Exchange rate and inflation dynamics in Zambia

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By OLIVER MORRISSEY, GREGORY SMITH AND LIONEL ROGER*

We investigate the dynamics between the exchange rate and consumer price inflation in Zambia in a structural vector autoregression (SVAR), using a combination of short-run sign- and zero-restrictions to identify relevant global and domestic shocks. Our findings suggest that the pass-through of exchange rates to consumer prices depends greatly on the shock that originally caused the exchange rate to fluctuate. While the price of copper is the most important driver of the exchange rate, the fluctuations caused by it are associated with a low pass-through of only about 8%. On the other hand, exchange rate fluctuations caused by monetary shocks come with a pass-through of up to 25%. Food inflation, while equally affected by genuine exchange rate shocks, appears more reactive to changes in copper prices or money supply. Historical variance decomposition shows that, across periods, the main drivers of exchange rate fluctuations varied substantially.

* Morrissey: University of Nottingham, University Park, Nottingham NG7 2RD (e-mail: oliver.morrissey@nottingham.ac.uk). Smith: World Bank, Washington D.C, USA (e-mail: gsmith3@worldbank.org). Roger: University of Nottingham, University Park, Nottingham NG7 2RD (e-mail: lionel.roger@nottingham.ac.uk).

1. Introduction

Recently, the Zambian economy has experienced a period of unusual volatility. Between January and August 2015, the Zambian Kwacha lost about 21% of its value against the US dollar. In the ten weeks that followed, it depreciated by another 60%; from November to December, the currency then appreciated by 27%. Overall, this led to loss of value of 42% in 2015. The weakness of the currency abruptly fed through to consumer prices in October, and monthly inflation jumped from an average of 0.7% to 6.2% in October and another 5% in November; overall, consumer prices had risen by 21% in 2015.

A number of global and domestic factors may have contributed to this tumultuous episode. First, on the global level, there was a trend for investors moving back from a 'search for yield' in emerging markets to safer and more conventional investments. Second and relatedly, markets expected an increase in the federal funds rate after seven years of near zero interest rates; these expectations were met in December 2015. Third, the global copper price was on a steady and sharp decline from mid-2011 to end-2015; copper accounts for about 75% of Zambian exports, and its price is typically considered a major driver of the exchange rate. Domestically, the central bank remained relatively passive until an aggressive tightening of monetary policy in November 2015, reversing some of the preceding depreciation. Furthermore, poor rainfall earlier that year contributed to a rise in food prices, which besides its direct effects on inflation may have put additional pressure on the exchange rate.

Our aim in this study is to gain an understanding of the dynamics and relative importance of the multiple factors that affect the value of the Kwacha and, in turn, consumer price inflation in Zambia. While there is a general consensus that a depreciation in the exchange rate translates into increases in consumer prices as imported goods become more expensive, the extent of this effect – the exchange rate pass through (ERPT) – can be difficult to quantify[1]. Moreover, the ERPT need not be the same for all the shocks that drive the exchange rate (Shambaugh, 2008; Forbes et al., 2015): A depreciation caused by global market conditions may be associated with very different price dynamics than the same depreciation caused by, for instance, expansionary monetary policy by the domestic central bank. The focus of our paper is then to disentangle the dynamics between the exchange rate and consumer price inflation, and to explore the possibility of a differential ERPT depending on the shock that originally caused the exchange rate to move.

To this end, we identify six shocks to key variables of the Zambian economy (namely shocks to the copper price, external interest rate, output, domestic money supply, exchange rate and inflation) in the framework of a structural vector autoregression (SVAR). Since its introduction by Sims (1980), Blanchard and Watson (1986) and Bernanke (1986), this method has found thousands of applications in empirical macroeconomics. The most common identification scheme remains a triangular Cholesky decomposition, which reduces the amount of free parameters exactly to the point where the system is just-identified. This approach, however, often implies assumptions that are hard to justify, and the results may be susceptible to the ordering of the variables. Uhlig (2005) suggests to address this using economically plausible but less restrictive sign restrictions on the impulse response functions, which can be estimated in a Bayesian VAR. His 'agnostic' approach has since inspired hundreds of papers to adopt similar methodologies. However, Baumeister and Hamilton (2015, henceforth BH) show that statistical models that appear to be 'agnostic' at first can in fact be heavily influenced by the priors imposed by the researcher, even if they were originally designed to be *uninformative*, that is, designed to have little impact on the results. Indeed, they show that there can be situations where results may be driven solely by the priors unintentionally imposed by the researcher. BH suggest to impose *informative priors* on economically interpretable parameters instead, where the prior values can, for instance, be derived from earlier empirical literature or from theory. We acknowledge their argument but note that, especially in larger VARs and for less studied economies and questions, there may simply not exist conceptually similar estimates for the relevant parameters, and that parameters from theoretical models can rarely be directly mapped to the empirical model.

For these reasons, our identification strategy consists in a combination of zero-restrictions and sign-restrictions that reflect basic macroeconomic relationships. We will start from a Cholesky decomposition and only relax those restrictions which we find particularly hard to defend[2]; namely, we remove the contemporaneous zero-restriction between the exchange rate

[1] For an excellent and comprehensive overview of the theoretical and empirical literature on the exchange rate pass-through in developing and emerging markets see Aron et al. (2014).

[2] In this respect, our identification strategy is closest to Bjørnland, and Halvorsen (2014). Muhanga, et al. (2014) estimate a system very similar to ours, but only rely on zero-restrictions.

and consumer prices. We then estimate this in a Bayesian VAR using the algorithm proposed by BH; in order to obtain relevant priors, we first estimate the system using a strict Cholesky decomposition in different variable orderings, and use the parameters thereby obtained as priors.

Our study is closely related to a growing body of literature that is concerned with the exchange rate and inflation dynamics in Zambia. Nearly all of them isolate the copper price as the single most important factor in the determination of the exchange rate: This is the case for Muhanga, Zyuulu and Adam (2014) when focussing on the short run in an SVAR, and for Bova (2009) and Chipili (2015) when focussing on long-run cointegrating relationships. The same is true for Cashin, Céspedes and Sahay (2002), who test for a long-run relationship between main export commodities and the exchange rate in a sample of 58 countries, and conclude that the Zambian Kwacha is a 'commodity currency'. Pamu (2011), on the other hand rejects this qualification on the basis that he cannot discern a relationship between the price of copper and the exchange rate. Concerning the drivers of inflation, and its interaction with inflation, the literature is, to the best of our knowledge, much scarcer; Adam (1995) discusses the possible implications of Zambia's then recent financial liberalisation efforts for inflation dynamics, and Mutoti et al. (2011) establish the importance of the oil price in inflation.

The remainder of this paper proceeds as follows: Section 2 discusses relevant aspects of the institutional and historical background in Zambia. Section 3 lays out or methodology and discusses the underlying assumptions. Section 4 describes the data, its basic time series properties, and any transformations. Section 5 presents the results, and section 6 concludes.

