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# Financial Volatility and Economic Activity



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## Abstract

Does uncertainty in capital markets affect the business cycle? We find that financial volatility predicts 30% of post-war economic activity in the United States, and that during the Great Moderation, aggregate stock market volatility explains, alone, up to 55% of real growth. In out-of-sample tests, stock price volatility helps predict turning points over and above traditional financial variables such as credit or term spreads, and other leading indicators. Combining stock volatility and the term spread leads to a proxy for (i) aggregate risk, (ii) risk-premiums and (iii) a gauge of monetary policy conduct, which tracks and anticipates the business cycle. At the heart of our analysis is a notion of volatility based on a slowly changing measure of return variability. This volatility is designed to capture long-run uncertainty in capital markets, and is particularly successful at explaining trends in the economic activity at horizons of six months and one year.

**Keywords:** Capital Markets Uncertainty; Asset Prices and the Business Cycle; Macroeconomic Risk; Volatility Spillovers; the Great Moderation.

**JEL Codes:** E17; E32; E37; G01; G12; G17.

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## 1 Introduction

One systematic feature of modern capital markets is the countercyclical behavior of asset price volatilities, such as those of common stocks, Treasury returns, or corporate bonds. For example, in the last fifty years, the S&P 500 return volatility was 14.18%, on average, annualized. Yet during recessions, this volatility increased to 17.39%, 23 per cent higher than the overall average. During expansions, however, this same volatility attained an average of 13.5%, a modest 4 per cent below the overall average.

That capital markets uncertainty is countercyclical does not immediately lead the conclusion that financial volatility anticipates real economic activity. Rather, two key questions arise: does capital market volatility affect investment decisions in the real sector of the economy? Does volatility help predict the business cycle? These issues have outstanding policy implications, and are, of course, of immediate concern to corporate decision makers, even in

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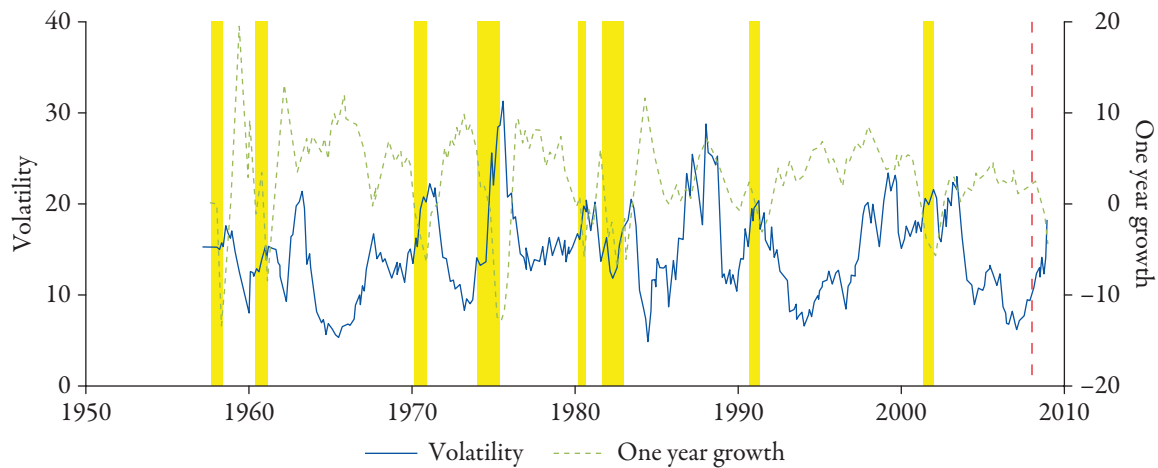
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the simple case where a sustained stock volatility merely anticipates, without affecting, the business cycle. Guided by this motivation, this paper aims to provide a systematic summary of the information financial volatility encodes about developments in the business cycle.

We analyze post-war economic activity in the United States and find that movements in financial volatility are extremely informative about future economic activity. For example, we find that financial volatility explains between 30% and 40% of the industrial production growth at horizons of one and two years. We successfully control these findings against the information content of a number of macroeconomic variables and other traditional indicators, such as real leading indicators, financial variables such as short-term interest rates, the corporate spread, or stock returns and less standard indicators of macroeconomic volatility. Together with financial volatility, indicators of macroeconomic volatility explain more than 50% of the industrial production growth at the one year horizon.

In the most recent sub-samples, stock market volatility explains, *alone*, between 35% and 55% of future real economic activity, at horizons of one and two years. More generally, we find that the predicting power of stock market volatility has increased in the last twenty-five years, a period that includes a sustained decline in the volatility of real aggregates, notoriously dubbed as the Great Moderation. Over this period, stock volatility has a predictive power that is quite comparable to that of a traditional leading indicator: the term spread. In fact, we find that combining the term spread with aggregate stock market volatility leads to a predicting block that anticipates the business cycle reasonably well, delivering quite isolated false signals of economic slowdowns relative to the recession indicator calculated by the National Bureau of Economic Research (NBER), with no such false signals over the Great Moderation period. We argue that combining the term spread with stock market volatility helps predict the business cycle for two reasons: *(i)* aggregate stock market volatility conveys information about the general macroeconomic risk surrounding the economic environment; and *(ii)* the term spread subsumes information about risk-premiums and the conduct of monetary policy. In other words, we suggest that aggregate risk, risk-premiums and monetary policy, provide complementary pieces of information about future movements in real macroeconomic aggregates. Needless to mention, we undertake out-of-sample experiments and submit these findings to reality checks. In these experiments, developments in the term spread and stock market volatility anticipate all the NBER-dated recessions that are left by the data and our estimation constraints, including the recession episode related to the 2007 subprime crisis.

Relating capital markets uncertainty to future economic fluctuations is an issue that has received little attention in both the empirical and theoretical literature. It was first raised by Schwert (1989a) and, more recently, by Campbell, Lettau, Malkiel and Xu (2001). Schwert concludes that stock market volatility does not anticipate major financial crises and panics between 1834 and 1987. Rather, he shows, stock volatility rises after the onset of a crisis. Naturally, recessions may develop independently of financial crises and panics. Moreover, financial turmoil might anticipate recessions as, for example, the 2007 subprime crisis may suggest. Campbell, Lettau, Malkiel and Xu (2001) observe indeed that stock volatility might help predict GDP growth, with post-war data. Our paper provides a detailed empirical account of the many issues left unexplored in these two isolated contributions, such as: *(i)* the relation between financial volatility and both future real



**Figure 1:** Aggregate stock market volatility and industrial production growth.

*Note:* This Figure plots aggregate stock market volatility against one year industrial production growth in the United States. Volatility as of month  $t$  is defined as the annualized moving average of the absolute monthly returns in the previous year,  $\frac{k}{\sqrt{12}} \sum_{i=1}^{12} |R_{t+1-i}|$ , where  $R_t$  is the return on a stock price (total return) index at month  $t$ , and  $k$  is a scaling factor defined in the main text.

One year industrial production growth as of month  $t$  is defined as  $\ln(IP_t/IP_{t-12})$ , where  $IP_t$  is the seasonally adjusted industrial production index at month  $t$ . The sample covers monthly data for the period from January 1957 to September 2008. Shaded areas (in yellow) track NBER-dated recessions, and the vertical dashed line (in red) indicates the beginning of the latest NBER-dated recession.

aggregates (industrial production growth) and the general state of the economy (NBER business cycle phases), analyzed both in sample and through reality checks and other out-of-sample experiments; *(ii)* the information content conveyed by a combined use of stock volatility with other predictors, such as, e.g., the term spread; *(iii)* the control of the findings, based on traditional business cycle predictors; *(iv)* the exploration of the predicting power of a number of financial volatility variables on top of stock market volatility, such as the volatility of the term spread, the volatility of stock market volatility, the volatility of oil and metals price indices or, even, the volatility of real economic aggregates; *(v)* the analysis of the historical periods over which the predicting power of stock volatility has been strongest, which we identify in the Great Moderation, as we have explained. In recent work, Chauvet, Senyuz and Yoldas (2010) provide additional empirical evidence on business cycle predictability using volatilities at industry levels and bond market volatility.

Figure 1 sketches the origins of our results. It depicts our post-war measure of aggregate stock market volatility, designed to smooth transitory episodes of high volatility, which likely have weak linkages with the low frequency nature of the business cycle. Not only, then, does Figure 1 reveal that stock volatility is countercyclical, in that it raises during all NBER-dated recessions, as originally uncovered in seminal work by Schwert (1989b). Figure 1 also illustrates our findings that stock volatility anticipates NBER recessions, increasing roughly one year ahead of all of such recession, with the exception of the 1981-1982 episode, as we further elaborate in Section 4.

*Post hoc ergo propter hoc?* Or, does a sustained stock market volatility create the premises for future economic slowdowns? The extant empirical literature mostly focusses on whether business cycle factors might explain stock volatility (e.g., Officer (1973), Schwert

(1989b), Hamilton and Lin (1996), Brandt and Kang (2004), Adrian and Rosenberg (2008), Engle and Rangel (2008), Corradi, Distaso and Mele (2009)). Bloom (2009) and Bloom, Floetotto and Jaimovich (2009) are two important contributions directly related to our work. Bloom (2009) argues, theoretically and empirically, that uncertainty shocks affect short-run fluctuations in economic activity. Bloom, Floetotto and Jaimovich (2009) show that uncertainty indexes are negatively correlated with future economic activity, in the short-run.

Our paper, and results, while consistent with the hypothesis of volatility spillovers over real aggregates, does not necessarily point in favour of this hypothesis. In Section 2, we provide arguments in support of both the «correlation» and «causation» scenarios. We show, with a simple example, that volatility might merely help predict the business cycle, even when there is no causal link between volatility and future economic activity. The mechanism builds on the assumption that markets process publicly available information rationally and quickly. Under the circumstances, all the variables relating to future production growth and, hence, affecting asset valuation, also impinge upon stock volatility. Therefore, stock volatility helps predict decisions taken in the real sphere of the economy, in the presence of the model's misspecification – i.e., when the econometrician's information set does not include the exact asset pricing model used by market participants. At the same time, we do not rule out volatility spillovers. Such spillovers may occur, for example, when uncertainty is time-varying, as put forward by Bloom (2009) and Bloom, Floetotto and Jaimovich (2009), as we shall review. Moreover, volatility spillovers might arise due to financial frictions. For instance, we shall explain, financial intermediaries, be they risk-averse or subject to institutional constraints, would scale back their lending activities after a rise in uncertainty, as expected collateral values might be affected by an increased capital markets volatility.

