CHAPTER 7

Financial Conditions

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> *Financial conditions are important. They matter enormously to monetary policy because their movements can often diverge from the trajectory of short-term rates, and because they affect economic activity and the economic outlook. While it is essential to account for financial conditions appropriately in conducting monetary policy, it is also important not to overreact to every short-term wiggle in financial markets. In addition, it is important to remember that the policy goal is not the level of financial conditions per se, but the achievement of the Federal Reserve's dual mandate objectives.—W. Dudley (2017)*

Financial conditions play an important role in monetary policy. In general, indices of financial conditions gauge how easily money and credit flow through the economy via financial markets by examining indicators such as borrowing costs, risk spreads, asset price volatility, exchange rates, inflation rates, and commodity prices. Central banks commonly adjust their policy stances and their forward guidance as a function of shocks to financial conditions. For example, the asset purchase programs that major central banks undertook after the global financial crisis were aimed at influencing financial conditions in risky asset markets, such as longer-term sovereign debt markets through term premiums, mortgage markets through mortgage spreads, and even credit markets in some jurisdictions.

Financial conditions are therefore highly significant forecasting variables for the conditional distribution of the output gap. This chapter extends recent work by Adrian, Boyarchenko, and Giannone (2016) to a multicountry setting. We document that loose financial conditions forecast a high output gap and low output gap volatility, a finding that is robust to variations in the indicators of financial conditions, countries, and time samples used.

We summarize the downside risk to GDP using the notion of growth at risk (GaR), which was developed by the IMF and explained in the October 2017 *Global Financial Stability Report* (IMF 2017). GaR(τ) is the value at risk (VaR) of

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the GDP gap τ quarters into the future. GaR is shown to vary primarily as a function of financial conditions but not as a function of other nonfinancial economic conditions (such as inflation or unemployment), as discussed in IMF (2017). Financial conditions should be a key variable for the conduct of monetary policy, even if they do not enter the central bank's objective (or loss) function, because they significantly determine GaR.

To study the quantitative importance of GaR for monetary policymaking, we calibrate an optimal monetary policy rule in a reduced form macro-financial model. The model features a standard New Keynesian setup with a Phillips curve that is determined by producers with staggered price setting. A financial intermediation sector is added on to the standard New Keynesian model of Woodford (2001) and Galí (2015) and is subject to a VaR constraint, as in Adrian and Duarte (2016). The price of risk varies as a function of the tightness of the VaR constraint of intermediaries, shifting the household consumption Euler equation (the investment/saving (IS) curve). Notably, the state variables that impact the second moment of consumption also impact its first moment. Hence, monetary policy moves both first and second moments. This is important to link monetary policy to the volatility of output.

The optimal monetary policy rule in this reduced form setting depends not only on the output gap and inflation, but also on financial conditions. We calibrate the optimal monetary policy rule across countries, and find that optimal monetary policy deviates significantly from a classic Taylor rule.[1] This is because financial conditions carry important information about the evolution of the variance of output gaps. In other words, financial conditions help policymakers better take into account the distribution of output gaps, including downside risks.

There are sizable welfare gains from using an augmented Taylor rule that includes financial conditions over a classic Taylor rule. In the augmented Taylor rule, monetary policy is allowed to respond to financial conditions, whereas it is constrained from doing so when following a classic Taylor rule. Results are robust to the choice of country and time sample, and to whether or not we include the global financial crisis. Welfare gains are approximately equal for advanced and emerging market economies, although the trade-off between the mean and variance of the output gap appears somewhat more attenuated in emerging markets. In all cases, however, optimal monetary policy responds to financial conditions.

These findings contribute to the recent debate about the role of financial stability in monetary policy. To date, the debate has essentially focused on whether monetary policy should pursue an additional mandate—that of minimizing the risks of costly financial crises. The literature, summarized in Smets (2014) and expanded in IMF (2015) and Svensson (2015), focuses on the costs and benefits of increasing policy rates above what is warranted to satisfy inflation and output

[1]The Taylor rule, named after Taylor (1993), is taken here to be a simple rule used to set monetary policy in response to the output gap and deviations of inflation from target.

objectives so as to diminish the risks of occasional crises. As explained in Chapter 6, in general and under plausible calibrations, the costs of doing so tend to outweigh the benefits. In addition, macroprudential policy appears better suited to directly target the imperfections that undermine financial stability, with the implication that monetary policy should remain focused on its output and price stability mandates. We maintain that assumption in this chapter—with the innovation that to do so optimally, monetary policymakers should use financial conditions to forecast not only the mean (as in standard analyses), but also the variance of output.

Our findings are closely related to the recent literature on the role of financial intermediation in monetary policy. Curdia and Woodford (2010), Gertler and Karadi (2011), and Gambacorta and Signoretti (2014) consider the welfare gains of monetary policy responding to credit spreads. They generally find that such a response is preferable following financial sector shocks but not necessarily in response to others, such as productivity shocks. This chapter studies instead a nonlinear model better suited to emphasize second moments—namely, the variance of GDP—because of the capacity of financial conditions to forecast downside risks to GDP.

FINANCIAL CONDITIONS AND GROWTH AT RISK

We investigate the conditional distribution of the GDP gap as a function of financial conditions by modeling the mean and variance of the output gap as functions of financial conditions for a sample of advanced and emerging market economies. We run panel regressions to gauge average behavior across countries.

The goal in this initial analysis is to quantify the trade-off between the mean and variance of the output gap. This trade-off is a key ingredient in monetary policy decisions, because output and inflation stabilization crucially depend on the conditional mean and variance of the output gap.

We find a clear negative relationship between the mean and variance of the output gap. When financial conditions become tighter (higher credit spreads or higher price of risk), the output gap falls and its variance grows. This emphasizes a key trade-off for policymakers. These results are robust to the sample and period of study, although there is heterogeneity across countries. If anything, the trade-off has become less pronounced more recently and is somewhat smaller in emerging market economies than in advanced economies.

We use quarterly data throughout. Consumer price indices (CPIs) and real GDP are obtained from the IMF's International Financial Statistics database. The output gap is computed by applying to the GDP data a Hodrick-Prescott filter with coefficient $\lambda = 1600$. The inflation rate is defined as the year-over-year percentage change in consumer prices. The financial conditions indices (FCIs) employed in the analysis are from the IMF's *Global Financial Stability Report* (IMF 2017). Univariate FCIs offer a parsimonious way of summarizing the

TABLE 7.1.

Country Coverage	
Advanced Economies	**Emerging Markets**
Australia (AUS)	Brazil (BRA)
Canada (CAN)	Chile (CHL)
France (FRA)	China (CHN)
Germany (DEU)	India (IND)
Italy (ITA)	Indonesia (IDN)
Japan (JPN)	Korea (KOR)
Sweden (SWE)	Mexico (MEX)
United Kingdom (GBR)	Russia (RUS)
United States (USA)	South Africa (ZAF)
	Turkey (TUR)

Note: Three-letter country codes are from the International Organization for Standardization.

information contained in asset prices and credit aggregates from broad sets of domestic and global financial variables.[2] Higher FCI values correspond to tighter financial conditions or a higher price of risk. All estimations use the logarithm of the FCIs.[3] The panels are unbalanced, with data for advanced economies starting in 1973 and for emerging market economies starting in 1990. Country coverage is presented in Table 7.1.