2. Background

Zambia is a small open commodity-dependent economy and faces challenges from supply shock. These include shifts in the global copper price, rain-fed agricultural outputs, hydro-electric generation output, and the global price of fuel. Zambia has been a copper producer since prior to its independence in 1964. However, from the early 1970's production fell considerably. Nationalisation in 1973 and low prices meant there was very little investment in the sector until the 2000s. Fresh investment followed privatisation and better copper prices in the mid-2000s supported a doubling of copper production between 2004 and 2014. The boost to the economy from the copper industry was also complemented by better macroeconomic fundamentals in the 2000s. For example, Zambia maintained a fairly low level of inflation, judged by its historical standards, and substantial debt relief in 2005 improved investors' perception of the country after Zambia qualified for the HIPC/ MDRI initiatives in 2005. These factors supported expansion of the economy and annual GDP growth, averaged 7.4% between 2004 and 2014.

As the copper production increased and the economy prospered, much larger foreign exchange inflows came from the mining sector. Added to this in the late 2000s were inflows from large Chinese infrastructure lending and from 2012 in the form of large commercial Eurobonds placements (2012 and 2014). Figure 1 suggests co-movement of the exchange rate (USD/ZMW), copper price (in USD) and CPI from 1995 until early 2003. There was then an apparent divergence of the exchange rate and copper price until 2005. The exchange rate and copper price appear to mover together since 2005, and since 2011 there is evidence that the exchange rate depreciation with a falling copper price has been associated with rising inflation.

Since the introduction of a floating exchange rate in 1994 the role of the central bank has

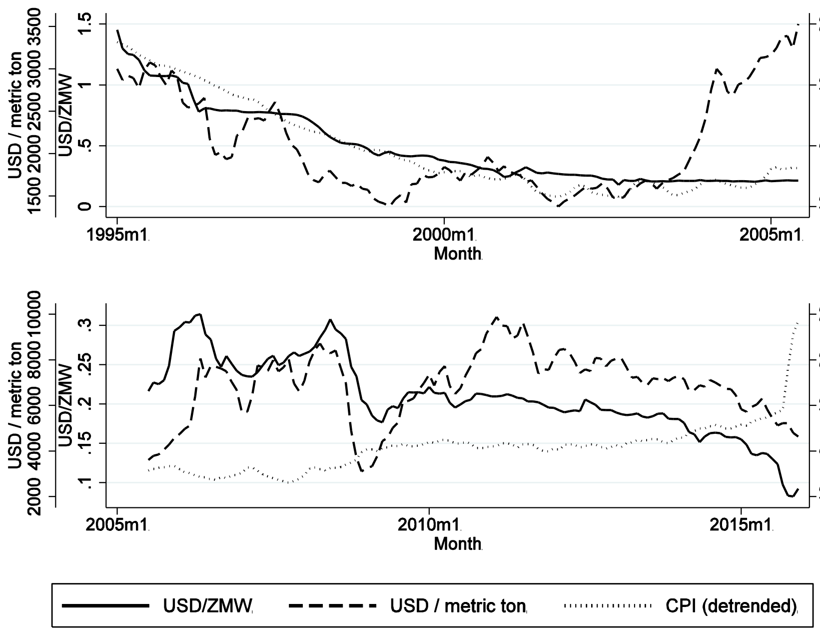


Figure 1: Key variables from 1995 to 2015 (monthly data)

been to intervene only in order to reduce volatility and manage exchange rate stability. Key microelements of Zambia's foreign exchange markets are that they are 'thin', there is not much trading, and a few players dominate the markets, including the large mining firms, the commercial banks, and the Bank of Zambia. There are often times of low trading volume, when large players are not trading and the exchange rate is fairly stable. The participants that are large relative to the level of transactions can exert influence over the exchange rate, sometimes by the timing their transactions, even if they do not intend to.

In 2014 and 2015 the economy experienced several shocks including a further decline in copper prices and after nearly a decade of running a trade surplus, the external account fell into deficit in December 2014. The initial consequence was at first a steady depreciation of the Kwacha in 2015, but in August 2015 confidence of the economy was eroded further as a power crisis began to impact on all sectors of the economy, and the trade deficit accelerated. Between August and November the currency depreciated by 60% as anxiety switched to panic. Some gains were recovered in 2016 following much tighter monetary policy, but the kwacha remains substantially weaker than prior to the shock.

3. Methodology

We estimate the effect of exchange rate fluctuations in a structural VAR. The crucial problem to solve in this framework is the identification of the respective shocks. Most of the earlier literature achieves this through a Cholesky decomposition, imposing zero restrictions on the contemporaneous reactions of certain variables to a particular shock. Generally, these are based on timing assumptions, that is, certain variables are assumed to respond to shocks only with a lag. For instance, variables like output are often considered to adjust only slowly to changes in the economy, and policy variables like interest rates may only respond to other variables once the information has become available to decision makers. The issue with this identification strategy is that it often requires assumptions that may be hard to maintain, but can have a strong impact on the results.

Starting with Uhlig (2005), recent implementations of the SVAR approach have increasingly relied on sign-restrictions. Unlike just-identified VARs like those obtained from a Cholesky decomposition, they impose less restrictive assumptions, *set*-identifying parameter combinations that are consistent with restrictions on the signs of the (short run or long run) reactions of the variables to each other. The respective parameters are most commonly elicited in a Bayesian framework, where the general procedure is to iterate through a wide range of parameter combinations. Starting from a prior distribution (determined by the researcher), an algorithm is used to systematically vary the relevant parameters in order to elicit their 'true' distribution[3]. This approach clearly has its benefits, but comes with an array of new econometric problems (see Stock and Watson, 2016). Baumeister and Hamilton (2015) show that, while researchers typically try (and claim) to employ *flat* (uninformative) priors on the parameters they estimate, commonly used methodologies tend to effectively impose strong priors on the parameters of interest, e.g. the impulse response function. By formulating their priors on parameters without economic interpretation, researchers therefore unintentionally impose meaningless priors on economically relevant quantities – instead of being *flat*, these priors can under some circumstances entirely determine the results. Baumeister and Hamilton (ibid.) suggest to instead impose the priors directly on the matrix of contemporaneous coefficients, using meaningful priors that are informed from outside estimates or economic theory.

In practice, and especially in VARs with a larger amount of variables, it can however be difficult to obtain meaningful priors for all the coefficients in the system, and a specification of appropriately loose priors (expressing a lot of insecurity about the size of the coefficients) will results in poor or no identification of the shocks. On the other hand, overly confident priors will result in inference that is strongly biased towards the expectations of the researcher. Our approach therefore relies on a combination of zero restrictions and sign-restrictions to identify the relevant shocks. Like in a classical Cholesky decomposition, we impose zero restrictions on the contemporaneous reactions of variables where a delayed response is a credible assumption, but we relax this restriction where it isn't. In order to obtain meaningful set-identification, we do instead impose sign-restrictions on the free parameters where this is warranted by macroeconomic consensus.

[3] Typically, a version of the Metropolis-Hastings algorithm is employed: in each iteration, each parameter is either randomly varied, or sampled again. Crucially, parameter values that are more likely to have generated the observed values of the variables (given the postulated likelihood function) are also more likely to be sampled. Asymptotically, these resulting distributions then converges to the 'true' distribution. A more formal and comprehensive discussion of the predominant algorithms in the context of time series analysis is provided by Barber et al. (2011).