The remainder of the paper is organized as follows. In the next section, we suggest hypotheses that might help explain the predictive power of volatility that we uncover in this paper. In Section 3, we describe the data set and measurement methods. Section 4 hinges upon the extant literature about the predicting power of financial variables, and motivates the sets of predictors and controls we employ in our in-sample and out-of-sample tests. Section 5 provides in-sample evidence. Section 6 contains out-of-sample results. Section 7 concludes. A small appendix contains a few details omitted from the main text.

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## 2 What Might Explain the Predicting Power of Financial Volatility?

Why is financial volatility countercyclical? Why should it help predict the business cycle? This section reviews arguments that attempt to answer these questions. In Section 2.1, we develop a simple laboratory model of a production economy, which illustrates why stock volatility can be a valid type of conditioning information to learn about the future state of the economy. Then, we review a number of channels that may lead stock volatility to be countercyclical, or even anticipate economic activity. These channels include time-varying expected returns (Section 2.2), the presence of nonconvex adjust-

ment costs and time-varying uncertainty (Section 2.3) and, finally, financial frictions and procyclicality of capital markets (Section 2.4).

## 2.1 Production and Incomplete Information

Consider a two-period production economy with a monopolist firm. In the first period, the firm engages in a production decision. In the second period, the firm sells the output produced in the first period. This firm faces a linear inverse demand,

$$D^{-1}(Q) \equiv a + \tilde{v} - \lambda Q,$$

where  $a$  and  $\lambda$  are constants,  $Q$  is total demand, and  $\tilde{v}$  is a demand shock. We assume that  $\tilde{v} \sim N(0, \sigma^2)$ , and that prior to production decisions, the firm observes a signal  $s$  on  $\tilde{v}$ ,  $s = \tilde{v} + \epsilon$  where  $\epsilon \sim N(0, \sigma_\epsilon^2)$ . Finally, we assume that: (i) the firm faces linear costs, i.e.  $C(Q) = zQ$  for some constant  $z > 0$ ; (ii) the firm's managers are risk-neutral, and maximize the value of the firm; and (iii) a safe asset is elastically supplied so as to make the safe interest rate zero. Under these conditions, production takes place only when the signal  $s$  takes a sufficiently favorable cutoff value  $\hat{s} \equiv -\frac{a-z}{\theta}$ , where  $\theta = \frac{n-1}{n}$ , and  $n$  is the signal-to-noise ratio. Accordingly, in the Appendix, we show that the value of the firm (the stock price)  $P$ , production  $Q$  and return volatility  $\text{Vol}$  (say) are all functions of the current signal  $s$ , and equal

$$(1) \quad P(s) = \frac{\theta}{4\lambda}(s - \hat{s})^2 \mathbb{I}_{s > \hat{s}}, \quad Q(s) = \frac{\theta}{2\lambda}(s - \hat{s}) \mathbb{I}_{s > \hat{s}}, \quad \text{Vol}(s) = \frac{2\sigma\sqrt{1-\theta}}{\theta(s - \hat{s})} \mathbb{I}_{s > \hat{s}}$$

where  $\mathbb{I}$  is the indicator function. According to Eq. (1), production grows linearly with the signal  $s$ . The stock price, instead, «overreacts» to this signal in good times, as it increases disproportionately as  $s$  increases. Finally, volatility is strongly countercyclical, as it increases severely as signals on future demand worsen.

If we knew the structure of this economy, we could predict output by just observing the current stock price. Indeed, by Eq. (1), we could invert the observed stock price  $P(s)$  for  $s$ , and then plug  $s$  in  $Q(s)$ . In fact, price and volatility would convey the *same* information about output, in this economy. However, consider an econometrician who is not aware of the exact pricing relations in Eq. (1), but still observes realizations of asset price and volatility. Conditioning upon the realization of these variables facilitates identifying the state of the economy. Table 1 reports the findings from a Monte Carlo experiment explained in detail in the Appendix, where output is regressed on (i) volatility, (ii) price, and (iii) volatility and price.

In this experiment, both prices and volatility help predict output, although none of these variables allows for a perfect prediction. An econometrician who ignores the exact nonlinear relations in Eq. (1), but understands the economics underlying output, asset prices and volatility, would benefit from using data on both asset price and volatility to estimate the state of the economy.

**Table 1:** Model's misspecification and the predictive ability of asset price and volatility

	const	Vol	R <sup>2</sup>	const	Price	R <sup>2</sup>	const	Vol	Price	R <sup>2</sup>
Avg estim	0.32	-0.17	0.91	0.08	0.55	0.97	0.17	-0.06	0.36	0.99
Avg t-stat	100.88	-53.61		100.16	99.92		153.05	-71.86	14.45	

## 2.2 Time-Varying Expected Returns

Time-varying risk-aversion is perhaps the first channel the literature has identified as conducive to countercyclical volatility. Campbell and Cochrane (1999) consider a model with external habit formation, which predicts that risk-premiums and, hence, expected returns, are high during recessions, i.e. when investors' consumption gets closer to the habit level. Their model explains why risk-premiums are countercyclical, an empirical regularity known since Fama and French (1989) and Ferson and Harvey (1991). Barberis, Huang and Santos (2001) elaborate on prospect theory to generate a similar countercyclical variation in the expected returns.

However, countercyclical risk-premiums do not necessarily lead to countercyclical volatility. Mele (2007) develops a theoretical framework and shows that for stock volatility to be countercyclical, risk-premiums must increase more in bad times than they decrease in good times. This condition is satisfied in the Campbell and Cochrane economy, but not necessarily in economies with alternative habit formation mechanisms. The intuition behind this risk-premium channel is that asset prices are discounted risk-adjusted expectations of future dividends. If risk-aversion rises more in bad times than it decreases in good, asset prices fluctuate more in bad times than in good. Naturally, asymmetric movements in risk-premiums can be activated by channels not strictly related to habit formation. For example, the Basak and Cuoco (1998) model of restricted stock market participation predicts that risk-premiums are inversely and asymmetrically related to the market participants' consumption share. Danielsson, Shin and Zigrand (2009) consider a model with risk-neutral financial institutions subject to procyclical financial constraints. In their economy, the Sharpe ratio is positive, due to the constraints, and inversely and asymmetrically related to economic capital, thus making stock volatility countercyclical.

## 2.3 Uncertainty and Irreversible Investments

Option pricing theory predicts that uncertainty raises the value to wait. This conclusion often relies upon comparative statics, which track how «exercise boundaries» change with the «uncertainty parameters». Touzi (1999) confirms this general conclusion in the case where uncertainty is a stochastic process – the case of American options with stochastic volatility. Bloom (2009) introduces time-varying uncertainty of business conditions in an otherwise standard model of firms growth, and assumes that total factor productivity has stochastic volatility. His model, which includes irreversible investments and nonconvex adjustment costs, predicts that firms freeze investments during uncertain times, as the value to waiting increases in such periods. Bloom, Floetotto and Jaimovich (2009) reach a similar conclusion within a calibrated real business cycle model: uncertainty shocks are impulses that generate rich propagation mechanisms.

## 2.4 Procyclicality

The previous models assume asset prices and volatility respond passively to changes in the economic conditions. An alternative assumption is that asset prices have the power to feed back the real economy, an hypothesis known as procyclicality of capital markets. The idea underlying this hypothesis is that firms' capital structure matters in the presence of capital market frictions. One well-known mechanism is that in bad times, agency frictions make the cost of external funds increase and the availability of funds decrease, which amplifies small shocks occurring in the real sectors of the economy. For example, the financial accelerator hypothesis holds that in bad times, financial intermediaries reduce their funding activities as the collateral value is also reduced in bad times. Bernanke, Gertler and Gilchrist (1999) present a unified view of how agency problems make funding opportunities depend on firms' collateral. Borio, Furfine and Lowe (2001) explain that the agents' misperception of risk might constitute an additional amplification mechanism. For example, the credit/GDP ratio might be procyclical because financial intermediaries under-estimate risk in good times, and over-estimate risk in bad, thereby lending too much in good times and too less in bad.

How does financial volatility relate to procyclicality? If financial intermediaries are risk-averse, or subject to institutional constraints, time varying volatility in capital markets might affect lending and investment decisions. Consider the following arguments. In bad times, when financial volatility increases, the value of future collateral becomes more uncertain. In anticipation of this increased uncertainty, the volume of funds financial intermediaries would supply decreases, with a possible cost increase, thereby exacerbating the current economic conditions. This explanation is consistent with the mechanism put forward by Borio, Furfine and Lowe (2001). Indeed, if financial markets are rational and quick processors of information, it might be that financial volatility increases precisely towards the end of the build-up of risk-taking behavior in good times, but just enough before an economic downturn.

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## 3 Data and Volatility Measurement

We investigate the predictive power of financial volatility for the economic activity in the United States. Our data set includes (i) macroeconomic variables such as the seasonally adjusted industrial production index, the consumer price index, the unemployment rate and an index of leading indicators; and (ii) financial variables such as the broad S&P500 stock price (total return) index, the price-dividend ratio, the government bond yield (10-year rate), the 3 month rate, the term spread and the corporate spread. We define the term spread as the difference between the 10 year government bond yield and the yield on 3 month Treasury Bills. Our measure of the corporate spread is the difference between the BAA industrial bond yield and the 10-year Government bond yield. Finally, our dataset includes the oil price index and a price index of metals. We make use of monthly observations from January 1957 to September 2008, for a total of 621 observations. All data are collected from Global Financial Data, available through the ECB electronic library service, with the exception of the industrial production index, which is taken from the IMF Financial Statistics database.



### 3.1 Economic Activity

We quantify the predicting power of financial volatility on economic activity through two complementary search strategies.

- First, we predict the growth of industrial production at horizons of three, six, twelve and twenty-four months. Accordingly, we define log-changes in the industrial production index,

$$(2) \quad G_{t \rightarrow t+k} = \ln\left(\frac{IP_{t+k}}{IP_t}\right), \quad k \in \{3, 6, 12, 24\},$$

where  $IP_t$  is the industrial production index as of month  $t$ .

- Second, we predict probabilities of recessions, by utilizing the NBER-dating series as a recession variable,

$$(3) \quad \text{Rec}_t \equiv \mathbb{I}_{\text{NBER}_t=1},$$

which equals one if the US economy is in recession at time  $t$ , and zero otherwise. We set the value of this series equal to zero even after the beginning of the last recession, i.e. December 2007, as this recession was announced by the NBER business cycle dating committee in December 2008 and therefore after the end of the sample we consider.