Estimation

For the panel estimation, we apply a two-step procedure.

$$\Delta y_{i,t} = \alpha_0 + \alpha_{i,1} + \alpha_{21} s_{i,t-1} + \alpha_{23} y_{i,t-1} + \alpha_{34} \pi_{i,t-1} + \epsilon_{i,t}, \tag{7.1}$$

where $y_{i,t}$ is the output gap for country i and $\Delta y_{i,t}$ is its change between periods $t-1$ and t, $\pi_{i,t-1}$ is the lagged inflation rate, $s_{i,t-1}$ is the lagged FCI, and $\epsilon_{i,t}$ is a heteroscedastic error term.

In the second step, we model the heteroscedasticity in $\Delta y_{i,t}$ by taking the estimated residuals $\widehat{\epsilon}_{i,t}$ and we calculating $ln\left(\widehat{\epsilon}_{i,t}^{\,2}\right)$. We interpret these log-squared residuals as the realized volatility of the output gap and we regress them on the same variables used in equation (7.1):

$$ln\left(\widehat{\epsilon}_{i,t}^{\,2}\right) = \beta_0 + \beta_{i,1} + \beta_{12} s_{i,t-1} + \beta_{23} y_{i,t-1} + \beta_{34} \pi_{i,t-1} + \nu_{i,t} \tag{7.2}$$

Both panel regressions are estimated by ordinary least squares (OLS) with fixed effects and robust standard errors. Results for regressions 7.1 and 7.2 are presented in Table 7.2.

[2]See IMF (2017) for more details on the underlying data and estimation methods.

[3]As FCIs are standardized, a country-common positive constant for the FCIs is added first to have strictly positive domain and then standardize the resulting logarithm. Results are robust to the choice of the constant.

TABLE 7.2.

Output Gap Conditional Mean and Volatility from Panel Estimates

	Advanced Economies		Emerging Markets	
	(1)	(2)	(1)	(2)
	$\Delta y_{i,t}$	$ln(\widehat{\epsilon_{i,t}^2})$	$\Delta y_{i,t}$	$ln(\widehat{\epsilon_{i,t}^2})$
$S_{i,t-1}$	−0.57*	0.65*	−1.28*	0.93**
$y_{i,t}$	−0.18*	0.05	−0.30*	0.14*
$\pi_{i,t}$	0.01	0.09*	−0.00	0.01
Constant	0.64*	−3.32*	0.41*	−1.84*
Observations	1,602	1,602	918	918
R^2	0.13	0.04	0.18	0.03
Number of countries	10	10	10	10

Sources: Data for Real GDP and consumer price index inflation come the IMF's International Financial Statistics database. Data for financial conditions indices come from IMF (2017). Sample for advanced economies covers 1973:Q1 to 2016:Q4, while emerging markets' sample covers 1990:Q1 to 2016:Q4.

Notes: $S_{i,t}$ = financial conditions index; $y_{i,t}$ = output gap; $\pi_{i,t}$ = consumer price index inflation rate; $\hat{\epsilon}_t$ = residuals from equation (7.1)
*p<0.01, **p<0.05.

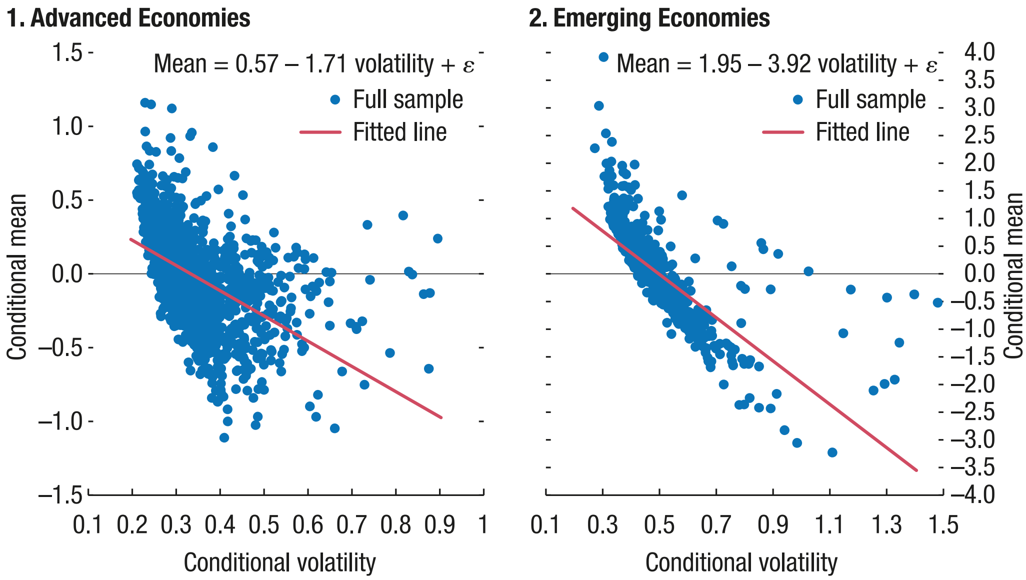
The estimates from regressions (7.1) and (7.2) show that financial conditions are significant in explaining the first and second moments of the output gap, both for advanced economy and emerging market economy samples. This is in line with Adrian and Duarte (2016) and IMF (2017). The output gap depends negatively on financial conditions (a higher FCI, namely higher spreads, induces a lower output gap), whereas the correlation is positive for the variance of the output gap. As a result, the unconditional distribution of the output gap is skewed, even if shocks are normal. This is as in Adrian, Boyarchenko, and Giannone (2016).

To show the negative conditional relationship between the mean and variance of the output gap, we regress the fitted values of the dependent variable in Equation 7.1 on the fitted values of the dependent variable in equation (7.2). Figure 7.1 shows the scatter plots and fitted OLS line.

The negative relationship underscores the intratemporal trade-off faced by policymakers. A closed output gap (an output gap of zero) is consistent with a positive variance, a result of the positive intercept. The trade-off that arises is captured by the slope of the best-fit line. Reducing the output gap from a positive level to zero, for instance, comes with an increase in variance. The steeper the line, the shallower the trade-off. In the limiting case of a vertical line, the trade-off disappears. Variance would be constant (homoscedastic), and the central bank would be able to adjust the output gap with no cost to volatility.

This trade-off seems to have diminished in recent years. The absolute values of both the intercept and the slope have increased over time; that is, curves have become steeper. Figure 7.2 shows the scatter plot and fitted OLS regression lines for two subsamples. For advanced economies, the sample is divided into two periods, from 1973 to the end of 1990 and from 1991 to the end of 2016. For emerging market economies, the sample is divided into the periods between 1990 and 1995, and 1996 to the end of 2016. If anything, the trade-off between the mean and the variance of the output gap appears somewhat stronger for advanced economies than for emerging market economies.

Figure 7.1. Estimated Mean and Volatility from Panel Estimation



Source: Authors' calculations.

The Model

The model, taken from Adrian and Duarte (2016), is a microfounded nonlinear New Keynesian model augmented by a financial intermediation sector with vulnerabilities, but otherwise standard.