3.1 Identification

Using the notation of Ramey (2016) and Stock and Watson (2016), we estimate the macroeconomic dynamics of interest in the framework a vector autoregression of the form

$$A(L)Y_t = \eta_t$$

Where η_t is a vector of reduced form VAR innovations, $A(L) = I - \sum_{k=1}^{p} A_k L^k$, and L is the lag operator. We make the usual assumptions that the innovations have a zero mean, constant variance, and are uncorrelated with each other.

Consider further a set of very general structural equations describing our system:

$$\begin{gathered}
Fed_t = \varepsilon_{F,t} \\
Copper_t = \ \Phi_C Fed_t + \ \varepsilon_{C,t} \\
Money_t = \phi_M Fed_t + \kappa_M Copper_t + \varepsilon_{M,t} \\
Output_t = \phi_Y Fed_t + \kappa_Y Copper_t + \mu_Y Money_t + \varepsilon_{Y,t} \\
ER_t = \ \phi_E Fed_t + \kappa_E Copper_t + \mu_E Money_t + \upsilon_E Output_t + \pi_E Infl_t + \varepsilon_{Y,t} \\
Infl_t = \ \phi_P Fed_t + \kappa_P Copper_t + \mu_P Money_t + \upsilon_P Output_t + \xi_P ER_t + \varepsilon_{Y,t}.
\end{gathered}$$

We could represent the dynamic behaviour of this system in matrix notation

$$Y_t = \Phi(L)Y_t + \ \Omega\varepsilon_t$$

where $\Phi(L) = \Phi_0 + \sum_{k=1}^{p} \Phi_k L^k$. The structural coefficients in system one are captured in the contemporaneous matrix Φ_0, while the dynamics of additional lags are captured in the matrices Φ_k. The ε's are the structural shocks we will aim to identify, entering the system as determined by matrix Ω. We follow common practice in assuming that each *structural* shock only enters one equation, or $\Omega = I$. The structural shocks ε are related to the VAR innovations η in the following way:

$$\eta_t = H\varepsilon_t,$$

where $H = [I - \Phi_0]^{-1}\Omega$. The matrix H then describes the contemporaneous relationships between the structural shocks ε_t and the reduced form VAR residuals η_t. We will normalise it such that the structural shocks have unit effect, that is, its diagonal elements are unity. In order to identify the shocks however, it will be necessary to impose some more restrictions on H.

As outlined above, we will do this with a combination of zero restrictions and sign restrictions. Specifically,

$$H^{-1} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ \phi_F & 1 & 0 & 0 & 0 & 0 \\ \phi_M & \kappa_M & 1 & 0 & 0 & 0 \\ \phi_Y^+ & \kappa_Y & \mu_Y & 1 & 0 & 0 \\ \phi_E & \kappa_E^- & \mu_E^- & \upsilon_E & 1 & \pi_E^- \\ \phi_P & \kappa_P & \mu_P^+ & \upsilon_P & \xi_P^- & 1 \end{pmatrix}$$

This specification is similar to a Cholesky decomposition, but it relaxes the restrictions on the contemporaneous interactions on our main variables of interest, inflation and the exchange rate. Instead, we impose a number of sign restrictions on the parameters, indicated by the superscripts '–' and '+'. More specifically, this specification reflects three types of assumptions:

1. *Small economy*: The domestic macroeconomic variables in Zambia are assumed to have no contemporaneous impact on the two global variables in the system, the fed funds rate and copper prices. Given the importance of copper as an export in Zambia, the latter may seem restrictive; however, Zambia only accounts for about 2% of the global copper production.
2. *Delayed responses*: Monetary policy is assumed to react only with a delay to developments in the economy. This assumption commonly made and rooted in the observation that information on macroeconomic variables typically becomes available only with a lag. Similarly, output is typically observed to react to changes in other variables only with a lag. The ordering above implies that output may respond to monetary policy contemporaneously, but not vice versa. It could be argued that the opposite is equally plausible; in a robustness check, we changed the order, and the results were robust to this choice.
3. *Sign restrictions*: We impose sign restrictions on contemporaneous parameters where we deem this choice consistent with a broad range of macroeconomic theories. Specifically, the exchange rate is constrained to depreciate (if anything) as the fed funds rate increases, as broad money increases, and as domestic inflation increases. Similarly, we constrain the contemporaneous impact of an exchange rate appreciation on prices to be negative or zero, thus excluding parameter combinations that would imply a negative ERPT at impact. Further, the contemporaneous reaction of output to an increase in copper prices is assumed to be positive or zero, as well as that of inflation to an expansionary monetary shock.

3.1 Priors

As our system is not fully identified as in the pure Cholesky case, we follow the literature in taking a Bayesian approach in order to estimate the VAR. This requires us to select sensible priors. As shown by Baumeister and Hamilton (2015) and discussed above, seemingly uninformative priors (e.g., the commonly used Haar prior) can effectively be very influential in an economically unintuitive manner. This can be the case when the outcome of interest (e.g., the impulse response function) is a non-linear transformation of the parameters the priors are imposed on. Instead, they suggest to formulate informative priors directly on parameters with an intuitive economic interpretation, namely the contemporaneous coefficients in matrix H. We will follow their approach, and furthermore use their numerical algorithm to obtain our results.

The requirement for the priors to be meaningful however poses a fundamental challenge: It is not common for the empirical literature to report the contemporaneous coefficients making up the matrix H,[4] and the theoretical literature is generally not parametrised in a way that

[4] In the literature using a Cholesky decomposition, this matrix is commonly referred to as A. We stick to Ramey (2016) and Stock and Watson (2016)'s notation to facilitate reference to their excellent discussion of the matter.

suggests any particular amplitudes for the coefficients in our empirical model. For instance, Muhanga et al. (2014), even though they study the same country with a similar research question and a comparable set of variables, only report their results in the form of impulse response functions, and thus do not offer a starting point for our priors. What is more, even if they reported the contemporaneous coefficients, the fact that they use data of a different frequency essentially renders coefficients incomparable. Deriving priors from the theoretical literature is equally complicated. To illustrate this, consider Forbes et al. (2016), who propose a DSGE model to motivate a subsequent empirical analysis of differential exchange rate pass-through akin to ours: First, like most cutting edge theoretical literature, their analysis is tailored to developed economies. As a result, essential characteristics of a small developing economy do not feature in their model; in the case of Zambia, this most strikingly concerns its resource dependence. Second, and more fundamentally, while model parameters are often (not always) explicitly reported, these generally refer to relationships at the microeconomic level, and cannot be mapped to our macroeconomic parameters of interest in any tractable manner.

In order to obtain sensible priors nonetheless, we choose a different approach. Instead of collecting or deriving coefficients from earlier literature, we generate our own priors from a more traditional approach (*as if* there was previous literature sufficiently consistent with our study). We start by estimating the model using a conventional Cholesky decomposition, thereby obtaining results based on more restrictive assumptions as they are typically made in the earlier literature. We then feed the resulting estimates as the prior modes into the system described earlier. Said differently, we take traditional estimates with all their shortcomings as a *first guess*, and then use state-of-the-art algorithms to improve on them.