### 3.2 Volatility

We use continuously compounded returns to track variations in price indexes. That is, given a price index  $P_p$  and its dividend index  $D_p$ , we define the total return index as of time  $t$  as,  $R_t \equiv \ln\left(\frac{P_t + D_t}{P_{t-1}}\right)$ . We aim to extract the long-run component of stock market volatility. Isolated episodes of financial turmoil are not necessarily informative about the future state of the economy. Consequently, they need to be smoothed out. To address this issue, we define volatility as a moving average of past absolute returns,

$$(4) \quad \sigma_t(\ell) = \sqrt{6\pi} \cdot \frac{1}{\ell} \sum_{i=1}^{\ell} |R_{t+1-i}|,$$

where we use the lag  $\ell$  to create volatility estimates from past returns<sup>1</sup>.

The idea to use absolute returns to track volatility goes back at least to Taylor (1986), Schwert (1989a,b) and Ding, Granger and Engle (1993). Volatility estimates based on absolute returns are known to be more robust to the presence of outliers than volatility

<sup>1</sup> Fix  $j$  and  $\ell$ , and for a given return series  $R_p$ , let  $\bar{\sigma}_t(\ell) \equiv \frac{1}{\ell} \sum_{i=1}^{\ell} |R_{t+1-i}|$ . The measure  $\bar{\sigma}_t(\ell)$  is an estimate of the average volatility as of time  $t$  in the last  $\ell$  periods, obtained with  $\ell$  lagged absolute returns. To annualize this volatility estimate, we multiply  $\bar{\sigma}_t(\ell)$  by  $\sqrt{12}$ . The term  $\sqrt{6\pi}$  in Eq. (4) arises for the following reason. If we assume that a given return  $R = \sigma u$ , where  $\sigma$  is a positive constant and  $u$  is a standard unit normal, then  $E(|R|) = \sigma \sqrt{\frac{2}{\pi}}$ . Eq. (4) follows by multiplying  $\sqrt{12} \bar{\sigma}_t(\ell)$  by  $\sqrt{\frac{\pi}{2}}$ . This correction has been suggested by Schwert (1989b) in a related context.

estimates based on squared returns, as noted by Davidian and Carroll (1987) in a general context. Instead, our device to use *moving averages* of past absolute returns relates to Officer (1973).

While implementing Eq. (4), we experimented with different windows. We find the predictive power of volatility to be somewhat limited when  $\ell$  equals one or two months – volatility is quite noisy with such windows and unlikely to exhibit any linkages with the business cycle. Its predicting power increases dramatically when  $\ell = 12$  months, which is the window we shall use throughout the paper. From now, then, we set  $\sigma_t \equiv \sigma_t(12)$ .

## 4 Predictors

### 4.1 Stock Volatility as a Leading Indicator: Preliminary Scrutiny

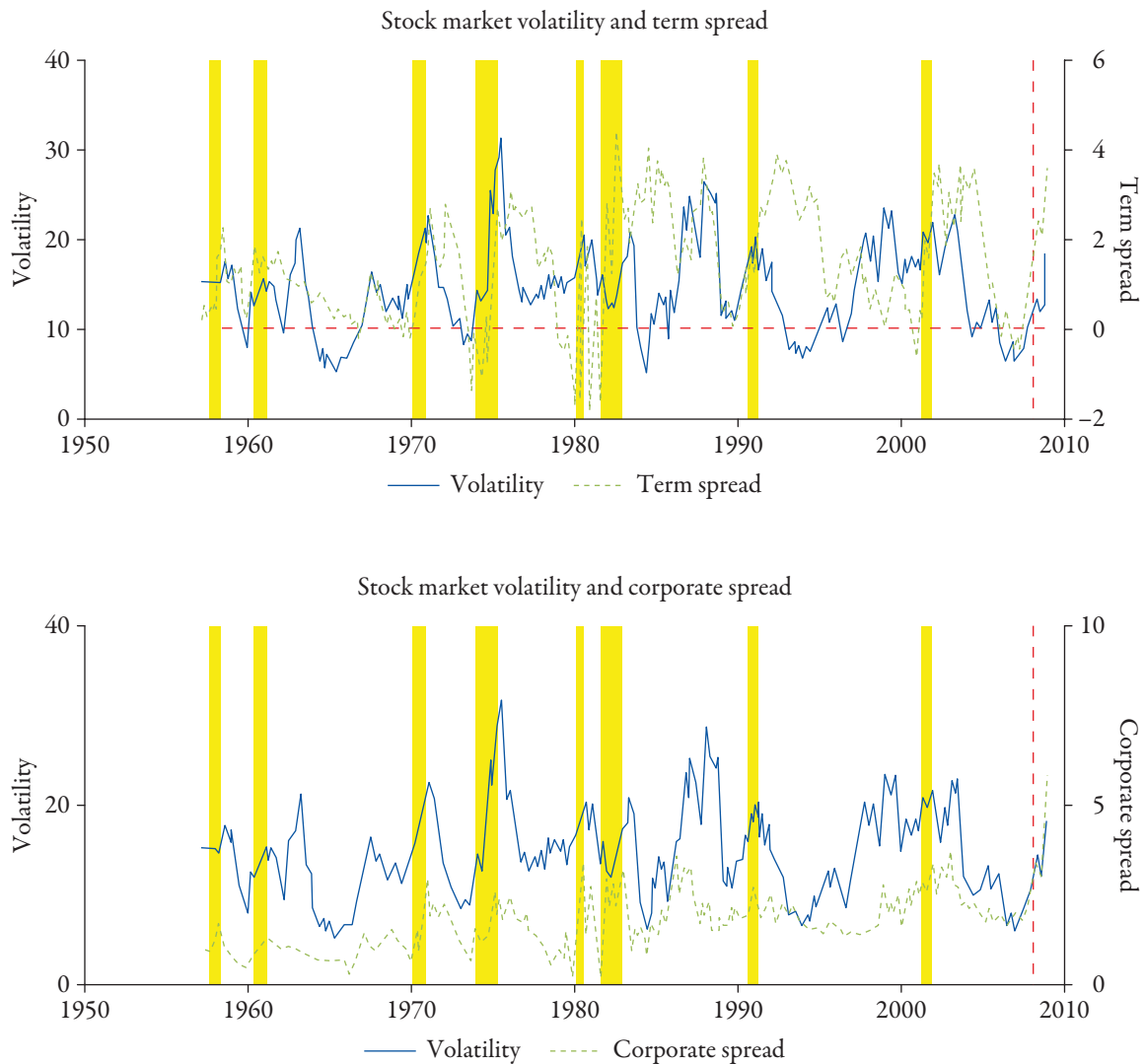
Figure 1 depicts the time series behavior of two fundamental variables of this paper: (i) aggregate stock market volatility,  $\sigma_t$  in Eq. (4), and (ii) industrial production growth at one year,  $G_{t-t+12}$  in Eq. (2). Remarkably, all NBER-dated recessions are associated with an increase in stock market volatility. Moreover, stock volatility is negatively correlated with one year growth, at about  $-37\%$ . This is the countercyclical property of stock volatility. Figure 2 compares stock volatility with two traditional financial leading indicators: the term spread and the corporate spread. Stock volatility is negatively correlated with the term spread, at about  $-10\%$ , and positively correlated with the corporate spread, at about  $39\%$ .

To investigate the leading properties of stock volatility, we consider the following regression:

$$\sigma_t = c + \sum_{i \in \{3, 12, 24, 36\}} b_i \sigma_{t-i} + \gamma_1 \mathbb{I}_{t \in O(\text{NBER},=1)} + \gamma_2 \mathbb{I}_{\text{NBER},=1} + u_t^\sigma$$

where the indicator function  $\mathbb{I}_{t \in O(\text{NBER},=1)}$  is always zero, except during the twelve months preceding any NBER-dated recession;  $\mathbb{I}_{\text{NBER},=1}$  equals one only during any NBER-dated recession, and is zero otherwise; finally,  $u_t^\sigma$  is a residual term.

Table 2 reports the estimates and t-statistics, computed through heteroskedasticity and autocorrelation consistent standard errors, for the parameters  $c$ ,  $b_i$  and  $\gamma_i$ . We analyze the whole sample period as well as two subsamples that have approximately the same number of observations, as further elaborated in Section 5.1. Over the whole sample, the estimates of  $\gamma_1$  and  $\gamma_2$  are positive and highly significant. Over the sampling period from 1957 to 1982, the estimate for  $\gamma_1$ , while positive, is no longer significant, which largely reflects the fact that stock volatility did not rise ahead of the 1981-1982 recession. Over the period including the Great Moderation, however, the estimates of  $\gamma_1$  and  $\gamma_2$  are positive, and quite comparable both in size and significance. Thus, according to this preliminary evidence, not only is stock volatility countercyclical. It also anticipates economic activity, especially during the period including the Great Moderation.



**Figure 2:** Aggregate stock market volatility, the term spread and the corporate spread.

*Note:* This figure plots aggregate stock market volatility against two traditional financial predictors of economic activity in the United States: the term spread (top panel) and the corporate spread (bottom panel). Volatility as of month  $t$  is defined as the annualized moving average of the absolute monthly returns in the previous year,  $\frac{k}{\sqrt{12}} \sum_{i=1}^{12} |R_{t+1-i}|$ , where  $R_t$  is the return on a stock price (total return) index at month  $t$ , and  $k$  is a scaling factor defined in the main text. The term spread is obtained as the difference between the 10 year government bond yield and the yield on 3-month Treasury Bills. The corporate spread is the difference between the baa yield and the 10 year Government bond yield. The sample covers monthly data for the period from January 1957 to September 2008. Shaded areas (in yellow) track NBER-dated recessions, and the vertical dashed line (in red) indicates the beginning of the latest NBER-dated recession.

## 4.2 Predicting Blocks of Economic Activity, and Controls

Financial volatility might be countercyclical, and anticipate the business cycle, because it merely reflects information conveyed by other factors. To assess if financial volatility accounts for additional pieces of information, we need to specify sets of control variables. Table 3 lists all the variables that we use in this paper, be they financial volatility variables or not.

