News Shocks and Asset Price Volatility in a DSGE Model*

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Abstract

We study exchange rate and equity price volatility, in general equilibrium, in the presence of news shocks about future productivity and monetary policy. While in a partial equilibrium present discounted value model the provision of news about the future cash flow reduces asset price volatility (West 1988), we show that introducing news shocks in a canonical dynamic stochastic general equilibrium model needs not reduce asset price volatility under plausible parameter assumptions. This is because, in general equilibrium, the asset cash flow itself may be affected by the change in the information structure of the model induced by the introduction of news shocks, while the latter is constant in a present discounted value model. In addition, we show that neglecting to account for policy news shocks (e.g., policy announcements) can potentially bias empirical estimates of the impact of monetary policy shocks on asset prices.

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1 Introduction

Cochrane (1994) and more recently Beaudry and Portier (2004) revived the idea that "news shocks" may be important sources of aggregate business cycle fluctuations. Cochrane (1994), in particular, noted that one reason why traditional demand and supply sources of business cycle fluctuations fared badly against the data was that economic agents may be subject to (and hence observe) shocks that are not observable to macroeconomists or the econometricians. He then went on to conjecture that one such set of shocks may be represented by changes in expectation about the future realization of economic fundamentals (the so-called "news shocks").

While news shocks are attractive in principle, because they provide a clear and plausible example of disturbances unobservable to the econometricians but observable to economic agents, in practice it has proven difficult to build models in which they fit the business cycles well. More recently, however, Beaudry and Portier (2004, 2007), Jaimovich and Rebelo (2009), and Schmitt-Grohe and Uribe (2008) set up dynamic stochastic general equilibrium models (DSGE) in which news shocks contributes significantly to explain aggregate fluctuations in the data.[1]

If news shocks can drive the business cycle, they should also be important for asset prices that are inherently forward looking variables. For instance, Beaudry and Portier (2006) and Gilchrist and Leahy (2002) study the interaction between asset prices and news shocks. Moreover, Engel, Mark, and West (2008) show that the main reason why fundamentals have such a hard time predicting exchange rates is that currencies indeed depends heavily on expectations of future fundamentals as opposed to their current values as standard models suggest. But it is difficult to measure expectations about future fundamentals as they are not a simple function of the present and the past as it is often assumed in canonical models. Thus, it is useful to model the role of information about future fundamentals separately from information about current fundamentals.

Nonetheless, theoretical results by West (1988) imply that conditioning on information sets that include also information about the future value of fundamentals should reduce the conditional variance of asset prices in present discounted value models (PVM) relative to conditioning only on current and past value of fundamentals. Since DSGE models typically generate less asset price volatility than in the data, it would seem that incorporating news

[1] Devereux and Engel (2006, 2007) study optimal monetary policy in the presence of news shocks in a two-country open economy model. Other recent studies include: Christiano, Ilut, Motto, and Rostagno (2008), who study the implications for the conduct of monetary policy of the presence of a disturbance about the future value of the economy's fundamentals; Fujiwara, Hirose, and Shintani (2008), who examine the role of news shocks in aggregate fluctuations for Japan and the United States.

shocks into DSGE models should make it even harder to generate asset price volatility that can match the data.

This paper incorporates news shocks about technology and monetary policy in a relatively simple, two-country DSGE model and show that the model's ability to generate asset price volatility is not necessarily undermined. The paper also discusses, in partial equilibrium, why it is important to include news shocks explicitly in a model to design better empirical studies of their impact on asset prices.

More specifically, the paper's contribution is twofold. First, the paper studies the role of news shocks for asset price volatility in a present discount value model. After providing a general definition of 'news', we show that if news shocks are positively correlated with current shocks to fundamentals (which we call correlated news shocks for brevity), then the data generating process for the fundamental is serially correlated.[2] As a result, with correlated news shocks, in a present discounted value model, asset price volatility can increase with the magnitude of this correlation and can even become larger than the unconditional variance of the fundamental, holding the latter constant. For example, if news about higher (lower) future dividend growth tomorrow tends to be accompanied by unexpected higher (lower) dividend growth today, then the equity price becomes more volatile than the dividend growth, holding the variance of dividend growth constant.

The fact that a persistent fundamental leads to a volatile asset price is well known in the literature.[3] The difference between a persistent fundamental process and a process with positively correlated news shocks, however, is that in the latter case the asset price depends both on news and current (and past) values of fundamentals, whereas in the former it depends only on current and past values of fundamentals. This distinction is important because correlated news shocks can thus help to explain why a standard asset price model tend to fare badly against the data, consistent with the insight of Chocrane (1994) and Engel, Mark, and West (2008).

Second and more importantly, we show that, in a general equilibrium model, introducing news shocks need not decrease asset price volatility relative to the volatility generated allowing agents to see only current and past value of fundamentals.[4] The reason is that, in

[2]It is therefore impossible for the econometrician, who does not observe news shocks, to distinguish between a model in which agents observe correlated news shock and a model in which the fundamental process is persistent.

[3]See for instance Frenkel (1976) on the so-called "magnification effect" of a persistent money supply process on exchange rates volatility. More recently, interest rate smoothing has been used to explain high exchange rate volatility—e.g., Chari, Kehoe, and McGrattan (2002), Benigno (2004), Monacelli (2004), and Groen and Matsumoto (2004).

[4]We call a model "partial equilibrium" when cash flow process is exogenous, i.e., invariant to information set, as in West (1988), and "general equilibrium" when the dividend process is endogenous and affected by the information assumptions.

general equilibrium, the stochastic process for the endogenous fundamental (e.g., the cash flow from the asset) is no longer invariant to the information set. In contrast, a crucial assumption of West (1988) is that the stochastic process for the cash flow of the asset is invariant to the information set. For example, in a PVM, the dividend process would be the same regardless of whether agents receive news about future dividends or not. However, in general equilibrium, this may not be the case as alternative information assumptions may change the behavior of economic agents. For example, news shocks about future technology can change consumption and pricing behavior even though the exogenous stochastic process for technology is invariant to the introduction of news shocks. As a result, the profit of the firm and the dividend process can depend on whether agents receive the news about future productivity or not.

The DSGE model we set up is a standard two-country model with production, sticky prices in local currency, and complete international asset markets. The model is simple enough to yield closed-form solutions for key variables and their conditional variances. By assuming complete markets, we can derive the equity price for each country and the exchange rate easily. In addition, by solving for the world equity price, we can also derive implications for a closed economy setting.

The only model novelty is the introduction of both monetary and technology news shocks. While allowing for news shocks to aggregate technology in DGSE models is not controversial, considering monetary policy news shocks is more novel. We think about monetary policy news as the by-product of an active communication strategy aimed at guiding expectations about the future course of monetary policy, as we observe it in practice. In this paper, we do not provide the rationale for an active monetary policy communication strategy, but we study its effect on exchange rate and equity price volatility.

While the DSGE model we set up is too simple to quantify the general equilibrium effects uncovered in the analysis, it is useful to show the transmission mechanism of news shocks. By doing so, we can illustrate the pitfalls of empirical analyses of the impact of monetary policy shocks on asset prices. In practice, monetary policy news shocks ought to be important for asset prices as evidenced by the federal fund rate future moving following FOMC meetings and the release of its communications without changes in the federal fund target rate. Indeed, it is often assumed (based on event studies) that new information about monetary policy plays an important role for both asset prices and macroeconomic dynamics, but there is limited understanding of the precise transmission mechanism of news shocks, which should proceed an assessment of their quantitative importance for macroeconomic and asset price dynamics. In particular, as we shall see, our analysis suggests that event studies of the effect of monetary policy shocks on equity prices may be biased if they focus only on actual unanticipated policy changes.[5] We conclude from the analysis that while it is impossible to identify news shocks in the data based only on the stochastic process for the fundamental, including also asset prices in the analysis may help the econometrician to achieve proper identification.

The rest of the paper is organized as follows. In Section 2, we provides a general definition of news shocks and a partial equilibrium example that illustrates both the result of West (1988) as well as the working of correlated news shocks and their methodological implications. Section 3 sets up the general equilibrium model we use. Section 4 reports and discusses the main result of the paper on the impact of news shocks on equity price volatility in general equilibrium. Section 5 concludes. The full solution of the model, as well as other technical details are reported in an appendix at the end of the paper.

2 A Partial Equilibrium Example

In this section we first illustrates the result of West (1998). Then, with an an example, we discuss one condition under which news shocks can be added to a partial equilibrium model without necessarily loosing ability to generate asset price volatility that exceed that of the fundamentals'. This example also permits to illustrate why it is important to model explicitly news shocks even if they reduce asset price volatility relative to a model without news shocks. In the process, we will establish useful notation and intuition for the general equilibrium results that we present in section 4.

Let $\{\mathcal{F}_t\}$ be a increasing sequence (i.e. $\mathcal{F}_t \subset \mathcal{F}_{t+1}$) of linear spaces spanned by the history (current and past values) of a finite number of random variables, with $\{f_t\}$ being one of these variables. We shall call $\{f_t\}$ a fundamental variable or the cash flow of an asset. Then, let $\{\mathcal{H}_t\}$ and $\{\mathcal{I}_t\}$ be two other increasing sequences, with $\mathcal{H}_t$ being a strict subset of $\mathcal{I}_t$, which contain at least the history of $\{f_t\}$.

Consistent with the specific definitions of news shocks currently used in the DSGE literature—see for instance Jaimovich and Rebelo(2009) and Schmitt-Grohe and Uribe (2008)—we define "news" as information that helps better predict the *future value* of the fundamentals, i.e., information that reduces the conditional variance of future fundamentals. Thus, a random variable z_t can be defined as news about the future fundamental f_{t+j} if there exists a positive integer $j > 0$ such that

$$\mathrm{Var}(f_{t+j}|\mathcal{I}_t) < \mathrm{Var}(f_{t+j}|\mathcal{H}_t) \qquad \text{with} \quad z_t \in \mathcal{I}_t \quad \text{but} \quad z_t \notin \mathcal{H}_t. \tag{1}$$

[5] Rigobon and Sack (2004) is a notable exception as their empirical approach does not require the strong assumptions typically needed with an event study approach.