Note that – given our structure of choice described above – it is not possible to estimate π_E and ξ_P simultaneously. In order to obtain priors for both, we estimate the system twice, once as described above, and then reversing the order of the last two variables (exchange rate and inflation). All other parameters are those obtained from the estimation with the order as described throughout the article (exchange rate before inflation). Beyond the prior mode, in order to complete the specification of our priors, we need to specify the nature of our prior distribution (as the parameters are inherently treated as random variables). In line with Baumeister and Hamilton (2015), we formulate the priors on the parameters in H as student t distributions with 3 degrees of freedom, and a scale parameter of 0.6 reflecting moderate confidence in our prior modes. Appendix A explicitly reports the prior modes.

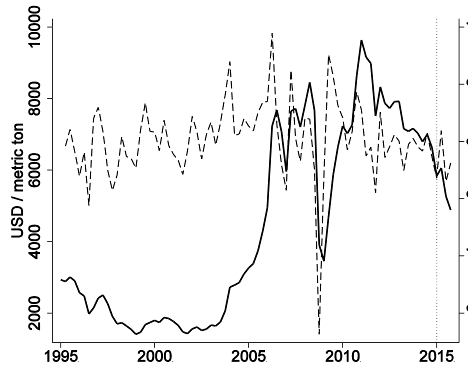
4. Data

We use quarterly data from 1995:2 to 2014:4. This corresponds to a period of relative stability in the Zambian economy, and a constant regime of flexible exchange rates that has been introduced in 1994; we deliberately exclude the tumultuous year 2015 from the main analysis as it exhibits extreme developments that are likely to dominate and distort our baseline estimations.

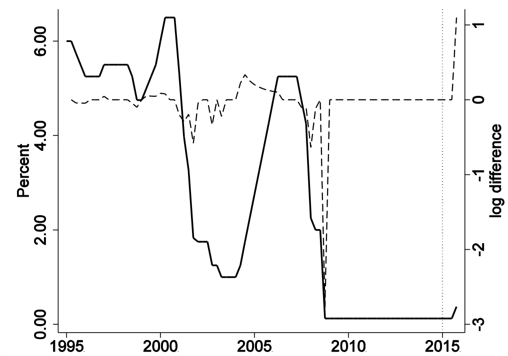
We obtain the price of copper from the IMF's Primary Commodity Price database; the Federal funds rate, the nominal USD/ZMW exchange rate (that is, a *decrease* corresponds to *devaluation*) and the Zambian Consumer Price Index from the IMF's International Financial Database; Broad Money (M2) from the Bank of Zambia's fortnightly statistics; and an internal estimate of the output gap kindly provided to us by the Bank of Zambia. All series are originally obtained at a monthly frequency and averaged over quarters, except for the output gap which was provided to us at quarterly frequency.

Figure 2 plots all variables in levels (solid lines) and in log differences (dashed lines). All series, except for the output gap (especially in early periods) resemble non-stationary series; the differenced series however appear stationary. This is confirmed by Augmented Dickey-Fuller tests reported in Appendix B: Augmented Dickey Fuller tests for a unit root. As our study focusses on relatively short time horizons, we will restrict our attention to the differenced series.

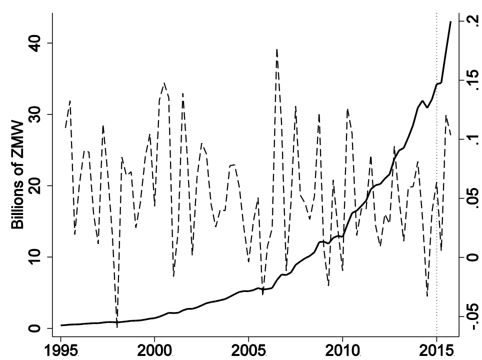
Specifically, we use the log-difference (multiplied by 100) of the copper price, money, the exchange rate and the consumer price index, so as to measure percentage changes between quarters. The fed funds rate, already expressed in percentages, will be included in first differences, therefore reflecting changes in percentage points. The output gap is expressed in percentage deviations from potential output and will be included as is. Furthermore, we de-trend the consumer price and money series.



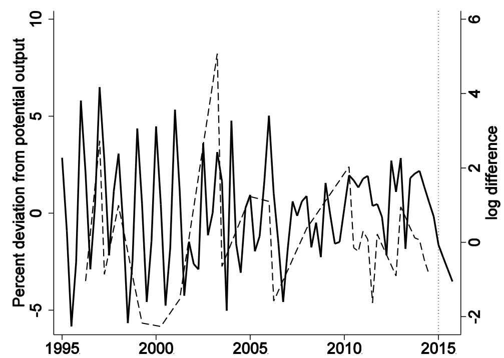
(a) Copper price



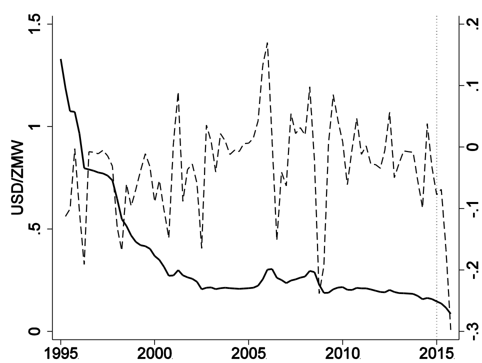
(b) Fed funds rate



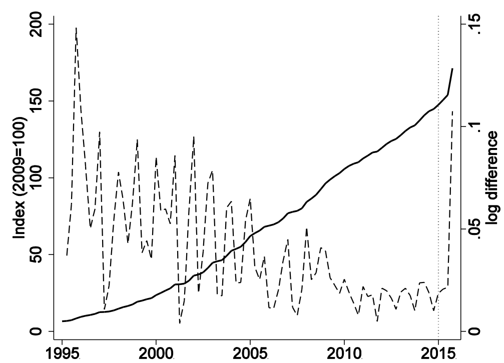
(c) Money (M2)



(d) Output gap



(e) Exchange rate



(f) Consumer Price Index

Notes: The solid lines describe the variables in levels and native units (see left y-axis), the dashed lines indicate are the first differences of the logarithm of these series. The dotted vertical line at the beginning of 2015 indicates the end of the sample period used for our main specification. See main text for further transformations applied to the series.

Figure 2: Variables in levels and log differences

5. Results

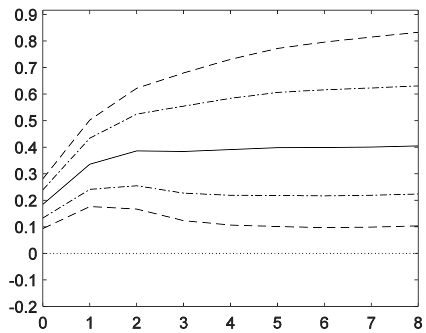
We will discuss our results in three steps. First, we will present the basic impulse response functions of our main variables of interest, the exchange rate and inflation. These indicate a strong dependence of the exchange rate on copper, as well as a sizeable effect of the exchange rate on price levels. Second, we will report variance decompositions over the sample periods in order to isolate the most important contributing factors on each of the variables, and the evolution of this pattern over time. Third, we will analyse whether there is a differential ERPT depending on the shock that drives the exchange rate fluctuation. We further investigate whether and to what extent food and non-food inflation are affected differently, and also report differential ERPTs obtained using the respective disaggregated CPIs.