First, we include the volatility of three financial variables: stock market returns, the term spread, and the corporate spread. For reasons developed below, we include a fourth financial volatility variable: the volatility of stock market volatility. The volatility of the

**Table 2:** Stock market volatility before and during NBER-dated recessions

Panel A: Full sample, 1957-2008							
	$c$	$b_3$	$b_{12}$	$b_{24}$	$b_{36}$	$\gamma_1$	$\gamma_2$
Estimate	3.11	0.94	-0.15	-0.01	-0.01	0.48	1.51
t-stat	7.18	40.10	-6.48	-0.65	-0.98	2.52	5.80
Panel B: 1957-1982							
	$c$	$b_3$	$b_{12}$	$b_{24}$	$b_{36}$	$\gamma_1$	$\gamma_2$
Estimate	3.60	0.98	-0.24	0.02	-0.04	0.34	1.87
t-stat	6.19	27.83	-8.85	1.07	-1.91	1.41	5.50
Panel C: 1983-2008							
	$c$	$b_3$	$b_{12}$	$b_{24}$	$b_{36}$	$\gamma_1$	$\gamma_2$
Estimate	2.88	0.94	-0.09	-0.05	-0.01	1.01	1.22
t-stat	4.76	32.56	-2.28	-1.86	-0.41	3.35	3.36

*Note:* This table report parameter estimates and t-statistics computed through heteroskedasticity and autocorrelation consistent standard errors for the linear regression:

$$\sigma_t = c + \sum_{i \in \{3,12,24,36\}} b_i \sigma_{t-i} + \gamma_1 \mathbb{I}_{t \in O(\text{NBER}_t=1)} + \gamma_2 \mathbb{I}_{\text{NBER}_t=1} + u_t^\sigma,$$

where  $\sigma_t$  is the aggregate stock market volatility as of month  $t$ , estimated as the annualized moving average of the absolute monthly returns in the previous year,  $\frac{k}{\sqrt{12}} \sum_{i=1}^{12} |R_{t+1-i}|$ ,  $R_t$  is the per cent return on a stock price (total return) index at month  $t$ ,  $k$  is a scaling factor defined in the main text, and  $u_t^\sigma$  is a residual term. The indicator function  $\mathbb{I}_{t \in O(\text{NBER}_t=1)}$  equals one, in the twelve months preceding any NBER-dated recession, and zero otherwise. The indicator function  $\mathbb{I}_{\text{NBER}_t=1}$  equals one, during any NBER-dated recession, and zero otherwise. The sample covers monthly data from January 1957 to September 2008.

term spread and that of the corporate spread are computed similarly as stock volatility (see Section 2.2), as follows:

$$(5) \quad \sigma_t^y \equiv \sqrt{6\pi} \cdot \frac{1}{\ell} \sum_{i=1}^{\ell} |\Delta y_{t+1-i}|.$$

where  $\Delta y_t$  is the monthly variation of the variable of interest  $y_t$ , and where we set  $\ell = 12$ . For the term spread, we take  $y_t = \text{term\_spread}_t$  and  $y_t = \text{corp\_spread}_t$ , with straight forward notation.

Not only is stock market volatility countercyclical. As Figure 1 shows, stock volatility increases sharply as the economy deteriorates. Therefore, the volatility of stock market volatility likely embeds information about the development of the business cycle. To investigate this issue further, we estimate the volatility of stock market volatility, as follows:

$$(6) \quad \text{VolVol}_{t+\ell} \equiv \frac{1}{\ell} \sum_{i=1}^{\ell} |\sigma_{t+i} - \hat{\sigma}_{t+i}|, \quad \hat{\sigma}_{t+\ell} \equiv \frac{1}{\ell} \sum_{i=1}^{\ell} \sigma_{t+i}, \quad t = 1, \dots, T - \ell,$$

where again,  $\ell = 12$ , as discussed in Section 3.2.

The second set of variables includes controls, relating to the volatility of five macro-economic variables: the return on the oil price index, the growth of industrial production, inflation, the unemployment rate and metals prices. These volatilities are computed through Eq. (5), as follows. Define the inflation rate  $\text{infl}_t = \ln\left(\frac{\text{CPI}_t}{\text{CPI}_{t-1}}\right)$ , where  $\text{CPI}_t$  is the consumer price index as of month  $t$ , and let  $\text{UR}_t$  and  $\text{MP}_t$  be the unemployment and metal price index at month  $t$ . In Eq. (5), we use  $y_t = \ln(\text{OP}_t)$  for the oil price index,  $y_t = \ln(\text{IP}_t)$  for industrial production,  $y_t = \text{infl}_t$  for inflation,  $y_t = \text{UR}_t$  for unemployment and, finally,  $y_t = \ln(\text{MP}_t)$  for the metals prices.

**Table 3:** Predictors of economic activity

Financial Volatility
P1 = stock market volatility
P2 = volatility of the term spread
P3 = volatility of the corporate spread
P4 = volatility of stock market volatility
Macroeconomic Volatility
P5 = volatility of oil return
P6 = volatility of industrial production growth
P7 = volatility of inflation
P8 = volatility of unemployment rate
P9 = volatility of metal return
Traditional Predictors
P10 = term spread
P11 = corporate spread
P12 = stock returns
P13 = oil return
P14 = index of leading indicators, growth
P15 = 3 month interest rate
P16 = inflation
P17 = dividend yield
P18 = lagged industrial production growth

**Table 4:** Predicting blocks of economic activity

B0 = lagged industrial production
B1 = term spread, corporate spread, 12 month stock market returns
B2 = term spread, short-term rate
B3 = stock market volatility, term spread volatility
B4 = stock market volatility, term spread
B5 = volatility of stock market volatility, short-term rate
B6 = volatility of stock market volatility, term spread
B7 = volatility of stock market volatility, stock market volatility, term spread
B8 = volatility of stock market volatility, stock market volatility, interaction term, term spread
Macroeconomics controls
B9 = volatilities of: oil return, industrial production growth, inflation, metal return
B10 = oil return, index of leading indicators (growth), inflation, dividend yield

The third set of variables is also a set of controls, which include traditional predictors of economic activity: the term spread, the corporate spread, a 12 month moving average of past stock returns, the return on the oil price index, the rate of growth on the index of leading indicators, the 3 month rate, the previously defined inflation rate, the dividend yield and, finally, lagged industrial production growth. The return on the oil price index and the rate of growth on the index of leading indicators have the same horizon as the forecasting horizon of the industrial production growth,  $k$ , in Eq. (2).

From the predictors in Table 3, we create eight predicting blocks, which are listed in Table 4, and discussed below.

Block B1: *Term spread, corporate spread, and 12 month stock market returns.*

Stock market returns are the oldest financial indicator to predict future economic activity, but they are also known to display poor predictive power, as reviewed for example by Stock and Watson (2003a). To enhance the predicting power of stock returns, this block includes variables tracking the market participants risk-appetite, which is widely acknowledged to be procyclical, as discussed further in Section 6.2. Naturally, procyc-

clical risk-appetite translates into countercyclical premiums for long-term investments and the risk of default of corporations. For this reason, and because monetary policy is countercyclical, the term spread and the corporate spread contain valuable information about the business cycle. For example, it is well-known since at least Kessel (1965) or, later, Laurent (1988, 1989), Stock and Watson (1989a), Estrella and Hardouvelis (1991) and Harvey (1991, 1993), that inverted yield curves predict recessions with a lead time of about one to two years. Likewise, default risk-premiums are known to contain predictive power since at least Stock and Watson (1989a) and Bernanke and Blinder (1992).

Block B2: *Term spread, short-term rate.*

More recently, Ang, Piazzesi and Wei (2006) argue that the short-term rate has larger marginal predictive power than the term spread. This finding differs from the extant empirical evidence (see, e.g., Plosser and Rouwenhorst, 1994), as it relies on a model that accounts for no-arbitrage relations between the yield curve and the growth of GDP. Such a novel empirical evidence on GDP growth motivates this second block, which is not no-arbitrage as in Ang, Piazzesi and Wei (2006) but still uses both the term spread and the short-term rate to predict the rate of growth of industrial production and NBER-dated recessions.

Block B3: *Stock market volatility, term spread volatility.*

Before recessions, the yield curve tends to invert, as discussed above. Moreover, near recessions, the term spread literally precipitates (as in Fig. 2, top panel), suggesting that the volatility of the term spread might contain information about the pace at which economic conditions deteriorate. We use term spread volatility, in conjunction with stock market volatility, to build this block. Stock volatility, which is the core variable of this paper, is included here, as we wish to consider a parsimonious predicting block entirely relying on financial volatility variables: on the one hand, term spread volatility carries information about the speed at which risk-premiums and monetary policy change in bad times; on the other hand, stock market volatility links to the business cycle perhaps more broadly, through the mechanisms explained in Section 6, and possibly carries information not captured by the term spread volatility.

Block B4: *Stock market volatility, term spread.*

This predicting block is at the heart of the paper. It differs from the two previous blocks, in that it replaces the short-term rate in Block B2 with stock volatility, and the term spread volatility in Block B3 with the term spread. By replacing the short-term rate with stock volatility, we aim to test whether stock volatility provides a better predicting power than the short-term rate in Block B2, once the term spread is included. Likewise, we include the term spread to assess whether this variable has better predictive content than the term spread volatility in Block B3, once stock market volatility is included. Note, finally, that this block carries an interesting economic interpretation, as it combines two variables that relate to (i) aggregate financial risk (stock market volatility) and (ii) economic risk-premiums and, monetary policy (the term spread).

Block B5: *Volatility of stock market volatility, short-term rate.*

This block replaces the term spread of Block B2 with the volatility of the stock price volatility. Its aim is to explore whether the term spread has less predicting power than the swings in stock volatility that were discussed while motivating Eq. (6). Naturally, the volatility of volatility also generates false signals, by occasionally increasing in good times.

For example, in 1984 and 1985, stock volatility precipitated (see Fig. 1), as a result of a quite sharp improvement in the business cycle, which led the volatility of volatility to increase. The possibility of occurrence of such false signals calls for controls, which we introduce in Block B8 discussed below.

Block B6: *Volatility of stock market volatility, term spread.*

This block investigates the same issues discussed for the fifth block, but replaces the short-term rate with the term spread. A comparison between the predicting ability of these two blocks, therefore, leads to assess the relative predicting power of the term spread over the short-term rate, gauged through the lenses of the volatility of stock market volatility.

Block B7: *Volatility of stock market volatility, stock market volatility, term spread.*

This block, and the following, simply expand on Block B6, by adding additional information such as stock market volatility and, as discussed below, an interaction term between stock market volatility and the volatility of stock market volatility.

Block B8: *Volatility of stock market volatility, stock market volatility, interaction term, term spread.*

The interaction term in this block is the product between lagged stock market volatility and the volatility of volatility at time  $t$ , i.e.  $\sigma_{t-\tau} \cdot \text{VolVol}_t$ , for  $\tau$  fixed. This term aims to help cope with false signals the volatility of volatility might generate. As discussed while motivating Block B5, there might be two sorts of «VolVols»: a «good» and a «bad», where the «bad» occurs when economic growth accelerates in such a way to make volatility fall rapidly, thereby inducing the volatility of volatility to increase in good times. The interaction term has the potential to dampen the issues arising from these events. In our tests, we find that the best out-of-sample performance occurs with  $\tau$  equal to twelve months, which we use throughout the paper.

Further to these eight blocks, we consider the predicting ability of a simple model including lagged values of the industrial production growth, which we label Block B0. Finally, the two «macroeconomic» blocks B9 and B10 in Table 4, are needed to control out-of-sample results, and are discussed in Section 6.2.