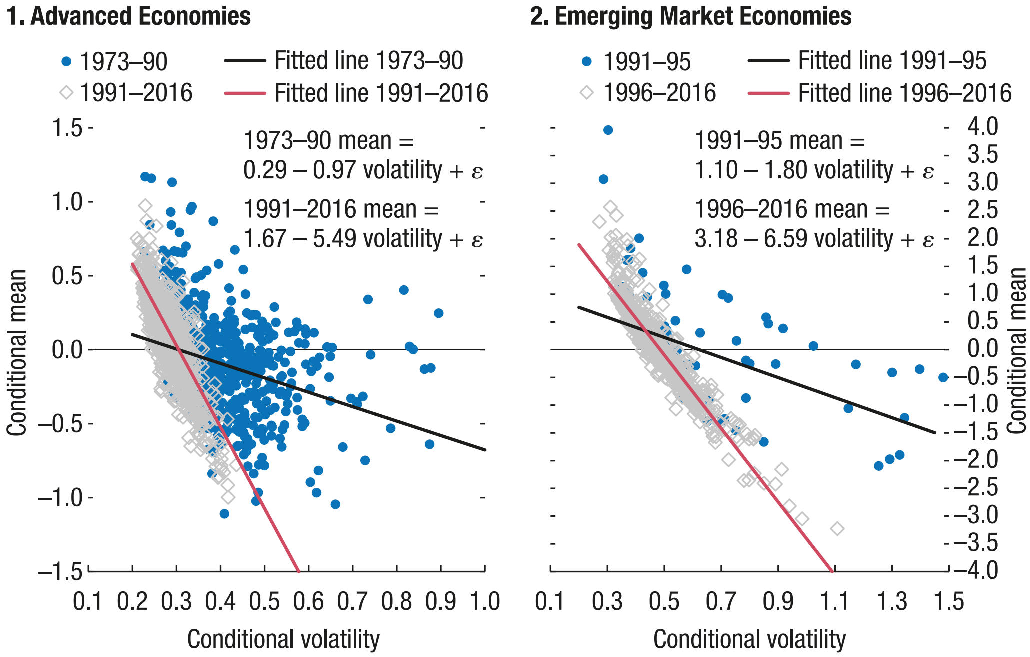
There are four types of agents in the economy: a representative household, firms that produce consumption goods, banks that intermediate household savings and finance producers, and a central bank.

Firms are exactly as in the standard New Keynesian model. They produce a continuum of differentiated goods in a monopolistically competitive way with sticky (Calvo-style, assuming a fixed probability of being able to reset prices at any given time) prices using a production technology that is linear in labor. There is no physical capital and productivity is constant.

The representative household maximizes its utility of consumption and leisure subject to its budget constraint. Unlike the standard New Keynesian model, the household cannot directly finance the firms that produce consumption goods in the economy. Instead, it can only invest in the intermediary sector by trading a complete set of zero-net-supply Arrow-Debreu securities with intermediaries (which can replicate, among other payoffs, the payoff of riskless deposits).

The intermediary sector invests the resources obtained from households and its previously accumulated net worth in a portfolio of assets. Intermediaries have the necessary information, expertise, or relationships to directly finance goods producers. Therefore, intermediaries can hold in their portfolios the stocks and bonds of the goods-producing firms. Each intermediary can also hold stocks and

Figure 7.2. Estimated Mean and Volatility from Panel Estimation on Subsamples



Source: Authors' calculations.

bonds of other intermediaries and trade a complete set of Arrow-Debreu securities with the household and with other intermediaries. There are two frictions in the intermediary sector. First, intermediaries are subject to exogenous preference shocks, which are the only shocks in the economy. These preference shocks can be interpreted as shocks that shift intermediaries' effective risk aversion or their beliefs. Second, when picking their optimal portfolio to maximize the expected net present value of dividends (shareholder value), intermediaries are subject to a VaR constraint that limits the amount of tail risk they can take.[4]

The *central bank* has a dual mandate to minimize the present value of mean square deviations of inflation and the output gap from target.

Policy can achieve neither the first- nor the second-best equilibrium. The first-best is the allocation that coincides with the one obtained in the decentralized equilibrium in which firm prices are fully flexible and households can finance firms without any frictions (without the need for an intermediary). The second-best can be obtained when retaining sticky prices but removing the friction that households cannot invest in firms without an intermediary. For both the first- and second-best equilibriums, all endogenous variables are constant since the only shock in the economy is to the preferences of intermediaries, and they

[4]Adrian and Shin (2010) provide extensive motivation.

are bypassed completely.[5] In the presence of the three introduced frictions—the inability of the household to finance firms directly, the preference shocks to intermediaries, and the VaR constraint—the decentralized equilibrium always results in allocations with lower welfare than in the second-best case.[6] This holds true independent of monetary policy. From the point of view of the central bank, the frictions are taken as given and cannot be eliminated by monetary policy. The best the central bank can achieve is a third-best equilibrium.

The reduced-form version of the model is given by

$$dy_t = \frac{1}{\gamma}(i_t - \pi_t - r)dt + d(rp_t), \tag{7.3}$$

$$d\pi_t = (\beta\pi_t - \kappa y_t)dt, \tag{7.4}$$

$$i_t = \psi_0 + \psi_\pi \pi_t + \psi_y y_t + \psi_v V_t, \tag{7.5}$$

$$V_t = -\mathbb{E}_t[dy_t]\tau - \alpha \mathbb{V}_t[dy_t]\sqrt{\tau}, \tag{7.6}$$

$$d(rp_t) = \xi(V_t - s_t)dZ_t, \tag{7.7}$$

$$ds_t = -\rho_s(s_t - \bar{s}) + \sigma_s dZ_t. \tag{7.8}$$

The core of the model consists of traditional IS and Phillips curves, although the former is expanded to include the risk premium. Equation (7.3) is the dynamic IS equation, the linearized first-order condition[7] of the representative household. The constant $\gamma - 1 > 0$ is the elasticity of intertemporal substitution,[8] and the constant r is the natural rate of interest. The endogenous variables in the dynamic IS equation are the output gap, y_t, the nominal interest rate, i_t, inflation, π_t and the risk premium rp_t. Equation (7.4) is the New Keynesian Phillips curve, the firms' linearized first-order conditions when they maximize profits by picking the price of differentiated consumption goods under monopolistic competition while subject to consumers' demand and Calvo pricing. The constant $\beta > 0$ is the representative household's discount rate and $\kappa > 0$ is related to the amount of price stickiness in the economy. As $\kappa \to \infty$, prices become fully flexible, while as $\kappa \to 0$, prices become fixed.

[5]There is also an inefficiency associated with the monopoly power of firms, which we reduce to zero in steady-state by means of an appropriate tax.

[6]If the decentralized economy with all three frictions were to replicate the first or second best, it would have to feature constant consumption for the household. The trading between the household and the intermediaries would have to be such that intermediaries provide full insurance to the household against all shocks. If that were the case, intermediaries would bear all the risk in the economy, which always implies that, eventually, intermediaries must violate their VaR constraint, showing that no equilibriums exist with constant consumption for the household.

[7]For all stochastic processes, linearization means linearizing the drift and stochastic parts of the true nonlinear process around the deterministic steady-state.

[8]The representative agent has constant relative risk aversion (CRRA) utility, and hence γ is its coefficient of relative risk aversion.

Equation (7.5) is the central bank's policy rule, where ψ_0, ψ_π , ψ_y and ψ_v are constants picked by the central bank. In addition to responding to inflation and the output gap, as is typical in a traditional Taylor rule, the central bank can also respond to output gap vulnerability, V_t.

Output gap vulnerability is defined in equation (7.6) as the VaR of the growth rate of the output gap projected at horizon $\tau > 0$ and level $\mathcal{N}(-\alpha)$, where $\mathcal{N}$ is the cumulative distribution function of a standard normal distribution. This means that V_t is the $\mathcal{N}(-\alpha)$ quantile of the projected distribution of $dy_{t+\tau}$ conditional on time t information. For example, if $\tau = 1$ and $\alpha = \mathcal{N}^{-1}(0.05) = -1.96$, V_t is the 5th percentile of the one-year-ahead output gap growth distribution.