This definition characterizes a news with two attributes. First, news is information about the future value of fundamentals.[6] Second, it is "useful" information in the sense that it reduces the conditional variance of the future fundamental.

Consider now the following present discounted value asset pricing model (PVM)

$$x_t(\mathcal{F}_t) = \sum_{j=0}^{\infty} \beta^j \, \mathrm{P}(f_{t+j} | \, \mathcal{F}_t) \tag{2}$$

where $x_t(\mathcal{F}_t)$ is the asset price, $\mathrm{P}(f_{t+j}|\mathcal{F}_t)$ is the linear projection of f_{t+j} onto linear space $\mathcal{F}_t$, with $j \geq 0$ and β is the discount rate. Importantly, note that the process for f_{t+j} itself is invariant to the assumption made on the conditioning information set, although its expected future values and present discounted value obviously depend on this.

In such a PVM, West (1988) showed that given $\mathcal{H}_t \subset \mathcal{I}_t$.[7]

$$\mathrm{Var}(x_t(\mathcal{I}_t)|\mathcal{I}_{t-1}) \leq \mathrm{Var}(x_t(\mathcal{H}_t)|\mathcal{H}_{t-1}) \tag{3}$$

where

$$\mathrm{Var}(x_t(\mathcal{F}_t)|\mathcal{F}_{t-1}) = \mathrm{E}[x_t(\mathcal{F}_t) - \mathrm{P}(x_t(\mathcal{F}_t)|\mathcal{F}_{t-1})]^2 \tag{4}$$

is the conditional variance of x_t given $\mathcal{F}_{t-1}$. The result says that if agents receive any information in addition to the history of the cash flows, the conditional variance of the asset price will be smaller or equal to what it would obtain if agents were to observe only the history of the cash flow at some horizon j.

We now construct an example of a PVM in which news shocks possibly correlated with current shocks (which we call correlated news shocks for brevity) can generate asset price volatility higher than the volatility of the fundamentals. Let now $\mathcal{I}_t$ be a linear space spanned by the history of $\{f_t\}$ and $\{z_t\}$ up to time t, and $\mathcal{H}_t$ a linear space spanned by the history of $\{z_t\}$ up to $t-1$ only, and assume $f_0 = 0$. Thus, $z_t \in \mathcal{I}_t$, $z_t \in \mathcal{H}_{t+1}$, but $z_t \notin \mathcal{H}_t$. In other words, under these assumptions, news are observed by agents with information set given by $\mathcal{I}_t$, not by agents with information set $\mathcal{H}_t$.[8]

Consider now the following fundamental process that is driven by a current (ε_t) and a

[6] Empirical work sometime defines 'news' as new contemporaneous information, i.e., a surprise to current variables. We use "current shocks" to label surprises to current variables while "news" strictly refers to innovations in the future value of a variable.

[7] Note that this proposition requires only that one information set is a subset of the other. Of course, the proposition can be applied specifically to the case in which the difference between the two information sets is the news about the future value of the fundamental.

[8] We call the latter agents "uninformed".

A third case in which, unlike the model agents, the econometrician cannot even observe the past values of z_t.is discussed below possibly correlated news shocks (z_t):

$$f_t = f_{t-1} + \varepsilon_t + z_{t-1} \tag{5}$$

where $(\varepsilon_t, z_t)'$ are jointly i.i.d. zero mean processes, with $\mathrm{Var}(\varepsilon_t) = \sigma_1^2$, $\mathrm{Var}(z_t) = \sigma_2^2$ and $\mathrm{Cov}(\varepsilon_t, z_t) = \varrho\sigma_1\sigma_2$ and $-1 < \varrho < 1$. These assumptions imply that

$$z_t = \varrho\frac{\sigma_2}{\sigma_1}\varepsilon_t + \eta_t \tag{6}$$

where η_t is orthogonal to ε_t and $\mathrm{Var}(\eta_t) = (1-\varrho^2)\sigma_2^2$. This equation characterizes z_t as a linear projection onto ε_t plus an error term, η_t. Thus η_t is the portion of z_t that is orthogonal to the current shock and, strictly speaking, it is also "news" according to the definition we provided above.[9]

So the process for the fundamental can be rewritten as:

$$\begin{aligned} f_t &= f_{t-1} + \varepsilon_t + z_{t-1} & (7)\\ &= f_{t-1} + \varepsilon_t + \varrho\frac{\sigma_2}{\sigma_1}\varepsilon_{t-1} + \eta_{t-1} & (8)\\ &= f_{t-1} + \theta_t + \varrho_\theta\theta_{t-1}, & (9) \end{aligned}$$

where θ_t and ϱ_θ are defined in Appendix 1. This representation of the process for f_t shows that an identical fundamental process can be expressed in three different ways depending on alternative specifications of the information set. While the economic interpretations of these alternative representations are different, it is evident that it is impossible to identify the specific information set at work observing only the time series process for the fundamental. Note in particular that the surprise component, $f_t - \mathrm{E}_{t-1}(f_t)$, for those who observe z_t is ε_t, whereas for the uninformed agents the surprise component is $\varepsilon_t + \eta_{t-1}$. Uninformed agents therefore attribute to "current shocks" what actually stems from news shocks. However, uninformed agents, can still obtain information about the future value of the fundamental from the current shock ε_t. (They can observe ε_t because $z_{t-1} \in H_t$). But informed agents who observe z_t will form different expectations from uniformed ones even though the underlying fundamental process is exactly the same.[10]

[9] Indeed, the orthogonality condition defining η_t may permits to identify it as such in the data. For our illustrative purposes, however, it is preferable to consider the whole of z_t and not only η_t as news. This is because z_t represents new information arriving at time t about future fundamental f_{t+1}: $z_t = \mathrm{E}_t(\Delta f_{t+1}) - \mathrm{E}_{t-1}(\Delta f_{t+1})$. Nonetheless, the results that follow apply to both z_t and η_t, showing that without additional restrictions one cannot identify 'news' from the data.

[10] Obviously, agents who cannot even distinguish η_{t-1} from ε_t, because they do not observe even the history of z_t, such as the econometricians, will forms yet different expectations for the same process. This

The *conditional* variance of the fundamental process with respect to the these two information sets is

$$
\begin{aligned}
&\operatorname{Var}(f_t|\mathcal{I}_{t-1}) = \operatorname{Var}(\varepsilon_t) = \sigma_1^2 \\
\leq\, &\operatorname{Var}(f_t|\mathcal{H}_{t-1}) = \operatorname{Var}(\varepsilon_t + \eta_{t-1}) = \sigma_1^2 + (1-\varrho^2)\sigma_2^2
\end{aligned}
\tag{10}
$$

with the equality holding if $|\varrho| = 1$, i.e., when the current innovation reveals all the information contained in z_t.[11] When the absolute value of ϱ is close to one, the "usefulness" of news is diminishing, for given σ_1 and σ_2 (i.e., holding the *unconditional* variance of underlying fundamental $\operatorname{Var}(\Delta f_t)$ constant). Then, the difference between the conditional variances of the fundamental with or without news depends on $1 - \varrho^2$. This means that as $|\varrho|$ tends to one, agents who do not observe z_t can extract information about future fundamentals from ε_t with increasing precision. Thus, the economic interpretation of ϱ close to one is that current innovation and the news shock tend to be similar. Note finally that the data generating process of the fundamental is invariant to the information set of the agent, but it does change depending on the value of ϱ, even though the unconditional variance of fundamentals remains unchanged with respect to ϱ.

Introducing news shocks explicitly in the model is useful even if it reduces asset price volatility. In fact, correlated news shocks can provide an economic interpretation of what may appear to the econometrician as a "persistent" process. In other words, a stochastic process for the fundamental appearing to be persistent to the econometrician may be also due to positively correlated news shocks that are not observed by the econometrician. For instance, persistent interest rate processes may be interpreted as being generated by correlated news shocks. For example, FOMC announcements regarding future policy (news shocks) tend to be similar to the actual policy actions (current shocks) but they are sometimes different form the actual policy action providing more information about future interest than it can be inferred by simply assuming that interest rates are persistent.[12]

Let's now explore the implications for asset price volatility. The asset price at time t conditional on $\mathcal{I}_t$ is

$$
x_t(\mathcal{I}_t) = \sum_{j=0}^{\infty} \beta^j \operatorname{E}(f_{t+j}|\mathcal{I}_t) = \frac{1}{1-\beta} f_t + \frac{\beta}{1-\beta} z_t
\tag{11}
$$

third case (equation 9) is discussed briefly in Appendix 1.

[11] Note that z_t is indeed "news" as it reduces the conditional variance of the fundamental.

[12] Interest rate smoothing is used to explain high exchange rate volatility. See, for example, Chari, Kehoe, and McGrattan (2002), Benigno (2004), Monacelli (2004), and Groen and Matsumoto (2004).

while the asset price at time t conditional on $\mathcal{H}_t$ is

$$x_t(\mathcal{H}_t) = \sum_{j=0}^{\infty} \beta^j \, \mathrm{E}(f_{t+j}|\mathcal{H}_t) = \frac{1}{1-\beta} f_t + \frac{\beta}{1-\beta} \varrho \frac{\sigma_2}{\sigma_1} \varepsilon_t. \tag{12}$$

Therefore, the conditional variances of the asset price under the two information assumptions are, respectively

$$\begin{aligned} \mathrm{Var}(x_t(\mathcal{I}_t)|\mathcal{I}_{t-1}) &= \mathrm{Var}\left(\frac{1}{1-\beta}(\varepsilon_t + \beta z_t)\right) \\ &= (1-\beta)^{-2}\left((\sigma_1^2 + 2\beta\varrho\sigma_1\sigma_2 + \beta^2\sigma_2^2)\right) \end{aligned} \tag{13}$$

$$\begin{aligned} \mathrm{Var}(x_t(\mathcal{H}_t)|\mathcal{H}_{t-1})) &= \mathrm{Var}\left(\frac{1}{1-\beta}(\varepsilon_t + \eta_{t-1} + \beta\varrho\varepsilon_t)\right) \\ &= (1-\beta)^{-2}\left((\sigma_1^2 + 2\beta\varrho\sigma_1\sigma_2 + [\beta^2 + (1-\beta^2)(1-\varrho^2)]\sigma_2^2)\right). \end{aligned} \tag{14}$$

Thus, consistent with West (1988), the conditional variance of the asset price with news shocks is still smaller than without news shocks by the factor $(1-\beta^2)(1-\varrho^2)\sigma_2^2$. Including news shocks in the PVM above, however, needs not reduce asset price volatility relative to the *unconditional* variance of the underlying fundamental. The unconditional variance of fundamental is

$$\mathrm{Var}(\Delta f_t) = \mathrm{Var}(\varepsilon_t + z_{t-1}) = \sigma_1^2 + \sigma_2^2, \tag{15}$$

which does not depend on ϱ. Thus, a larger ϱ can increase the conditional variance of the asset price while leaving the unconditional variance of fundamental unchanged. And when ϱ is close to one, correlated news shocks generate higher asset price volatility like models with persistent fundamentals in which there is the so-called magnification effect (e.g., Frankel, 1986). This is because the fundamental process becomes more persistent as ϱ increases as we explained above.