## 5 In-Sample Evidence

### 5.1 Linear Predictions of Economic Activity

Given a monthly predicting horizon  $k \in \{3, 6, 12, 24\}$ , we regress industrial production growth  $G_{t \rightarrow t+k}$  on to the predictors listed in Table 3 and the predicting blocks in Table 4. For every single regressor or predicting block, we include five lags: the current period plus four additional lags  $l_i^k$ ,  $i = 1, 2, 3, 4$ , where the lag structure  $l_i^k$  is initially selected according to the highest  $R^2$  criterion.

The regressions based on the predictors in Table 3 take the following form:

$$(7) \quad G_{t \rightarrow t+k} = \alpha^k + \sum_{j=1}^{P_i} \sum_{\text{lag} \in \{0, l_1^k, \dots, l_4^k\}} \beta_j^k(\text{lag}) \cdot \text{Regressor}_j(t - \text{lag}) + \text{Error}(t+k), \quad k \in \{3, 6, 12, 24\},$$

where, for  $i = 1, \dots, 18$ ,  $P_i$  is the number of regressors, and  $\alpha^k, \{\beta_j^k(\text{lag})\}_{\text{lag} \in \{0, l_1^k, \dots, l_4^k\}}$  are the parameters to be estimated. For the only purpose of simplifying the presentation, we report

**Table 5:** R<sup>2</sup> for in-sample regressions on predictors of economic activity

Predictors	Panel A: Full sample, 1957-2008			
	3m	6m	1Y	2Y
P1 = stock market volatility	<b>0.01</b>	<b>0.02</b>	0.06	0.11
P2 = volatility of the term spread	<b>0.06</b>	0.09	0.14	0.17
P3 = volatility of the corporate spread	0.09	0.14	0.21	0.28
P4 = volatility of stock market volatility	0.14	0.21	0.29	0.37
P5 = volatility of oil return	0.22	0.31	0.34	0.43
P6 = volatility of industrial production index	0.27	0.36	0.38	0.47
P7 = volatility of inflation	<b>0.33</b>	0.43	0.45	0.68
P8 = volatility of unemployment rate	<b>0.38</b>	0.50	0.53	0.80
P9 = volatility of metal return	<b>0.39</b>	<b>0.51</b>	0.57	0.83
P10 through P18	<b>0.61</b>	0.75	0.85	0.92
Predictors	Panel B: 1957-1982			
	3m	6m	1Y	2Y
P1 = stock market volatility	0.01	0.01	0.04	0.09
P2 = volatility of the term spread	0.05	0.08	0.14	0.18
P3 = volatility of the corporate spread	0.09	0.15	0.24	0.32
P4 = volatility of stock market volatility	0.26	0.42	0.55	0.63
P5 = volatility of oil return	0.51	0.63	0.70	0.74
P6 = volatility of industrial production index	0.55	0.70	0.73	0.75
P7 = volatility of inflation	0.61	0.76	0.78	0.89
P8 = volatility of unemployment rate	0.60	0.77	0.81	0.92
P9 = volatility of metal return	0.62	0.78	0.85	0.92
P10 through P18	<b>0.72</b>	<b>0.86</b>	<b>0.94</b>	0.97
Predictors	Panel C: 1983-2008			
	3m	6m	1Y	2Y
P1 = stock market volatility	0.12	0.23	0.35	0.55
P2 = volatility of the term spread	0.23	0.37	0.50	0.70
P3 = volatility of the corporate spread	0.26	0.40	0.55	0.75
P4 = volatility of stock market volatility	0.33	0.49	0.60	0.79
P5 = volatility of oil return	0.44	0.59	0.70	0.84
P6 = volatility of industrial production index	0.43	0.59	0.71	0.86
P7 = volatility of inflation	0.46	0.64	0.73	0.87
P8 = volatility of unemployment rate	0.49	0.71	0.85	0.92
P9 = volatility of metal return	0.50	0.73	0.88	0.94
P10 through P18	<b>0.60</b>	0.86	0.95	0.97

*Note:* This Table provides cumulative R<sup>2</sup> for in-sample forecasts of industrial production growth at horizons of 3 months, 6 months, 1 year and 2 years, obtained through the predictors in Tables 3. The sample covers monthly data for the period from January 1957 to September 2008. Figures in bold indicate marginal significance levels for F-stats greater than 95%, against the null hypothesis that the stock market volatility coefficients are all zero.

results arising from the use of a uniform lag structure, where each regression in Eq. (7) is performed against predictors lagged at 3, 12, 18, 24 and 36 months. The predictability pattern of our financial volatility indicators is quite robust to the choice of these lags.

The first of these linear regressions includes stock market volatility as a regressor, which is Predictor P1 in Table 3. The second regression includes stock market volatility and the volatility of the term spread, which are Predictors P1 and P2. The last regression has all the eighteen regressors listed on Table 3. Table 5, Panel A, reports cumulative R<sup>2</sup> for these regressions, along with information about Granger causality test statistics, summarized by the F-statistics for the null hypothesis that the loadings on stock market volatility are all zero, at the 5% confidence level. Panels B and C in Table 5 report cumulative R<sup>2</sup> for regressions performed on two sub-samples: a first sub-sample, spanning the period from January 1957 to December 1981, which includes 300 observations; and a second, from January 1982 to September 2008, which has 321 observations. We choose



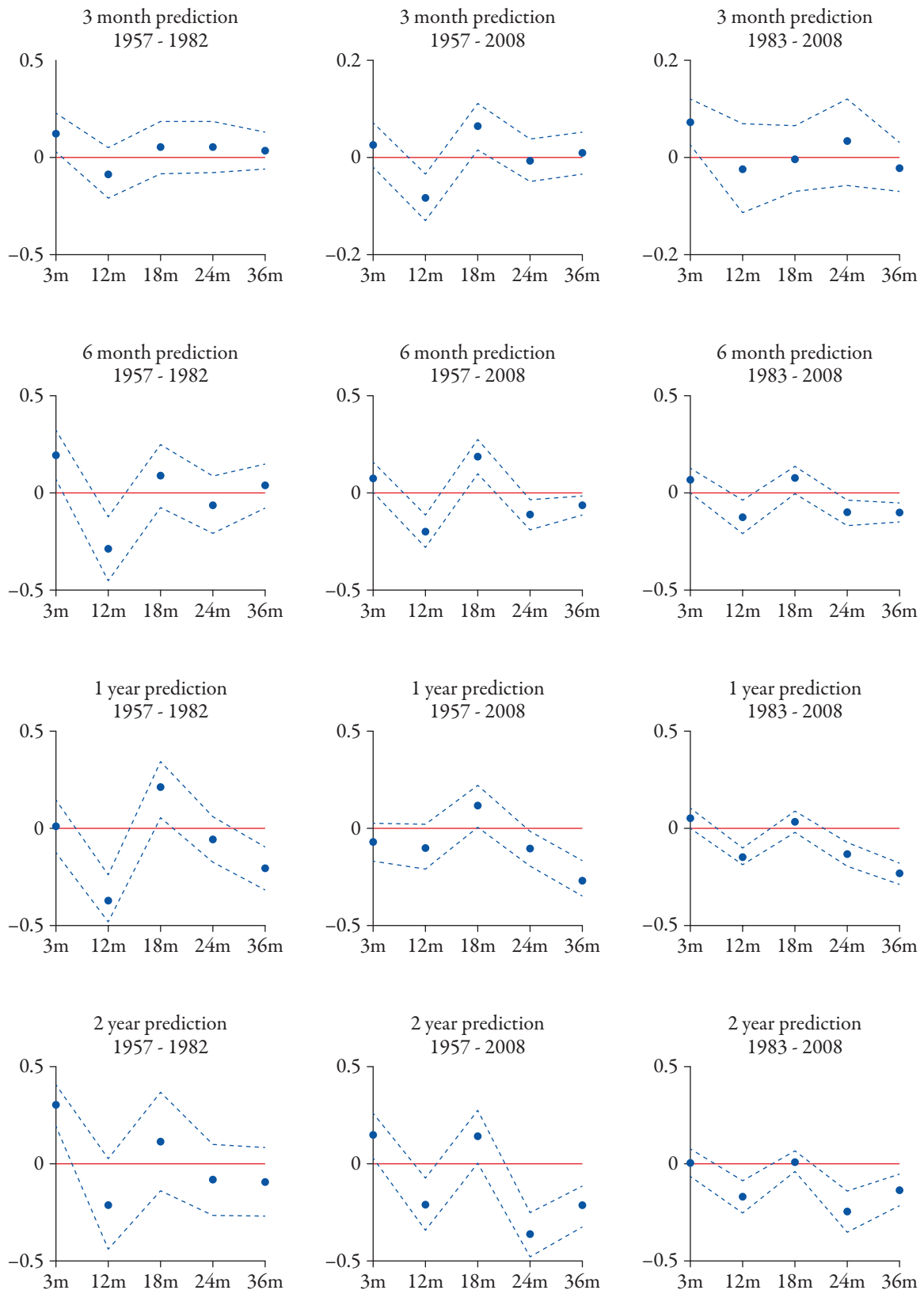
these two sub-samples because they have approximately the same size, and because the year 1982 likely marks the beginning of structural changes, ranging from the inauguration of the Federal Reserve monetary policy turning point, to the lower volatility of real macroeconomic variables (e.g., Blanchard and Simon, 2001) – the Great Moderation (e.g., Bernanke, 2004).

Our results are easily summarized. We find that for the whole sample, the first four predictors, based on financial volatility, explain about 30% of industrial production growth, at one year forecasting horizon, and about 40% at two year forecasting horizon. The predicting power of stock market volatility over the Great Moderation is striking: it explains, alone, from 35% to 55% of growth, at horizons of one year and two years. In contrast, the same volatility explains 4% of growth, at one year horizon, in the first sub-sample. Naturally, these  $R^2$  need to be interpreted cautiously, as the ordering of regressors does obviously matter. To address this issue, we check the significance of the coefficient estimates on stock market volatility, and look at the F-tests that these coefficients are all zero. In both cases, we use heteroskedasticity and autocorrelation consistent standard errors, which are needed to deal with the serial dependence of the regressands.

For space reasons, we do not report all coefficients estimates. Instead, Figure 3 reports point estimates and confidence intervals of the loadings for stock market volatility only, when *all* the regressors in Table 3 are used. At a forecasting horizon of six months or more, volatility is negatively related to future economic activity, especially at recent and distant lags. This pattern seems to be consistent across all predicting horizons and, also, the sampling periods, although the most significant estimates occur over the Great Moderation period. The F-tests suggest that stock market volatility is not picking up information already conveyed by other predictors, at horizons ranging from six months to two years. Again, the F-tests confirm that stock volatility is a robust predictor of growth, over the Great Moderation: only at three month horizon, do these tests reject the null of Granger causality, at the conventional 95% level.