The central bank may want to respond to vulnerability because, as shown in equation (7.7), it is the key endogenous determinant of the risk premium rp_t that, in turn, directly contributes to the output gap dynamics in the IS equation. The parameter ξ in equation (7.7) is a reduced-form parameter that captures the strength of the frictions—preference shocks and VaR constraint—in the intermediation sector. When $\xi = 0$, the risk premium is constant (in particular, it is constant with a value of 0) and the model collapses to a standard deterministic New Keynesian model in continuous time identical to that studied in Werning (2011) and Cochrane (2017). When $\xi \neq 0$, on the other hand, fluctuations in risk premiums induce changes in the conditional volatility of the output gap through equation (7.3).

Output gap vulnerability is a consequence of intermediaries' VaR constraint combined with the trading between the household and intermediaries of a complete set of Arrow-Debreu securities. The VaR constraint creates vulnerability in the intermediaries' net worth; the trading between the household and intermediaries equalizes their marginal utilities, transmitting the vulnerability from intermediaries to households. Of course, without any risk in the economy, the VaR constraint would never bind, so it is crucial to have some uncertainty for vulnerability to arise.

Uncertainty comes from exogenous shocks to vulnerability given by s_t, which also affect the risk premium as shown in equation (7.7). The process for s_t is a simple autoregressive process given by equation (7.8). The constant s is the long-term mean of s_t, $\sigma_s > 0$ is its instantaneous volatility and $\rho_s > 0$ controls its rate of mean reversion.

This model exhibits a key amplification mechanism. Fluctuations in risk premiums induce changes in the conditional volatility of the output gap, as discussed earlier. Changes in the output gap feed into vulnerability through equation (7.6). As vulnerability changes, so do risk premiums, and this again affects the output gap, vulnerability, and so on. The endogenous feedback between risk premiums, vulnerability, and the output gap is the result of the amplification mechanisms in the intermediation sector that arise due to financial frictions.[9]

[9]See Adrian and Shin (2009) for an illustration of how a VaR constraint can generate amplification.

As a result, when considering how to conduct monetary policy, the central bank must consider vulnerability not only because it is informative about the state of the economy but also because changes in policy endogenously change V_t, and changes in V_t feed back into inflation and the output gap. Note that even if the central bank set $\psi_v = 0$, it would still have an important impact on V_t through its influence on π_t and y_t.

CALIBRATION

For simplicity, we now consider a simplified version of the model in which prices are fully rigid. This implies inflation is identically equal to zero at all times. Plugging equation (7.7) into equation (7.3), the dynamics of the economy reduce to

$$dy_t = \frac{1}{\gamma}\left(i_t - r + \gamma\hat{\eta}\xi\left(V_t - s_t - \frac{1}{2}\frac{\hat{\eta}}{\xi\gamma}\right)\right)dt + \xi(V_t - s_t)dZ_t \tag{7.9}$$

$$V_t = -\mathbb{E}_t[dy_t]\tau - \alpha\mathbb{V}_t[dy_t]\sqrt{\tau} \tag{7.10}$$

$$ds_t = -\rho_s(s_t - \bar{s}) + \sigma_s dZ_t \tag{7.11}$$

where y_t is the output gap, i_t is the nominal (and real, since inflation is zero) risk-free rate, V_t is vulnerability, as defined by equation (7.10), s_t is an exogenous shock, and Z_t is a standard Brownian motion. As for the constants, $\gamma - 1$ is the elasticity of intertemporal substitution, r is the natural rate, and $\hat{\eta}$, ξ, α, τ, ρs, $\bar{s}$, σs are parameters related to vulnerability that have to be calibrated.

To calibrate, we use the time series for the conditional mean, $\mathbb{E}_t\,[dy_t]$, and conditional volatility, $\mathbb{V}_t\,[dy_t]$, of output gap growth that we obtained above. In the model, these are given by

$$\mathbb{E}_t[dy_t] = \frac{1}{\gamma}\left(i_t - r + \gamma\hat{\eta}\xi\left(V_t - s_t - \frac{1}{2}\frac{\hat{\eta}}{\xi\gamma}\right)\right) \tag{7.12}$$

$$\mathbb{V}_t[dy_t] = \xi(V_t - s_t) \tag{7.13}$$

Using equations (7.9), (7.10), (7.12), and (7.13), we get

$$\mathbb{E}_t[dy_t] = -\frac{1 + \alpha\sqrt{\tau}\,\xi}{\tau\xi}\mathbb{V}_t[dy_t] - \frac{1}{\tau}s_t. \tag{7.14}$$

This equation shows that the model can generate the same linear relation between the conditional mean and conditional volatility of the output gap that we observe in the data, displayed in Figure 7.1. In addition, as in the data, the model can generate dispersion around the mean-volatility line. In the model, the variation in the mean and volatility of the output gap occurs through the vulnerability shock s_t. Shocks to vulnerability shift the mean-volatility line up and down in parallel fashion (by changing the value of its intercept).

To estimate the parameters of the model, we run a regression of $\mathbb{E}_t[dy_t]$ on $\mathbb{V}_t[dy_t]$

$$\mathbb{E}_t[dy_t] = A \times \mathbb{V}_t[dy_t] + B + \varepsilon_t \tag{7.15}$$

and obtain OLS estimates for $\hat{A}$ and $\hat{B}$. We compare equations (7.14) and (7.15) to identify

$$\hat{A} = -\frac{1+\alpha\sqrt{\tau}\,\xi}{\tau\xi}$$

$$\hat{B} = -\frac{1}{\tau}\bar{s}$$

$$\hat{\varepsilon}_t = -\frac{1}{\tau}(s_t - \bar{s})$$

We set by hand

$$\alpha = -1.645$$

$$\sqrt{\tau} = 1$$

to have a one-year horizon ($\tau = 1$) VaR at around the 5 percent level ($\alpha = -1.645$). It then follows that

$$\bar{s} = -\hat{B}\tau$$

$$\xi = -\frac{1}{\hat{A}\tau + \alpha\sqrt{\tau}}$$

$$\rho_s = -\log\left(\frac{Cov(\hat{\varepsilon}_{t+1}, \hat{\varepsilon}_t)}{Var(\hat{\varepsilon}_t)}\right)$$

$$\sigma_s = \frac{Std(\hat{\varepsilon}_t)}{\sqrt{\Delta t}}$$

where σ_s is adjusted by $1/\sqrt{\Delta t}$ so that it represents an annual volatility (Δt is the frequency of the data used in regression (7.15); for example, if the data are quarterly, then $\Delta t = 1/4$).

Table 7.3 shows the calibrated parameter values from estimating the conditional mean and conditional volatility obtained with the panel data regressions.

In the next section, when calculating welfare, we reintroduce the Phillips curve. We calibrate κ by choosing $\beta = 0.01$, and then estimating the model's Phillips curve country-by-country and averaging the values.

TABLE 7.3.

