Shin null hypothesis of stationarity for these variables.

When we consider the results for the lending rate we note that while the Augmented Dickey-Fuller test suggest that we are unable to reject the null hypothesis of non-stationarity, the Phillips-Perron test suggests that we can reject the null hypothesis of non-stationarity for this variable. In addition, the Kwiatkowski-Phillips-Schmidt-Shin test statistic for the lending rate suggest that we are unable to reject the null hypothesis of stationarity at the 10% level of significance. Then lastly, the Zivot-Andrews test suggests that when we allow for an endogenous structural break we are able to reject the null hypothesis of non-stationarity at the 1% level of significance.

The results for the foreign interest rate are somewhat contradictory in that the Augmented Dickey-Fuller test suggests that we are able to reject the null hypothesis of non-stationarity at the 5% level of significance, while the other tests suggest that this variable may be non-stationary. Since this measure for the interest rate is largely made up of developed world economies, many of which maintained interest rates at a level that was constant and relatively low for an extended period of time after the Global Financial Crisis, we follow the literature on estimated DSGE models (such as those cited in Christiano *et al.* (2018)) and do not elect to take the first difference of foreign interest rates. Hence, these results suggest that there is at least some evidence to suggest that each of the variables that are presented in Table 2 may be stationary.

1.2 Autocorrelation

The sample autocorrelation statistics for the variables that are included in the respective models suggest that the effect of shocks are relatively short-lived. These are displayed in Table 3. The only exception to this general finding pertains to foreign interest rates, where the effect of a shock takes ten quarters to subside.

1.3 Additional statistical properties of the variables

Details of the first four statistical moments of the model variables are contained in Table 4. In addition, we have also included the results of the Jarque-Bera statistic that can be used as a measure for normality. These suggest that only the foreign inflation rate may be normally distributed. Given that most of the variables are not normally distributed this may imply that a regime-switching model may be more appropriate, particularly if the variables have a multimodal distribution.

Variables	Transformation	ADF-stat	KPSS-stat	PP-stat	ZA-stat
Uganda					
Domestic real GDP	$\triangle \log(y_t)$	-8.7263***	0.0953	-13.2917***	-6.5685***
Terms of trade	$\triangle \log(s_t)$	-6.888***	0.0499	-10.4094***	-6.1975***
Nominal exchange rate	$\triangle \log(q_t)$	-6.1591***	0.0994	-6.5975***	-4.66*
Domestic policy rate	R_t	-3.3886**	0.194	-3.3878**	-5.6799***
Inflation rate	π_t	-4.0442***	0.1903	-4.4149***	-4.5097
Lending rate	R_t^b	-2.5254	0.4065*	-2.6205*	-5.5784***
Non-performing loans to total loans	χ_t	-4.3541***	0.3012	-3.5375***	-4.4881
Foreign economy					
Foreign real GDP	$\triangle \log(y_t^*)$	-3.9752***	0.1124	-4.8529***	-4.8888**
Foreign policy rate	R_t^*	-3.476**	0.8413***	-2.4643	-4.2467
Foreign inflation rate	π_t^*	-4.4728***	0.3143	-4.6991***	-4.4854

Table 2: Unit root tests for variables that are included in the models

Notes: This table provides specific details relating to the variable transformation and the unit-root test statistics. The column labelled ADF-stat contains the Augmented Dickey-Fuller test statistics for the null hypothesis of non-stationarity, where we include a constant in the regression. The column labelled KPSS-stat contains the Kwiatkowski-Phillips-Schmidt-Shin test statistic for the null hypothesis of stationarity. The column labelled PP-stat contains the Phillips-Perron test statistic for the null hypothesis of non-stationarity. The column labelled ZA-stat contains the Zivot-Andrews test statistic for the null hypothesis of non-stationarity. *,**, and *** indicates that we are able to reject the null hypothesis at 10%, 5%, and 1% significance levels, respectively.