Next, we perform the regression in Eq. (7), using the first nine predicting blocks of Table 4. Table 6 reports  $R^2$  for all the separate regressions of industrial production growth onto these blocks, for the selected forecasting horizons. The most remarkable explanatory power is that of (i) Block B2, which contains the term spread and the short-term rate, and (ii) Block B4, which includes aggregate stock market volatility and the term spread. For example, Block B4 explains about 50% of one-year growth in the first sub-sample, and 57% of one-year growth during the Great Moderation. In the first sub-sample, Block B2 explains more than Block B4, while in the second sample, it is Block B4 that explains more than Block B2.

The two blocks, B1 and B5, provide the highest explanatory power, for the whole sample. Block B1, which includes the term spread, corporate spread and stock returns, is, however, less parsimonious than blocks B2 and B4. Moreover, it explains less than B2 and B4, over each separate sub-sample. Block B5, which has the volatility of stock market volatility and the short-term rate, seems to perform quite well in the first sub-sample, explaining about 64% of real growth at one year horizon, more than blocks B2 and B4 do. The same figure, however, drops to 12% in the sub-sample spanning the Great Moderation. Finally, the two blocks B7 and B8, which contain the term spread and volatility of volatility variables,



**Figure 3:** Estimates of volatility loading on industrial production growth.

*Note:* Point estimates and 95% confidence bands for the loadings on stock market volatility lagged at 3, 12, 18, 24 and 36 months, in regressions of 3 month, 6 month, 1 year and 2 year industrial production growth on stock market volatility and the additional predictors listed on Table 3. Confidence bands are obtained with heteroskedasticity and autocorrelation consistent standard errors.

explain a large proportion of growth, especially during the Great Moderation. At the same time, these blocks lack parsimony, as they have three (B7) or four (B8) regressors.

To summarize, our preliminary, in-sample, findings suggest that the two predicting blocks B2 and B4, are those providing both an important explanatory power and relatively stable links with future growth. The term spread is in common in these two blocks. The difference between B2 and B4 stems from the additional conditioning information: the short-term rate (B2), and aggregate stock market volatility (B4). We shall gauge the relative predicting ability of these two non-nested blocks while implementing out-of-sample predictions, in Section 6.

## 5.2 Probabilities of Recessions

We estimate probabilities of recessions through Probit models applied to the first nine predicting blocks in Table 4. As in Estrella and Hardouvelis (1991), we model recessions in Eq. (3) by setting  $\text{Rec}_t = 1$ , if some latent variable  $\text{Rec}_t^* \geq 0$ , and  $\text{Rec}_t = 0$ , otherwise. For each predicting horizon  $k$ , we model the predictive part of  $\text{Rec}_t^*$  as a linear combination of the variables included in each block,

$$\text{Rec}_t^* = B_{t-k}^i + u_t, \quad k \in \{3, 6, 12, 24\},$$

where  $i = 0, 1, \dots, 8$ ,  $u_t$  is independent and identically distributed as a standard normal variable, and  $B_t^i$  is a linear combination of the variables included in any Block  $Bi$  of Table 4, with each regressor lagged as in Eq. (7). Thus,  $B_{t-k}^i$  includes predictors observed or measured at time  $t - (3 + k)$ ,  $t - (12 + k)$ ,  $t - (18 + k)$ ,  $t - (24 + k)$  and  $t - (36 + k)$  months.

The weights of the linear combinations  $B_t^i$  are estimated via maximum likelihood, where the log-likelihood of a single observation is given by  $\text{Rec}_t \ln \Phi(B_{t-k}^i) + (1 - \text{Rec}_t) \ln(1 - \Phi(B_{t-k}^i))$ , and  $\Phi$  is the standard cumulative normal distribution. Thus, the probability of a NBER recession at time  $t$ , predicted by any block  $Bi$ , at horizon  $k$ , is:

$$(8) \quad \text{Probit}_t(\text{Rec}_t | Bi) \equiv \Phi(\hat{B}_{t-k}^i), \quad k \in \{3, 6, 12, 24\},$$

where  $\hat{B}_t^i$  denotes the linear combination  $B_t^i$ , evaluated at the estimated parameters. Naturally, the probabilities in Eq. (8) are computed conditionally upon the entire sample. Out-of-sample forecasts of recession probabilities are discussed, and computed, in Section 6.

Table 7 reports pseudo  $R^2$ , along with frequencies of correctly identified recessions and expansions, for each block in Table 4. We define a recession to be correctly identified if the probability in Eq. (8) predicted by any block exceeds 16.22%, which is the fraction of time the US spent in recession over the entire sample period. Figure 4 depicts the probabilities of NBER-recessions predicted by blocks B1 through B8, obtained setting  $k = 12$  months in Eq. (8).

Probit analysis is quite consistent with our previous findings about growth. Blocks B7 and B8, which include the term spread, stock market volatility and the volatility of the

**Table 6:** R<sup>2</sup> for in-sample regressions on predicting blocks of economic activity

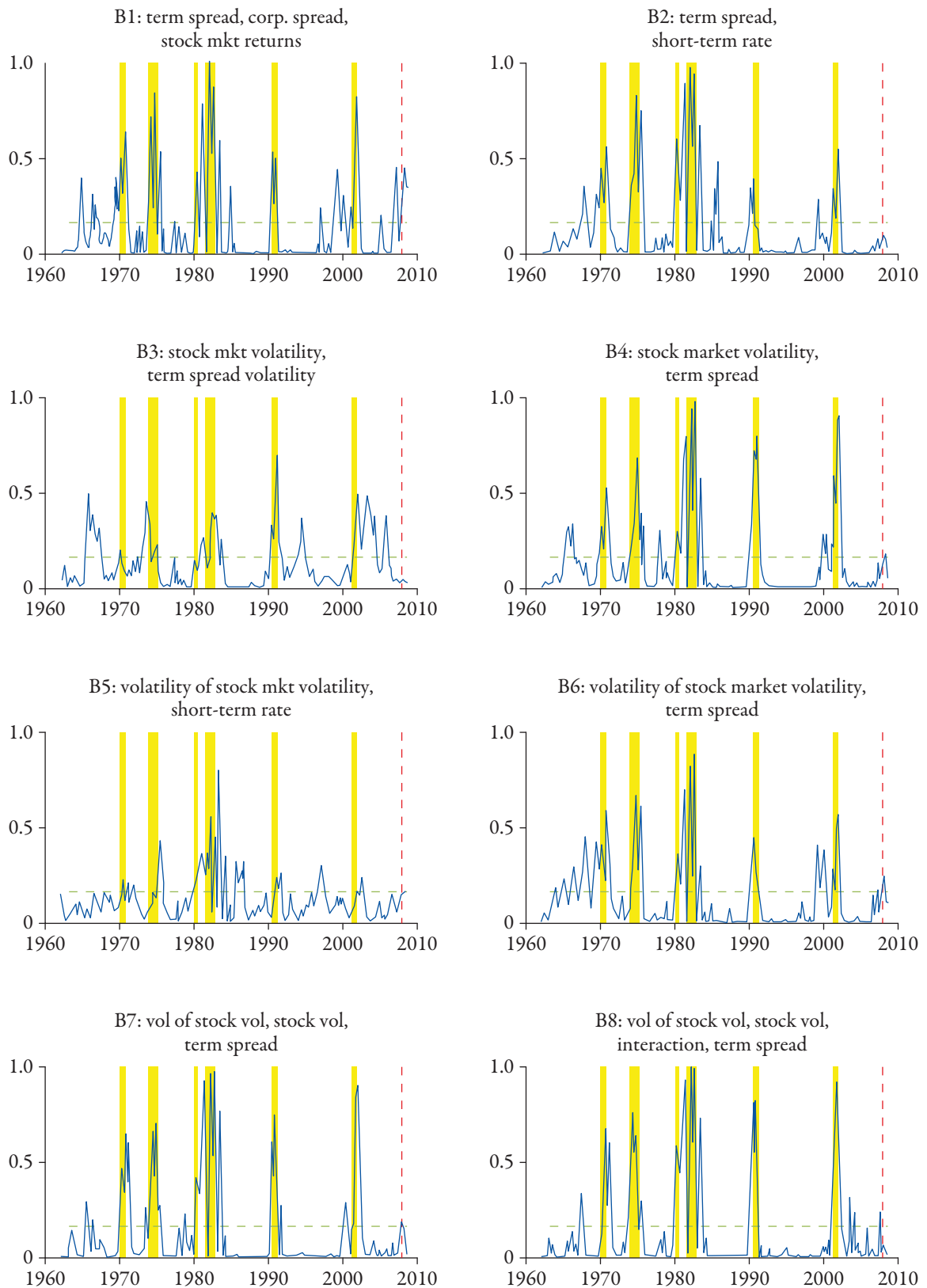
Predicting block	Panel A: Full sample, 1957-2008			
	3m	6m	1Y	2Y
B0	0.18	0.09	0.04	0.03
B1	0.27	0.28	0.38	0.41
B2	0.17	0.27	0.38	0.39
B3	0.17	0.09	0.13	0.18
B4	0.12	0.15	0.24	0.32
B5	0.18	0.28	0.39	0.38
B6	0.10	0.15	0.17	0.15
B7	0.15	0.19	0.28	0.38
B8	0.23	0.29	0.37	0.40
Predicting block	Panel B: 1957-1982			
	3m	6m	1Y	2Y
B0	0.17	0.09	0.05	0.11
B1	0.32	0.40	0.56	0.49
B2	0.27	0.43	0.61	0.66
B3	0.18	0.18	0.22	0.25
B4	0.21	0.35	0.50	0.38
B5	0.29	0.46	0.64	0.74
B6	0.25	0.35	0.47	0.47
B7	0.28	0.45	0.60	0.53
B8	0.41	0.50	0.65	0.55
Predicting block	Panel C: 1983-2008			
	3m	6m	1Y	2Y
B0	0.18	0.08	0.05	0.06
B1	0.41	0.31	0.40	0.47
B2	0.25	0.33	0.42	0.46
B3	0.25	0.40	0.54	0.72
B4	0.26	0.47	0.57	0.68
B5	0.11	0.10	0.12	0.12
B6	0.15	0.21	0.26	0.27
B7	0.26	0.48	0.63	0.78
B8	0.26	0.48	0.63	0.79

*Note:* This table provides R<sup>2</sup> for in-sample forecasts of industrial production growth at horizons of 3 months, 6 months, 1 year and 2 years, obtained through the first nine predicting blocks in Table 4. The sample covers monthly data for the period from January 1957 to September 2008. Keys: B0: Lagged industrial production; B1: Term spread, Corp. spread, Stock mkt returns; B2: Term spread, short rate; B3: Stock mkt volatility, Term spread volatility; B4: Stock mkt volatility, Term spread; B5: Vol of stock mkt vol, Short-rate; B6: Vol of stock mkt vol, Term spread; B7: Vol of stock mkt vol, Stock mkt vol, Term spread; B8: Vol of stock mkt vol, Stock mkt vol, Interaction, Term spread.