5.1 Impulse response functions

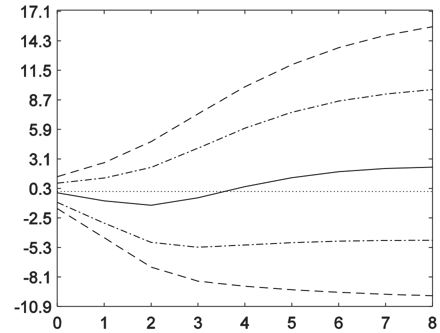
Figure 3 depicts the cumulative impulse response functions (IRF) for the exchange rate as a reaction to a 1% positive shock in the other variables. The solid line reports the pointwise mean IRF, which is the recommended point estimate to be reported given a linear loss function (Baumeister and Hamilton, 2015). The dashed lines depict the 68% and 90% credible intervals respectively.

Panel *(a)* summarises one of the key results of this exercise: the exchange rate reacts strongly and quickly to an increase in copper prices. The mean response suggests that, at impact (within the quarter), an unanticipated 1% rise in copper prices leads to an exchange rate appreciation of 0.2%. The exchange rate continues to markedly appreciate for the next two quarters, up until 0.4%, and then stays at roughly that level. This is slightly lower than the 4.8% appreciation following a 10% increase in copper prices in the long run reported by Chipili (2015), although this estimate is included in the 68% credible interval.

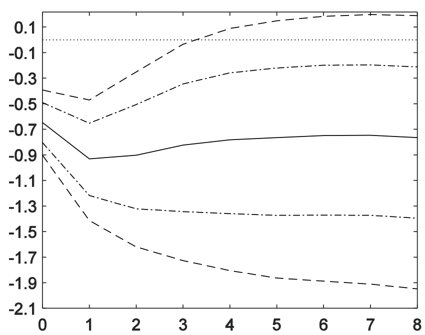
An expansionary monetary shock of 1% (panel *(c)*) is estimated to induce a marked depreciation of about 0.7% within the quarter, reaching its peak in the next quarter at 0.9%. The point estimates suggest a slight overshooting here, and the persistent effect is of about 0.8%. Note that after 3 quarters, the estimates become less confident to the point where a zero effect cannot be excluded based on the 90% credible interval.



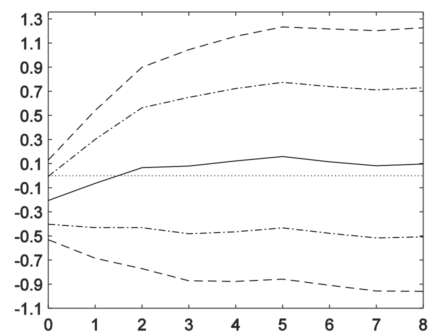
(a) Copper prices



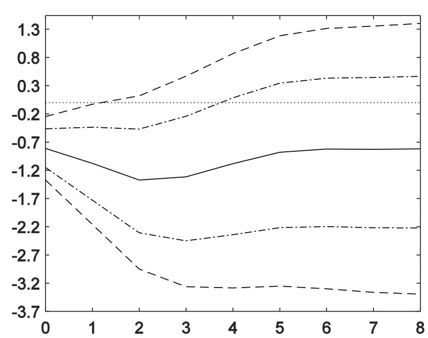
(b) Fed funds rate



(c) Monetary (expansionary)



(d) Output gap

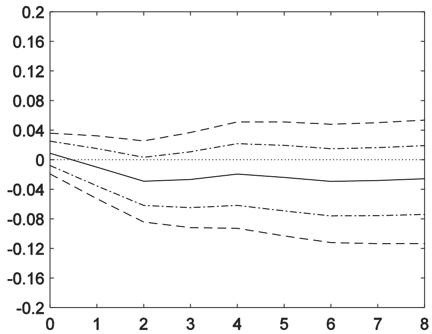


(e) CPI

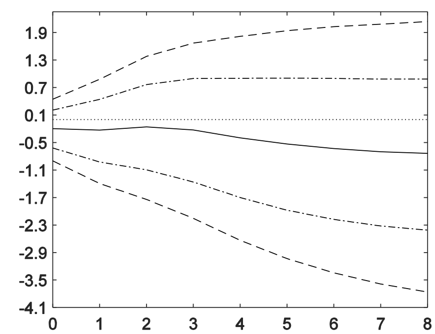
Figure 3: Response of the exchange rate to a 1% shock to key variables

The third most salient driver are domestic prices, reported in panel *(e)*. Although the estimates are too imprecise for any stark conclusions, the point estimates suggest a contemporaneous depreciation of about 0.8% following a 1% inflationary shock to CPI. The median response suggests a peak depreciation at about 1.4% after one quarter, which then levels off at about 0.9% after 5 quarters.

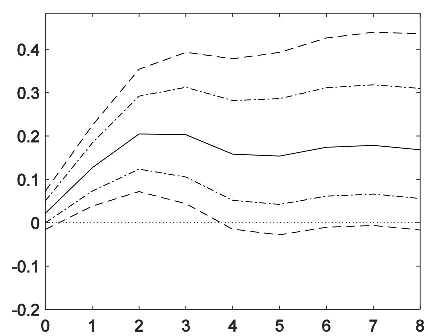
The effect of the output gap and the fed funds rate, panels (b) and (d), are ambiguous and estimated with little precision.



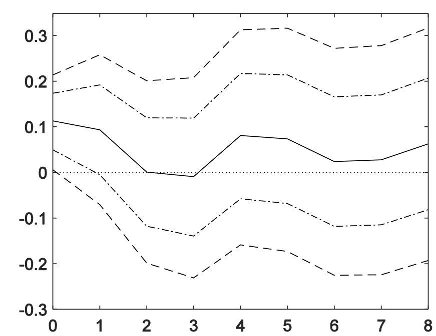
(a) Copper prices



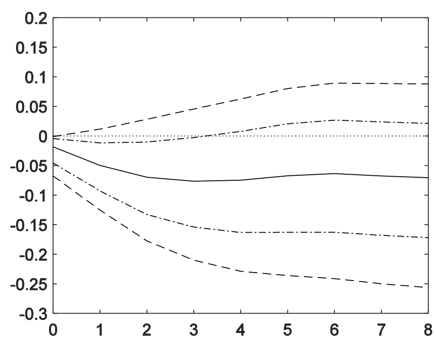
(b) Fed funds rate



(c) Monetary (expansionary)



(d) Output gap



(e) Exchange rate

Figure 4: Response of consumer prices to a 1% shock to key variables

Figure 4Figure 4 is identical in notation and plots the responses of consumer prices to 1% shocks to any of the other variables. The general picture here is that consumer prices do not react very strongly to the other macro variables, at least based on the short run dynamics analysed in our framework.

