Volatility Driven Capital Flows in Emerging Market Economies

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Abstract

Gross capital inflows and outflows in many emerging market economies are characterized by large cyclical fluctuations. This paper analyzes these cyclical fluctuations from the perspective of changes in macroeconomic volatility for the case of Mexico. The first part estimates an open economy dynamic stochastic general equilibrium model with stochastic volatility shocks in TFP and investment efficiency to derive theory based restrictions for a structural VAR. It then continues and applies in the second part a SVAR approach with combined sign and zero restrictions to estimate the impact of volatility shocks on Mexican gross capital flows. Both the DSGE model and the SVAR with sign restrictions are able to generate a negative effect on capital inflows and a positive effect on capital outflows after a shock in domestic stochastic volatility.

Keywords: Capital flows, Stochastic volatility, Sign restrictions, SVAR, DSGE

JEL Classification: F32, F41

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1 Introduction

Emerging market economies are characterized by high volatility in capital inflows and outflows. Among the countries that are particularly affected by this are the major Latin American economies of Mexico, Brazil, and Argentina for instance. At the same time, macroeconomic volatility is subject to large swings in most of these countries. Fluctuations in output, government spending, or total factor productivity are much higher than in developed countries. The aim of this paper is to bridge the gap between economic uncertainty in the form of volatility in TFP and investment efficiency on the one side and cross-border gross capital flows on the other side.

Large gross positions in capital flows pose a potential threat to these countries and the international financial system as these flows might be subject to sudden stops. Having a small relative decrease in gross capital inflows can have a much more severe effect on net capital flows than under a scenario with small capital flows. So that, even for countries with a balanced net flow, a relatively small decrease in inflows can result in a severe imbalance.

In an environment of high economic uncertainty, i.e. high perceived relative volatility of macroeconomic variables, risk averse domestic agents might increase their holdings of foreign assets which might then be reflected in increased capital outflows by domestic agents in an open economy. In addition to this mechanism, foreign investors might care about relative volatility when to decide to withdraw capital from emerging markets when idiosyncratic volatility increases. Hence leading to reduced capital inflows by foreigners from those countries. In previous studies, relatively little attention was paid to the individual study of capital inflows and outflows.

This paper contributes to the existing literature on international capital flows and current account movements under stochastic volatility shocks threefold.

First, this paper contributes by using an open economy DSGE model with portfolio holdings of stocks that is augmented for stochastic volatility shocks to derive impulse responses of gross capital flows after a volatility shock in TFP and investment efficiency.

Second, the paper further not only addresses the change in net capital flows as most previous research in this area did, but it widens the view and focuses on gross capital flows. This becomes especially important by the fact that for many countries net capital flows reverted to an almost balanced level whereas gross inflows and outflows continue to grow and exhibit a significant volatility.

And third, it contributes by using a structural VAR which allows to account for potential reverse causality between gross capital flows and idiosyncratic volatility in economic variables that can potentially arise in panel data settings. The structural VAR applies combined sign and zero long run restrictions for the identification of the volatility shocks. Sign and zero long run restrictions have so far not been applied to analyze international capital flows. The vector autoregressive approach will then allow to obtain impulse responses to shocks in idiosyncratic TFP and investment efficiency on capital inflows and
outflows and their dynamic impact and compare them to the previously obtained results from the DSGE model. Using a structural VAR comes with the advantage of a less restrictive approach that is more data driven and relies less on a specific form of a model.

In general, this paper fits into the broad literature of stochastic volatility in macroeconomic models like Justiniano and Primiceri (2008) and Fernandez-Villaverde et al. (2011). The latter show that time-varying volatility in the real interest rate increased in the emerging market economies of Argentina, Brazil, Ecuador, and Venezuela. They can subsequently show that increases in volatility of the real interest rate can decrease output, consumption, investment, hours, and debt in a standard small open economy business cycle model. For this they estimate the stochastic process of the real interest rate using a particle filter that can then be integrated into a DSGE model. Kollmann (2016) considers the effect of output volatility shocks in a two country model on consumption, trade flows and the real exchange rate. Further recent research with regard to volatility is Seoane (2016) who looks at the propagation of volatility shocks through mark-ups in a small open economy model. Mumtaz and Theodoridis (2017) use a factor model to decompose time-varying variance of macroeconomic and financial variables into country-specific and common factors. A DSGE model then allows them to conclude that increased globalization and trade openness are the driving force behind the increased cross-country correlation that can be observed in volatility.

When volatility is considered as a major source of uncertainty, this paper also relates to the pioneering work by Bloom (2014) on macroeconomic uncertainty. Major recent contributions to the study of capital flows in DSGE models are Tille and van Wincoop (2010) who use a DSGE model to analyze net and gross portfolio asset flows in a two-country framework. Devereux and Sutherland (2009) build a DSGE model with an emerging market economy and a developed economy. Their model can account for the large holdings of foreign assets by emerging markets and at the same time allows for large inflows of foreign direct investment into the emerging market economy. The empirical part using a structural VAR with sign restrictions is also closely related to work by Uhlig (2005) and Mountford and Uhlig (2009) who use a structural VARs with sign restrictions to study monetary and fiscal policy effects. Scholl and Uhlig (2008) use sign restrictions to study the effect of US monetary policy on exchange rates between the US and Germany. However, there is so far no application of this identification scheme to international capital flows and stochastic volatility. It also relates to work by Fogli and Perri (2015) who find a strong relationship between uncertainty as measured by the variance of a country’s GDP and the accumulation of net foreign assets in a panel of OECD countries. In addition, Elgin and Kuzubs (2013) find an association in a larger set of countries in a panel between current account deficits and high output volatility. However, most of the current literature on capital flows does not look at gross capital flows and does not address the problem of reverse causality sufficiently. An exception is Broner et al. (2013) who show that differentiating and disentangling capital inflows and capital outflows proves important as gross flows might significantly contribute to global imbalances. Further work is done by e.g. Schmidt and Zwick (2015) who further analyze
governors addressed the persistently low inflation, which causes capital to move around the world. There are several channels through which inflation uncertainty affects capital flows. Gourio et al. (2016) use stock market volatility to establish a causal relationship between volatility and gross capital flows within a panel of 26 emerging countries. By distinguishing between global volatility and country specific stock market volatility they are then able to reconcile their empirical results in a portfolio choice model.

This paper is different in applying stochastic volatility shocks to TFP and the investment efficiency in a two country model with stock holdings. It is able to get dynamic responses of gross capital flows after a shock in domestic and foreign stochastic volatility. A structural VAR with sign and zero restrictions is then applied for the first time to gross capital flow data.

The rest of this paper is structured as follows. The second part will introduce the data and discuss some volatility measures. In the third part an open economy DSGE model with stochastic volatility is constructed and the parameter of the stochastic process are estimated for Mexican data using a Bayesian approach. The fourth part will show the empirical observations for the case of Mexico using a SVAR with combined sign and zero restrictions derived from the DSGE model. The fifth part will compare the results from the DSGE model and the structural VAR with restrictions derived from the DSGE model and part six will finally conclude and guide to future avenues of research.

2 Data

In the following we need data to estimate the stochastic process of TFP and investment efficiency for Mexico and the US that is used in the DSGE model. We further need data for the structural analysis applied to Mexico that consists of a seven variable SVAR that includes the Mexican-US interest rate differential, an idiosyncratic volatility measure for TFP and investment efficiency, capital inflows and outflows as well as the differential between Mexican and US GDP growth and inflation differentials. All data is of quarterly frequency and ranges from the first quarter 1980 to the fourth quarter of 2014. Mexican and US variables used to estimate the structural VAR and to estimate stochastic processes for the DSGE model are from the FRED database of the Federal Reserve Bank of St Louis. Mexico is chosen in this paper as a representative of a large emerging market economy since the Mexican economy is less susceptible to sudden capital flow movements caused by changes in commodity prices and demand like Argentina or Brazil for instance. It further exhibits strong interlinkages with the US as the representative of the rest of the world. A detailed overview about all data sources is available in Table 10 in the Appendix.

2.1 SVAR Data

As we are interested in the behavior of gross capital flows, it is important to clearly disentangle these two. Hence, capital inflows by foreign agents are defined as the sum of
portfolio investment liabilities and other investment liabilities which include bank flows, other public and private loans, and trade credit for Mexico from the financial account of the balance of payments. Capital outflows by domestic agents are defined as the corresponding asset components of the financial account, namely portfolio investment assets and other investment assets for Mexico.\footnote{This approach is hence similar to Broner et al. (2013) who additionally include direct foreign investment liabilities and assets to their definition of capital inflows by foreigners and capital outflows by domestic agents. We drop FDI flows due to limited data availability for Mexico.} A positive value for capital inflows therefore indicates an inflow by foreign agents into Mexico whereas a negative value indicates a withdrawal of capital from Mexico by foreign agents. A positive value for capital outflows indicates an increase in the holdings of foreign assets by Mexican agents whereas a negative value indicates a repatriation of capital by Mexican agents back to Mexico.\footnote{This is the gross term refers to capital flows being disentangle into flows by foreign agents and domestic agents, respectively. However, the paper uses net capital flows for each group of agents. This allows for a one to one mapping in the model later on.} Inflows and Outflows are then constructed relative to GDP to normalize the variables by country size. US interest rates used in the SVAR are the effective Fed funds rate and Mexican interest rates are approximated by 3-month Mexican treasury securities. Inflation data for Mexico and the US is the growth rate with respect to the previous period of the consumer price index and includes all items. GDP growth rates are the growth rates with respect to the previous period of constant prices GDP and are seasonally adjusted. Differentials of interest rates (Interest Rate Diff), GDP growth (\(\Delta GDP Diff\)) and CPI growth (\(\Delta CPI Diff\)) are then constructed by subtracting the US value from the Mexican data. Where data is not available in constant US Dollar terms, data series are transformed using the quarterly GDP deflator for Mexico and then converted to constant US Dollar.