In practice we could increase the conditional variance of asset prices by simply assuming MA(1) process like equation (16) above. Proceeding in this manner, however, is problematic if indeed agents observe news about the future value of fundamentals. This is because the actual realization of news shocks may or may not be similar to the current shocks. That is, in general $\eta_t \neq 0$, meaning that uninformed agents always make errors in making inference about news based on ε_t. Unlike the fundamental process which is invariant to the information set, the realization of the asset prices will be affected by the assumption on the observability (or lack thereof) of z_t. Thus, model based asset prices will be different depending on the inclusion or not of news, i.e., $x_t(\mathcal{I}_t) \neq x_t(\mathcal{H}_t)$. In addition, even if the econometrician extracts the best possible information from the fundamental process without news, it will always be different from the model with news shocks, i.e., $x_t(\mathfrak{I}_t) \neq x_t(\mathcal{H}'_t)$.While *ceteris paribus* a higher value of ϱ mitigates the problem by allowing uninformed agents or econometricians to extract better information from current fundamentals, a higher value of σ_2 may exacerbate this problem by increasing the importance of news about future in the data generating process.

In sum, as shown in the seminal contribution of West (1988), the introduction of news shocks per se reduces asset price volatility, measured by the conditional variance of the asset price, relative to a world without news shocks, given the underlying cash flow process. Our example suggests that if news shocks are positively correlated with current shocks, asset price volatility relative to the volatility of the fundamental can increase with this correlation given the variance of the cash flow process.[13] The reason is that correlated news shocks induce a "magnification effect" in the asset price volatility generated by a fundamental process that appears persistent to the econometrician or the uniformed agent. We have also shown that, although it is difficult to measure news shocks, modeling news shocks can help to explain why asset prices do not simply depend on current fundamentals. In other words, the point made by Cochrane (1994) about news shocks and the business cycle also applies to asset prices. It is therefore important to allow for news shocks in asset price models even though they may reduce the conditional variance of asset prices relative to a world without news shocks. More importantly, this volatility reducing effect, as we shall see in section 4, is not necessarily present in general equilibrium.

3 A DSGE Model

We employ a relatively simple dynamic stochastic general equilibrium (DSGE) model to characterize the effects of news shocks on asset prices in general equilibrium. Except for news shocks, the model and its solution are standard.

The model is a two-country world economy with production, nominal rigidity in local currency, complete international financial markets, and news shocks. There are two equally sized and perfectly symmetric countries, Home and Foreign, and we denote quantities and prices in Foreign with an asterisk, "*". In each country, there are two exogenous processes, for the money supply and total factor productivity, and we assume that agents can receive new information about both processes one period in advance. Firms are monopolistic competitors that use a linear technology with no capital. All goods are traded, but markets

[13]As we have demonstrated (and by the proposition of West), if agent do not observe news shocks, then the conditional variance of asset price is even larger in a partial equilibrium model, holding the data generating process of the cash flow.

are segmented. Goods prices are set one period in advance in the currency of the final consumer. International financial markets are complete in nominal terms. This is allows us to study asset price behavior independently of portfolio allocations. Under complete markets, equity prices are the present discounted sum of future profits and are easily priced ruling out bubble solutions. In the rest of this section, we describe the model setup in more detail. Its full solution is reported in the appendix.

3.1 Households

The representative Home household j maximizes

$$\max_{C_t(j),M_t(j),L_t(j)} \mathrm{E}_t \sum_{s=t}^{\infty} \frac{C_s(j)^{1-\rho}}{1-\rho} + \frac{\kappa_1}{1-\varepsilon}\left(\frac{M_s(j)}{P_s}\right)^{1-\varepsilon} - \frac{\kappa_2}{1+\psi} L_s(j)^{1+\psi}, \tag{16}$$

subject to a budget constraint in which we assume that asset markets are complete in nominal terms and households receive a lump-sum transfer from the national government generated by seignorage.The consumption basket is $C_t(j)$, $\frac{M_t(j)}{P_t}$ is real money balance, and $L_t(j)$ is the labor supply.The following parameter restrictions are assumed to hold on the intertemporal substitution elasticity, money demand interest rate semi-elasticity, labor supply elasticity, and the weights of money balances and labor disutility in the period utility flow, respectively: $\rho > 0$, $\varepsilon > 0$, $\psi \geq 0$, κ_1 and $\kappa_2 > 0$. The consumption basket $C_t(j)$ is defined as

$$C_t(j) \equiv \left[\left(\frac{1}{2}\right)^{1/\omega} C_{h,t}(j)^{(\omega-1)/\omega} + \left(\frac{1}{2}\right)^{1/\omega} C_{f,t}(j)^{(\omega-1)/\omega}\right]^{\omega/(\omega-1)}, \tag{17}$$

where $\omega > 0$ is the elasticity of substitution between Home and Foreign produced goods.The consumption basket of Home produced goods, $C_{h,t}$ is

$$C_{h,t}(j) \equiv \left[\left(\frac{1}{2}\right)^{-1/\lambda} \int_0^{\frac{1}{2}} C_{h,t}(j,i)^{(\lambda-1)/\lambda} di\right]^{\lambda/(\lambda-1)}, \tag{18}$$

where $\lambda > 1$ denotes the elasticity of substitution among different varieties. The consumption basket of Foreign produced goods, $C_{f,t}$, is defined analogously. Given these baskets, the aggregate price index can be written as

$$P_t = \left[\frac{1}{2}P_{h,t}^{1-\omega} + \frac{1}{2}P_{f,t}^{1-\omega}\right]^{1/(1-\omega)}, \tag{19}$$

where

$$P_{h,t} = \left[2\int_0^{\frac{1}{2}} P_{h,t}(i)^{1-\lambda}di\right]^{1/(1-\lambda)}, \quad P_{f,t} = \left[2\int_{\frac{1}{2}}^{1} P_{f,t}(i)^{1-\lambda}di\right]^{1/(1-\lambda)}, \tag{20}$$

with $P_{h,t}(i)$ denoting the nominal price of Home good i, and $P_{f,t}(i)$ the price of Foreign traded good i sold in the Home market.

Given prices and the total consumption basket C_t, the optimal consumption allocations satisfy (since households are identical, we can suppress the index j)

$$C_{h,t}(i) = 2\left(\frac{P_{h,t}(i)}{P_{h,t}}\right)^{-\lambda} C_{h,t}, \qquad C_{f,t}(i) = 2\left(\frac{P_{f,t}(i)}{P_{f,t}}\right)^{-\lambda} C_{f,t} \tag{21}$$

$$C_{h,t} = \frac{1}{2}\left(\frac{P_{h,t}}{P_t}\right)^{-\omega} C_t, \qquad C_{f,t} = \frac{1}{2}\left(\frac{P_{f,t}}{P_t}\right)^{-\omega} C_t. \tag{22}$$

The other first order conditions are

$$W_t = \kappa_2 \frac{L_t^{\psi}}{C_t^{-\rho}/P_t}, \qquad \text{labor supply} \tag{23}$$

$$\left(\frac{M_t}{P_t}\right)^{\varepsilon} = \kappa_1 \frac{C_t^{\rho}}{1 - \mathrm{E}_t\, \beta D_{t,t+1}}, \qquad \text{money demand,} \tag{24}$$

where

$$D_{t,t+s} \equiv \frac{C_{t+s}^{-\rho}/P_{t+s}}{C_t^{-\rho}/P_t}$$

is the stochastic discount factor or the Home currency pricing kernel.

As it is known, under a complete asset market structure in nominal terms, and full symmetry between the Home and Foreign economy, we have

$$\frac{S_t P_t^*}{P_t} = \frac{C_t^{*-\rho}}{C_t^{-\rho}}. \tag{25}$$

3.2 Firms

Firms are monopolistic competitors with a linear technology in labor:

$$Y_t(i) = A_t L_t(i), \tag{26}$$

where $Y_t(i)$ is firm i's production, $L_t(i)$ is firm i's labor input, and A_t is Home productivity, common across all Home firms.

Firms supply goods as demanded.We assume that international good markets are segmented, and firm i presets its prices for the Home market ($P_{h,t}(i)$) and the Foreign market

($P^*_{h,t}(i)$) in local currencies (LCP) one period in advance. The firm's output price is set to maximize its discounted profit, given other firms' prices. The discounted profit for firm i is

$$D_{t-1,t}\Pi_t(i) = D_{t-1,t}[P_{h,t}(i)Y_{h,t}(i) + S_t P^*_{h,t}(i)Y^*_{h,t}(i) - W_t L_t(i)], \tag{27}$$

where the Home and Foreign demands for firm i's good are, respectively,

$$Y_{h,t}(i) = \left(\frac{P_{h,t}(i)}{P_{h,t}}\right)^{-\lambda}\left(\frac{P_{h,t}}{P_t}\right)^{-\omega} C_t, \quad Y_{f,t}(i) = \left(\frac{P^*_{h,t}(i)}{P^*_{h,t}}\right)^{-\lambda}\left(\frac{P^*_{h,t}}{P^*_t}\right)^{-\omega} C^*_t. \tag{28}$$

Thus, the optimal prices for the two markets are

$$P_{h,t}(i) = \frac{\lambda}{\lambda-1}\frac{\mathrm{E}_{t-1}\, D_{t-1,t}\dfrac{W_t}{A_t}C_t}{\mathrm{E}_{t-1}\, D_{t-1,t}C_t}, \quad P^*_{h,t}(i) = \frac{\lambda}{\lambda-1}\frac{\mathrm{E}_{t-1}\, D_{t-1,t}\dfrac{W_t}{A_t}C^*_t}{\mathrm{E}_{t-1}\, D_{t-1,t}C^*_t S_t}. \tag{29}$$

Since all firms are homogenous, $P_{h,t}(i) = P_{h,t}$ for all i. Foreign firms are characterized by a fully symmetric set of equations and assumptions.