The most pronounced effect comes from monetary shocks (panel *(c)*): While a monetary expansion does not have much of an impact contemporaneously, after two quarters, a 1% monetary shock is estimated to induce a 0.2% increase in prices.

Panel *(e)*, reporting the response of CPI to a shock in the exchange rate – the exchange rate pass-through to consumer prices – reveals a very moderate response of consumer prices to changes in the exchange rate based on the short run dynamics. At impact, there is no evidence for an increase in consumer prices. While the precision of the estimate is very low given the small amplitude of the effect, the median IRF suggests a steady decrease (increase) in prices following an unanticipated appreciation (depreciation) of the exchange rate. The effect tapers off after 4 quarters, when consumer prices have decreased (increased) by about 0.07%.

Our estimates therefore imply an ERPT to consumer prices of 7% after 4 quarters. This is very low compared to other estimates in the literature: Choudhri and Hakura (2006) estimate an ERPT to domestic prices in Zambia of 15% at impact, and 41% after 4 quarters[5]. The average pass-through after 4 quarters they obtain for developing countries is 24% (although with some notable exceptions, like 9% in Burundi, and -1% in Colombia).

It is worth noting that our decision to leave the initial impact of inflationary shocks on the exchange rate, π_E, unrestricted, turns out to be quite influential for this result. Estimating the same set of equations with full identification through a classical Cholesky decomposition ($\pi_E = 0$, no sign restrictions) leads to a higher ERPT estimate of 9% at impact and about 15% in the 4th and following quarters. This is indeed what much of the previous literature has been doing, suggesting that some of the results are inflated as causality was constrained to go from exchange rates to prices.

A second factor may be the fact that we study a later period, which has been marked by significantly lower inflation in general. It is an established finding in the literature that low-inflation environments are associated with a smaller ERPT (see Choudhri and Hakura, *ibid.*). Our results may therefore reflect a genuine increase in the resilience of the Zambian economy until 2014.

5.2 Historical decomposition

Figure 6 and Figure 7 describe the historical contributions of each of the shocks to the changes in the exchange rate and consumer prices. The red line is the observed value of the respective (de-trended) series, expressed in quarter to quarter changes. The coloured bars indicate the contribution of each of the shocks to this value over the 8 periods (2 years) prior to the indicated date, computed from the median IRFs discussed in the previous section. These illustrate the decompositions reported in Table 1, which shows that money supply (M2) and the copper price account for most of the variation in exchange rates, and M2 is usually the more important factor (except for 1996-99 and 2008-11). The lower panel shows that the output gap,

[5] Note that, besides other important methodological differences in their study, Choudhri and Hakura (2006) study the period 1979-2000, which overlaps with our sample for only 5 years. The discrepancy is somewhat consistent with the main point of their paper: low inflation is associated with a low pass-through. In our sample period, Zambian inflation is much more moderate than in earlier decades (on average, 71% from 1986-2000 compared to 18% from 1995-2014 (World Bank, 2016)).

money supply and the copper price account for most of the variation in exchange rates (their relative importance varies, which M2 generally becoming more important over time). The role of domestic inflation as a driver of the exchange rate appears to have steadily declined, from 19% in 1996-99 to 6% in 2012-14.

		1996q2-1999q4	2000q1-2003q4	2004q1-2007q4	2008q1-2011q4	2012q1-2014q4
Exchange rate	Fed	3%	8%	9%	6%	3%
	Copper	22%	13%	16%	29%	15%
	M2	15%	24%	24%	20%	31%
	Output Gap	9%	10%	9%	4%	6%
	Exchange Rate	30%	32%	33%	32%	40%
	CPI	19%	13%	8%	8%	6%
CPI	Fed	2%	4%	5%	6%	1%
	Copper	10%	6%	13%	23%	14%
	M2	7%	15%	18%	20%	24%
	Output Gap	21%	21%	15%	10%	21%
	Exchange Rate	5%	3%	8%	6%	6%
	CPI	55%	51%	41%	35%	34%

Notes: The first panel reports the contribution of each variable to the fluctuations of the exchange rate averaged across quarters within five sub-periods. The second panel reports the same information for fluctuations in CPI.

Table 1: Historical variance decomposition of exchange rate and price fluctuations

Figure 6 illustrates these results for the exchange rate and depicts the year by year variation. It is apparent that the factors contributing to exchange rate fluctuations have varied quite substantially over time, but also that the amplitude of the shocks – and therefore that of the exchange rate fluctuations – has declined since about 2009. The graph also offers insights about the nature of individual fluctuations. For instance, the early 2000s saw a number of stark movements in the exchange rate, with money appearing to be the main driver. The strong appreciation around 2006 is explained by a combination of exchange rate shocks, a rising copper price and changes in money supply. While the proportional contribution of the price of copper appears rather moderate over much of the sample period, the abrupt depreciation in 2009 illustrates its potential importance, as it accounts for about two thirds of the variation.

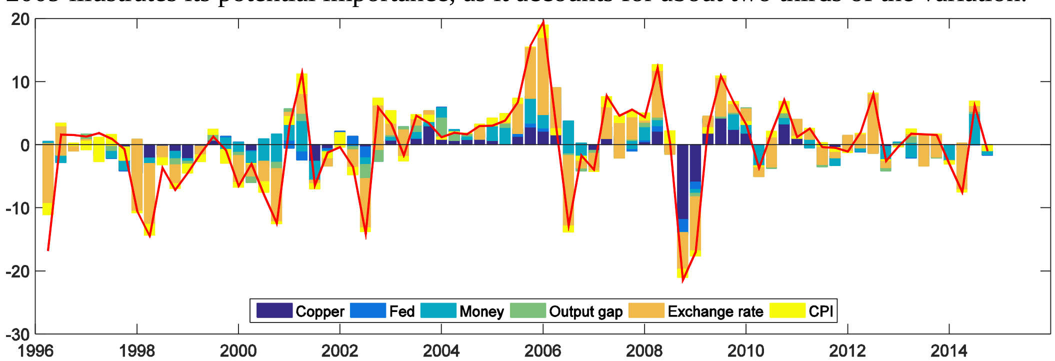


Figure 5: Historical decomposition of changes in the exchange rate (USD/ZWA)

Figure 7 decomposes changes in consumer prices in the same way. As expected from the low amplitude of the IRFs presented in section 5.1, the contribution of the other variables in our system to changes in CPI appears to be relatively limited, and much of the variance is attributed to price shocks that are exogenous to our system. However, as fluctuations decline over time, it is apparent from Table 1 that the role of our macrovariables is increasing towards the end of the period: over the sample period, the role of genuine price shocks steadily decreases from 55% in 1996-99 to 34% in 2012-14. A few factors have a notable impact in certain periods. This is the case for the fluctuations in output, especially in periods before 2002. Contractionary monetary shocks contributed to slowdowns in inflation in 2001 and in 2006. While copper prices do not play a prominent role in determining inflation in the first half of the sample period, it becomes more important in the late 2000s. This is plausible, as both copper production as well as prices were significantly higher in later periods (see section 2).