Variables	Transformation	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6	Lag 7	Lag 8	Lag 9	Lag 10	Lag 11	Lag 12
Uganda													
Domestic real GDP	$\triangle \log(y_t)$	-0.359	-0.07	0.077	-0.049	-0.179	0.12	0.13	-0.223	0.258	-0.037	-0.221	0.038
Terms of trade	$\triangle \log(s_t)$	-0.127	-0.017	-0.217	0.127	-0.213	0.014	0.052	-0.062	-0.111	-0.076	0.104	0.025
Nominal exchange rate	$\triangle \log(q_t)$	0.229	-0.09	-0.206	-0.149	0.161	0.027	-0.211	-0.137	0.163	0.164	0.163	-0.143
Domestic policy rate	R_t	0.781	0.546	0.242	-0.034	-0.211	-0.287	-0.291	-0.209	-0.116	-0.046	0.061	0.144
Inflation rate	π_t	0.591	0.306	0.014	-0.128	-0.032	0.034	0.075	0.035	0.086	0.006	0.067	0.051
Lending rate	R_t^b	0.849	0.7	0.515	0.346	0.186	0.108	0.013	-0.014	0.014	0.059	0.123	0.21
Non-performing loans to total loans	χt	0.793	0.582	0.407	0.224	0.153	0.121	0.092	0.082	0.115	0.129	0.192	0.217
Foreign economy													
Foreign real GDP	$\triangle \log(y_t^*)$	0.511	0.289	0.093	0.147	0.069	-0.002	-0.15	-0.221	-0.164	-0.005	-0.088	-0.15
Foreign policy rate	R_t^*	0.939	0.84	0.718	0.59	0.47	0.356	0.264	0.181	0.102	0.031	-0.025	-0.064
Foreign inflation rate	π_t^*	0.509	0.197	0.164	0.144	0.299	0.387	0.252	0.078	0.117	0.196	0.081	0.006

Table 3: Autocorrelation statistics for variables that are included in the models

Variables	Transformation	Mean	Standard Deviation	Skewness	Kurtosis	JB-stat
Uganda						
Domestic real GDP	$\triangle \log(y_t)$	0.0144	0.022	-0.521	2.4365	0
Terms of trade	$\triangle \log(s_t)$	0.0036	0.0782	0.5804	1.558	0.0013
Nominal exchange rate	$\triangle \log(q_t)$	0.012	0.0434	0.7215	1.4329	0.0008
Domestic policy rate	R_t	0.0259	0.0097	0.688	-0.2057	0.0448
Inflation rate	π_t	0.0148	0.0127	1.844	5.6979	0
Lending rate	R_t^b	0.0493	0.0047	0.7164	-0.2318	0.0341
Non-performing loans to total loans	χ_t	4.7533	2.437	1.3527	1.8333	0
Foreign economy						
Foreign real GDP	$\triangle \log(y_t^*)$	0.0075	0.0047	-2.3106	7.0386	0
Foreign policy rate	R_t^*	0.0042	0.0047	1.0719	-0.1603	0.0006
Foreign inflation rate	π_t^*	0.0078	0.0036	0.2127	-0.0695	0.745

Table 4: Statistical moments and normality test for variables that are included in the models

Notes: This table summarises statistical properties of the data that has been used in the respective models. The column labelled JB-stat contains the p value for the Jarque-Bera statistic.

2 Shocks

The shocks to the structural equations in the models are identified from the structural parameters in the model that describe the household preferences along with the technological and institutional constraints (Smets & Wouters, 2003). These stochastic shocks that give rise to economic fluctuations that trace the transmission of innovations throughout the economy (Rao *et al.*, 2010).

To derive a single estimate for the shocks in the regime-switching models we take the product of the time-varying transition probabilities and the shocks that were identified for each regime.

2.1 Model without regime-switching

2.1.1 Autocorrelation

The sample autocorrelation statistics for the shocks that are included in the model without any regime-switching suggest that the effect of shocks are relatively short-lived. These are displayed in Table 5.