**Table 7:** R<sup>2</sup> for in-sample Probit-based predictions of recessions, and frequencies of correctly identified business cycle conditions

Predicting block	3 months			6 months			1 Year			2 Years		
	R <sup>2</sup>	Rec	Exp	R <sup>2</sup>	Rec	Exp	R <sup>2</sup>	Rec	Exp	R <sup>2</sup>	Rec	Exp
B0	0.10	0.73	0.76	0.02	0.57	0.67	0.02	0.51	0.68	0.03	0.67	0.68
B1	0.36	0.90	0.79	0.36	0.89	0.80	0.29	0.89	0.78	0.04	0.62	0.69
B2	0.32	0.84	0.81	0.39	0.87	0.85	0.28	0.89	0.83	0.05	0.66	0.74
B3	0.25	0.87	0.77	0.23	0.71	0.76	0.13	0.71	0.73	0.16	0.83	0.73
B4	0.30	0.83	0.76	0.41	0.91	0.84	0.28	0.90	0.81	0.08	0.67	0.72
B5	0.32	0.85	0.79	0.34	0.95	0.83	0.07	0.73	0.73	0.07	0.67	0.74
B6	0.29	0.89	0.76	0.35	0.90	0.82	0.20	0.88	0.75	0.05	0.67	0.70
B7	0.37	0.91	0.83	0.46	0.94	0.85	0.34	0.93	0.86	0.05	0.67	0.70
B8	0.48	0.96	0.89	0.60	0.94	0.91	0.38	0.89	0.88	0.12	0.80	0.69

*Note:* This table provides pseudo R<sup>2</sup>, and the frequencies of correctly identified NBER recessions and expansions, for in-sample forecasts of probabilities of NBER recessions, obtained through Probit models fed by the first nine predicting blocks in Table 4. The sample covers monthly data from January 1957 to September 2008. A correctly identified recession (resp., expansion) occurs when the probability of recession (resp., expansion) predicted by a given block exceeds (resp., does not exceed) 16.22%, which is the fraction of time the US economy spent in recession in the sample, according to NBER dating. For each predicting horizon (3 and 6 months, 1 Year and 2 Years), the column labeled R<sup>2</sup> reports pseudo R<sup>2</sup>, and the columns labeled Rec and Exp report frequencies of correctly identified recessions and expansions. Keys: B0: Lagged industrial production; B1: Term spread, Corp. spread, Stock mkt returns; B2: Term spread, short rate; B3: Stock mkt volatility, Term spread volatility; B4: Stock mkt volatility, Term spread; B5: Vol of stock mkt vol, Short-rate; B6: Vol of stock mkt vol, Term spread; B7: Vol of stock mkt vol, Stock mkt vol, Term spread; B8: Vol of stock mkt vol, Stock mkt vol, Interaction, Term spread.



**Figure 4:** Probabilities of recession predicted by in-sample estimates of Probit models.

*Note:* In-sample forecasts of recession probabilities one year ahead, obtained through the predicting blocks in Table 4, B1 through B8. The horizontal dashed line (in green) is drawn at a value equal to 16.22%, which is the fraction of time the US economy spent in recession in the sample, according to NBER dating. The sample covers monthly data for the period from January 1957 to September 2008. Shaded areas (in yellow) track NBER-dated recessions, and the vertical dashed line (in red) indicates the beginning of the latest NBER-dated recession.

stock price volatility, deliver the highest  $R^2$ . These  $R^2$ , however, might be attributable to the large number of regressors in these blocks. Blocks B2 (term spread and short-term rate) and B4 (stock market volatility and term spread) are, instead, more parsimonious, and yet they explain NBER-dated recessions reasonably well, with  $R^2$  equal to approximately 40% (six month horizon) and 30% (one year horizon).

Block B1 (term spread, corporate spread and stock returns) has also explanatory power, comparable to that of B2 and B4. However, it is less parsimonious and seems to generate wrong recession signals more frequently than B2 and B4, for example around the two years 1983 and 1998 (see Fig. 4). Quantitatively, Table 7 confirms that at horizons of six months or longer, the frequency of correctly identified expansions is lower for B1 than for B2 and B4: B1 produces too many wrong signals in good times, compared to B2 and B4. The performances of B2 and B4 seem to be quite comparable, in terms of the statistics in Table 7. At the same time, Figure 4 reveals that block B2 produces one wrong and sizeable recession signal (a predicted recession probability of almost 50%), just after the Monetary experiment of the early 1980s, which Block B4 does not predict. These two different predictions are due to the effects the new monetary policy regime had on interest rates and stock market volatility. On the one hand, soon after the FOMC meeting on October 5<sup>th</sup>, 1982, when Federal Reserve Chairman Volcker concluded that money supply could be increased more rapidly than in the previous three years, capital markets expectations stabilized, and led to an extraordinary low aggregate stock market volatility (see Figg. 1 and 2). On the other hand, the short-term rate did continue to rise, after the Monetary experiment. These two circumstances explain why block B2 (which includes the short-term rate) produces a recession signal in the mid 1980s, while block B4 (which includes stock market volatility) does not. Naturally, this is a particular episode of financial history, but it does illustrate in an exemplary manner the role stock volatility could play in informing about the development of the business cycle.

Except perhaps block B1, no block really helps predict the last recession in the sample, which started in December 2007. It is an important failure, as the latest predictions produced by these models may be safely interpreted as coincident recession forecasts, due to our assumption that  $Rec_t = 0$  in Eq. (3) after December 2007 (see Section 3.1). The explanation for this failure is that our in-sample analysis averages out complex and temporally heterogeneous relations: arguably, the links between capital markets volatility and the business cycle over the 2007 recession might be distinct, at least quantitatively, from those occurred half a century earlier. For example, our findings in Section 5.1 suggest that these links are much stronger over the Great Moderation. Estimating Probit models using data for the whole sample may simply dilute the strength of these links. We address this issue while implementing our out-of-sample analysis, discussed in the next section.

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## 6 Out-of-Sample Predictions

This section assesses the relative accuracy of the predicting blocks in Table 4. We consider both linear predictions of industrial production growth and predictions of recession probabilities, at horizons of 3 months, 6 months, 1 year and 2 years.

## 6.1 Assessing Predictive Accuracy

For both the linear predictions of industrial production growth and recession probabilities, we implement rolling estimates and real-time multi-step ahead predictions. We utilize a lag structure with a span larger than that we used over the in-sample analysis, with predictors lagged at 3, 6, 12, 36 and 48 months<sup>2</sup>. The use of a larger span is needed, as multi-step ahead predictions inevitably lead to dissipation of long-term information, as we explain below.

Instead, the rationale behind the use of rolling regressions is that the relations linking capital markets to the state of the economy may undergo structural shifts. To illustrate, the legal system, the state of technology or the monetary regime are all inherently heterogeneous. For example, the spectacular drop in the economic activity over the 2007 subprime crisis might be pointing to reversals in the low macroeconomic volatility known under the Great Moderation. A second example of a structural shift relates to our in-sample analysis of Section 5.1, where we uncover evidence of substantial changes in the linkages between financial volatility and economic conditions, occurred around the inception of the Great Moderation. The models we use hinge upon the simple predicting blocks in Table 4, and do not necessarily account for these sources of heterogeneity. In fact, many authors suggest that using predicting variables with limited memory helps handle the nonstationary nature of economic data (e.g., Clements and Hendry (1999), Giacomini and White (2006)). Rolling regressions, introduced by Fama and MacBeth (1973) in a different context, easily address these issues.

We use rolling estimates that comprise  $M$  observations, with  $M = 120$  and 90 months. For each predicting horizon target for growth,  $G_{t-k \rightarrow t}$  in Eq. (2), we use  $M$  observations prior to  $t$  and estimate the linear regression,  $G_{t-k \rightarrow t} = B_{t-k}^i + z_t$ , where  $B_t^i$  is a linear combination of the variables in any block  $Bi$  of Table 4, lagged at 3, 6, 12, 36 and 48 months, and  $z_t$  is a residual term. The forecast for growth at horizon  $k$ , formulated at  $t$ , is:  $\hat{G}_{t \rightarrow t+k}^i \equiv \hat{B}_t^i$ , where  $\hat{B}_t^i$  is the linear combination  $B_t^i$ , evaluated at the estimated parameters. The forecast errors are:

$$(9) \quad \epsilon_{t,k}^i \equiv G_{t \rightarrow t+k} - \hat{G}_{t \rightarrow t+k}^i, \quad i = 0, 1, \dots, 8, \quad t = M, \dots, N - k, \quad k \in \{3, 6, 12, 24\},$$

where  $N$  is the sample size. Prediction errors arising in the context of Probit models are defined in a similar way. To save on notation, they are denoted as the previous forecasting errors, viz

$$(10) \quad \epsilon_{t,k}^i \equiv \mathbb{I}_{\text{NBER}_{t+k}=1} - \text{Probit}_t(\text{Rec}_{t+k} | Bi), \quad i = 0, 1, \dots, 8, \quad t = M, \dots, N - k, \quad k \in \{3, 6, 12, 24\},$$

where  $\mathbb{I}_{\text{NBER}_{t+k}=1}$  is defined as we explained after Eq. (3), and  $\text{Probit}_t(\text{Rec}_{t+k} | Bi)$  is the probability of a NBER-dated recession at time  $t + k$ , predicted by a Probit model, given all available information provided by a given Block  $Bi$  from time  $t - M$  to time

<sup>2</sup> We experimented with lag structures aiming at maximizing the out-of-sample performance of the blocks, according to the criteria explained below, and obtained results quite close to those we report here.

$t$ :  $\text{Probit}_t(\text{Rec}_{t+k} | B_i) \equiv \Phi(\hat{B}_t^i)$ , where  $\hat{B}_t^i$  is defined as  $\hat{B}_t^i$  in Eq. (8), except that the parameters in  $\hat{B}_t^i$  are estimated using sample data from  $t - M$  to  $t$ , not the entire sample data.