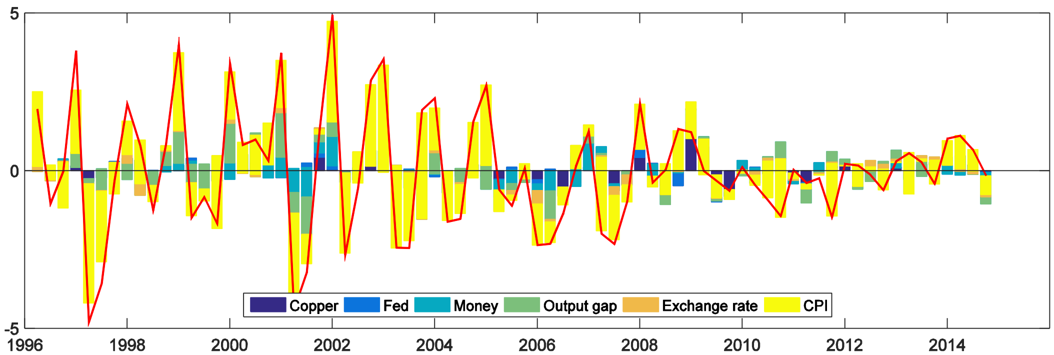


Figure 6: Historical decomposition of changes in Zambian consumer prices

5.3 Differential exchange rate pass through

We will now examine the extent to which different shocks that affect the exchange rate entail different reactions of consumer prices. Our approach is similar to Forbes et al. (2015), in that we use the ratio of the IRF of CPI over the IRF of the exchange rate a shock to any given variable. These estimates therefore indicate the change in *consumer prices induced by a shock that leads to a 1% appreciation in the exchange rate* in any period. The interpretation is then slightly different to the IRFs reported in section 5.1. These traced the effect of a shock that causes a 1% appreciation *at impact.* The measures reported here are computed for a shock that causes a 1% appreciation in *the period itself.* For instance, in order for a shock to the copper price to lead to an exchange rate appreciation of 1% *at impact*, it needs to have an amplitude of ca. $1\%/0.2 = 5\%$ (see figure Figure 3). But the shock takes some time to fully deploy its effect on the exchange rate; a copper price shock that leads to an appreciation of 1% *after 4 quarters* therefore only needs to have an amplitude of $1\%/0.4 = 2.5\%$.

Note also that the direction of the original shocks we consider in this section need not be identical to that we discussed in section 5.1 when describing the IRFs. Specifically, Figure 8 reports the result of a *contractionary* monetary shock (reducing inflation), while our previous discussion as well as Figure 3 and Figure 4 were based on *expansionary* shocks (increasing inflation). This is because we consider shocks that lead to an exchange rate *appreciation*, which for money needs to be a contractionary one.

Since in section 5.1 we established that both the fed funds rate and the output gap had little discernible effect on the exchange rate, we focus on shocks to copper prices, money and the exchange rate itself.[6]

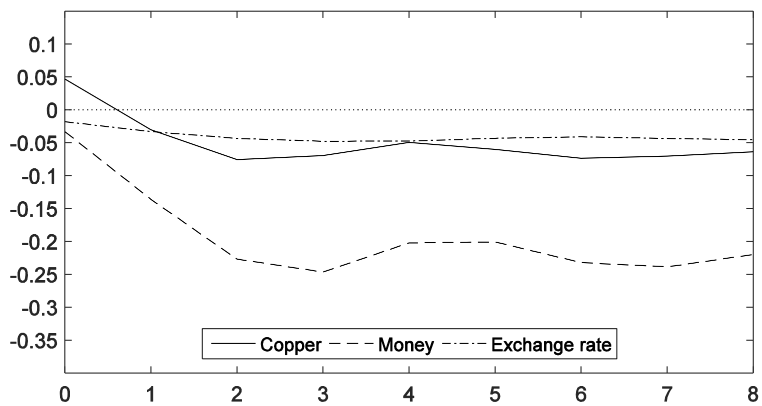


Figure 7: Pass through to consumer prices for different shocks

Horizon	**0**	**1**	**4**	**8**
Copper	0.06	-0.02	-0.03	-0.04
Money	-0.03	-0.14	-0.21	-0.22
Exchange rate	-0.02	-0.03	-0.05	-0.05

Figure 7 plots the results. First, note that for a shock to the exchange rate, the effect is even slightly lower than that reported in section 5.1. This is because a shock that raises the exchange rate by 1% at impact still raises it in the subsequent periods; effectively, figure Figure 8 therefore refers to smaller exchange rate shocks in all periods after impact.

A 1% increase in the exchange rate caused by a shock to copper prices even comes with an increase consumer prices 0.05%, implying a negative pass-through at impact of about -5%. This may reflect aggregate demand effects related to the stimulus to the copper industry (increased employment, rents). The effect is reverted in later periods, with a pass through between 5% and 8% in the following quarters.

Finally, monetary shocks are by a wide margin those associated with the strongest pass-though: Exchange rate fluctuations that are caused by a monetary shock are estimated to translate into consumer prices with an ERPT of about 25% after three quarters, with a lasting effect of about 23%. This is particularly relevant in the view of the results from the historical variance decomposition in section 5.2, which indicate that, while the variation of the exchange rate has markedly declined overall, it has recently increasingly been driven by monetary shocks. The remaining exchange rate fluctuations may therefore be disproportionately associated with consumer prices. Note however that this is more than offset by the smaller amplitude of the fluctuations in general.

[6] The latter may seem redundant, as conceptually it is very similar to the exchange rate pass-through already quantified above. Because of calculation in each period, and because an exchange rate shock that raises it by 1% in the first period may (and does) have a different effect in the second period, it is not identical.