3.3 Market Clearing and Equilibrium

Labor and goods markets clear as follows:

$$Y_t = A_t L_t; \tag{30}$$

$$Y_t = \frac{1}{2}\left(\frac{P_{h,t}}{P_t}\right)^{-\omega} C_t + \frac{1}{2}\left(\frac{P^*_{h,t}}{P^*_t}\right)^{-\omega} C^*_t. \tag{31}$$

Given good prices, households satisfy the first order conditions for Home goods consumption, equation (21), and Foreign analogous. The money market clears equating money demand from the households' first order conditions and money supply as specified below. In the initial state, we assume that $A_0 = A^*_0 = 1$ and $P_0 = P^*_0 = S_0 = 1$ or $M_0 = M^*_0$. We also assume that there is no news about the future at time 0. Given the exogenous processes for productivity and money supply, equilibrium is defined as usual.

3.4 Stochastic Processes and Information Assumptions

The assumptions on the stochastic processes driving the model dynamics are different from those used in typical DSGE models, but they are now standard in the news literature. We assume that aggregate productivity levels, $\ln(A_t)$ and $\ln(A^*_t)$ have a unit root but share a common stochastic trend, and thus cointegrate. This implies assuming a two-component process for productivity consistent with the solution approach we follow. This has the additional advantage of permitting to investigate the effects on asset prices of both a persistent mean-reverting process and a unit root process.[14] Specifically,

$$a_t^R \equiv \ln(A_t) - \ln(A_t^*) = \theta a_{t-1}^R + \nu_{1,t}^R + \nu_{2,t-1}^R \tag{32}$$

$$a_t^W \equiv \frac{1}{2}\left[\ln(A_t) + \ln(A_t^*)\right] = a_{t-1}^W + \nu_{1,t}^W + \nu_{2,t-1}^W \tag{33}$$

where $|\theta| < 1$ and $\left(\nu_{1,t}^X,\, \nu_{2,t}^X\right)'$ are jointly i.i.d. over time with mean zero, $\mathrm{Var}(\nu_{1,t}^X) = \sigma_{\nu_1^X}^2$, $\mathrm{Var}(\nu_{2,t}^X) = \sigma_{\nu_2^X}^2$, and $\mathrm{Cov}(\nu_{1,t}^X, \nu_{2,t}^X) = \varrho_a^X \sigma_{\nu_1^X}\sigma_{\nu_2^X}$. Also, superscript W denotes the world average of log deviations, and superscript R denotes relative variables, defined as the log difference between Home and Foreign for all variables. We use super script X to denote 'either W or R'.[15] Symmetry of the processes and equal size of the two economies imply that there is no correlation between world variables and relative variables.

Note that $\nu_{1,t}$ is a traditional productivity shock, which we call a "current shock", while $\nu_{2,t}$ provides information about productivity one period in advance, i.e., on a_{t+1}. Thus, $\nu_{2,t}$ is news about productivity as the conditional variance of a_{t+1} is smaller when we include $\nu_{2,t}$ in the information set. To label alternative information sets, we use the same notation developed in Section 2. That is $\nu_{2,t} \in I_t$ and $\nu_{2,t-1} \in H_t$ but $\nu_{2,t} \notin H_t$.

For the money supply, we assume the following processes:

$$\ln(M_t) = \ln(M_{t-1}) + \mu_t \tag{34}$$

$$\ln(M_t^*) = \ln(M_{t-1}^*) + \mu_t^* \tag{35}$$

where μ_t^X $(X \in \{W, R\})$ is

$$\mu_t^X = \nu_{3,t}^X + \nu_{4,t-1}^X + \chi_1^X \nu_{1,t}^X + \chi_2^X \nu_{2,t-1}^X + \chi_3^X \nu_{2,t}^X,$$

with $\left(\nu_{3,t}^X,\, \nu_{4,t}^X\right)$ jointly i.i.d. over time, with mean zero, $\mathrm{Var}(\nu_{3,t}^X) = \sigma_{\nu_3^X}^2$, $\mathrm{Var}(\nu_{4,t}^X) = \sigma_{\nu_4^X}^2$, $\mathrm{Cov}(\nu_{3,t}^X, \nu_{4,t}^X) = \varrho_m^X \sigma_{\nu_3^X}\sigma_{\nu_4^X}$, and independent from $\nu_{1,t}^X$ and $\nu_{2,t}^X$.

Here, $\nu_{3,t}$ and $\nu_{4,t}$ are traditional shocks to the current period money stock and the news shock about next period's money stock, respectively, while χ_1, χ_2, and χ_3 are monetary

[14] Engel and Matsumoto (2009) set up world and relative productivity processes in this way.

[15] Note that the relative values of nominal variables such as profit (or inflation) are the difference between the log deviation of Home profits in Home currency and the log deviation of Foreign profits in Foreign currency. Returns on equities are also denominated in firm currency rather than investor currency unless otherwise noted.

policy responses to current and future technology shocks. This implies that $\chi_2 \nu_{2,t-1}$ is the delayed monetary policy response to the productivity news shock. These monetary policy responses are neither realistic nor optimal in this fully symmetric world economy, but the setup highlights the linkage between the monetary policy responses to different shocks and asset prices.

For ease of interpretation of the results in the next section, it is useful to define the following variables:

$$\mu_{1,t}^X \equiv \nu_{3,t}^X + \chi_1^X \nu_{1,t} + \chi_3^X \nu_{2,t}^X, \quad \mu_{2,t}^X \equiv \nu_{4,t}^X + \chi_2^X \nu_{2,t}^X, \tag{36}$$

so that $\mu_t^X = \mu_{1,t}^X + \mu_{2,t-1}^X$where $\mu_{1,t}^X$ are the surprise components of the money supply, or the unanticipated policy changes, and $\mu_{2,t}^X$ is news about future money supply plus the delayed (thus anticipated) policy response to the news about future productivity.

4 Solution and General Equilibrium Results

We solve the model by log-linearizing around an initial fully symmetric steady state. For any variable, lower case stands for its log-deviation from the initial symmetric steady state. The appendix reports a complete model solution. In the rest of this section, we discuss the implications of the model's solution for exchange rate and equity price volatility.

4.1 News Shock and the Exchange Rate

News shocks help to understand why econometricians have a hard time to evaluate exchange rate models. As we saw in the case of the present discounted value model example of the previous section, asset prices depend on the information assumptions made (i.e., on the presence of news shocks and the assumptions on who observes what).

This is also true in the DSGE model we set up. From the solution of the linearized model, we obtain the following expression for the exchange rate:

$$s_t = \underbrace{\mathrm{E}_{t-1}\, m_t^R}_{\mathrm{E}_{t-1}\, s_t} + [(1-\beta)\varepsilon + \beta] \underbrace{(m_t^R - \mathrm{E}_{t-1}\, m_t^R)}_{\mu_{1,t}^R} + \beta \underbrace{(\mathrm{E}_t\, m_{t+1}^R - m_t^R)}_{\mu_{2,t}^R}. \tag{37}$$

This expression is familiar except that $\mathrm{E}_t\, m_{t+1}^R \neq m_t^R$. If the money supply followed a martingale process so that $\mathrm{E}_t\, m_{t+1}^R = m_t^R$, the exchange rate would depend only on the *current* relative money supply. Thus, innovation to the exchange rate would be $\mu_{1,t}^R$. However, in this model, agents have more information about future money supply, $\mathrm{E}_t\, m_{t+1}^R = m_t^R + \mu_{2,t}^R$, due to both news about the future money supply (e.g., announcements as part of a monetary policy communication strategy) as well as to the known monetary policy response to the news about future relative productivity. If exchange rate models are evaluated only based on current fundamentals, as in Meese and Rogoff (1983), then the econometrician will reject them even though it might be the case that the information assumptions made rather than model per se that are failing. Thus exchange rate models should be evaluated by allowing for the presence of news shocks. Engel, Mark, and West (2007) indeed find that news shocks affect exchange rates and conclude that the canonical monetary exchange rate model is not as bad as we might think. In light of this, they note that even using the realized value of current fundamentals may not improve the model's forecasting power if the they are correlated with unobservable determinants of exchange rate, e.g., news.

How do news shocks affect the conditional variance of the exchange rate? While adding news shocks to the canonical monetary exchange rate model can help to explain its poor empirical performance, the inclusion of news shocks does not help generating higher exchange rate volatility than the case in which agents do not observe news about the future value of the money supply in our simple model with exogenous monetary policy.[16] That is, in general, in the model we set up, consistent with the partial equilibrium analysis of section 2, we have that

$$\mathrm{Var}(s_t(\mathcal{I}_t)|\mathcal{I}_{t-1}) \leq \mathrm{Var}(s_t(\mathcal{H}_t)|\mathcal{H}_{t-1}). \tag{38}$$

Nonetheless, another challenge for modeling exchange rates in DSGE is to generate realistic volatility relative to the unconditional variance of the fundamentals—e.g., the relative money supply growth or the relative inflation rate in our specific case.[17] News shocks can help to increase the conditional variance of the exchange rate, holding the unconditional variance of the relative money supply constant, if news shocks are correlated with current shocks, as we have seen in a present discounted value model.

To see this, assume for simplicity that there is no monetary response to productivity shocks, then the unconditional variance of relative money supply growth is

$$\mathrm{Var}(\Delta m_t^R) = \mathrm{Var}(\nu_{3,t}^R + \nu_{4,t-1}^R) = \sigma^2_{\nu_3^R} + \sigma^2_{\nu_4^R}, \tag{39}$$

[16]Mathematically, $\mathrm{Var}(s_t(\mathcal{I}_t)|\mathcal{I}_{t-1}) > (s_t(\mathcal{H}_t)|\mathcal{H}_{t-1})$ only if $\varepsilon < 0$, which is not a plausible assumption.