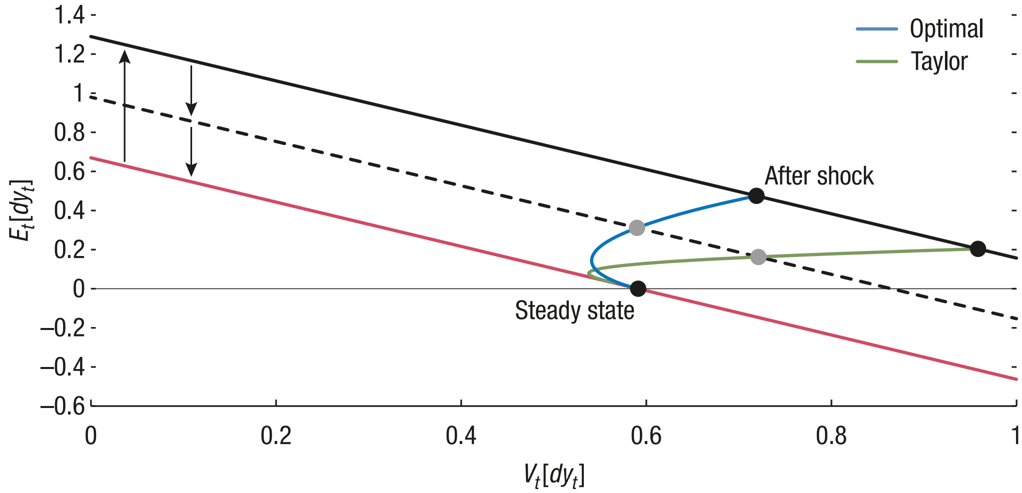
Calibration Values from Panel Estimates

	AE (1973–2016)	AE (1973–90)	AE (1991–2016)	EME (1996–2016)
s	−0.57	−0.29	−1.67	−3.18
ξ	0.30	0.38	0.14	0.12
ρ_s	0.14	0.21	0.12	0.15
σ_s	0.27	0.29	0.19	0.25
κ	0.18	−0.04	0.20	−0.36

Source: Authors' calculations.

Notes: AE = advanced economies; EME = emerging market economies. Coefficients are drawn from equations (7.3) to (7.8).

Figure 7.3. Changes in the Mean and Variance of Output Gap Growth after Looser Financial Conditions, an Illustration



Source: Authors' calculations.

WELFARE GAINS

To investigate the welfare gains from responding to financial conditions, we consider both a classic Taylor rule, under which central banks are constrained to respond only to changes in output gaps and inflation, and an augmented rule, under which central banks can also respond to changes in financial conditions. In all cases, central banks pick coefficients in the Taylor rule to minimize the net present value of the same loss function.

To develop intuition, Figure 7.3 shows how the mean and volatility of output gap growth change after a shock that loosens financial conditions.[10] We assume the economy is initially at the deterministic steady state (the black dot on the horizontal axis). The red line is the mean-volatility line described by equation (7.14) evaluated at the steady-state level of s_t. After a shock that loosens financial conditions, the mean-volatility line jumps up (black line). The economy must always be on this line. Depending on what monetary policy rule the central bank implements, the economy can jump to any point in the new mean-volatility line. For the two rules we consider, both the mean and volatility of output gap growth initially increase. However, the optimal rule places a higher weight than the Taylor rule on the stabilization of volatility. As the economy adjusts back toward steady state, the line reverts continuously to its initial position, with the economy moving along with it. The slope of the line is the same throughout, as it is

[10]For this illustrative example, we use the parameters from Adrian and Duarte (2016) ($\bar{s}$ = –0.67, ξ = 0.36, ρ_s = –log(0.12), σ_s = 0.31, r = 0.04, $\hat{\eta}$ = 0.05, γ = 2) and consider a two standard deviation shock to s_t.

TABLE 7.4.

Monetary Policy Rule Coefficients

	Optimal rule			Taylor rule		
	y_t	π_t	s_t	y_t	π_t	s_t
AE 1973–2016	−3.54	3.13	−0.14	−3.46	3.06	0.00
AE 1973–1990	−2.86	2.59	−0.64	−2.65	2.49	0.00
AE 1991–2016	−3.86	3.38	−0.01	−3.85	3.38	0.00
EME 1990–2016	−3.82	3.36	−0.03	−3.80	3.34	0.00
EME 1990–1995	−3.57	3.16	−0.50	−3.21	3.04	0.00
EME 1995–2016	−3.87	3.39	−0.01	−3.86	3.38	0.00

Source: Authors' calculations.
Notes: AE = Advanced economies; EME = Emerging market economies. s_t: FCI, y_t: Real GDP, π_t CPI inflation rate.

determined by α , τ , and ξ , the parameters that determine the strength of the frictions—and the amplification—in the intermediation sector. Monetary policy determines where in the line the economy is at each point in time but takes the line and its dynamics as given.

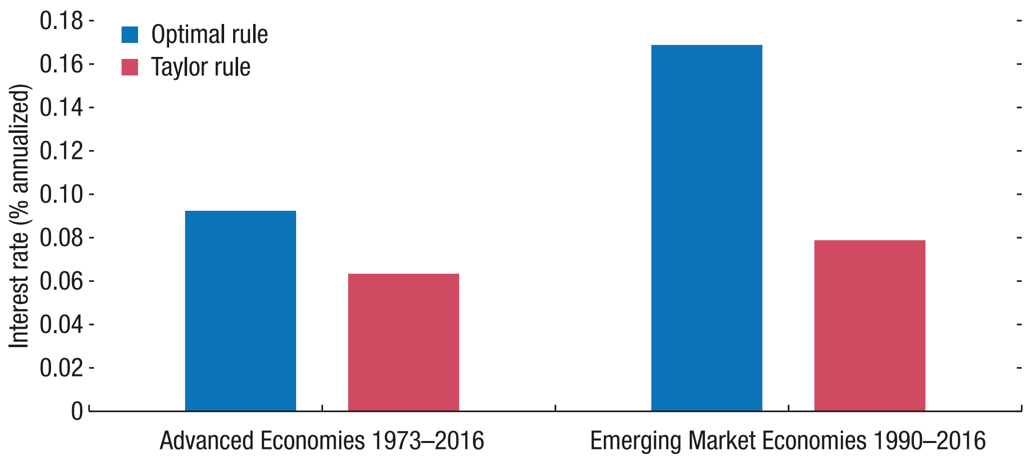
For the two interest rate rules we consider, central banks chose to increase interest rates in response to looser financial conditions. Looser financial conditions are accompanied by a higher output gap and higher inflation. The coefficients reported in Table 7.4 show that the optimal rule responds to the higher output gap by lowering interest rates, but to higher inflation and the lower vulnerability shock by increasing interest rates. Quantitatively, the net effect is positive, so interest rates end up increasing. For the classic Taylor rule, the responses to the output gap and inflation are more attenuated when compared with the optimal rule (coefficients tend to be closer to zero), while the response to the vulnerability shock s_t is zero by assumption. The end result is that interest rates also increase in response to looser financial conditions but by less than in the optimal rule.[11] Figure 7.4 shows the initial increase in interest rates implied by our calibrations after a one-standard-deviation shock to financial conditions.

The results are robust to the choice of country and time samples, despite some heterogeneity. Coefficients on output and inflation are relatively stable across rules and samples.

Coefficients on financial conditions may appear small, but this does not mean central banks put little emphasis on financial conditions in their optimal responses. A shock to financial conditions also affects the output gap and inflation. Thus, by optimally choosing high weights on these variables, the central bank is in practice already responding to financial conditions.