5.4 Food versus non-food inflation

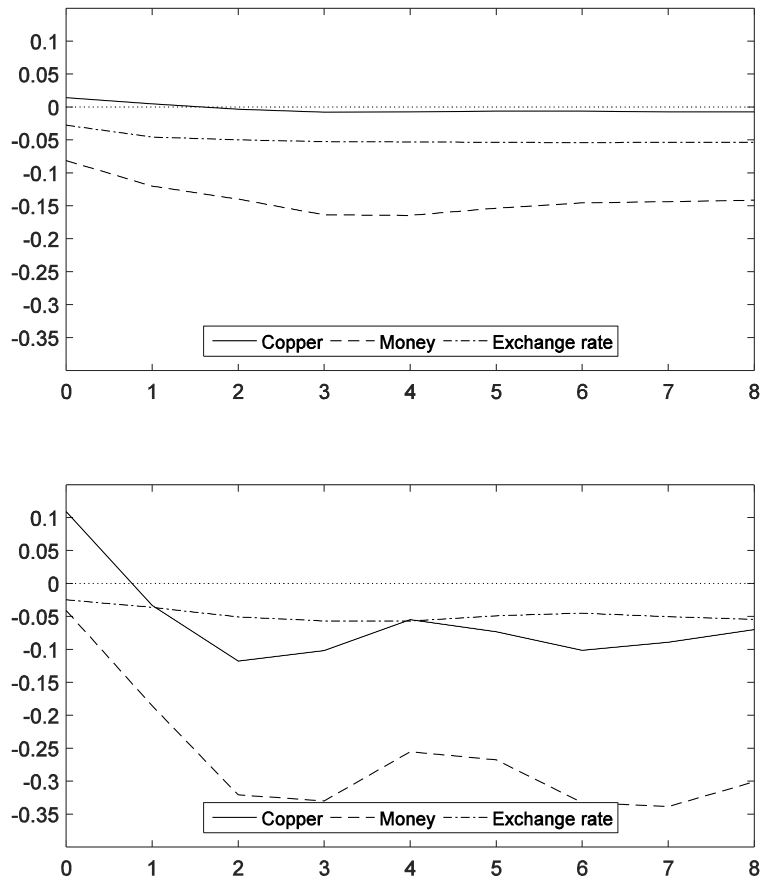


Figure 8: Differential ERPTs for non-food (top) and food (bottom) inflation

We further repeat the previous exercise with disaggregated measures of inflation, that is, we repeat the entire analysis as outlined previously, replacing only the overall CPI series with the food and non-food CPI respectively. Appendix A also reports the priors employed in this additional exercise, which we derived for each CPI category separately in the same manner as the one employed previously and described in section 3.1. For the sake of conciseness, we restrict our discussion to the differential exchange rate pass-through; a document containing all the graphs from the results section for the alternative CPI measures can be provided by the authors upon request.

Figure 8 then summarises the differential pass-through, with an interpretation identical to that of Figure 8 in the previous sub-section. For genuine exchange rate shocks, the difference appears to be only marginal with an ERPT of about 5%. As for monetary and copper price shocks, there seems to be a marked difference between food and non-food inflation: Non-food inflation (top panel) appears almost indifferent to the exchange rate fluctuations induced by copper price shocks, and exhibits a pass-through of about 15% for fluctuations driven by monetary shocks, as opposed to nearly 25% in the case of overall inflation (previous section). In fact, the exercise suggests that the overall pass-through is overwhelmingly driven by food prices (bottom panel): Exchange rate fluctuations induced by copper prices come with a pass through of up to 10%, those resulting from monetary shocks with up to 33%.

6. Conclusions

We investigated the dynamics of the exchange rate and its interaction with consumer prices in Zambia in a structural VAR framework, identifying shocks with a combination of theoretically plausible zero-restrictions and sign-restrictions. Crucially, we imposed minimal restrictions on the interaction between these two key variables. Furthermore, we explored the possibility of differential pass-throughs depending on which shock originally caused the exchange rate to fluctuate.

Our findings suggest that the pass-through from the exchange rate to consumer prices is relatively moderate for genuine exchange rate shocks; we estimate a 10% depreciation to induce an increase in consumer prices of ca. 0.7% after 1 year, corresponding to an ERPT of 7%. This is substantially less than what other studies typically find for small, low income countries, and far below the 41% estimated for Zambia by Choudhri and Hakura (2006). This is likely due to two factors: First, unlike much of the comparable literature, we do not impose any directionality on the contemporaneous relationship between the exchange rate and inflation. When doing so, our estimates of the ERPT are more than doubled. Second, we study more recent periods where Zambia has maintained a fairly low level of inflation judged by historical standards. It is a well-established finding that countries with lower inflation typically have a smaller ERPT, and Zambia may indeed have successfully reduced its vulnerability to global shocks in this respect.

Variance decomposition suggests that the main drivers of exchange rate fluctuations are, as suggested by much of the earlier literature, copper prices and the money supply. The relative importance of these factors has varied over time; while money supply has typically accounted for the largest share of the fluctuations, copper was relatively more important in the period 2008-11. The role of inflation in the determination of the exchange rate declined throughout the sample period.

We further investigated whether the ERPT varies with the shock that initially caused the exchange rate to fluctuate. Our findings suggest that, as opposed to exchange rate fluctuations caused by copper shocks or genuine exchange rate shocks, those fluctuations going back to monetary shocks are associated with a much larger pass-through of about 25%. When considering only food inflation, this figure is even higher with up to 33%. Our findings therefore suggest that, if consumer prices – especially food prices – are the outcome of interest, monetary policy must be conducted with great care, in the sense that counteracting exchange rate fluctuations with monetary interventions may have substantial repercussions on consumer prices.

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APPENDIX

Appendix A: Prior values of contemporaneous matrix H

		Shock					
	CPI type	Fed	Copper	Money	Output	Exchange rate	Price
Fed funds rate	All Non-Food Food	1	0	0	0	0	0
Copper	All	8.52	1	0	0	0	0
	Non-Food	9.42					
	Food	8.53					
M2	All	-2.65	-0.04	1	0	0	0
	Non-Food	-2.53	-0.04				
	Food	-2.47	-0.04				
Output Gap	All	-0.49	**0.03**	-0.02	1	0	0
	Non-Food	0.05	**0.03**	-0.03			
	Food	-0.64	**0.04**	0.00			
Exchange rate	All	**-1.77**	0.21	**-0.76**	0.28	1	**-0.85**
	Non-Food	**-2.98**	0.22	**-0.79**	0.16		**-1.30**
	Food	**-1.67**	0.18	**-0.77**	0.34		**-0.47**
Inflation	All	-0.11	0.02	-0.07	0.04	**-0.09**	1
	Non-Food	0.25	0.02	-0.04	0.05	**-0.11**	
	Food	-0.55	0.03	-0.11	0.08	**-0.09**	

Notes: Priors reported in bold digits are subject to a sign restriction. The respective sign can be inferred from the reported value of the prior.
The priors are obtained from just-identified Cholesky decompositions as described in section 3.1.

Appendix B: Augmented Dickey Fuller tests for a unit root

		Intercept	Trend	*t*-statistic	5% CV	*p*-value
Copper price	Level	yes	no	-1.11	-2.90	0.71
	1st Diff	no	no	-3.71	-1.95	0.00
Fed funds rate	Level	no	no	-1.50	-1.95	0.13
	1st Diff	no	no	-2.97	-1.95	0.00
Money	Level	yes	yes	3.47	-3.47	1.00
	1st Diff	yes	no	-3.20	-2.90	0.02

Output gap	Level	no	no	-3.98	-1.95	0.00
	1st Diff	no	no	-6.34	-1.95	0.00
Exchange rate	Level	yes	yes	-1.77	-3.47	0.71
	1st Diff	yes	no	-4.37	-2.90	0.00
CPI	Level	yes	yes	-2.53	-3.47	0.31
	1st Diff	yes	yes	-5.29	-3.47	0.00

Notes: All tests have been carried out with trends and intercept where the graphs in section 4 suggested their relevance, and removed when they turned out insignificant in the Dickey Fuller regression. The tests in first differences were carried out with the *log* differenced series as this corresponds to the series eventually included in out estimation for most variables. The exception is the output gap, where logs cannot be taken because of negative values. All results refer to a test with 4 lags of the variable for consistency with the main analysis.