\subsection*{2.2 TFP and Investment Efficiency Data}

The TFP data used to estimate the stochastic volatility process is estimated using a log-linearized Cobb-Douglas production function of the form

\[
\hat{y}_t = \hat{a}_t + \alpha \hat{k}_t + (1 - \alpha) \hat{l}_t
\]

where \(\hat{y}_t\) is the log-deviation of output from the steady state, \(\hat{a}_t\) is the log-deviation of TFP, \(\hat{k}_t\) is the log-deviation of the capital stock, and \(\hat{l}_t\) is the log-deviation of hours worked.\footnote{Since capital stock data is only available at an annual frequency, the data is converted to a quarterly frequency using spline interpolation.} The data used to construct TFP is first detrended using a quadratic trend as in Mendoza (1991) so that e.g. \(\hat{y}_t\) corresponds to the log-deviation of output from its quadratic trend. Data on investment efficiency for Mexico and the US is constructed following Basu and Thoenissen (2011) so that the relative price of investment goods to consumption goods
can be approximated around it’s steady state using a log-linear approximation as

\[
\frac{P_I}{P_t} = (\theta_C - \theta_I) \hat{T}_t - \hat{\chi}_t
\]

where \( P_I \) is the price of investment, \( P_t \) is the price of consumption, and \( T_t \) denotes the terms of trade expressed in import prices over export prices. \( \theta_C \) and \( \theta_I \) denote the share of domestic goods in consumption and investment and \( \chi_t \) denotes the investment efficiency term. A hat denotes log-deviations from the steady state of the respective variable. Data on investment and consumption prices is then detrended using a quadratic trend as in the case of TFP. This shows that the investment efficiency \( \chi_t \) can be expressed as the relative prices of investment and consumption as long as the share of domestic goods in consumption is the same as in investment.\(^4\) Calculating TFP and investment efficiency data using the production function provides the advantage that the estimates for TFP and the investment efficiency are grounded in economic theory and have a one to one mapping in the DSGE model. It further comes with the advantage that comparable data series can be constructed for both Mexico and the US at a quarterly frequency.

2.3 Capital Flows

Figure 1 shows capital inflows by foreigners and capital outflows by domestic agents relative to GDP for Mexico. As previously noted in the text and in accordance with Broner et al. (2013) the term gross flows refers to the distinction in the financial account between domestic agents and foreign agents. However, they are net in the sense that capital inflows and capital outflows by each group are shown as net flows. Capital flows are not trending since each time series shows the net flow for each group i.e. a net change in the Mexican asset and liability position.

2.4 Volatility Measures

In general four broad categories of uncertainty measures can be characterized as described by Bloom (2014) who provides a comprehensive review of uncertainty measures. First, volatility in macroeconomic variables like output, government spending, interest rates or TFP which can easily be estimated using econometric methods. Second, indicators of stock market volatility like the widely used VIX index of stock option prices for the US that measures volatility in financial markets. Third, micro based indicators based on firm level data or the spread in business forecasts. And finally, measures of political uncertainty as described in Baker et al. (2016). The latter two are difficult to obtain for a large set of countries over long time horizons. Whereas the former two are more easily available for a broad set of countries.

\(^4\)The investment efficiency \( \chi_t \) will be constructed assuming that \( \theta_C = \theta_I \). Although \( \theta_C \) and \( \theta_I \) will later be allowed to differ in the DSGE model. This, however, would require a costly re-estimation of the stochastic process for any given pair of \( \theta_C \) and \( \theta_I \).
All available uncertainty measures come with some apparent advantages and disadvantages. Changes in general macroeconomic variables like output or government expenditure are easily available and might closely mirror agents perceived uncertainty. Exchange rate volatility might be important in the decision of optimal portfolio allocations but it comes most likely with the biggest problem of reverse causality. Sudden inflows or outflows of capital might have a non-neglectable impact on nominal exchange rates.

In the following analysis, two different measures of volatility are used. The first indicator used is the variability of domestic TFP. Changes in total factor productivity are known to be a major driver of macroeconomic fluctuations and hence volatility in TFP might constitute a major factor in the allocation of assets. The second measure is the volatility in investment efficiency, as it will determine uncertainty in the returns to physical capital investment as described by Justiniano and Primiceri (2008) and Justiniano et al. (2010). It is important to note that what ultimately matters is idiosyncratic volatility that is caused by country specific factors and not global volatility that affects all countries in the same way. As global shocks are uninsurable, and hence bilateral flows cannot be used as an insurance mechanism through a reoptimization of portfolios. That is, as volatility increases globally, investors cannot benefit from shifting assets to other countries which is quite similar to a shock in the global rate of return on assets which would have no impact on the portfolio allocation. Therefore the approach suggested by Gourio et al. (2016) and applied by them to stock market returns is used to obtain idiosyncratic volatility measures in this paper. This procedure is similar to the approach in the Capital Asset Pricing Model and assumes that world variables measure aggregate, systematic risk. In the case

Note: Figure 1 shows the Mexican capital flows relative to GDP from 1980 to 2014. Capital inflows by foreigners are shown in blue and capital outflows by domestic persons are shown as the red line, respectively. Shaded periods indicate recessions of the Mexican economy as defined by the OECD. The data is quarterly and ranges from 1980Q1 to 2014Q4.
of TFP volatility, the squared Mexican TFP is regressed on the squared US TFP as an approximation for global volatility in TFP\(^5\)
\[
\left( \hat{\alpha}_{t}^{MX} \right)^{2} = \alpha^{MX} + \beta^{MX} \left( \hat{\alpha}_{t}^{US} \right)^{2} + \xi_{t}^{MX}
\]  
(3)

where \(\hat{\alpha}_{t}^{MX}\) is the log-deviation from the quadratic trend of Mexican TFP at time \(t\) and \(\hat{\alpha}_{t}^{US}\) is the log-deviation from the quadratic trend of US TFP at time \(t\). The OLS regression coefficients are denoted by \(\alpha^{MX}\) and \(\beta^{MX}\), respectively. Then the idiosyncratic component of volatility can be recovered as the OLS constant \(\alpha^{MX}\) and the sum of error terms \(\xi_{t}^{MX}\) as
\[
\sigma_{t}^{MX} = \frac{1}{1 + \tau} \sum_{t = t' - \tau}^{t} \left( \alpha^{MX} + \xi_{t}^{MX} \right)
\]  
(4)

and the US component as
\[
\sigma_{t}^{US} = \frac{1}{1 + \tau} \sum_{t = t' - \tau}^{t} \beta^{MX} \left( \hat{\alpha}_{t}^{US} \right)^{2}
\]  
(5)

where \(t'\) denotes the last period of the rolling time window and \(\tau\) corresponds to the length of the rolling time window, which is set to a period of 20 quarters. The idiosyncratic volatility component for Mexico is then set in relation to the US volatility by calculating the difference between both volatility series. The same procedure is used to construct the idiosyncratic volatility of the investment efficiency series.

### 2.5 Empirical Regularities of Volatility and Capital Flows in Mexico

We now document some empirical regularities of TFP and investment efficiency volatility and capital flows in Mexico. Figure 2 shows the contemporaneous correlations of idiosyncratic TFP and investment efficiency volatility with capital inflows and outflows for different values of \(\tau\). Capital inflows are strongly negatively correlated with TFP and investment efficiency volatility for all values of \(\tau\). For capital outflows the correlation is positive as expected but much lower. For comparison the dashed-dotted blue line shows the correlation of a simple moving variance estimate for the same values of \(\tau\) constructed as the difference between Mexican and US variance over a moving window. Clearly the difference in the moving variance is characterized by a relatively low correlation of volatility and capital flows as it does not clearly distinguish between Mexican and US volatility. For capital outflows the moving variance might even indicate a negative relationship, further showing the need for a decomposition of volatility into country specific and global components. Again, the simple measure of a moving volatility is not able to produce any significant cross-correlations.

Figure 3 shows the cross-correlation of capital inflows with TFP and investment efficiency

\(^5\)Approximating global variables by the US is not only justified as the US is the largest world economy, but also that the US is by far the largest trading partner of Mexico.
volatility for different leads and lags in the upper panel and for capital outflows in the lower panel. The idiosyncratic TFP and investment efficiency volatility is negatively correlated with capital inflows and positively correlated with capital outflows at lag zero. For the correlation of TFP and investment efficiency with inflows it becomes apparent that correlations vary strongly for different lags or leads. As the overall correlation of TFP and investment efficiency is much lower for outflows now clear pattern emerges for different lags or leads.

Due to the change of key characteristics of the data it is self-evident to split the sample into two subperiods and analyze both separately. The first sample period will consist of quarterly data from 1980 to 1999 that includes major episodes of volatility for the Mexican economy like the debt crises of the 1980’s and the 1994 Peso crisis. The second sample will include the period 2000 to 2014, which is characterized by a relatively stable behavior of macroeconomic variables. Table 1 shows the standard deviations of the main macroeconomic variables that are used in the structural estimation. The differential of the Mexican and US data series is characterized by high amounts of volatility in output and inflation in the 1980’s and a subsequent turn to more moderate inflation and growth figures especially after the implementation of economic reforms including the introduction of the New Mexican Peso in the 1990’s. These patterns are especially pronounced in the differential between Mexican and US interest rates. For the period 1980 to 1999 the standard deviation is high with 16.13 and falls to 0.96 for the period 2000 to 2014. The idiosyncratic TFP and IE volatility series relative to the US show a similar pattern, where the second period shows less variation then the sample comprising 1980 to 1999. Both the standard deviation of capital inflows by foreigners as well as capital outflows by domestic agents show a decrease in the second sample period. Variability in the differential of the consumer price index as measured by the standard deviation decreased from 7.79 for the period 1980 to 1999 to only 1.21 for the period 2000 to 2014.