[11]For this analysis, it is important to recall that there is a single shock that simultaneously affects vulnerability, the output gap, and inflation. Instead of the linear interest rate rules that we consider, which are a function of two or three variables, they can also be thought of as nonlinear rules in a single variable (which can be taken to be vulnerability or the output gap). In addition, because our model does not have the usual demand and supply shocks that are standard in the New Keynesian model, the sign and magnitude of the coefficients in Table 7.4 need not resemble the usual coefficients (of about 2 for inflation and about 1 for the output gap).

Figure 7.4. First Period Response of Policy Rates to Looser Financial Conditions



Source: Authors' calculations.

The fact that optimal policy responds at all to financial conditions, over and above its decisive reaction to output and inflation, is a notable feature of the model. Financial conditions contain information about the variance of output, which enters the central bank's loss function through the expected squared deviation of the output gap from target. Importantly, the strong relationship between the mean and variance of output, as documented earlier, holds conditional on financial variables. Thus, if the central bank does not respond to, or is oblivious to, the financial conditions shock, it will not be able to anticipate changes to the variance of the output gap. From the standpoint of the data, this is equivalent to saying that the unconditional relationship between the mean and variance of output gaps is nonlinear; knowing the realization of one, at any given time, is not especially informative for the level of the other. In addition to using financial conditions as a signal about the state of the economy, monetary policy also takes into account the fact that it can endogenously affect them. Optimal policy understands there is feedback between interest rates and the conditional mean and the conditional volatility of the output gap.

Consequently, the welfare gains from responding to financial conditions are significant. Table 7.5 shows welfare in consumption-equivalent units. In most cases, they are on the order of 10 percent. Again, results are robust to the choice of sample, as shown in Table 7.5. Interestingly, welfare gains have decreased in the more recent sample. This is consistent with the lower trade-offs between mean and variance of output gaps in recent years (as documented and discussed in the section on Financial Conditions and Growth at Risk). On the whole, welfare gains are approximately equal among advanced and emerging market economies.

In reality, welfare differences between the classic and augmented Taylor rules are likely to be greater than suggested by this stylized model. For instance, in the data the effect of a financial conditions shock on output is not immediate. Thus,

TABLE 7.5.

Welfare under Optimal and Classic Taylor Monetary Policy Rules

	Optimal rule	Taylor rule	Difference in welfare	Welfare gain (in percent)
AE 1973–2016	3.03	2.72	0.32	0.12
AE 1973–1990	3.53	2.58	0.95	0.37
AE 1991–2016	2.34	2.22	0.12	0.06
EME 1990–2016	5.64	5.21	0.43	0.08
EME 1990–1995	4.53	2.23	2.30	1.03
EME 1995–2016	5.15	4.73	0.42	0.09

Source: Authors' calculations.
Notes: AE = advanced economies; EME = emerging market economies.

responding to changes in financial conditions allows monetary policy to be more forward looking, as opposed to responding only after the output gap appears. Also, a richer model with capital and investment could produce a drop in inflation following a compression of financial conditions; lower credit spreads would decrease the cost of capital and thus the marginal costs of production, as in Gourio, Kashyap, and Sim (2017). In such a model, the classic Taylor rule might respond by cutting rates due to lower inflation. However, an augmented rule that takes spreads into account might instead recommend a lower cut. In this model, a financial conditions shock is similar to a demand shock in that it increases output and inflation and therefore requires an unequivocal hike without a stark trade-off between output and inflation stabilization.[12]

RELATED LITERATURE

In exploring the role of financial conditions in the relation between policy interest rates and the mean and variance of output gaps for a cross-section of countries two steps are relevant: linking policy rates to financial conditions, and linking financial conditions to output. Both steps are underpinned by a rich literature—empirical and theoretical—emphasizing financial frictions.

The link between policy rates and financial conditions rests on the risk-taking capacity of intermediaries. As this capacity evolves over time, in part due to changes in policy rates, so does the compensation intermediaries require to hold risk—the risk premium. In segmented markets, this determines credit spreads as well as asset prices. Risk-taking capacity is typically limited by intermediaries' balance sheets—their size, value of collateral, net worth, value at risk, or other such measures—in what is referred to as a financial friction. Examples are Adrian, Moench, and Shin (2010), and Adrian, Etula, and Muir (2014), in which broker-dealers price assets according to their balance sheets; if these are strong and the marginal value of wealth is low, expected returns on risky assets can also afford

[12]The similarity is all the more striking when digging into the model; as explained earlier, the financial conditions shock is modeled as a shock to the preferences of bankers that is transmitted to households' marginal utilities through trade.

to be low. This chapter's model shares these mechanisms, insofar as policy rates affect the VaR constraint of intermediaries.

A growing empirical literature documents the link between policy rates and financial conditions. Gilchrist and Zakrajšek (2012) provide a hint: shocks to profits of broker-dealers—presumably coming in part from monetary policy—affect their credit default swap rates and the excess bond premiums (a measure of credit spreads). Gertler and Karadi (2015), and Boyarchenko, Haddad, and Plosser (2016) examine the issue directly, while carefully identifying monetary policy shocks using high-frequency analysis. In both cases, higher policy rates increase credit spreads.

The link between financial conditions and output has been explored by, among others, Philippon (2009), Gilchrist and Zakrajšek (2012), Krishnamurthy and Muir (2016), and López-Salido, Stein, and Zakrajšek (2017). A common result emerges despite the differences in methods and samples: higher credit spreads—or tighter financial conditions—coincide with a contraction in output. The forecasting power of spreads varies somewhat among papers. Krishnamurthy and Muir (2016) document that before financial crises spreads remain particularly tight despite strong credit growth. Similarly, López-Salido, Stein, and Zakrajšek (2017) suggest that spreads are mean-reverting so that a period of tight spreads forecasts one of wider spreads and lower growth.

Some empirical papers extend the analysis from the mean to the variance of output. Notably, Adrian, Boyarchenko, and Giannone (2016) emphasize that deteriorating financial conditions (wider spreads) are associated with an increase in the conditional volatility of GDP growth and a decrease in its conditional mean. Together, these results increase downside risks to GDP growth, and emphasize the importance of financial conditions for forecasting downside risks—or vulnerabilities—to growth. These same findings emerge from this chapter's model and are corroborated by its empirical investigation.

The relationship between financial conditions and output finds root in an older theoretical literature. Seminal contributions of Bernanke and Gertler (1989), Kiyotaki and Moore (1997), and Bernanke, Gertler, and Gilchrist (1999) emphasize the role of the financial sector in amplifying the effects of monetary policy shocks. These models exhibit borrowing and lending (between households and firms; later models introduce heterogeneous households). But equity issuance is constrained due to agency costs, and debt issuance is subject to frictions that are either exogenous or depend endogenously on collateral values or levels of debt. As a result, monetary policy shocks have a larger effect on output than shown in representative agent models that abstract from the financial sector.

The more recent theoretical literature has evolved in two ways: one explaining, and the other expanding upon, basic dynamics. A first strand has rationalized why agents take on excessive debt or leverage if doing so undermines economic stability. The answer lies in overlooking the macro implications of individual actions—a phenomenon called externalities (see, for instance, Stein 2012; Dàvila and Korinek 2016; Farhi and Werning 2016; as well as Korinek and Simsek 2016).