2.1.2 Additional statistical properties of the shocks

Details of the first four statistical moments of the shocks in the model without regime-switching features are contained in Table 6. In addition, we have also included the results of the Jarque-Bera statistic that can be used as a measure for normality.

Shocks	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6	Lag 7	Lag 8	Lag 9	Lag 10	Lag 11	Lag 12
η_t^R	-0.127	0.222	0.065	0.078	0.12	0.122	-0.033	0.088	0.218	-0.054	0.113	-0.013
η_t^{R*}	0.707	0.475	0.41	0.269	0.102	0.023	-0.035	-0.115	-0.173	-0.226	-0.293	-0.342
η_t^{cp}	0.204	-0.066	-0.271	-0.025	0.054	0.077	-0.153	-0.017	0.016	0.286	0.169	-0.205
η_t^c	-0.737	0.405	-0.319	0.316	-0.221	0.064	0.065	-0.106	0.145	-0.185	0.165	-0.057
η_t^χ	-0.081	0.121	0.035	-0.313	-0.057	-0.016	0.03	0.004	0.082	-0.097	0.124	0.004
$\eta_t^{\pi*}$	-0.173	-0.282	-0.012	-0.161	0.059	0.213	0.064	-0.227	-0.037	0.211	-0.048	-0.112
η_t^{rp}	-0.192	0.032	0.059	0.115	-0.08	0.031	0.147	-0.061	0.122	0.072	-0.041	0.034
η_t^{y*}	-0.241	-0.021	-0.249	0.147	0.004	0.07	-0.087	-0.135	-0.106	0.256	-0.028	-0.184
η_t^z	-0.334	0.255	0.055	0.082	-0.013	0.091	0.166	-0.108	0.165	0.084	0.066	0.015

Table 5: Autocorrelation statistics for the shocks in the model without regime-switching

Shocks	Mean	Standard Deviation	Skewness	Kurtosis	JB test
η_t^R	-0.244	0.984	-0.476	1.375	0.007
η_t^{R*}	-0.056	0.95	-1.429	2.229	0
η_t^{cp}	-0.208	0.974	-0.61	1.439	0.002
η_t^c	0.077	1.026	-0.001	0.114	0.94
η_t^χ	0.502	0.728	0.36	4.356	0
$\eta_t^{\pi*}$	0.206	0.982	-0.397	0.468	0.219
η_t^{rp}	-0.053	0.983	-0.188	0.022	0.782
η_t^{y*}	0.222	0.984	0.333	6.352	0
η_t^z	-0.026	1.008	0.095	0.613	0.428

Table 6: Statistical moments and normality test for the shocks in the model without regime-switching

Notes: This table summarises statistical properties of the shocks that have been included in the model. The column labelled JB-stat contains the p value for the Jarque-Bera statistic.

2.2 Model with regime-switching in the monetary policy rule (only)

2.2.1 Autocorrelation

The sample autocorrelation statistics for the shocks that are included in the model with regime-switching in the monetary policy rule suggest that the effect of shocks are relatively short-lived. These are displayed in Table 7.

2.2.2 Additional statistical properties of the shocks

Details of the first four statistical moments of the shocks in the model with regime-switching features in the monetary policy rule are contained in Table 8. In addition, we have also included the results of the Jarque-Bera statistic that can be used as a measure for normality.