<table>
<thead>
<tr>
<th>Table 1</th>
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</thead>
</table>

| Standard Deviations of Macroeconomic Variables |

<table>
<thead>
<tr>
<th>Interest Rate Diff</th>
<th>12.22</th>
<th>16.13</th>
<th>0.96</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatility TFP</td>
<td>1.33</td>
<td>1.39</td>
<td>1.24</td>
</tr>
<tr>
<td>Volatility IE</td>
<td>2.01</td>
<td>2.17</td>
<td>1.65</td>
</tr>
<tr>
<td>Inflows</td>
<td>14.73</td>
<td>17.51</td>
<td>9.41</td>
</tr>
<tr>
<td>Outflows</td>
<td>11.34</td>
<td>12.88</td>
<td>8.83</td>
</tr>
<tr>
<td>ΔGDP Diff</td>
<td>1.29</td>
<td>1.53</td>
<td>0.79</td>
</tr>
<tr>
<td>ΔCPI Diff</td>
<td>7.03</td>
<td>7.79</td>
<td>1.21</td>
</tr>
</tbody>
</table>

Note: Table 1 shows standard deviations of the data for the whole sample and the two subperiods.

Table 2 shows the correlations of the major economic variables of interest. Striking is the strong negative correlation between capital inflows by foreigners and capital outflows by domestic agents. That is in periods of high capital inflows by foreigners, domestic agents repatriate assets from the foreign country back home so that capital outflows turn negative. Also as expected, capital inflows show a positive correlation with the differential
in output growth rates and a negative correlation with the inflation differential between Mexico and the US.

**Table 2**
Correlations of Macroeconomic Variables

<table>
<thead>
<tr>
<th></th>
<th>Interest Rate Diff</th>
<th>Volatility TFP</th>
<th>Volatility IE</th>
<th>Inflows</th>
<th>Outflows</th>
<th>ΔGDP Diff</th>
<th>ΔCPI Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest Rate Diff</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volatility TFP</td>
<td>-0.03</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volatility IE</td>
<td>-0.01</td>
<td>0.16</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflows</td>
<td>0.04</td>
<td>-0.36</td>
<td>-0.20</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outflows</td>
<td>-0.02</td>
<td>0.08</td>
<td>0.03</td>
<td>-0.46</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔGDP Diff</td>
<td>-0.07</td>
<td>0.08</td>
<td>0.15</td>
<td>0.25</td>
<td>-0.02</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>ΔCPI Diff</td>
<td>0.15</td>
<td>-0.17</td>
<td>-0.30</td>
<td>-0.15</td>
<td>-0.01</td>
<td>-0.42</td>
<td>1.00</td>
</tr>
</tbody>
</table>

*Note: Table 2 shows the correlations of the main variables used in the structural estimation for the whole sample period from 1980 to 2014. Boldfaced values are significant.*

Table 3 shows the contemporaneous correlations of capital inflows by foreigners and capital outflows by domestic agents with idiosyncratic TFP and investment efficiency volatility of Mexico relative to the US. Both TFP and investment efficiency volatility seem to have a higher correlation with capital inflows than with capital outflows as is also visible in Figure 3. Correlations with capital inflows range from -0.31 for TFP volatility in the period 2000 to 2014 to -0.51 for TFP volatility in the period 1980 to 1999. Correlations of capital inflows with investment efficiency volatility is slightly lower with -0.40 for the period 1980 to 1999 and even slightly, but non-significantly positive for the period 2000-2014. For capital outflows, correlations range from 0.06 for the period 1980 to 1999 to 0.20 for the period 2000 to 2014 in the case of TFP volatility. For capital outflows and investment efficiency volatility only the period 2000 to 2014 is noteworthy to mention with a correlation of 0.14.

**Table 3**
Correlations of Capital Flows and Volatility

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Volatility TFP/Volatility IE</td>
<td>0.16</td>
<td>0.15</td>
<td>0.00</td>
</tr>
<tr>
<td>Inflows/Outflows</td>
<td>-0.46</td>
<td>-0.37</td>
<td>-0.58</td>
</tr>
<tr>
<td>Inflows/Volatility TFP</td>
<td>-0.36</td>
<td>-0.51</td>
<td>-0.31</td>
</tr>
<tr>
<td>Outflows/Volatility TFP</td>
<td>0.08</td>
<td>0.06</td>
<td>0.20</td>
</tr>
<tr>
<td>Inflows/Volatility IE</td>
<td>-0.20</td>
<td>-0.40</td>
<td>0.22</td>
</tr>
<tr>
<td>Outflows/Volatility IE</td>
<td>0.03</td>
<td>-0.01</td>
<td>0.14</td>
</tr>
</tbody>
</table>

*Note: Table 3 shows the contemporaneous correlations of capital inflows and outflows with idiosyncratic TFP and investment efficiency volatility. τ is set to 20. Boldfaced values are significant.*
Note: Figure 2 shows the contemporaneous correlation of Mexican capital inflows and the volatility of TFP and IE for different values of $\tau$ in the upper panel. The lower panel shows the contemporaneous correlation of Mexican capital outflows and the volatility of TFP and IE for different values of $\tau$. The moving volatility is shown as the dashed-dotted blue line. The 5 and 95 percent confidence bands of the correlation are the shaded area. The data is quarterly and ranges from 1980Q1 to 2014Q4.
Figure 3
Cross-Correlations of Mexican Gross Capital Flows and Idiosyncratic Volatility

Note: Figure 3 shows the cross-correlation of Mexican capital inflows and the volatility of TFP and IE for different lags in the upper panel. The lower panel shows the correlation of Mexican capital outflows and the volatility of TFP and IE for different lags. \( \tau \) is set to 20. The moving volatility is shown as the dashed-dotted blue line. The 5 and 95 percent confidence bands of the cross-correlation are the shaded area. The data is quarterly and ranges from 1980Q1 to 2014Q4.
3 An Open Economy DSGE Model

The correlations obtained in the previous sections are unconditional and hence cannot identify the role of volatility shocks on gross flows. To identify the effect and contribution of TFP and IE volatility shocks, we use a structural VAR (SVAR). The SVAR allows us to identify shocks without imposing very strong restrictions on the data. However, identification needs to be disciplined by a theoretical model of capital flows and volatility shocks. The model is used to derive robust restrictions for the SVAR and allows us to develop the economic intuition behind the mechanisms at work.

3.1 The Model

The model is a real two-country international business cycle model with equity holdings as described in Coeurdacier and Rey (2013) which is similar to Coeurdacier et al. (2010). The model is only extended to include stochastic volatility processes as in Fernandez-Villaverde et al. (2011) for the exogenous variables which are total factor productivity \( a_t \) and an investment efficiency term \( \chi_t \). A two-country model is used to explicitly model not only the capital allocations and flows of the home country but also of the foreign country. This is necessary to get a complete look at capital inflows and outflows for the home country as capital inflows to the home country consist of repatriation of capital held by country 1 residents in country 2 stocks and investment by country 2 agents in country 1 stocks. In the remainder home variables are indexed by 1 and foreign variables are indexed by 2.

Representative households maximize life-time utility of the form

\[
E_0 \left[ \sum_{t=0}^{\infty} \beta^t \left( \frac{c_{1t}^{1-\sigma} - l_{1t}^{1+\omega}}{1 - \sigma \omega} \right) \right]
\]

where \( \omega \) is the inverse of the Frisch elasticity of labor supply with \( \omega > 0 \) and \( \sigma \) is the relative risk aversion parameter of the households. Further, \( C_{i,t} \) is consumption and \( l_{i,t} \) is labor supply by the households in country \( i \), respectively. Consumption \( C_{i,t} \) is a composite good consisting of country 1 and country 2 goods for \( i = 1, 2 \) and \( j \neq i \)

\[
C_{i,t} = \theta C_{c_i} \left( c_{i,t}^{\frac{1}{\phi C}} \right)^{\phi C - 1} + (1 - \theta C) \left( c_{j,t}^{\frac{1}{\phi C}} \right)^{\phi C - 1} \]

where \( c_{j,t}^{i} \) is country \( i \)'s consumption of the good produced in country \( j \) and \( \theta C \in (0, 1) \) is the share of the country \( i \) good in composite consumption. Finally, \( \phi C > 0 \) is the elasticity of substitution between country \( i \) and country \( j \) consumption goods. The corresponding

\footnote{For the ease of reading parameters are not indexed with country subscripts in what follows. The baseline version of the model assumes that all parameters are equal across countries except for the domestic share in the input function. However, later to verify robustness the parameters are allowed to vary between countries.}
consumption price index for \( i = 1, 2 \) and \( j \neq i \) is then

\[
P_{C,i}^t = \left[ \theta_C \left( p_{i,t} \right)^{1-\phi_C} + (1 - \theta_C) \left( p_{j,t} \right)^{1-\phi_C} \right]^{\frac{1}{1-\phi_C}}.
\] (8)

where \( p_{i,t} \) and \( p_{j,t} \) are the prices of country \( i \) and country \( j \) goods, respectively.