A second strand has emphasized nonlinear effects of financial frictions on intermediaries' balance sheets, as in He and Krishnamurthy (2014) and Brunnermeier and Sannikov (2014). Doing so allows for stronger amplification effects—closer to those observed in the data. The new models study global dynamics since they are not linearized around a steady state. And as constraints on the balance sheets of intermediaries bind only occasionally (and following negative rather than positive shocks), the models allow for more realistic dynamics: asymmetric amplification of shocks and periods of crisis following others of more normal growth. He and Krishnamurthy (2014) show that such dynamics help explain asset prices. Brunnermeier and Sannikov (2014) also show important implications for regulation; the model economy can remain in a crisis state for a prolonged time if initial capital cushions are too slim. This chapter's underlying model shares these same characteristics, as needed to explicitly study output volatility.

While this newer class of models does not dwell on monetary policy—unlike this chapter—somewhat older papers do. Curdia and Woodford (2010), spurred by the global financial crisis, consider whether monetary policy should respond to financial conditions—credit spreads in particular—following the recommendations of McCulley and Toloui (2008) and Taylor (2008), while Christiano and others (2010) favor a response to aggregate credit growth. Gambacorta and Signoretti (2014) build on Curdia and Woodford (2010) by adding further frictions, and Gertler and Karadi (2011) advance a model where central banks can complement the private sector's intermediation function, carving out a role for asset purchases.

In these models, the welfare gains from monetary policy responding to financial conditions are not clear cut (especially in Curdia and Woodford [2010]). Gains are greater following a shock to credit spreads, but not in response to other shocks. A productivity shock, for instance, will increase output and encourage lending, thereby raising credit spreads. But a cut in interest rates to stabilize spreads would lead to inefficient inflation. In the end, welfare gains from responding to financial conditions are shock dependent. This chapter instead remains focused on the effects of a single shock to financial conditions.

CONCLUSIONS

Economists and policymakers have debated for some time the degree to which financial conditions should or should not enter monetary policy rules. Some, including Bernanke, Gertler, and Gilchrist (1999), Bernanke and Gertler (2001), and Svensson (2017), have argued that monetary policy should take financial conditions into account only to the extent that they change the forecast of inflation or output. We extend that logic by arguing that monetary policymakers should care not just about the conditional mean forecasts of inflation and output, but also about the downside risks of those quantities. A monetary policymaker who aims to minimize the expected present discounted value of squared output losses and squared inflation deviations would naturally care about the conditional variance of output and inflation, and not just the conditional mean.

Empirically, this analysis shows that both the conditional mean and the conditional volatility of the output gap are significantly related to financial conditions. This builds on a robust literature on the forecasting power of term spreads, credit spreads, and market volatility for downside risks to output. Notably, the conditional means and conditional volatilities of the output gap are negatively correlated: when financial conditions deteriorate, the conditional mean declines and the conditional volatility increases. This negative correlation between the conditional mean and the conditional volatility of GDP gives rise to a strongly negatively skewed unconditional distribution of GDP. These findings are present in advanced economies and emerging markets alike.

In calibrating a reduced-form New Keynesian model with financial frictions to the empirical relationship between financial conditions and the time-varying moments of the output gap distribution, we demonstrate the importance of financial vulnerability in central bank considerations. The micro foundation of that model is provided by Adrian and Duarte (2016). Using the optimal monetary policy rule, we find that monetary policy should be conditioned on financial vulnerability in addition to the output gap and inflation. The welfare gains from doing so are significant. Intuitively, monetary policy that takes financial conditions into account mitigates GDP risk.

The results are particularly robust across time periods (before and after the global financial crisis) and types of countries. Welfare gains from responding to financial conditions are broadly equal for advanced and emerging market economies. Our results suggest the need to reformulate the policy approach to the relationship between financial stability and monetary policy. Clearly, monetary policy should take financial conditions into account, even if macroprudential policy is the appropriate tool to lean against the buildup of significant financial imbalances. Indeed, Peek, Rosengren, and Tootell (2016) document that references to financial conditions are increasingly common in monetary policy statements.

ANNEX 7.1. OPTIMAL MONETARY POLICY

The central bank solves

$$L(y_t, \pi_t, s_t) = \min_{\{i_s\}_{s=t}^{\infty}} \mathbb{E}_t \int_t^{\infty} e^{-s\beta} \left(y_s^2 + \pi_s^2\right) ds$$

subject to equations (7.3)–(7.8). Using equations (7.25) and (7.26) from Annex **7.2**, the central bank's problem can be written as

$$L(y_t, \pi_t, s_t) = \min_{\{V_s\}_{s=t}^{\infty}} \mathbb{E}_t \int_t^{\infty} e^{-s\beta} \left(y_s^2 + \pi_s^2\right) ds$$

such that

$$dy_t = -\xi \left(\frac{1 + \alpha\xi\sqrt{\tau}}{\xi\tau} V_t - \frac{\alpha}{\sqrt{\tau}} s_t \right) dt + \xi \left(V_t - s_t \right) dZ_t$$

$$d\pi_t = \left(\beta \pi_t - \kappa y_t \right) dt$$

$$ds_t = -\kappa(s_t - \bar{s}) + \sigma_s dZ_t.$$

The Hamilton-Jacobi-Bellman (HJB) equation is

$$0 = \min_V \left\{ \xi\left(\sigma_s L_{ys} - ML_y\right) V + \frac{\xi^2}{2}(V-s)^2 L_{yy} \right\}$$
$$+y^2 + \pi^2 - \beta L + \frac{\xi\alpha}{\sqrt{\tau}} L_y s - \kappa(s-\bar{s}) L_s + \left(\beta\pi - \kappa y\right) L_\pi + \frac{\sigma_s^2}{2} L_{ss} - \sigma_s \xi L_{ys} s.$$

The first order condition (FOC) is

$$V = s + \frac{M}{\xi}\frac{L_y}{L_{yy}} - \frac{\sigma_s}{\xi}\frac{L_{ys}}{L_{yy}}.$$

Plugging the optimal V into the HJB gets

$$0 = 3M\sigma_s \frac{L_{ys}L_y}{L_{yy}} - \frac{\sigma_s^2}{2}\frac{L_{ys}^2}{L_{yy}} - \frac{M^2}{2}\frac{L_y^2}{L_{yy}} + y^2 + \pi^2 - \beta L$$
$$+\xi\left(\frac{\alpha}{\sqrt{\tau}} - M\right) L_y s - \kappa(s-\bar{s}) L_s + \left(\beta\pi - \kappa y\right) L_\pi + \frac{\sigma_s^2}{2} L_{ss}.$$

A solution is needed for the form

$$L(y,\pi,s) = c_0 + c_1 y + c_2 y^2 + c_3 s + c_4 s^2 + c_5 ys + c_6 \pi + c_7 \pi^2 + c_8 y\pi + c_9 \pi s.$$