[17]As exchange rate returns are hard to predict, the conditional and unconditional volatility of exchange rate returns are usually very close in the data. In the model, since the conditional variance is smaller than the unconditional variance of the fundamental, we focus on the relation between the conditional variance of the exchange rate and the unconditional variance of the money supply and productivity.

while, the conditional variance of the exchange rate is

$$\begin{aligned}\mathrm{Var}_{t-1}(s_t) =& \mathrm{Var}\Big([(1-\beta)\varepsilon+\beta]\nu^R_{3,t}+\beta\nu^R_{4,t}\Big)\\ =&[(1-\beta)\varepsilon+\beta]^2\sigma^2_{\nu^R_3}+\beta^2\sigma^2_{\nu^R_4}+2[(1-\beta)\varepsilon+\beta]\beta\varrho^R_m\sigma_{\nu^R_3}\sigma_{\nu^R_4}.\end{aligned} \tag{40}$$

If $\varepsilon = 1$, as it is often assumed, for $\varrho^R_m > \frac{1-\beta^2}{2\beta}\frac{\sigma_{\nu^R_4}}{\sigma_{\nu^R_3}} > 0$, the exchange rate can become more volatile than the money supply growth.[18] More generally, the conditional variance of the exchange rate can increase with ϱ^R_m while the unconditional variance of relative money supply stays constant as the latter does not depend on ϱ^R_m.

In sum, therefore, news shocks can help to explain the apparent lack of dependence of exchange rates on current fundamentals by allowing them to depend not only on current but also on future fundamentals. They can also induce more volatility via a traditional magnification effect if news shocks are correlated with current shocks, although the effect may be weaker than the traditional magnification effect.

4.2 News Shocks and Equity Prices

The analysis of equity return volatility is more complex than that of exchange rate volatility, and, as we shall see, the role of news shocks for equity price dynamics is richer, in general equilibrium, than in the case of the exchange rate. Equity prices are discounted present values of dividends, but dividends in general equilibrium depend not only on the underlying exogenous stochastic processes for productivity and money supply but also on news about their future values. That is, news shocks can affect the dividend process itself unlike in the present discounted value example of section 2. This is because, in general equilibrium, consumption, the wage rate, sales, and hence profits all depends on current as well as news shocks. Intuitively, consumption is going to be different when the information set is different: if agents know today (via news shocks) that tomorrow is going to be a good time, then they start adjusting today. This in turn affects sales and firms' profit. As a result, in general equilibrium, we can observe a more volatile equity price than the case in which there is no news shocks with certain parameter values. In contrast, in our relatively simple model, the exchange rate happens to look like the present discounted value of relative money supply whose fundamental process is invariant to the information set assumed.

Unlike the exchange rate return, the equity return depends on both world and country

[18]Note that when $\varepsilon = 1$, the exchange rate equation becomes a present discounted value model as shown in section 2.

specific shocks. Without loss of generality, we therefore focus on the world equity return and the relative return separately. Note importantly that the world equity return can be viewed as the equity return in a closed economy model. Equity price dynamics also depends on the currency denomination of the firm profit. For this reason, we distinguish between the relative return on equity denominated in the currency of local firms and the currency of a representative Home or Foreign investor.

Equities in our model are claims that pay off the firms' profits every period. Firms do not have physical capital, but they have monopolistic power that generates profit. Under the assumption of complete markets, given the discount factor, the pre-dividend price of a claim on the firm's profit can be written as

$$Q_t = \Pi_t + E_t \beta D_{t,t+1}(Q_{t+1}). \tag{41}$$

Thus, the linearized equity price is

$$q_t = \beta \, \mathrm{E}_t \, q_{t+1} + (1-\beta)\pi_t - \beta i_t, \tag{42}$$

where $i_t = E_t(-d_{t,t+1})$ is the (linearized) nominal interest rate between period t to $t+1$.[19] Then, it is straightforward to derive the following expression for the return on equity:[20]

$$r_{t+1} - i_t = (q_{t+1} - \mathrm{E}_t \, q_{t+1}). \tag{43}$$

This expression shows that the excess return of equity over the nominal interest rate is equal to the surprise component of equity prices. That is, the variance of the excess returns is the same as the conditional variance of the equity price innovation. Given our definition of relative and world variables, the excess return on Home equity over the Home interest rate is

$$q_{t+1} - \mathrm{E}_t \, q_{t+1} = (r^W_{t+1} - i^W_t) + \frac{1}{2}(r^R_{t+1} - i^R_t). \tag{44}$$

[19]Note that i_t is the log deviation from the steady state net interest rate, $\frac{1-\beta}{\beta}$.

[20]Notice that the return on equity is not i.i.d., as the nominal interest rate is known at time t, but its excess return over the nominal interest rate is indeed an i.i.d. process as one would expect.

4.2.1 World Equity Prices (Or the Closed Economy Equity Price)

Consider the world equity price, which one can interpret as the closed economy equity price. Its surprise component is

$$\begin{aligned}
&q_{t+1}^W - \mathrm{E}_t\, q_{t+1}^W = r_{t+1}^W - i_t^W \\
=&(\Lambda_1 + \Lambda_2)\nu_{1,t+1}^W + \Lambda_2 \nu_{2,t+1}^W \\
&+ \left[1 + (1-\beta)\left(\frac{1-\rho}{\rho} - \frac{\zeta}{1-\zeta}\frac{\rho+\psi}{\rho}\right)\right]\left[(1-\beta)\varepsilon(\mu_{1,t+1}^W) + \beta(\mu_{1,t+1}^W + \mu_{2,t+1}^W)\right]
\end{aligned} \tag{45}$$

where

$$\begin{aligned}
\Lambda_1 \equiv&(1-\beta)\frac{\zeta}{1-\zeta}(\psi+1) \\
\Lambda_2 \equiv&\left\{\left[1 + (1-\beta)\left(\frac{1-\rho}{\rho} - \frac{\zeta}{1-\zeta}\frac{\rho+\psi}{\rho}\right)\right]\rho\left(1 - \frac{1}{\varepsilon}\right) + (1-\rho)\right\}\beta\frac{\psi+1}{\rho+\psi}
\end{aligned}$$

From this expression, we can see that news shocks about future productivity affect the world excess return, unless $\Lambda_2 = 0$ (i.e., both $\varepsilon = 1$ and $\rho = 1$). Let's now study the volatility impact of news shocks and correlated news shocks in turn.

Effects of News on Equity Price Volatility With news shocks about future productivity, the conditional variance of the world equity price can increase in general equilibrium. Let $q_t(\mathcal{I}_t)$ be the equity price when, at time t, agents observe a news shock ($\nu_{2,t}^W$) and $q_t(\mathcal{H}_t)$ be the equity price when agents do not observe this shock at time t. Further, and importantly, to isolate the general equilibrium effect of news shocks, assume $\varrho_a^W = 0$. Assuming $\varrho_a^W = 0$ simplifies the analysis because the surprise component of productivity to the agents who do not observe news shocks is the same as the actual productivity change. That is, $a_{t+1}^W - \mathrm{E}(a_{t+1}^W|\mathcal{H}_t) = \Delta a_{t+1}^W = \nu_{1,t+1}^W + \nu_{2,t}^W$. In contrast, the surprise component of productivity to the agents who do observe news shocks is $a_{t+1}^W - \mathrm{E}(a_{t+1}^W|\mathcal{I}_t) = \nu_{1,t+1}^W$.

Ignoring monetary shocks and the monetary reaction to the technology shocks for simplicity, we can rewrite the surprise component of the world equity price with news shocks as follows:

$$q_{t+1}^W(\mathcal{I}_{t+1}) - \mathrm{E}(q_{t+1}^W(\mathcal{I}_{t+1})|\mathcal{I}_t) = (\Lambda_1 + \Lambda_2)\nu_{1,t+1}^W + \Lambda_2\nu_{2,t+1}^W \tag{46}$$

When agents do not observe news shocks, in the above equation, we can replace $\nu_{2,t+1}^W$ with zero and $\nu^W_{1,t+1}$ with $\nu^W_{1,t+1} + \nu^W_{2,t}$.[21] Without news shocks, instead, we have

$$q^W_{t+1}(\mathcal{H}_{t+1}) - \mathrm{E}(q^W_{t+1}(\mathcal{H}_{t+1})|\mathcal{H}_t) = (\Lambda_1 + \Lambda_2)\left(\nu^W_{1,t+1} + \nu^W_{2,t}\right) \tag{47}$$

The difference in the conditional variances of these two surprise components is given by the following expression:

$$\begin{aligned} &\mathrm{Var}(q^W_{t+1}(\mathcal{I}_{t+1})|\mathcal{I}_t) - \mathrm{Var}(q^W_{t+1}(\mathcal{H}_{t+1})|\mathcal{H}_t) \\ =& -(\Lambda_1 + 2\Lambda_2)\Lambda_1\sigma^2_{\nu 2}. \end{aligned} \tag{48}$$

Asset price volatility with news shocks is larger than one without news shocks i.e., the sign of this expression is positive, when $\Lambda_1 + 2\Lambda_2 < 0$ as $\Lambda_1 > 0$. In general, $\Lambda_1 + 2\Lambda_2$ can be either positive or negative for plausible parameter values. However, it is possible to find cases in which its value is positive for plausible assumptions on the parameter values. For instance, suppose $\varepsilon = 1$ and $\psi = 0$ (i.e., unit interest rate elasticity $(1/\varepsilon)$ of money demand and linear disutility of labor, as often assumed in the literature). The above equation then simplifies to

$$\begin{aligned} &\mathrm{Var}(q^W_{t+1}(\mathcal{I}_{t+1})|\mathcal{I}_t) - \mathrm{Var}(q^W_{t+1}(\mathcal{H}_{t+1})|\mathcal{H}_t) \\ =& -\left[2\beta\frac{1-\rho}{\rho} + (1-\beta)\frac{\zeta}{1-\zeta}\right](1-\beta)\frac{\zeta}{1-\zeta}\sigma^2_{\nu 2}, \end{aligned} \tag{49}$$

which is positive, for example, if $\zeta = 2/3$, $\beta = .95$ and $\rho \geq (1 - \frac{1-\beta}{2\beta}\frac{\zeta}{1-\zeta})^{-1} \approx 1.06$. Alternatively, the expression (48) is positive if $\rho = 1$, $\varepsilon = .8$, $\zeta = 2/3$ and $\beta = .95$.