### 3.1.1 Technologies and Capital Accumulation

The production function follows the standard Cobb-Douglas form with the capital share \( \alpha \in (0, 1) \) and \( a_{i,t} \) represents total factor productivity and is exogenously determined and is subject to a stochastic volatility shock so that output for \( i = 1, 2 \) is

\[
y_{i,t} = a_{i,t} k_{i,t}^{\alpha} l_{i,t}^{1-\alpha}. \tag{9}
\]

Capital follows the law of motion for \( i = 1, 2 \)

\[
k_{i,t+1} = (1 - \delta) k_{i,t} + \chi_{i,t} I_{i,t} \tag{10}
\]

where \( \delta \in (0, 1) \) is the depreciation rate of capital and \( I_{i,t} \) is gross investment by country \( i \). \( \chi_{i,t} \) denotes the stochastic investment efficiency term that is subject to stochastic volatility.

Gross investment \( I_{i,t} \) is generated using country 1 and country 2 inputs so that for \( i = 1, 2 \) and \( j \neq i \)

\[
I_{i,t} = \left[ \theta_I \frac{1}{\eta_I} \left( i_{j,t} \right)^{\frac{\phi_I - 1}{\eta_I}} + (1 - \theta_I) \frac{1}{\eta_I} \left( i_{j,t} \right)^{\frac{\phi_I - 1}{\eta_I}} \right]^{\frac{\phi_I}{\phi_I - 1}} \tag{11}
\]

where \( i_{j,t} \) is the amount of good \( j \) used for investment in country \( i \) and \( \theta_I \in (0, 1) \) is the share of domestic components in investment spending and \( \phi_I > 0 \) is the substitution elasticity between country 1 and country 2 investment goods.\(^7\) The corresponding investment price index \( P_{I,i}^t \) for \( i = 1, 2 \) and \( j \neq i \) is then

\[
P_{I,i}^t = \left[ \theta_I \left( p_{i,t} \right)^{1-\phi_I} + (1 - \theta_I) \left( p_{j,t} \right)^{1-\phi_I} \right]^{\frac{1}{1-\phi_I}}. \tag{12}
\]

where \( p_{i,t} \) and \( p_{j,t} \) are the prices of country \( i \) and country \( j \) goods, respectively.

### 3.1.2 Firms’ Decision

As the production function is of standard Cobb-Douglas form, workers receive a share \( 1 - \alpha \) of output in each country \( i = 1, 2 \) as a wage \( w_{i,t} \)

\[
w_{i,t} = (1 - \alpha) p_{i,t} y_{i,t} \tag{13}
\]

\(^7\)For simplicity \( \theta_C = \theta_I \) and \( \phi = \phi_I \) in the following. However, one can easily allow for different input shares and substitution elasticities between consumption and investment.
and shareholder receive a share $\alpha$ of country $i$ output net of physical investment as a dividend $d_{i,t}$ so that for $i = 1, 2$

$$d_{i,t} = \alpha p_{i,t} y_{i,t} - P^I_{i,t} I_{i,t}. \quad (14)$$

Then follow the first-order conditions for $i = 1, 2$

$$P^I_{i,t} = \beta \mathbb{E}_t \left[ \left( \frac{C_{i,t+1}}{C_i} \right)^{-\phi} \left( \frac{p^C_{i,t}}{p^C_{i,t+1}} \right) x_{i,t} \left[ p_{i,t+1} a_{i,t+1} \alpha k_{i,t+1}^{-1} \right] \right]. \quad (15)$$

Intratemporal allocations for investment goods for $i = 1, 2$ and $j \neq i$ follow from the firm’s cost minimization problem as

$$i^I_{i,t} = \theta I \left( \frac{p_{i,t}}{P^I_{i,t}} \right)^{\phi_I} I_{i,t} \quad (16)$$

and

$$i^I_{j,t} = (1 - \theta_I) \left( \frac{p_{j,t}}{P^I_{i,t}} \right)^{\phi_I} I_{i,t}. \quad (17)$$

### 3.1.3 Financial Markets and Instantaneous Budget Constraint

International trade occurs in stocks. Stocks issued by country $i$’s firm grant a right to the dividends $d_{i,t}$ i.e. a share of country $i$ output. The budget constraint at date $t$ for country $i = 1, 2$ and $j \neq i$ becomes

$$P^C_{i,t} C_{i,t} + p_{i,t}^S S^i_{i,t+1} + p_{i,t}^S S^j_{j,t+1} = w_{i,t} I_{i,t} + \left( d_{i,t} + p_{i,t}^S \right) S^i_{i,t} + \left( d_{j,t} + p_{j,t}^S \right) S^j_{j,t} \quad (18)$$

where $p_{i,t}^S$ is the price of stock $i$ and $S^i_{j,t}$ denotes the holdings of country $i$ of country $j$ stocks at time $t$.

### 3.1.4 Household Decisions and Market Clearing Conditions

Households in each country choose consumption and labor allocations to maximize lifetime utility. The first order conditions for the optimal allocation of consumption spending across goods for $i = 1, 2$ and $j = 1, 2$ implies

$$c^I_{i,t} = \theta_C \left( \frac{p_{i,t}}{P^C_{i,t}} \right)^{\phi_C} C_{i,t} \quad (19)$$

$$c^I_{j,t} = (1 - \theta_C) \left( \frac{p_{j,t}}{P^C_{i,t}} \right)^{\phi_C} C_{i,t}. \quad (20)$$
The labor supply decision for $i = 1, 2$ depends on the inverse of the Frisch elasticity of labor supply $\omega$

$$l_{i,t}^\omega = \left(\frac{w_{i,t}}{P_{j,t}}\right) C_{i,t}^{-\sigma}. \quad (21)$$

The Euler equations with respect to country 1 and country 2 stocks for $i = 1, 2$ and $j = 1, 2$ are then

$$1 = \mathbb{E}_t \beta \left[ \left( \frac{C_{i,t+1}}{C_{i,t}} \right)^{-\sigma} \frac{p^C_{i,t+1}}{p^C_{i,t}} \right] R^S_{j,t+1} \quad (22)$$

where

$$R^S_{j,t+1} = \frac{p^S_{j,t+1} + d_{j,t+1}}{p^S_{j,t}} \quad (23)$$

are the gross returns of stocks between period $t$ and $t+1$. Market clearing in goods markets requires

$$c^1_{1,t} + c^2_{1,t} + i^1_{1,t} + i^2_{1,t} = y_{1,t} \quad (24)$$
$$c^1_{2,t} + c^2_{2,t} + i^1_{2,t} + i^2_{2,t} = y_{2,t} \quad (25)$$

and market clearing in stock markets requires that country 1 stocks are either held by country 1 or by country 2. In the same way country 2 stocks are either held country 1 or by country 2 so that

$$S^1_{1,t} + S^2_{1,t} = S^1_{2,t} + S^2_{2,t} = 1 \quad (26)$$

where stocks are normalized to one.

### 3.2 Portfolio Allocations

A major feature of the model is the dynamic allocation of assets and the resulting gross capital flows after a stochastic volatility shock in TFP and investment efficiency. Tille and van Wincoop (2010) provide a method of solving the portfolio allocation problem in a two-country economy using an iterative numerical algorithm. In a series of papers Devereux and Sutherland (2009), Devereux and Sutherland (2010), and Devereux and Sutherland (2011) develop an approach that allows for the allocation of any number of arbitrary assets in an open economy model with complete or incomplete markets.\footnote{See the Appendix for a short explanation of the zero-order asset portfolio and the first-order asset dynamics.} The calculated steady states and portfolio dynamics by Devereux and Sutherland (2010) and Devereux and Sutherland (2011) can be shown to be identical to those obtained by Tille...
and van Wincoop (2010) for any given model. However, their approach allows for the fast analytical computation of impulse responses in domestic and foreign stock holdings for the home country after an arbitrary shock. The main advantage of the Devereux and Sutherland (2011) approach is in the wide applicability to any class of DSGE models.\(^9\) The algorithm uses a second-order approximation of the portfolio optimality conditions to determine the steady state and a third-order approximation to determine the first-order asset dynamics.\(^10\)

This paper especially uses a domestic and a foreign stock and an open economy two-country model. Where the gross returns on domestic and foreign stocks are given by \(R^S_{1,t+1}\) and \(R^S_{2,t+1}\) as determined in Equations (23).

Capital market clearing conditions are used to determine the asset allocations in country 2 and the resulting capital flows after a stochastic volatility shock. Capital inflows by foreigners and capital outflows by domestic persons for country \(i = 1, 2\) and \(j \neq i\) can then be defined as

\[
\text{Inflows}_{i,t} = \Delta S^i_{j,t},
\]

\[
\text{Outflows}_{i,t} = \Delta S^i_{j,t},
\]

where \(\Delta S^i_{j,t}\) denotes the change in the country \(i\) stock held by country \(j\) at time \(t\) that is flowing into country \(i\). Such that a positive value for \(\text{Inflows}_{i,t}\) indicates a flow of capital from country \(j\) into \(i\) by foreign agents whereas a negative value indicates a flow from country \(i\) back to \(j\). In the same way a positive value for \(\text{Outflows}_{i,t}\) indicates a flow of capital from \(i\) to \(j\) by domestic agents and a negative value in turn indicates a flow from \(j\) back to \(i\). The definition of capital inflows and capital outflows is therefore the same in the DSGE model and the empirical part allowing for an easy comparison of the results.

### 3.3 Shock Structure

Finally, the shocks in the model are structured to allow for stochastic volatility in total factor productivity and the investment efficiency in a similar fashion as in Fernandez-Villaverde et al. (2011). Shocks to the volatility of total factor productivity and the investment efficiency might a priori be seen as a major force in agents decision of the allocation of assets. Additionally, shocks in the volatility of the investment efficiency might make it harder for households to make informed decisions about future relative prices of investment and consumption and thus lead to an outflow of capital.