Plugging into the HJB, using

$$L_y = c_1 + 2c_2 y + c_5 s + c_8 \pi$$
$$L_{yy} = 2c_2$$
$$L_\pi = c_6 + 2c_7\pi + c_8 y + c_9 s$$
$$L_s = c_3 + 2c_4 s + c_5 y + c_9 \pi$$
$$L_{ss} = 2c_4$$
$$L_{ys} = c_5$$

and setting the coefficients in front of combinations of the state variables to zero, produces the following system of equations in c0, ..., c9:

$$[y^2]:0 = \left(1 - \beta c_2 - \kappa c_8 - c_2 M^2\right)$$
$$[y\pi]:0 = \left(-c_8 M^2 - 2\kappa c_7\right)$$
$$[ys]:0 = \left(2c_2\xi\left(\frac{\alpha}{\sqrt{\tau}} - M\right) - \kappa c_9 - \beta c_5 - M^2 c_5\right)$$
$$[y]:0 = \left(3\sigma_s c_5 M - c_1 M^2 - \beta c_1 - \kappa c_6\right)$$
$$[\pi^2]:0 = \left(\beta c_7 - \frac{1}{4}\frac{M^2}{c_2}c_8^2 + 1\right)$$
$$[\pi s]:0 = \left(c_8\xi\left(\frac{\alpha}{\sqrt{\tau}} - M\right) - \frac{1}{2}\frac{M^2}{c_2}c_5 c_8\right)$$

$$
\begin{aligned}
[\pi]:0 &= \left(\frac{3}{2}M\frac{\sigma_s}{c_2}c_5c_8 - \frac{1}{2}M^2\frac{c_1}{c_2}c_8\right)\\
[s^2]:0 &= \left(c_5\xi\left(\frac{\alpha}{\sqrt{\tau}} - M\right) - \beta c_4 - \frac{1}{4}\frac{M^2}{c_2}c_5^2\right)\\
[s]:0 &= \left(c_1\xi\left(\frac{\alpha}{\sqrt{\tau}} - M\right) - \beta c_3 + \frac{3}{2}M\frac{\sigma_s}{c_2}c_5^2 - \frac{1}{2}M^2\frac{c_1}{c_2}c_5\right)\\
[const]:0 &= \left(\sigma_s^2c_4 - \beta c_0 - \frac{1}{4}\frac{\sigma_s^2}{c_2}c_5^2 - \frac{1}{4}M^2\frac{c_1^2}{c_2} + \frac{3}{2}M\sigma_s\frac{c_1}{c_2}c_5\right)
\end{aligned}
$$

with solution

$$
c_8:\begin{cases}\dfrac{2\kappa(\beta+M^2)}{M^2\beta} & \text{, if}M^2 = \beta\\[2ex] \dfrac{1}{M^2-\beta}\left(-\dfrac{\beta}{\kappa}\pm\kappa\sqrt{\beta^2+4\kappa^2\left(M^2-\left(\dfrac{\beta}{M}\right)^2\right)}\right) & \text{, if}M^2 \neq \beta\end{cases}
$$

$$c_1:\frac{3\sigma_s}{M}\frac{2\xi}{M^2}\left(\frac{\alpha}{\sqrt{\tau}} - M\right)\left(\frac{1}{\beta+M^2} - \frac{\kappa}{\beta+M^2}c_8\right)$$

$$c_2:-\frac{1}{M^2+\beta}(\kappa c_8 - 1)$$

$$c_3:-\frac{6\sigma_s\xi^2\left(\alpha - M\sqrt{\tau}\right)^2}{M^3\beta\tau(M^2+\beta)}(\kappa c_8 - 1)$$

$$c_4:-\frac{\xi^2\left(\alpha - M\sqrt{\tau}\right)^2}{M^2\beta\tau(M^2+\beta)}(\kappa c_8 - 1)$$

$$c_5:-\frac{2\xi\left(\alpha - M\sqrt{\tau}\right)}{M^2(M^2+\beta)\sqrt{\tau}}(\kappa c_8 - 1)$$

$$c_6:\frac{6\beta\sigma_s\xi\left(\alpha - M\sqrt{\tau}\right)}{M^3\kappa(M^2+\beta)\sqrt{\tau}}(\kappa c_8 - 1)$$

$$c_7:-\frac{M^2}{2\kappa}c_8$$

$$c_9:\frac{2\xi\beta\left(\alpha - M\sqrt{\tau}\right)}{M^2\kappa(M^2+\beta)\sqrt{\tau}}(\kappa c_8 - 1)$$

$$c_0:\frac{1}{\beta}\left(\sigma_s^2c_4 - \frac{\sigma_s^2}{4}\frac{c_5^2}{c_2} - \frac{M^2}{4}\frac{c_1^2}{c_2} + \frac{3M\sigma_s}{2}\frac{c_1c_5}{c_2}\right).$$

ANNEX 7.2. DERIVATION OF THE SOLUTION

Plugging equation (7.7) into equation (7.3) it can be seen that

$$\mathbb{E}_t[dy_t] = \frac{1}{\gamma}(i_t - \pi_t - r) \tag{7.16}$$

$$\mathbb{V}_t[dy_t] = \xi(V_t - s_t) \tag{7.17}$$

so that equation (7.6) can be written as

$$V_t = -\frac{1}{\gamma}(i_t - \pi_t - r)\tau - \alpha\xi(V_t - s_t)\sqrt{\tau}. \tag{7.18}$$

Solving equation (7.18) for i_t gives

$$i_t = \pi_t + \mathrm{r} - \frac{\gamma(\alpha\xi\sqrt{\tau} + 1)}{\tau}\mathrm{V}_t + \frac{\gamma\alpha\xi}{\sqrt{\tau}}\mathrm{s}_t. \tag{7.19}$$

Using equation (7.19) in equation (7.3) gives

$$dy_t = -\xi\left(\frac{1 + \alpha\xi\sqrt{\tau}}{\xi\tau}V_t - \frac{\alpha}{\sqrt{\tau}}s_t\right)dt + \xi(V_t - s_t)dZ_t. \tag{7.20}$$

And again it can be identified that

$$\mathbb{E}_t[dy_t] = -\xi\left(\frac{1 + \alpha\xi\sqrt{\tau}}{\xi\tau}V_t - \frac{\alpha}{\sqrt{\tau}}s_t\right) \tag{7.21}$$

$$\mathbb{V}_t[dy_t] = \xi(V_t - s_t). \tag{7.22}$$

Eliminating V_t from equations (7.21) and (7.22) gets

$$\mathbb{E}_t[dy_t] = M \times \mathbb{V}_t[dy_t] - \frac{1}{\tau}s_t \tag{7.23}$$

where the definition of M is

$$M \equiv -\frac{1 + \alpha\xi\sqrt{\tau}}{\xi\tau}.$$

Plugging equation (7.5) into equation (7.18) and solving for V_t gives

$$V_t = -\frac{1}{\psi_v - M\gamma\xi}\left(\psi_0 - r + (\psi_\pi - 1)\pi_t + \psi_y y_t\right) + \frac{\alpha\gamma\xi}{\sqrt{\tau}(\psi_v - M\gamma\xi)}s_t. \tag{7.24}$$

Finally, plugging equation (7.24) into equation (7.20) and rearranging produces

$$dy_t = \frac{\xi M}{\psi_v - \xi M\gamma}\left(r - \psi_0 + (1 - \psi_\pi)\pi_t - \psi_y y_t + \frac{\alpha}{\sqrt{\tau}}\frac{\psi_v}{M}s_t\right)dt \tag{7.25}$$

$$+\frac{\xi}{\psi_v - \xi M\gamma}\left(r - \psi_0 + (1 - \psi_\pi)\pi_t - \psi_y y_t + \left(M\gamma\xi + \frac{\alpha}{\sqrt{\tau}}\frac{\gamma}{\xi} - \psi_v\right)s_t\right)dZ_t$$

$$d\pi_t = (\beta\pi_t - \kappa y_t)dt. \tag{7.26}$$

Equations (7.25) and (7.26) determine y_t and π_t as a function of the exogenous variables s_t and Z_t. Given y_t, π_t and the exogenous variables s_t and Z_t, equation (7.24) determines V_t. Once V_t has been found, equation (7.5) determines i_t.

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