With these parameter values, in the first of these two cases, a future productivity increase will reduce the future good price and hence future nominal profit. But today's prices are predetermined, and today's profit will increase as a result of a lower labor cost. When agents do not observe news, a positive current productivity shock has two offsetting effects on the equity prices—a positive effect on today's profit and a negative effect on tomorrow's nominal profit, although the effect on tomorrow's profit is usually larger. If agents observe news shocks, current profit does not respond[22], thus the equity prices respond to the effects on future profits without any offsetting effects from today's profit.

So while the size of the general equilibrium effect of news shocks of the world equity price conditional variance is clearly a quantitative matter, it is evident that is possible to generate it with plausible assumptions on parameter values. Unlike in a partial equilibrium setting,

[21] It is easy to see that if $\varrho^W_a \neq 0$, then we have to replace $\nu^W_{2,t+1}$ with $\varrho^W_a\sigma_2/\sigma_1\nu^W_{1,t+1}$ and $\nu^W_{1,t+1}$ with $\nu^W_{1,t+1} + \eta^W_t$ where $\eta^W_t \equiv \nu^W_{2,t} - \varrho^W_a\sigma_2/\sigma_1\nu^W_{1,t}$.

[22] When $\varepsilon \neq 1$, current profit will be affected by news shocks from consumption smoothing channel.

where the dividend process is invariant to the introduction of the news, news about future productivity affect all model variables in general equilibrium, including dividends. But one of the assumptions required to derive West's (1988) result is that the cash flow process, i.e., the dividend, is not affected by the change in information assumptions. Consumption, for example, depends on news shocks:

$$
\begin{aligned}
c_t^W =& \frac{1}{\rho}\left\{(1-\beta)\varepsilon(\mu_{1,t}^W) + \beta(\mu_{1,t}^W + \mu_{2,t}^W)\right\} \\
&+ \frac{\psi+1}{\rho+\psi}\left\{\mathrm{E}_{t-1}\, a_t^W + \beta\left[1-\frac{1}{\varepsilon}\right](\nu_{1,t}^W + \nu_{2,t}^W)\right\}.
\end{aligned} \tag{50}
$$

Recall now that $\mathrm{E}(a_t^W|\mathcal{I}_{t-1}) \neq \mathrm{E}(a_t^W|\mathcal{H}_{t-1})$, which implies that even if $\varepsilon = 1$, the realization of consumption depends on the assumption on the information set: $c_t^W(\mathcal{I}_t) \neq c_t^W(\mathcal{H}_t)$. Obviously, most DSGE models of the business cycle entail this kind of effects. Thus, we have shown that it is possible to increase asset price volatility by including news shocks in general equilibrium.

Effects of Correlated News Shocks on World Equity Price Let's now consider correlated news shocks, which may help to generate higher conditional variance of equity price holding the unconditional variance of productivity shocks constant. In general equilibrium, unlike in the simple present discounted value model of section 2 or the exchange rate return in our relatively simple DSGE model, correlated news shocks do not always induce higher conditional variance. While the unconditional variance of productivity growth,$\mathrm{Var}(\Delta a_{t+1}^W) = \mathrm{Var}(\nu_{1,t+1}^W + \nu_{2,t}^W) = \sigma^2_{\nu_1^W} + \sigma^2_{\nu_2^W}$, does not depend on the correlation (ϱ_a) between $\nu_{1,t+1}^W$ and $\nu_{2,t+1}^W$, the variance of $\mathrm{Var}_t\, q_{t+1}^W$ does depend on ϱ_a. Again ignoring for simplicity monetary shocks and the monetary response to productivity shocks, we have:

$$
\mathrm{Var}_t\, q_{t+1}^W = (\Lambda_1 + \Lambda_2)^2 \sigma^2_{\nu_1^W} + 2\Lambda_1\Lambda_2 \varrho_a^W \sigma_{\nu_1^W}\sigma_{\nu_1^W} + \Lambda_2^2 \sigma^2_{\nu_2^W}. \tag{51}
$$

So increasing the correlation of news shocks can increase equity price volatility if $\Lambda_2 > 0$, while it can decrease it (the more so the larger ϱ_a^W) if $\Lambda_2 < 0$ since $\Lambda_1 > 0$. The reason why the 'magnification effect' does not always operate here is also that, in general equilibrium, information about future can indeed change the behavior of agents.[23]

The solution for the world excess return also illustrates the transmission mechanism of monetary policy news to equity prices. Policy news shocks affect the world excess return if and only if current monetary policy shocks affect it. This is because $\mu_{1,t+1}^W$ and $\mu_{2,t+1}^W$ share

[23]Note that, even if agents do not observe news shocks, positively serially correlated productivity process could also reduce the conditional variance of the world equity price return.

the same coefficient in equation (45), and for either of them to have an impact it must be the case that $\left[1+(1-\beta)\left(\frac{1-\rho}{\rho}-\frac{\zeta}{1-\zeta}\frac{\rho+\psi}{\rho}\right)\right]\neq 0$. This has the important implication that it is difficult to measure the impact of monetary policy shocks on equity prices through event studies of actual policy changes.

The typical event study uses the change in adjusted federal funds rate futures at the time of a FOMC announcement on the right hand side of the estimated econometric equation. This, in principle, should capture current policy shocks, or $\mu^W_{1,t+1}$. FOMC announcements, however, often contain information about the future interest rates as well, $\mu^W_{2,t+1}$, and equity returns must reflect that information as well. If one regresses equity returns onto changes in federal funds rate futures,the estimate of the effect of current shocks on the equity return may be biased because the effect of news about the future is omitted from the econometrician's specification.

4.2.2 Relative Equity Return

Consider next the relative equity return. Recall that, in general, relative equity price dynamics depends on the currency denomination of the firm's profit. For this reason, in this subsection, we shall look in turn at the relative return on equity denominated in the currency of a representative Home or Foreign investor (which we label "equity return in investor currency"and denote $r^{R\$}$) and in the currency of local firms (which we label "equity return in firm local currency"and denote r^R).[24]

Relative Equity Return in Investor Currency As before, the excess return over nominal interest rate is the surprise component of equity prices. Obviously, the relative nominal interest rate in investor currency is zero.

Let $q^{R\$}_t$ be the relative equity price in investor currency. It is possible to show that

$$\begin{aligned} r^{R\$}_{t+1} =& r^R_{t+1}-\Delta s_{t+1}=q^{R\$}_{t+1}-\mathrm{E}_t(q^{R\$}_{t+1}) \\ =&(1-\beta)(\psi+1)\left[\left(\frac{\omega-1}{\omega\psi+1}\frac{\beta\theta}{1-\beta\theta}+\frac{\zeta}{1-\zeta}\right)\nu^R_{1,t+1}+\frac{\omega-1}{\omega\psi+1}\frac{\beta}{1-\beta\theta}\nu^R_{2,t+1}\right] \end{aligned} \tag{52}$$

This expression shows that $r^{R\$}_{t+1}$ depends only on current and news shocks to productivity but not on monetary policy shocks or the policy reaction to productivity shocks. This is because of the relatively simple structure of our model. Yet the model is rich enough to show that it is possible to generate a higher conditional variance of the relative equity return with news shocks that are either correlated or not correlated with current shocks.

[24]Hau and Rey (2006) investigate empirical characteristics of relative return in firms currency.

For ease of presentation, let's examine first the effect of correlated news shocks.[25] The expression for the unconditional variance of the relative return or, equivalently, the conditional variance of relative equity price in investor currency is:

$$\begin{aligned}
&\mathrm{Var}_t(q^{R\$}_{t+1}) = \mathrm{Var}(r^{R\$}_{t+1}) \\
=&[(1-\beta)(\psi+1)]^2 \left(\frac{\omega-1}{\omega\psi+1}\frac{\beta\theta}{1-\beta\theta}+\frac{\zeta}{1-\zeta}\right)^2 \sigma^2_{\nu_1^R} \\
&+2[(1-\beta)(\psi+1)]^2 \left(\frac{\omega-1}{\omega\psi+1}\frac{\beta}{1-\beta\theta}\right)\left(\frac{\omega-1}{\omega\psi+1}\frac{\beta\theta}{1-\beta\theta}+\frac{\zeta}{1-\zeta}\right)\varrho^R_a\sigma_{\nu_1^R}\sigma_{\nu_2^R} \\
&+[(1-\beta)(\psi+1)]^2 \left(\frac{\omega-1}{\omega\psi+1}\frac{\beta}{1-\beta\theta}\right)^2 \sigma^2_{\nu_2^R}.
\end{aligned} \tag{53}$$

In contrast, the unconditional variance of relative productivity is:

$$\mathrm{Var}(a^R_t) = \frac{1}{1-\theta^2}\left(\sigma^2_{\nu_1^R}+\sigma^2_{\nu_2^R}+2\theta\varrho^R_a\sigma_{\nu_1^R}\sigma_{\nu_2^R}\right). \tag{54}$$

Let $R(\varrho^R_a) \equiv \frac{\mathrm{Var}(r^{R\$}_{t+1})}{\mathrm{Var}(a^R_t)}$. Then, it is possible to show that

$$\begin{aligned}
\frac{\partial R}{\partial \varrho^R_a} \propto &\left(\frac{\omega-1}{\omega\psi+1}\frac{\beta}{1-\beta\theta}\right)\left(\frac{\omega-1}{\omega\psi+1}\frac{\beta\theta}{1-\beta\theta}+\frac{\zeta}{1-\zeta}\right)\left(\sigma^2_{\nu_1^R}+\sigma^2_{\nu_2^R}\right) \\
&-\left\{\left(\frac{\omega-1}{\omega\psi+1}\frac{\beta\theta}{1-\beta\theta}+\frac{\zeta}{1-\zeta}\right)^2\sigma^2_{\nu_1^R}+\left(\frac{\omega-1}{\omega\psi+1}\frac{\beta}{1-\beta\theta}\right)^2\sigma^2_{\nu_2^R}\right\}\theta
\end{aligned} \tag{55}$$

This expression shows that correlated news shock may or may not help increasing the conditional variance of the relative equity price in investor currency. When $\theta = 0$ and $\omega > 1$, correlated news shocks ($\varrho^R_a > 0$), can unambiguously increase the volatility of relative equity returns compared to the volatility of the relative productivity level with higher correlation. However, if $\omega \leq 1$ with $\zeta = 2/3$ and $\beta = .95$ correlated news shocks could also reduce the variance ratio above.