The endogenous variable in the system is described by a constant term and the exogenous shock element. In the case of the process for total factor productivity \(a_{i,t}\) this becomes for

---


\(^10\)Their approximation is therefore in line with Samuelson (1970) who states that for \(n\)-th order accuracy a \(n + 2\) order approximation of the portfolio problem is required.
\( i = 1, 2 \)

\[ a_{i,t} = \bar{a}_i + \epsilon_{a,i,t} \tag{29} \]

where \( \bar{a}_i \) denotes the mean total factor productivity in country \( i \) and \( \epsilon_{a,i,t} \) denotes a shock originating in country \( i \), respectively. The shocks to total factor productivity of country \( i = 1, 2 \) are then as follows

\[ \epsilon_{a,i,t} = \rho_{a_i} \epsilon_{a,i,t-1} + e^{\sigma_{a,i}} u_{a,i,t} \tag{30} \]

where \( u_{a,i,t} \) is a normally distributed random variable with mean zero and unit variance and can be considered a shock in levels to the corresponding variable

\[ u_{a,i,t} \sim N(0,1). \tag{31} \]

The variable \( \sigma_{a,i,t} \) is not assumed to be constant but instead follows an AR(1) process so that the volatility part then follows for \( i = 1, 2 \)

\[ \sigma_{a,i,t} = \left(1 - \rho_{\sigma_{a_i}}\right) \sigma_{a_i} + \rho_{\sigma_{a_i}} \sigma_{a,i,t-1} + \eta_{a_i} u_{\sigma_{a,i,t}} \tag{32} \]

where \( u_{\sigma_{a,i,t}} \) is again a normally distributed random variable with mean zero and unit variance and causes changes in the volatility

\[ u_{\sigma_{a,i,t}} \sim N(0,1). \tag{33} \]

The parameters \( \sigma_{a_i} \) and \( \eta_{a_i} \) in Equation (32) affect the degree of mean volatility and stochastic volatility in total factor productivity. A high \( \sigma_{a_i} \) causes a high degree of mean volatility and a high \( \eta_{a_i} \) causes a high degree of stochastic volatility in the process.\(^{11}\)

The remaining processes for investment efficiency \( \chi_{i,t} \) can then be analogously written as

\[ \chi_{i,t} = \bar{\chi}_i + \epsilon_{\chi,i,t} \tag{34} \]

and the shocks \( \epsilon_{\chi,i,t} \) as

\[ \epsilon_{\chi,i,t} = \rho_{\chi_i} \epsilon_{\chi,i,t-1} + e^{\sigma_{\chi_i}} u_{\chi,i,t} \tag{35} \]

and shocks follow a normal distribution with mean zero and unit variance

\[ u_{\chi,i,t} \sim N(0,1). \tag{36} \]

\(^{11}\)It is for simplicity assumed that the error terms \( u_t \) and \( u_{\sigma_t} \) are uncorrelated. However, Fernandez-Villaverde et al. (2011) argue that innovations to levels and volatility can be highly correlated.
Again the AR(1) process for $\sigma_{X_i,t}$ follows as

$$
\sigma_{X_i,t} = \left(1 - \rho \sigma_{X_i}\right) \sigma_{X_i} + \rho \sigma_{X_i,t-1} + \eta_{X_i} \epsilon_{X_i,t}
$$

with a normally distributed error term with mean zero and unit variance

$$
\eta_{X_i} \epsilon_{X_i,t} \sim N(0,1).
$$

The parameterization of the shocks poses a major burden as the stochastic processes in Equation (30) and Equation (32) are driven by two innovations, one innovation to levels and one innovation to volatility. The parameters are hence estimated using Bayesian estimation in the form of a particle filter i.e. a sequential Monte Carlo algorithm as used by Fernandez-Villaverde et al. (2011). Their approach proves convenient as it provides parameter estimates for a stochastic process which can then be used in a DSGE model to generate stochastic volatility. It is therefore superior to a GARCH approach which does not clearly distinguish between innovations in levels and innovations in volatility. Table 4 shows the used priors of the parameters of the shocks. The priors for $\rho$ and $\rho \sigma$ are assumed to be beta distributed with a mean of 0.75 and standard deviation of 0.02 and 0.05, respectively. This ensures that the prior values are bounded between zero and one.\(^{12}\) The chosen mean is reflecting the fact that the underlying data is quarterly data and that the data shows some persistence in the shocks. The priors of $\sigma$ and $\eta$ follow a normal and truncated normal distribution to ensure a positive posterior for $\eta$. The prior for $\eta$ is set to a conservative level of 0.5 implying an amplification of the stochastic shock by around 1.7. The standard deviation of 0.3 ensures some flexibility for the estimation of the posteriors. The priors for the parameter $\sigma$ that controls for mean volatility is derived from Mexican and US data from total factor productivity and investment efficiency. The value of -6.46 for Mexican TFP reflects the fact that Mexico as the home country shows about twice the degree of mean volatility in the data than the US as the foreign country with a value of -7.40. A similar pattern is observable for investment efficiency with a value of -1.88 for Mexico and -8.37 for the US.\(^{13}\) The subsequently used Metropolis-Hastings algorithm is run for 20000 iterations with 2000 particles or simulations per iteration with the first 5000 iterations being discarded as a burn-in period until equilibrium is reached.\(^{14}\) Table 5 shows the posterior distribution of the Bayesian estimation with the 2.5 and 97.5 percent confidence sets in parenthesis for the TFP and investment efficiency series. The posterior estimate for $\sigma$ reflects the fact that the US has a lower volatility in both TFP and investment efficiency.\(^{15}\)

\(^{12}\)This implies for the parameters of the beta distribution using the mean $\mu$ and variance $\sigma^2$ following $a = \left(\frac{1 - \mu}{\sigma^2}\right) \mu^2 - \mu$ and $b = \mu - a$ a value of $a = 350.81$ and $b = 116.94$ for $\sigma^2 = 0.02$ and $a = 55.5$ and $b = 18.5$ for $\sigma^2 = 0.05$, respectively.

\(^{13}\)In the model Mexican and US volatility shocks are assumed to be uncorrelated as what matters for the allocation of assets is the relative volatility.

\(^{14}\)The low dimensionality guarantees that the equilibrium is reached rather quickly and that 20000 iterations are sufficient to be confident to be in equilibrium.
TABLE 4
Priors of Shock Parameters

<table>
<thead>
<tr>
<th></th>
<th>TFP Mexico</th>
<th>TFP US</th>
<th>IE Mexico</th>
<th>IE US</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$</td>
<td>$B(0.75, 0.02)$</td>
<td>$B(0.75, 0.02)$</td>
<td>$B(0.75, 0.02)$</td>
<td>$B(0.75, 0.02)$</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>$N(-6.46, 0.4)$</td>
<td>$N(-7.40, 0.4)$</td>
<td>$N(-1.88, 0.4)$</td>
<td>$N(-8.37, 0.4)$</td>
</tr>
<tr>
<td>$\rho_{\sigma}$</td>
<td>$B(0.75, 0.05)$</td>
<td>$B(0.75, 0.05)$</td>
<td>$B(0.75, 0.05)$</td>
<td>$B(0.75, 0.05)$</td>
</tr>
<tr>
<td>$\eta$</td>
<td>$N^+(0.50, 0.3)$</td>
<td>$N^+(0.50, 0.3)$</td>
<td>$N^+(0.50, 0.3)$</td>
<td>$N^+(0.50, 0.3)$</td>
</tr>
</tbody>
</table>

Note: Table 4 shows the assumed priors of the parameter values of the stochastic shocks. Where the mean and standard deviation are in parentheses.

TABLE 5
Posteros of Shock Parameters

<table>
<thead>
<tr>
<th></th>
<th>TFP Mexico</th>
<th>TFP US</th>
<th>IE Mexico</th>
<th>IE US</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$</td>
<td>0.78</td>
<td>0.83</td>
<td>0.89</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>(0.75,0.81)</td>
<td>(0.80,0.86)</td>
<td>(0.87,0.91)</td>
<td>(0.78,0.84)</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>-4.12</td>
<td>-5.03</td>
<td>-3.30</td>
<td>-5.44</td>
</tr>
<tr>
<td></td>
<td>(-4.25,-3.97)</td>
<td>(-5.24,-4.81)</td>
<td>(-3.64,-2.99)</td>
<td>(-5.74,-5.00)</td>
</tr>
<tr>
<td>$\rho_{\sigma}$</td>
<td>0.74</td>
<td>0.77</td>
<td>0.81</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>(0.62,0.83)</td>
<td>(0.66,0.85)</td>
<td>(0.73,0.88)</td>
<td>(0.68,0.85)</td>
</tr>
<tr>
<td>$\eta$</td>
<td>0.09</td>
<td>0.25</td>
<td>0.33</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>(0.01,0.25)</td>
<td>(0.16,0.38)</td>
<td>(0.24,0.46)</td>
<td>(0.29,0.58)</td>
</tr>
</tbody>
</table>

Note: Table 5 shows the median of the posterior distribution of the parameter values of the stochastic shocks including the 2.5 and 97.5 percent confidence sets.

3.4 Solution Techniques

As we are interested in the effects of shocks to stochastic volatility, a higher order approximation is required than the usual approach of approximating the policy function up to second-order. In this case a third-order approximation of the policy functions is needed in order for the exogenous volatility shocks to have an independent effect on the endogenous variables. Otherwise volatility shocks would have only an indirect effect through the levels shock. Higher order perturbation methods e.g. Taylor series expansions around the steady state can suffer from explosive sample paths. Andreasen et al. (2017) provide an approach for third-order perturbation method approximations to avoid generating these explosive sample paths. This is done using pruned state space technique. All generated impulse responses in this paper therefore use the pruned state space technique to calculate higher order approximations. The model Equations (7) to (26) and the shocks structure in Equations (29) to (37) solve the model.