Shocks	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6	Lag 7	Lag 8	Lag 9	Lag 10	Lag 11	Lag 12
η_t^R	-0.338	0.201	0.03	-0.006	0.074	0.077	-0.066	0.034	0.16	-0.143	0.152	-0.1
η_t^{R*}	0.707	0.475	0.41	0.269	0.102	0.023	-0.035	-0.115	-0.173	-0.226	-0.293	-0.342
η_t^{cp}	0.203	-0.069	-0.27	-0.015	0.045	0.08	-0.152	-0.018	0.008	0.289	0.167	-0.195
η_t^c	-0.74	0.413	-0.325	0.325	-0.225	0.067	0.064	-0.103	0.144	-0.183	0.167	-0.065
η_t^χ	-0.081	0.121	0.034	-0.313	-0.057	-0.016	0.03	0.004	0.082	-0.097	0.124	0.004
$\eta_t^{\pi*}$	-0.175	-0.283	-0.013	-0.161	0.058	0.212	0.064	-0.228	-0.037	0.211	-0.048	-0.113
η_t^{rp}	-0.073	-0.115	0.13	0.073	-0.088	-0.068	0.203	0.009	0.114	0.015	-0.039	0.124
η_t^{y*}	-0.241	-0.021	-0.249	0.147	0.004	0.07	-0.087	-0.135	-0.106	0.256	-0.028	-0.184
η_t^z	-0.376	0.227	0.034	0.055	-0.028	0.086	0.164	-0.122	0.163	0.078	0.045	0.013

Table 7: Autocorrelation statistics for the shocks in the model with regime-switching in the monetary policy rule (only)

Shocks	Mean	Standard Deviation	Skewness	Kurtosis	JB test
η_t^R	-0.151	1	-0.256	2.855	0
η_t^{R*}	-0.055	0.95	-1.428	2.227	0
η_t^{cp}	-0.213	0.976	-0.513	1.113	0.017
η_t^c	0.072	1.032	0	0.049	0.973
η_t^χ	0.501	0.725	0.36	4.357	0
$\eta_t^{\pi*}$	0.181	0.988	-0.393	0.469	0.223
η_t^{rp}	-0.008	0.984	-0.032	-0.191	0.973
η_t^{y*}	0.22	0.984	0.337	6.36	0
η_t^z	-0.013	0.993	0.126	0.63	0.394

Table 8: Statistical moments and normality test for the shocks in the model with regime-switching in the monetary policy rule (only)

Notes: This table summarises statistical properties of the shocks that have been included in the model. The column labelled JB-stat contains the p value for the Jarque-Bera statistic.

2.3 Model with regime-switching in the monetary policy rule and the volatility of shocks

2.3.1 Autocorrelation

The sample autocorrelation statistics for the shocks that are included in the model with regime-switching in the monetary policy rule and the volatility of shocks suggest that the effect of shocks to both the first and second moment of these processes are relatively short-lived. These are displayed in Table 9 and Table 10.

2.3.2 Additional statistical properties of the shocks

Details of the first four statistical moments of the shocks in the model with regime-switching features in the monetary policy rule and the volatility of shocks are contained in Table 11 and Table 12. In addition, we have also included the results of the Jarque-Bera statistic that can be used as a measure for normality.

Shocks	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6	Lag 7	Lag 8	Lag 9	Lag 10	Lag 11	Lag 12
η_t^R	-0.176	0.201	0.034	0.041	0.064	0.066	-0.089	0.061	0.189	-0.081	0.1	-0.013
η_t^{R*}	0.702	0.471	0.419	0.308	0.15	0.106	0.032	-0.067	-0.139	-0.19	-0.258	-0.314
η_t^{cp}	-0.547	0.519	-0.226	0.394	-0.123	0.183	0.078	0.047	0.092	0.009	0.179	-0.027
η_t^c	-0.751	0.415	-0.315	0.294	-0.191	0.053	0.074	-0.129	0.162	-0.198	0.188	-0.069
η_t^χ	-0.081	0.121	0.035	-0.313	-0.057	-0.016	0.03	0.004	0.082	-0.097	0.124	0.004
$\eta_t^{\pi*}$	-0.133	-0.258	0.007	-0.151	0.074	0.226	0.075	-0.209	-0.027	0.212	-0.042	-0.101
η_t^{rp}	-0.088	0.419	0.103	0.378	0.091	0.209	0.244	0.139	0.204	0.126	0.227	0.11
η_t^{y*}	-0.24	-0.021	-0.249	0.147	0.005	0.07	-0.087	-0.135	-0.106	0.256	-0.029	-0.184
η_t^z	-0.705	0.398	-0.258	0.255	-0.152	0.072	0.083	-0.163	0.24	-0.22	0.179	-0.037