Focus now on the general equilibrium effects of news shocks that are not correlated with current shocks (i.e., assume $\varrho_a = 0$ to illustrate the pure general equilibrium effect). Because $r^{R\$}_{t+1}$ does not depend on the monetary policy shocks, we can focus specifically on productivity shocks. So rewrite equation (52) for the two alternative information assump-

[25] Recall that the underlying stochastic process, the process for relative productivity, is a persistent stationary process under our model assumptions.

tions:

$$\begin{aligned} &q^{R\$}_{t+1}(\mathcal{I}_{t+1}) - \mathrm{E}(q^{R\$}_{t+1}(\mathcal{I}_{t+1})|\mathcal{I}_t) \\ =&(1-\beta)(\psi+1)\left[\left(\frac{\omega-1}{\omega\psi+1}\frac{\beta\theta}{1-\beta\theta}+\frac{\zeta}{1-\zeta}\right)\nu^R_{1,t+1}+\frac{\omega-1}{\omega\psi+1}\frac{\beta}{1-\beta\theta}\nu^R_{2,t+1}\right] \end{aligned} \tag{56}$$

$$\begin{aligned} &q^{R\$}_{t+1}(\mathcal{H}_{t+1}) - \mathrm{E}(q^{R\$}_{t+1}(\mathcal{H}_{t+1})|\mathcal{H}_t) \\ =&(1-\beta)(\psi+1)\left(\frac{\omega-1}{\omega\psi+1}\frac{\beta\theta}{1-\beta\theta}+\frac{\zeta}{1-\zeta}\right)(\nu^R_{1,t+1}+\nu^R_{2,t}). \end{aligned} \tag{57}$$

Therefore we have that

$$\begin{aligned} &\mathrm{Var}(q^{R\$}_{t+1}(\mathcal{I}_{t+1})|\mathcal{I}_t) - \mathrm{Var}(q^{R\$}_{t+1}(\mathcal{H}_{t+1})|\mathcal{H}_t) \\ =&[(1-\beta)(\psi+1)]^2\left[\left(\frac{\omega-1}{\omega\psi+1}\frac{\beta}{1-\beta\theta}\right)^2-\left(\frac{\omega-1}{\omega\psi+1}\frac{\beta\theta}{1-\beta\theta}+\frac{\zeta}{1-\zeta}\right)^2\right]\sigma^2_{\nu^R_2} \end{aligned} \tag{58}$$

As we illustrated before in the case of world equity return, the introduction of news shocks can generate higher variance of asset price in general equilibrium. Two plausible examples are the case in which $\omega = 5$, $\psi = 0$, $\beta = .95$ $\theta = .8$ and $\zeta = 2/3$, or the case in which $\omega = .7$, $\psi = 0$, $\beta = .95$ $\theta = .8$ and $\zeta = 2/3$.[26]

In the first of these two cases, current productivity shocks do not have much impact on current profit as prices are preset. Information about future productivity drives the stock price more than current shocks—it is easiest to see this by assuming the unrealistic values $\theta = 0$ and $\omega = 100$. The current shock has impact only through the distribution of revenue between labor and firms, while the news shock increases firms revenue tomorrow through the terms of trade channel as firms can set prices accordingly. Note however that for this channel to work, the process has to be mean reverting, that is $\theta < 1$.

Relative Equity Return in Firm Local Currency Consider now the excess equity return in firm local currency:

$$r^R_{t+1} - i^R_t = \Delta s_{t+1} - \mathrm{E}_t\,\Delta s_{t+1} + r^{R\$}_{t+1}. \tag{59}$$

Note here that the variance of r^R_{t+1} depends on the comovement between the exchange rate and equity returns in investor currency. If there is no monetary policy response to productivity shocks, then the exchange rate is uncorrelated to $r^{R\$}_{t+1}$, because $r^{R\$}_{t+1}$ is a linear function of current and news shocks to productivity, as shown in equation (52). Thus, in

[26]While $\omega < 1$ may be unconventional, Heathcote and Perri (2002) estimate $\omega = .9$.

this case

$$\mathrm{Var}_t(r^R_{t+1}) = \mathrm{Var}_t(\Delta s_{t+1}) + \mathrm{Var}_t(r^{R\$}_{t+1}). \tag{60}$$

Instead, when monetary policy responds to productivity shocks, we have

$$\mathrm{Var}_t(q^R_{t+1}) = \mathrm{Var}_t(s_{t+1}) + 2\,\mathrm{Cov}_t(s_{t+1}, q^{R\$}_{t+1}) + \mathrm{Var}_t(q^{R\$}_{t+1}). \tag{61}$$

Now, we know from the analysis in the previous subsection that the first term, the volatility of the exchange rate, does not increase with introduction of news shocks (because the solution for the exchange rate is a present discounted value equation in our model when $\varepsilon = 1$). However, the last term can increase with the introduction of news shocks. The second term in the middle can potentially increase as well with news shocks, but the effect depends on the monetary policy reaction to productivity shocks. Assume that $\mu^R_t = \chi^R(\nu^R_{1,t} + \nu^R_{2,t-1})$, so that monetary policy does respond to the realization of actual productivity change. In other words, there is no immediate response to news shocks. This implies that a monetary reaction to productivity is invariant to the information structure. On the other hand, since agents know the monetary response function, informed agents anticipate the actual policy change when they observe news about future productivity, while uninformed agents do not anticipate this change. Further, assume that $\varepsilon = 1$, then we have

$$s_{t+1}(\mathcal{I}_{t+1}) - \mathrm{E}(s_{t+1}(\mathcal{I}_{t+1})|\mathcal{I}_t) = \chi^R\nu^R_{1,t+1} + \beta\chi^R\nu^R_{2,t+1} \tag{62}$$

$$s_{t+1}(\mathcal{H}_{t+1}) - \mathrm{E}(s_{t+1}(\mathcal{H}_{t+1})|\mathcal{H}_t) = \chi^R(\nu^R_{1,t+1} + \nu^R_{2,t}) \tag{63}$$

Therefore, given equation (52), we have

$$\begin{aligned}&\mathrm{Cov}(s_{t+1}, q^{R\$}_{t+1}|\mathcal{I}_t)\\ =&(1-\beta)(\psi+1)\left[\left(\frac{\omega-1}{\omega\psi+1}\frac{\beta\theta}{1-\beta\theta} + \frac{\zeta}{1-\zeta}\right)\chi^R\sigma^2_{\nu^R_1} + \frac{\omega-1}{\omega\psi+1}\frac{\beta}{1-\beta\theta}\beta\chi^R\sigma^2_{\nu^R_2}\right]\end{aligned} \tag{64}$$

$$\begin{aligned}&\mathrm{Cov}(s_{t+1}, q^{R\$}_{t+1}|\mathcal{H}_t)\\ =&(1-\beta)(\psi+1)\left(\frac{\omega-1}{\omega\psi+1}\frac{\beta\theta}{1-\beta\theta} + \frac{\zeta}{1-\zeta}\right)\chi^R(\sigma^2_{\nu^R_1} + \sigma^2_{\nu^R_2}).\end{aligned} \tag{65}$$

So $\mathrm{Cov}(s_{t+1}, q^{R\$}_{t+1}|\mathcal{I}_t) > \mathrm{Cov}(s_{t+1}, q^{R\$}_{t+1}|\mathcal{H}_t)$ if $\chi^R > 0$, $\omega = 5$, $\psi = 0$, $\beta = .95$ $\theta = .8$ and $\zeta = 2/3$. . So the introduction of news shocks can increase the covariance term with these parameter values, which also increase the conditional variance of relative equity price in investor currency. Thus, we can see from equation (61) that the introduction of news shocks can potentially increase the conditional variance of the relative equity price in firm currency.

Note finally that Home (or Foreign) equity prices, which can be written as the sum of world equity price and half of relative equity price, $q_t = q_t^W + 1/2q_t^R$, can also become more volatile with the introduction of news shocks depending on the parameter values assumed. This is because since news about relative productivity and world productivity are orthogonal under our model assumptions, they cannot offset (or compound) each other.

5 Conclusions

In this paper, we study the role of news shocks for asset price volatility in general equilibrium. Specifically, we investigate how news about future money supply and productivity affect equity price and exchange rate volatility in a standard two-country DSGE model with complete asset markets. To relate clearly our contribution to the previous literature, and also to highlights the fundamental difference between introducing news shocks in partial and general equilibrium, we also analyze a standard PVM.

First and most importantly we show that, in general equilibrium, news shocks about future productivity can increase the volatility of equity prices relative to a set up in which agents do not observe news under plausible assumptions on parameter values. This is in stark contrast to the volatility reducing effect of introducing news shocks in a PVM, as in the seminal analysis of West (1988). This is because, in general equilibrium, agents who observe news shocks change their behavior and thereby affect the cash flow stream on which asset prices are defined. This mechanism is not present in the typical PVM because the process for the asset cash flow is exogenous in that set up.

Second, we also show that news shocks positively correlated with current shocks can sometimes help increase the conditional variance of asset prices, holding the variance of underlying exogenous process constant, with effects similar to those induced by persistent exogenous processes. However, unlike in PVM, in general equilibrium, correlated news shocks could also reduce the variance of asset prices under certain assumptions on the parameter values.

Third and finally, the theoretical analysis in the paper has important implications for estimation of the impact of monetary policy shock on asset prices. We show in a simple PVM example that correlated news shocks can be observationally equivalent to a serially correlated fundamental process to the econometrician. However, while correlated news shocks can explain why an asset price model cannot fit the data, a model with persistent fundamentals cannot do so—a point that is consistent with Cochrane's (1994) observation that news shocks may help to explain a lack of empirical ability to explain the business cycle. As a result, econometric specifications of the analysis of the impact of fundamental shocks on asset prices that omit explicit considerations of the news shocks may be biased as we show in our DSGE model. This is notwithstanding the fact that the data generating process for the fundamentals is the same as without news shocks. The analysis in the paper thus shows the usefulness and the challenges of introducing news shocks to model asset prices.