3.5 Parameters

The model is parameterized in tradition of the standard international business cycle literature as in Backus et al. (1994) and in particular Coeurdacier et al. (2010). Table 6 shows the parameter values for Mexico as the home country and the US as the foreign country. As the model is used as a foundation for a structural VAR that uses quarterly data, the
discount factor $\beta$ is set to 0.99, thus corresponding to a yearly value of 0.96. The risk aversion $\sigma$ is fixed at 2 following standard literature in international macroeconomics. The capital share in the production function $\alpha$ is set at the conventional level of 0.40 for both countries. The inverse of the Frisch elasticity of labor supply $\omega$ is set to 0.40 for Mexico and the US and is in the middle of estimates by Chetty (2012). The substitutability between domestic and foreign consumption goods in the CES production function $\phi_C$ is assumed to be 2 for both countries. The model assumes a domestic share $\theta_C$ in the input function of 0.60 for Mexico as the home country and 0.85 for the US as the foreign country which is in line with empirical observations for Mexico and the US.

To verify the robustness of the results with respect to different parameters, random parameters are drawn from a uniform distribution. A uniform distribution is chosen to best model the uninformative prior. Table 6 shows the support of all parameter draws. The mean of the range is always chosen to coincide with the baseline parameters in Table 6. The estimated posterior distribution for the stochastic processes is then used to draw parameter values for the TFP and investment efficiency processes. $\rho$ and $\rho_e$ are both drawn from a beta distribution to obtain bounded values between 0 and 1. Further $\sigma$ is drawn from a normal distribution and $\eta$ is drawn from a truncated normal distribution to ensure positive values. This allows to incorporate the uncertainty of the parameter estimate into the DSGE model.

### Table 6
DSGE Model Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Baseline</th>
<th>Monte Carlo Prior</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>Capital Share</td>
<td>0.40</td>
<td>U (0.35, 0.45)</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Discount Factor</td>
<td>0.99</td>
<td>U (0.98, 0.999)</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Inverse of Frisch Elasticity</td>
<td>0.40</td>
<td>U (0.30, 0.50)</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Capital Depreciation Rate</td>
<td>0.025</td>
<td>U (0.02, 0.03)</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Risk Aversion</td>
<td>2.00</td>
<td>U (1.50, 2.50)</td>
</tr>
<tr>
<td>$\theta_C$</td>
<td>Domestic Share in Input Function - Consumption</td>
<td>0.60</td>
<td>U (0.50, 0.70)</td>
</tr>
<tr>
<td>$\theta_I$</td>
<td>Domestic Share in Input Function - Investment</td>
<td>0.60</td>
<td>U (0.50, 0.70)</td>
</tr>
<tr>
<td>$\phi_C$</td>
<td>Substitutability between Goods - Consumption</td>
<td>2.00</td>
<td>U (1.50, 2.50)</td>
</tr>
<tr>
<td>$\phi_I$</td>
<td>Substitutability between Goods - Investment</td>
<td>2.00</td>
<td>U (1.50, 2.50)</td>
</tr>
</tbody>
</table>

Note: Table 6 shows the parameter values in the DSGE model for Mexico as the home country and the US as the foreign country.

### 3.6 Monte Carlo Zero-Order Asset Portfolios

To verify the robustness of the steady state portfolio allocation simulated using the Devereux and Sutherland (2011) algorithm, 2500 simulations of the model are performed with uniform random parameter draws. Figure 4 shows the histogram of simulated steady state estimates of asset portfolios with the median estimate indicated by the black line and the estimate of the baseline estimation shown by the blue line. Due to the structure of the error terms the zero-order asset portfolios show some skewness in their distribution.
Figure 4: Monte Carlo Zero-Order Asset Portfolios

Note: Figure 4 shows the histogram of zero-order asset portfolios after 2500 simulations of the model. The median estimate is in black. The blue line denotes the results from the baseline version.

3.7 Monte Carlo First-Order Asset Dynamics

A stochastic shock to TFP volatility will have a direct effect on output volatility and therefore on dividend payments to shareholders and returns on equity. Shocks to the investment efficiency will affect the volatility of relative prices between investment and consumption goods and hence will affect capital accumulation. This will then affect output and hence dividends and returns on equity.

Figure 5 shows the impulse responses of a volatility shocks on country 1 capital inflows by foreigners and capital outflows by domestic agents with the 10th and 90th percentile bands. The median and the confidence bands are obtained from 1000 independent parameter draws. The displayed flows are deviations from their steady state value relative to output and are cumulated over the displayed time horizon. The impulse responses after a TFP volatility shock in each country on capital inflows and capital outflows have the expected sign and magnitude. However, only investment efficiency volatility shocks in country 1 have the expected sign. Investment efficiency shocks originating in country 2 behave against the expectation. Figure 6 shows a cross-section of the impulse responses for a country 1 TFP volatility shock on cumulated capital outflows by domestic agents.
Like the zero-order asset portfolios, the impulse responses exhibit some skewness, but are otherwise near normally distributed. Although the results of the Monte Carlo draws are not perfectly normal distributed it still allows us to construct confidence bands for the impulse responses.

**Figure 5**
Impulse Responses DSGE - Capital Flows with Monte Carlo Priors

Note: Figure 5 shows the median impulse responses on capital inflows by foreigners (upper panel) and capital outflows by domestic agents (lower panel) for country 1 in the DSGE model in black and the 10th and 90th percentile bands as the shaded area. The blue line denotes the results from the baseline version.
4 Structural Estimation with Sign and Zero Restrictions

We now apply a structural VAR with combined sign and zero restrictions for the identification of the structural shocks to Mexican capital flow data. The aim of this exercise is to show whether a structural VAR with theoretically derived restrictions is able to reproduce the results from a standard open economy DSGE model. The approach of combined sign and zero restrictions for potentially underidentified models is described by Binning (2013) who applies the derived algorithm to replicate the results by Smets and Wouters (2007). Sign restrictions come with the advantage of providing more flexibility when identifying the shocks as the identifying restrictions are less strict than the traditional way of imposing zero restrictions for the short run or the long run. All what is needed is an assumption of the initial sign of the impulse response either on impact or for a certain time horizon e.g. a positive response of capital outflows to an increase in idiosyncratic volatility for the first four quarters. However, in certain scenarios the long run effect is obvious and can hence serve as an additional identifying restriction. It might hence be justified to assume that a monetary policy shock has no long run impact on GDP growth.
rates as it is predominantly done in the literature. The work by Binning (2013) builds on previous work by Rubio-Ramirez et al. (2010) who develop an algorithm that allows for sign and zero restrictions in exactly identified models. The Binning (2013) approach can therefore be considered as a generalization of the Rubio-Ramirez et al. (2010) approach to allow for underidentified models to be estimated.

4.1 Identifying Restrictions

This paper uses the following identifying restrictions consisting of sign restrictions on impact and zero restrictions for the short and the long run.\(^{15}\) A positive monetary policy shock \(\epsilon^{MP}\) increases the interest rate differential between Mexico and the US and has a negative short run impact on GDP growth rate differentials as well as on inflation differentials. It is further assumed that the monetary shock has no long run impact on GDP growth following neutrality of money theory so that it is justified to impose a zero long run restriction as in Blanchard and Quah (1989) and Christiano et al. (2006). The paper imposes no a priori assumptions of the effect of monetary policy on capital inflows or capital outflows.

The restrictions for volatility shocks on capital outflows and capital inflows are derived from the DSGE model with stochastic volatility shocks for TFP and the investment efficiency. This part thus imposes a positive effect on impact of an idiosyncratic volatility shock on capital outflows by domestic agents and a negative effect on impact for capital inflows by foreigners for both the TFP and investment efficiency volatility shock denoted as \(\epsilon^{VolTFP}\) and \(\epsilon^{VolIE}\), respectively. Let us assume that the TFP volatility shock \(\epsilon^{VolTFP}\) leads to an increase in TFP volatility and that the investment efficiency volatility shocks leads to an increase in investment efficiency volatility.\(^{16}\) These identifying restrictions make sense as a positive volatility shock in TFP and the investment efficiency will increase capital outflows by domestic agents that try to benefit from lower uncertainty in the US and therefore transfer assets from Mexico to the US. In addition, US agents will repatriate assets from Mexico to the US in response to increased Mexican volatility hence leading to negative capital inflows by foreigners.\(^{17}\) To have unique identifying restrictions for the TFP and the investment efficiency shock it is further assumed that the TFP volatility shock has no short run impact on investment efficiency volatility and vice versa.\(^{18}\) This allows to impose a zero short run restriction. Both volatility shocks are assumed to have no effect on the GDP growth differential between Mexico and the US so that a zero long run restriction can additionally be imposed.

\(^{15}\)See Fry and Pagan (2011) for a review on sign restrictions in structural VARs.

\(^{16}\)Leduc and Liu (2016) find that uncertainty shocks are similar to demand shocks in their data and a DSGE model.

\(^{17}\)Coeurdacier et al. (2015) find that capital in many cases flows to developed countries as these countries face lower uncertainty.