Table 9: Autocorrelation statistics for the shocks in the model with regime-switching in the monetary policy rule and the volatility of shocks

Shocks	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6	Lag 7	Lag 8	Lag 9	Lag 10	Lag 11	Lag 12
η_t^R	-0.107	0.174	0.067	0.052	0.104	0.104	-0.065	0.105	0.21	-0.053	0.106	-0.076
η_t^{R*}	0.735	0.51	0.467	0.339	0.19	0.12	0.031	-0.072	-0.157	-0.204	-0.271	-0.328
η_t^{cp}	-0.519	0.539	-0.201	0.403	-0.115	0.178	0.11	0.036	0.143	-0.022	0.259	-0.088
η_t^c	-0.74	0.406	-0.277	0.29	-0.22	0.04	0.117	-0.192	0.211	-0.24	0.235	-0.133
η_t^χ	-0.086	0.144	0.044	-0.28	-0.055	-0.018	0.037	-0.006	0.085	-0.073	0.102	0.015
$\eta_t^{\pi*}$	-0.116	-0.258	0.034	-0.154	0.054	0.232	0.064	-0.198	-0.026	0.207	-0.04	-0.126
$\eta_t^{\tau^p}$	-0.08	0.421	0.09	0.371	0.068	0.192	0.227	0.12	0.194	0.1	0.219	0.058
η_t^{y*}	-0.268	0.004	-0.2	0.11	0.033	0.065	-0.098	-0.131	-0.101	0.246	-0.029	-0.171
η_t^z	-0.729	0.398	-0.248	0.254	-0.175	0.065	0.101	-0.193	0.257	-0.233	0.183	-0.055

Table 10: Autocorrelation statistics for the volatility of the shocks in the model with regime-switching in the monetary policy rule and the volatility of shocks

Shocks	Mean	Standard Deviation	Skewness	Kurtosis	JB test
η_t^R	-0.226	1.231	-0.546	1.843	0
η_t^{R*}	0.003	0.009	-0.184	0.593	0.381
η_t^{cp}	0.054	0.865	-0.025	-0.374	0.863
η_t^c	0.012	0.277	0.02	0.262	0.823
η_t^χ	0.54	0.782	0.363	4.355	0
$\eta_t^{\pi*}$	0.015	0.028	-0.428	0.417	0.202
η_t^{rp}	0.008	0.548	-0.121	-0.254	0.864
η_t^{y*}	0.009	0.037	0.323	6.328	0
η_t^z	0.062	0.981	-0.248	0.379	0.474

Table 11: Statistical moments and normality test for the shocks in the model with regime-switching in the monetary policy rule and the volatility of shocks

Notes: This table summarises statistical properties of the shocks that have been included in the model. The column labelled JB-stat contains the p value for the Jarque-Bera statistic.

Shocks	Mean	Standard Deviation	Skewness	Kurtosis	JB test
η_t^R	-0.232	1.401	0.073	0.162	0.877
η_t^{R*}	0.004	0.011	0.078	0.318	0.741
η_t^{cp}	0.12	1.206	0.181	-0.64	0.481
η_t^c	-0.005	0.445	-0.326	-0.147	0.497
η_t^χ	0.652	0.917	0.278	3.449	0
$\eta_t^{\pi*}$	0.019	0.035	-0.52	0.424	0.113
η_t^{rp}	0.008	0.677	-0.255	-0.458	0.517
η_t^{y*}	0.011	0.046	-0.054	6.178	0
η_t^z	0.048	1.208	-0.336	0.396	0.33

Table 12: Statistical moments and normality test for the volatility of the shocks in the model with regime-switching in the monetary policy rule and the volatility of shocks

Notes: This table summarises statistical properties of the shocks that have been included in the model. The column labelled JB-stat contains the p value for the Jarque-Bera statistic.

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