Our general equilibrium model is too simple for a quantitative exercise on the general equilibrium effects we uncovered. We regard the quantitative analysis of asset price volatility in DSGE models with news shocks, as well as the development of the implications of such analyses for the empirical identification and measurement of the effects of news shock on asset prices, as two interesting areas on future research.

A Appendix 1

In this section, we derive the implications for the partial equilibrium analysis of section 2 of assuming that news are not observable to the econometricians. That is, not only the current value of z_t but also the past values of z_t are not in the information set of the econometrician. So define $\mathcal{H}'_t$ a linear space spanned by only the history of $\{f_t\}$ up to time t and recall that

$$\Delta f_t = \varepsilon_{1,t} + \rho \frac{\sigma_2}{\sigma_1} \varepsilon_{t-1} + \eta_{t-1}. \tag{66}$$

Since the econometricians cannot distinguish ε_t and η_{t-1}, the process must be appearing as

$$\Delta f_t = \theta_t + \rho_\theta \theta_{t-1}. \tag{67}$$

where ρ_θ is a root of the quadratic function:

$$\frac{\rho_\theta}{1+\rho_\theta^2} = \frac{\rho \sigma_1 \sigma_2}{\sigma_1^2 + \sigma_2^2} \left(= \frac{Cov(\Delta f_t, \Delta f_{t-1})}{Var(\Delta f_t)} \right) \tag{68}$$

and θ_t is an i.i.d shock with mean zero and variance, $\frac{\sigma_1^2+\sigma_2^2}{1+\rho_\theta{}^2}$. As $\frac{\sigma_1\sigma_2}{\sigma_1^2+\sigma_2^2} \leq 1/2$, it is easy to see that one of the root lies inside the unit circle and the other outside. Using the root with $|\rho_\theta| < 1$, we have

$$\theta_t = \sum_{j=0}^{\infty} (-\rho_\theta)^j \Delta f_{t-j} = \sum_{j=0}^{\infty} (-\rho_\theta)^j (\varepsilon_{t-j} + z_{t-1-j}). \tag{69}$$

Thus, the theoretical asset price modeled by econometricians

$$x_t(\mathcal{H}'_t) = \sum_{j=0}^{\infty} \beta^j \, \mathrm{E}(f_{t+j} | \mathcal{H}_t) = \frac{1}{1-\beta} f_t + \frac{\beta}{1-\beta} \rho_\theta \theta_t. \tag{70}$$

B Appendix 2

In this appendix we report the complete solution of the model described in section 3 and used in section 4.

B.1 Notation

We denote the log deviation of any variables from the initial symmetric steady state with lower case letters. That is

$$z_t \equiv \ln(Z_t) - \ln(Z_0). \tag{71}$$

We also use an asterisk $*$ to denote foreign variables, superscript R for relative variables, and superscript W for world average, i.e.,

$$\begin{aligned} z_t^R \equiv & z_t - z_t^* \\ z_t^W \equiv & \frac{1}{2} z_t + \frac{1}{2} z_t^* \end{aligned}$$

B.2 Model Equilibrium Conditions

The log-linear version of the model can be summarized by the following equations and their foreign counterparts:

$$\varepsilon(m_t - p_t) = \rho c_t + \frac{\beta}{1-\beta} \operatorname{E}_t d_{t,t+1} \tag{72}$$

$$d_{t,t+s} = \rho c_t + p_t - \rho c_{t+s} - p_{t+s} \tag{73}$$

$$i_t = - \operatorname{E}_t d_{t,t+1} \tag{74}$$

$$w_t = \psi l_t + \rho c_t + p_t \tag{75}$$

$$p_t = \frac{1}{2} p_{h,t} + \frac{1}{2} p_{f,t} \tag{76}$$

$$p_{h,t} = \operatorname{E}_{t-1}(w_t - a_t) \tag{77}$$

$$p_{f,t} = \operatorname{E}_{t-1}(w_t^* - a_t^* + s_t) \tag{78}$$

$$a_t + l_t = \frac{1}{2}\left[-\omega(p_{h,t} - p_t) + c_t\right] + \frac{1}{2}\left[-\omega(p_{h,t}^* - p_t^*) + c_t^*\right] \tag{79}$$

$$\rho(c_t - c_t^*) = s_t + p_t^* - p_t \tag{80}$$

$$\tau_t \equiv p_{h,t} - p_{f,t} = p_{h,t}^* - p_{f,t}^* \tag{81}$$

Home pre-dividend equity price and the equity return are, respectively:

$$q_t = (1-\beta) \sum_{s=0}^{\infty} \operatorname{E}_t \beta^s (d_{t,t+s} + \pi_{t+s}), \tag{82}$$

$$r_{t+1} = q_{t+1} - \frac{1}{\beta} q_t + \frac{1-\beta}{\beta} \pi_t. \tag{83}$$

B.3 Model Solution

Using the assumptions made in section 3 on the underlying shocks, the solution for relative variables is given by the following equations:

$$s_t = \mathrm{E}_{t-1} m_t^R + (1-\beta)\varepsilon(m_t^R - \mathrm{E}_{t-1} m_t^R) + \beta(\mathrm{E}_t m_{t+1}^R - \mathrm{E}_{t-1} m_t^R) \tag{84}$$

$$p_t^R = \mathrm{E}_{t-1} m_t^R \tag{85}$$

$$\rho c_t^R = (1-\beta)\varepsilon(m_t^R - \mathrm{E}_{t-1} m_t^R) + \beta(\mathrm{E}_t m_{t+1}^R - \mathrm{E}_{t-1} m_t^R) \tag{86}$$

$$\tau_t = -\frac{\psi+1}{\omega\psi+1} \mathrm{E}_{t-1} a_t^R \tag{87}$$

$$l_t^R = \omega\left(\frac{\psi+1}{\omega\psi+1}\right) \mathrm{E}_{t-1} a_t^R - a_t^R \tag{88}$$

$$\begin{aligned} w_t^R =& \psi\left[\omega\left(\frac{\psi+1}{\omega\psi+1}\right) \mathrm{E}_{t-1} a_t^R - a_t^R\right] \\ &+ \mathrm{E}_{t-1} m_t^R + (1-\beta)\varepsilon(m_t^R - \mathrm{E}_{t-1} m_t^R) + \beta(\mathrm{E}_t m_{t+1}^R - \mathrm{E}_{t-1} m_t^R) \end{aligned} \tag{89}$$

$$q_t^R = s_t + (1-\beta)(\psi+1)\left[\frac{\omega-1}{\omega\psi+1}\left(\frac{1}{1-\beta\theta}a_t^R - \nu_{1,t}^R + \frac{\beta}{1-\beta\theta}\nu_{2,t}^R\right) + \frac{\zeta}{1-\zeta}\nu_{1,t}^R\right] \tag{90}$$

$$\pi_t^R = s_t + (\psi+1)\left[\frac{\omega-1}{\omega\psi+1}(a_t^R - \nu_{1,t}^R) + \frac{\zeta}{1-\zeta}\nu_{1,t}^R\right] \tag{91}$$

$$\begin{aligned} r_t^R =& \Delta s_{t+1} \\ &+ (1-\beta)(\psi+1)\left[\left(\frac{\omega-1}{\omega\psi+1}\frac{\beta\theta}{1-\beta\theta} + \frac{\zeta}{1-\zeta}\right)\nu_{1,t+1}^R + \frac{\omega-1}{\omega\psi+1}\frac{\beta}{1-\beta\theta}\nu_{2,t+1}^R\right] \end{aligned} \tag{92}$$

where $\zeta \equiv \frac{\lambda-1}{\lambda}$ is labor share of the economy.

For world variables, we have

$$p_t^W = -\operatorname{E}_{t-1}\frac{\rho}{\varepsilon}\frac{\psi+1}{\rho+\psi}a_t^W + \operatorname{E}_{t-1} m_t^W \tag{93}$$

$$\begin{aligned} c_t^W =& \frac{1}{\rho}\left[(1-\beta)\varepsilon(\mu_{1,t}^W) + \beta(\mu_{1,t}^W + \mu_{2,t}^W)\right] \\ &+ \frac{\psi+1}{\rho+\psi}\left[\operatorname{E}_{t-1} a_t^W + \beta\left(1-\frac{1}{\varepsilon}\right)(\nu_{1,t}^W + \nu_{2,t}^W)\right] \end{aligned} \tag{94}$$

$$l_t^W = c_t^W - a_t^W \tag{95}$$

$$w_t^W = \psi l_t^W + \rho c_t^W + p_t^W \tag{96}$$

$$\pi_t^W = p_t^W + c_t^W + \frac{\zeta}{1-\zeta}\left[(\psi+1)(a_t^W - \operatorname{E}_{t-1} a_t^W) - (\rho+\psi)(c_t^W - \operatorname{E}_{t-1} c_t^W)\right] \tag{97}$$

$$q_t^W = (1-\rho)\beta(\operatorname{E}_t c_{t+1}^W - c_t^W) + c_t^W + p_t^W + (1-\beta)\frac{\zeta}{1-\zeta}\left[(\psi+1)\,a_t^W - (\rho+\psi)\,c_t^W\right] \tag{98}$$

$$\begin{aligned} r_{t+1}^W =& \Delta p_{t+1}^W + \rho(\operatorname{E}_t c_{t+1}^W - c_t^W) \\ &+ \beta(1-\rho)\left(\operatorname{E}_{t+1} c_{t+2}^W - \operatorname{E}_t c_{t+1}^W\right) + [\rho + (1-\beta)(1-\rho)](c_{t+1}^W - \operatorname{E}_t c_{t+1}^W) \\ &+ (1-\beta)\frac{\zeta}{1-\zeta}[(\psi+1)\,(a_{t+1}^W - \operatorname{E}_t a_{t+1}^W) - (\rho+\psi)\,(c_{t+1}^W - \operatorname{E}_t c_{t+1}^W)]. \end{aligned} \tag{99}$$

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