\(^{18}\)This assumption is justified by the low correlation between Mexican TFP and investment efficiency volatility. It comes with the huge advantage of unique identification of both shocks due to different restrictions.
A capital inflow shock $\epsilon^{In}$ as well as a capital outflow shock $\epsilon^{Out}$ will both increase TFP and investment efficiency volatility on impact. Capital flow shocks are assumed to have only a short run impact on volatility so that it is possible to impose zero long run restrictions for both types of capital flow shocks on volatility. It seems obvious that excessive capital inflows or capital outflows might temporarily increase idiosyncratic volatility. This might be most obvious when investment efficiency volatility is considered that can react significantly to capital inflows by foreigners and capital outflows by domestic agents. However, it might be more in line with economic theory that a capital inflow or outflow shock has no long run impact on volatility as volatility might eventually returns to its steady state value. The structural estimation does further not impose any a priori restrictions on the cross impact between capital inflow and capital outflow shocks on each other. However, the data might indicate a negative correlation between capital inflows by foreigners and capital outflows by domestic agents as seen in Table 3.

For completeness one can further assume that an aggregate demand shock $\epsilon^{AD}$ has a positive short run impact on the interest rate differential and differential of GDP growth rates as well as inflation differentials between Mexico and the US. It is further assumed that the long run effect on the differential in the GDP growth rate is zero for the aggregate demand shocks which is in line with the common assumptions for long run identification as e.g. in Blanchard and Quah (1989) and Christiano et al. (2006).

Finally, the unidentified shock $\epsilon^{Res}$ is left without any restrictions and is ordered last to catch any unexplained variation. The identifying restrictions of the SVAR are summarized in Table 7 where a + (-) indicates a positive (negative) impact upon the structural shocks $\epsilon$. Whereas 0 indicates no impact and blanks indicate no imposed long run restriction.

**Table 7**  
Identifying Restrictions SVAR - Baseline

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<tr>
<th></th>
<th>$\epsilon^{MP}$</th>
<th>$\epsilon^{VolTFP}$</th>
<th>$\epsilon^{VolIE}$</th>
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<th>$\epsilon^{Out}$</th>
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Note: Table 7 shows all the identifying restrictions for the short and the long run in the SVAR. A + (-) indicates a positive (negative) impact on the structural shocks $\epsilon$. Whereas 0 indicates no impact.
Using standard VAR notation allows to write the VAR using the lag operator as

$$Y_{t+1} = B(L) Y_t + u_{t+1}$$

(39)

and

$$E u_t u_t' = \Sigma$$

(40)

where $\Sigma$ is the covariance matrix of the forecast errors and $L$ is the lag operator so that

$$B(L) = B_1 + B_2 L + \ldots + B_p L^{p-1}$$

(41)

where $p$ is the number of lags of the VAR. Further imposing some structure on the error terms implies

$$u_t = Z \epsilon_t$$

(42)

$$ZZ' = \Sigma$$

(43)

where the $Z$ matrix maps the structural shocks $\epsilon_t$ into the reduced form shocks $u_t$. As $Z$ is not unique there are infinitely many solutions that satisfy equation (43). Some additional economy theory is therefore used to rule out unwanted matrices $Z$. The structural shocks $\epsilon_t$ are assumed to be orthogonal so that

$$\epsilon_t \epsilon_t' = I.$$  

(44)

Using the algorithm provided by Binning (2013) and following the same notation gives for the short run impact matrix $L_0$

$$L_0 = \begin{bmatrix}
+ & X & X & X & X & X & X \\
X & + & 0 & + & + & X & X \\
X & 0 & + & + & + & X & X \\
X & - & - & + & X & X & X \\
X & + & + & X & + & X & X \\
- & X & X & X & X & + & X \\
- & X & X & X & X & + & X
\end{bmatrix}$$

(45)

where a + indicates a positive impact and a − indicates a negative impact, respectively. Unclear impacts are denoted by $X$ and are not restricted so that they can be positive, negative or zero. In this seven variable VAR the ordering is as follows. Interest rate differentials are ordered first, followed by the measure of idiosyncratic TFP volatility and the volatility of the investment efficiency. Capital inflows relative to GDP, and capital outflows relative to GDP follow afterwards as these flows are assumed to be contemporaneously affected by monetary policy and volatility shocks. This is completed by the
differential of GDP growth and the differential of CPI changes that are ordered last so that they will react after each of the variables. The corresponding shocks are a monetary policy shock denoted \( e^{MP} \), an idiosyncratic TFP volatility shock \( e^{Vol_{TFP}} \), an idiosyncratic investment efficiency volatility shock \( e^{Vol_{IE}} \), and capital inflow and capital outflow shocks denoted \( e^{In} \) and \( e^{Out} \) as well as an aggregate demand shock \( e^{AD} \) and an unidentified shock \( e^{Res} \) that will account for all unidentified shocks. For the long run matrix including zero restrictions one then gets after imposing the restrictions

\[
L_\infty = \begin{bmatrix}
X & X & X & X & X & X & X \\
X & X & X & 0 & 0 & X & X \\
X & X & X & 0 & 0 & X & X \\
X & X & X & X & X & X & X \\
X & X & X & X & X & X & X \\
X & X & X & 0 & 0 & X & X \\
X & X & X & X & X & X & X \\
0 & 0 & 0 & X & X & 0 & X \\
X & X & X & X & X & X & X \\
\end{bmatrix}.
\]  

(46)

The short run and the long run matrix in (45) and (46) can then be combined to obtain

\[
f(Z, B) = \begin{bmatrix} L_0 \\ L_\infty \end{bmatrix}
\]  

(47)

where \( L_0 \) is the \( k \times k \) short run impact matrix and \( L_\infty \) is the \( k \times k \) long run impact matrix with \( k \) being the number of variables in the SVAR. A \( k \times 2k \) restriction matrix \( Q \) can then be derived such that

\[
Q_{j} f(Z, B) e_j = 0
\]  

(48)

where \( e_j \) is the \( j \)-th column of a \( k \times k \) identity matrix. The initial impact matrix is obtained as

\[
Z = CQ^*
\]  

(49)

where \( C \) is the lower Cholesky decomposition of the variance-covariance matrix \( \Sigma \) so that \( CC' = \Sigma \) and \( Q^* \) is a randomly drawn orthogonal matrix from a random normal distribution. For each additional draw the Cholesky decomposition \( C \) is then again multiplied by a randomly drawn orthogonal matrix \( Q^* \).

### 4.2 Impulse Responses

The structural VAR using the whole sample period and the two subperiods is estimated with four lags to minimize the BIC and 500 draws of the impact matrix \( Z \) that satisfy the sign restrictions of the impulse responses as imposed in Table 7. Figure 7 shows the impulse responses of capital inflows by foreigners and capital outflows by domestic agents
to a unity shock in idiosyncratic TFP and investment efficiency shocks in the structural VAR. The estimated system is underidentified as there are less than the $k(k-1)/2$ required identifying restrictions. Hence the $Z$ matrix is not unique so that $ZZ' = \Sigma$ can be satisfied by different $Z$ matrices. This in turn leads to a set of possible impulse responses being calculated for each structural shock that is not uniquely identified. The impulse responses in Figure 7 show the median estimate of all 500 draws and the 10th and 90th percentile bands as proposed by Fry and Pagan (2011). By construction, increases in TFP and investment efficiency volatility have a negative short run impact on capital inflows by foreigners and a positive impact on capital outflows by domestic agents. The impact of a idiosyncratic TFP volatility shock on capital inflows comes with a wider confidence band but still allows to conclude that cumulated changes in capital outflows remain negative for most of the 20 periods. The estimated confidence bands for a TFP volatility shock on capital outflows is relatively tight and allow to conclude that the cumulated response remains positive for the whole plotted period of 20 quarters. Shocks to the volatility in investment efficiency decrease capital inflows by foreigners and increase capital outflows by foreigners. In the case of investment efficiency shocks the confidence bands allow to conclude that the impulse responses remain negative for capital inflows and positive for capital outflows throughout the 20 quarters.

4.3 Forecast Error Variance Decomposition

The forecast error variance decomposition of the structural VAR can be seen in Table 8 for the whole sample period and the two subperiods. Using the forecast error variance decomposition allows to judge the relative importance of TFP volatility shocks and investment efficiency volatility shocks on capital inflows and capital outflows. The FEVD confirms that the SVAR is doing a good job when the two subperiods are considered separately. For the period 1980 to 1999 the shock in idiosyncratic TFP volatility can explain about 3 percent of the variation in capital inflows by foreigners. For the same period, shocks to idiosyncratic investment efficiency volatility can account for about 6 percent in capital inflows and about 4 percent in capital outflows by foreigners. For the period 2000 to 2014, however, TFP volatility can explain 6 percent of capital inflow variability. Looking at capital outflows, 3 percent in the variability can be attributed to investment efficiency. Looking at the whole sample the FEVD suggests a tiny effect of TFP and investment efficiency volatility on capital inflows and outflows of between 1 and 3 percent. Overall, this suggests that between 3 to 9 percent in the total variation of capital inflows and capital outflows can be attributed to shocks in volatility, either TFP or investment efficiency.
FIGURE 7
Impulse Responses SVAR - Baseline Restrictions

Note: Figure 7 shows impulse responses of capital inflows and outflows to a unity shock in the structural VAR with sign and zero restrictions for Mexico. The data is quarterly from 1980Q1 to 2014Q4. The median impulse response is shown in black and the 10th and 90th percentiles are in shaded gray. The sample consisting of data from 1980 to 1999 is shown as the red line and the sample from 2000 to 2014 is shown as the blue line.
## Table 8: Forecast Error Variance Decomposition SVAR

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Note: Table 8 shows the Forecast Error Variance Decomposition of the SVAR for the three sample periods at an infinite horizon. The data is quarterly data.
5 Comparison of the DSGE and SVAR Results

We now turn to a comparison of the impulse responses of the DSGE model incorporating stochastic volatility shocks to TFP and investment efficiency and the structural VAR with the same set of shocks.

5.1 Baseline Sign Restrictions

Figure 8 shows the impulse responses from the DSGE model and the SVAR for capital inflows by foreigners and capital outflows by domestic agents after a one standard deviation shock in domestic volatility. The upper half depicts the cumulated impulse responses of capital inflows by foreigners to an idiosyncratic TFP and investment efficiency volatility shock in the DSGE model and to shocks in idiosyncratic TFP and investment efficiency volatility in the SVAR with sign restrictions as in Table 7. The lower half then shows impulse responses for the same shocks on capital outflows by domestic agents estimated by the DSGE model and the SVAR. The slightly negative impact of a TFP volatility shock on capital inflows by foreigners generated by the DSGE model is well within the confidence bands of the SVAR similar to the positive impulse response of a TFP volatility shock on capital outflows by domestic agents.

5.2 Alternative Sign Restrictions

Table 9 shows an alternative set of identifying restrictions that allows for both volatility shocks to have either positive or negative impact on capital inflows and capital outflows. Figure 9 shows the impulse responses for the alternative set of sign restrictions. A TFP volatility shock in the SVAR again produces a slightly negative median impulse response of capital inflows by foreigners and a slightly positive median impulse response for capital outflows by domestic agents. In addition, the investment efficiency shock has a small but negative median impact on capital inflows by foreigners and a small but positive median impact on capital outflows by domestic agents. That implies even without imposing sign restrictions on the impact of a TFP and investment efficiency shock the SVAR is able to produce the expected signs. However, confidence bands are now much larger and well cover a possible positive as well as a negative response of TFP and investment efficiency shocks.

\[^{19}\text{Note that the remaining restrictions are still sufficient to correctly identify the TFP and investment efficiency shock.}\]
Note: Figure 8 shows the impulse responses from the DSGE model and the SVAR to a volatility shock in TFP and the investment efficiency on capital inflows in the upper half and capital outflows in the lower half, respectively. The SVAR impulse responses are the median of all draws for the whole sample period using the baseline restrictions and are shown in black. The 10 and 90 percentile confidence bands of the SVAR are the shaded area. Results for the baseline DSGE model are in blue. Shown are the deviations of capital flows relative to GDP from the steady state.
<table>
<thead>
<tr>
<th></th>
<th>$\epsilon_{MP}$</th>
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<th>$\epsilon_{VolIE}$</th>
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Note: Table 9 shows all the identifying restrictions for the short and the long run in the SVAR. A + (-) indicates a positive (negative) impact on the structural shocks $\epsilon$. Whereas 0 indicates no impact.
Figure 9
Impulse Responses Comparison - Alternative Restrictions

Note: Figure 9 shows the impulse responses from the DSGE model and the SVAR to a volatility shock in TFP and the investment efficiency on capital inflows in the upper half and capital outflows in the lower half, respectively. The SVAR impulse responses are the median of all draws for the whole sample period using the alternative restrictions and are shown in black. The 10 and 90 percentile confidence bands of the SVAR are the shaded area. Results for the baseline DSGE model are in blue. Shown are the deviations of capital flows relative to GDP from the steady state.
6 Conclusion

This paper examined the impact of stochastic volatility shocks on gross capital flows in an emerging market economy using a DSGE model parameterized to Mexican and US data. It derived identifying restrictions for a structural VAR from the impulse responses of the DSGE model. The DSGE model with stochastic volatility shows that shocks to the volatility of TFP and the investment efficiency can have a major impact on asset holdings and first-order asset dynamics i.e. gross capital flows between economies. To rule out any effect of misparameterization of the model, a Monte Carlo prior for the parameters of the model and the stochastic processes was used. Even after allowing for some variation in the parameters, the model is still able to generate the anticipated responses on gross capital flows. The structural VAR for Mexican data was then applied using sign restrictions from the DSGE model and additional zero long run restrictions. The SVAR confirms the significant negative impact of idiosyncratic volatility shocks in TFP and investment efficiency on capital inflows by foreign agents, and a significant positive impact on cumulated changes in capital outflows by domestic agents in an emerging market economy like Mexico. It is important to note that nothing in the setup of the DSGE model restricts its use to developing countries. The general setup can be applied to any country pair being it emerging market economies or developed countries.

A Appendix

A.1 Zero-Order Asset Portfolios

The zero-order or steady state vector of asset holdings \( \tilde{\alpha} \) in the \( n \) asset case can be written as

\[
\tilde{\alpha} = \left[ R_2 \Sigma D_2' R_1 - D_1 R_2 \Sigma R_2' \right]^{-1} R_2 \Sigma D_2' + O(\epsilon) \tag{A1}
\]

where \( \Sigma \) is the \( k \times k \) covariance matrix of the \( k \) exogenous shocks. \( D_1, D_2, R_1, \) and \( R_2 \) can be obtained from the state space solution. \( D_1 \) is in general a scalar containing the first-order decision rule of the wealth shock on consumption differences. \( D_2 \) is in general a \( 1 \times k \) vector containing the first-order decision rules of the \( k \) exogenous shocks on consumption differences. Further, \( R_1 \) is a \( n \times 1 \) vector of the first-order decision rules of the wealth shock on the \( n \) assets. Finally, \( R_2 \) is a \( n \times k \) matrix of first-order decision rules of the \( k \) exogenous shocks on the \( n \) assets. The decision rules can be derived from a first-order approximation of the form

\[
y_t = y^s + A y^h_{t-1} + B u_t \tag{A2}
\]

where \( y^s \) is the steady state value of \( y \) and \( y^h_t = y_t - y^s \). The matrices \( D_1, D_2, R_1, \) and \( R_2 \) can then be formed of the correct rows and columns of \( B \). It is noteworthy to mention,
that as Devereux and Sutherland (2011) describe, a second-order approximation of the underlying approximation equations can be derived using only first-order approximations. This arises because the underlying optimality conditions only contain products, and second-order accurate solutions for products can be obtained from first-order accurate solutions for individual variables. This is, the zero-order asset portfolios can be characterized by a first-order approximation. In general, it can be noted that for $n = 2$ a unique solution exists. For $n > 2$ multiple solutions may exist.

A.2 First-Order Asset Dynamics

The first-order dynamics of the asset holdings can be described as

$$
\gamma' = - (D_1 R_2 \Sigma R_5^2)^{-1} (R_2 \Sigma D_5^2 + D_2 \Sigma R_5^2) + O(\epsilon)
$$

where $\Sigma$ is the $k \times k$ covariance matrix of the $k$ exogenous shocks. $D_1, D_2, D_5, R_2,$ and $R_5$ can be obtained from the state space solution. $D_1$ is in general a scalar containing the first-order decision rule of the wealth shock on consumption differences. $D_2$ is in general a $1 \times k$ vector containing the first-order decision rules of the $k$ exogenous shocks on consumption differences. $R_2$ is a $n \times k$ matrix of first-order decision rules of the $k$ exogenous shocks on the $n$ assets as in the case of the zero-order asset portfolios. In addition, $D_5$ is in general a $z \times k$ matrix containing the second-order decision rules of the $k$ exogenous shocks on consumption differences. Where $z$ is the number of predetermined variables in the system. Finally, $R_5$ is in general a $z \times k$ matrix containing the second-order decision rules of the $k$ exogenous shocks on assets. The decision rules can be derived from a second-order approximation of the form

$$
y_t = y^s + \frac{1}{2} \Delta^2 + Ay^h_t + Bu_t + \frac{1}{2} C \left( y^h_{t-1} \otimes y^h_{t-1} \right) + \frac{1}{2} D (u_t \otimes u_t) + E \left( y^h_{t-1} \otimes u_t \right)
$$

where again $y^s$ is the steady state value of $y$ and $y^h_t = y_t - y^s$. Further, $\Delta^2$ is the shift effect of the variance of future shocks. The matrices $D_1, D_2, \text{and } R_2$ can then be formed of the correct rows and columns of $B$ in the same way as in the zero-order asset portfolio case. $D_5$ and $R_5$ can subsequently be formed of the correct rows and columns of $E$. Similar to the zero-order asset portfolios, a second-order approximation is all what is required to pin down the first-order accurate behavior of asset dynamics as noted by Devereux and Sutherland (2011).

A.3 Tables
### Table 10

#### Data Sources

<table>
<thead>
<tr>
<th>Variable</th>
<th>Series</th>
<th>FRED Identifier</th>
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<tbody>
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<td>Capital Inflows Foreigners</td>
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<td>Financial Account: Other Investment Liabilities for Mexico</td>
<td>BPFAI03MXQ637N</td>
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<td>Capital Outflows Domestic</td>
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<td>Mexico Recession Indicator</td>
<td>OECD based Recession Indicators for Mexico</td>
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<td>Consumer Price Index: Total All Items for Mexico</td>
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<td>3-Month or 90-day Rates and Yields: Treasury Securities for Mexico</td>
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<td>Mexico Consumption Prices</td>
<td>Consumer Price Index: All Items for Mexico</td>
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<td>Mexico Investment Prices</td>
<td>Price Level of Capital Formation for Mexico</td>
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<td>Number of Persons Engaged for Mexico</td>
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<td>Mexico Hours</td>
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<td>Consumer Price Index: Total All Items for the United States</td>
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<td>Effective Federal Funds Rate</td>
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<tr>
<td>US Hours</td>
<td>Weekly Hours Worked: Manufacturing for the United States</td>
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</table>

*Note: Table 10 shows the used data series and their FRED database identifier.*
References