Decisions about NBER-dating are taken later than recessions actually occur. A piece of information of considerable interest is an estimate of the probability of being in a recession *around* recession periods, which we estimate as a one-month ahead prediction of any Probit model, as follows:

$$(11) \quad \text{Probit}_t^k(\text{Rec}_{t+1} | B_i) \equiv \Phi(\hat{B}_{t-k+1}^i), \quad k \in \{3, 6, 12, 24\}.$$

Note that although the regressors in Eq. (11) are shifted away by the forecasting horizon,  $k$ , the parameter estimates in  $\hat{B}_{t-k+1}^i$  are obtained with sample data from  $t - M$  to  $t$ , thus providing fresh information about the nature of the links between any predicting block and the business cycle. Instead, the prediction  $\text{Probit}_t(\text{Rec}_{t+k} | B_i)$  in (10) utilizes parameter estimates that are  $k$  months «stale». Finally, in this context, forecasting errors are defined similarly as in Eqs. (9)-(10).

To measure the loss induced by all these forecast errors, we use an absolute error loss function,  $|\epsilon_{t,k}^i|$ , and implement two testing procedures: (i) an unconditional procedure, which aims to assess the relative merits of our predicting blocks, on average, as described in Section 6.1.1; and (ii) a conditional procedure, which compares the predictive ability of these blocks in different points in time and, presumably, states of the economy, as explained in Section 6.1.2.

### 6.1.1 Unconditional Predictive Ability

We test whether the predictive accuracy of a given block  $i$  is, unconditionally, higher than that of another block  $j$ , through the Diebold and Mariano (1995) (DM, henceforth) test statistic. Let

$$\bar{d}_{T,k}^{i,j} = \frac{1}{T} \sum_{t=1}^T (|\epsilon_{t,k}^i| - |\epsilon_{t,k}^j|),$$

where  $T = N - M - 1$  is the number of available forecasts. We test the null hypothesis that the predicting Block  $B_i$  has unconditionally lower expected loss than  $B_j$  through the standardized test statistics  $\sqrt{T} \bar{d}_{T,k}^{i,j} / V_{T,k}^{i,j}$ , where  $V_{T,k}^{i,j}$  is a consistent estimate of the long-variance of  $\bar{d}_{T,k}^{i,j}$ , obtained through the usual Newey-West estimator, with a truncation lag equal to the predicting horizon,  $k$ .

### 6.1.2 Conditional Predictive Ability

We utilize the testing strategy devised by Giacomini and White (2006) (GW, henceforth) to assess the relative conditional predictive accuracy of the blocks in Table 4. This strategy relies on rolling regressions for the forecasting target, similarly as for the DM



test<sup>3</sup>. Its novelty is its ability to test whether one predicting block performs better over the remaining ones, under any particular circumstances such as say, business cycle conditions or the monetary policy regime.

Define the difference in the loss functions generated by any two blocks  $i$  and  $j$  at time  $t$ , for the predicting horizon  $k$ , as  $\Delta\epsilon_{t,k}^{ij} \equiv |\epsilon_{t,k}^i| - |\epsilon_{t,k}^j|$ . The GW test is based on the regression of  $\Delta\epsilon_{t+1,k}^{ij}$  on some vector of variables  $h_{t,k}^{ij}$ , deemed to explain the failure of equal conditional predictive ability stemming from any two blocks:

$$(12) \quad \Delta\epsilon_{t+1,k}^{ij} = \delta_k^{ij} \cdot h_{t,k}^{ij} + u_{t+1,k}^{ij}, \quad t = M - 1, \dots, N - k,$$

where for any two predicting blocks  $i$  and  $j$ , and predicting horizon  $k$ ,  $\delta_k^{ij}$  is a vector of constants, and, finally,  $u_{t+1,k}^{ij}$  is a residual term. Under standard regularity conditions, the null of equal conditional predictive ability of any two blocks is rejected whenever  $T \cdot R^2 > \chi_{q,1-\alpha}^2$ , where: (i)  $R^2$  is the uncentered  $R^2$  of the regression in Eq. (12), and (ii)  $\chi_{q,1-\alpha}^2$  is the  $(1 - \alpha)$  quantile of a chi-square with  $q$  degrees of freedom, where  $q$  is the dimension of the test function  $h_{t,k}^{ij}$ . Naturally, the GW test is asymptotically equivalent to DM, once  $h_{t,k}^{ij}$  is chosen to be a vector of constants.

A crucial choice relates to the type of conditioning information to include in the vector  $h_{t,k}^{ij}$ . In Monte Carlo experiments, Giacomini and White (2006) show that the test has both reasonable size and power, once  $h_{t,k}^{ij} = [1 \ \Delta\epsilon_{t,k}^{ij}]^\top$ . This choice is appealing, in our context, as it connects failure of equal predictive ability with persistence and size of previous forecasting errors. Indeed, some blocks in Table 4 might perform better than others at predicting turning points, but can produce rather disappointing outcomes over periods of, say, prolonged expansions of the economy. The GW test can be used to implement an adaptive decision rule for selecting a predictive block over the others, thus exploiting the best conditional predictive power of any block.

This rule comprises two steps. In step one, one checks whether the null of equal conditional predictive ability is rejected. In case of rejection, one proceeds to step two, where one computes  $E_N(\Delta\epsilon_{N+1,k}^{ij}) \approx \hat{\delta}_k^{ij} \cdot h_{N,k}^{ij}$ , with  $E_N(\cdot)$  denoting the expectation conditional on the information set as of time  $N$ , and  $\hat{\delta}_k^{ij}$  denoting the estimate of  $\delta_k^{ij}$  in Eq. (12). Then, the rule is to select Block Bj if  $E_N(\Delta\epsilon_{N+1,k}^{ij}) > 0$ , and to select Block Bi otherwise. A useful summary statistics is the frequency at which this rule selects any one of two predicting blocks, over the out-of-sample period,  $(N - M - 1)^{-1} \sum_{t=M-1}^{N-1} \mathbb{I}(\hat{\delta}_k^{ij} \cdot h_{t,k}^{ij} > 0)$ , where  $\mathbb{I}$  is the indicator function.

## 6.2 Results

### 6.2.1 Linear Predictions

Table 8 reports out-of-sample tests of predictive accuracy, based on the DM statistics and the GW reality check of conditional predictive ability. Panel A reports the value of this test

<sup>3</sup> Note that the DM test can be applied to forecasts obtained with both rolling and expanding windows. By contrast, the GW test described below only applies to predictors with limited memory, such as those we consider in this section.

**Table 8:** Out-of-sample tests of predictive accuracy for linear models

Panel A: Rolling estimation window = 120 months																
	Diebold-Mariano statistics								Giacomini-White conditional choices (frequencies)							
	B1	B2	B3	B4	B5	B6	B7	B8	B1	B2	B3	B4	B5	B6	B7	B8
Predicting horizon = 3 months																
B0	-0.78	-1.09	-2.46	-0.50	-1.53	-2.17	-2.31	-3.21	0.45	0.46	0.39	0.48	0.43	0.43	0.40	0.36
B1	-	-0.44	-1.66	0.30	-0.89	-1.19	-1.50	-2.68	-	0.49	0.40	0.54	0.44	0.48	0.45	0.36
B2	-	-	-1.21	0.71	-0.47	-0.78	-1.05	-2.38	-	-	0.44	0.51	0.46	0.44	0.45	0.36
B3	-	-	-	1.96	0.76	0.55	0.24	-0.84	-	-	-	0.57	0.55	0.52	0.51	0.45
B4	-	-	-	-	-1.11	-1.48	-2.65	-3.34	-	-	-	-	0.42	0.45	0.35	0.39
B5	-	-	-	-	-	-0.50	-0.75	-2.03	-	-	-	-	-	0.46	0.48	0.40
B6	-	-	-	-	-	-	-0.42	-1.61	-	-	-	-	-	-	0.45	0.43
B7	-	-	-	-	-	-	-	-1.63	-	-	-	-	-	-	-	0.42
Predicting horizon = 6 months																
B0	0.10	-0.18	-3.08	0.63	-1.69	-0.91	-0.92	-2.34	0.49	0.49	0.37	0.54	0.41	0.51	0.48	0.41
B1	-	-0.28	-2.80	0.55	-1.67	-0.89	-1.01	-2.48	-	0.52	0.38	0.53	0.48	0.46	0.45	0.41
B2	-	-	-3.12	0.78	-1.62	-0.55	-0.71	-2.44	-	-	0.34	0.51	0.38	0.46	0.41	0.36
B3	-	-	-	3.31	1.47	2.33	2.33	0.91	-	-	-	0.63	0.55	0.59	0.57	0.52
B4	-	-	-	-	-2.12	-1.37	-2.42	-3.88	-	-	-	-	0.39	0.47	0.41	0.32
B5	-	-	-	-	-	1.11	0.82	-0.86	-	-	-	-	-	0.54	0.52	0.44
B6	-	-	-	-	-	-	-0.13	-1.77	-	-	-	-	-	-	0.52	0.42
B7	-	-	-	-	-	-	-	-2.33	-	-	-	-	-	-	-	0.43
Predicting horizon = 1 year																
B0	-0.81	0.17	-2.42	-0.36	-0.83	-0.38	-1.01	-2.40	0.41	0.52	0.40	0.50	0.46	0.49	0.48	0.41
B1	-	0.92	-1.85	0.43	-0.38	0.41	-0.32	-2.07	-	0.58	0.43	0.55	0.50	0.54	0.51	0.44
B2	-	-	-2.32	-0.55	-1.50	-0.56	-1.14	-2.55	-	-	0.42	0.46	0.38	0.42	0.41	0.34
B3	-	-	-	2.32	1.48	2.41	1.72	-0.07	-	-	-	0.59	0.60	0.61	0.59	0.48
B4	-	-	-	-	-0.65	0.01	-0.88	-2.96	-	-	-	-	0.48	0.48	0.44	0.36
B5	-	-	-	-	-	0.82	0.05	-1.99	-	-	-	-	-	0.49	0.46	0.37
B6	-	-	-	-	-	-	-0.97	-2.90	-	-	-	-	-	-	0.44	0.38
B7	-	-	-	-	-	-	-	-3.50	-	-	-	-	-	-	-	0.36
Predicting horizon = 2 years																
B0	0.40	-0.37	-1.15	3.30	0.50	2.05	0.99	-0.45	0.48	0.45	0.42	0.74	0.52	0.63	0.59	0.53
B1	-	-0.60	-1.32	1.75	0.27	1.79	0.87	-0.78	-	0.48	0.42	0.67	0.54	0.62	0.56	0.46
B2	-	-	-1.12	1.71	1.04	1.89	1.13	-0.11	-	-	0.44	0.65	0.54	0.63	0.60	0.53
B3	-	-	-	2.04	2.01	2.54	1.88	0.77	-	-	-	0.64	0.59	0.62	0.63	0.57
B4	-	-	-	-	-0.74	0.14	-0.61	-2.04	-	-	-	-	0.41	0.47	0.47	0.38
B5	-	-	-	-	-	1.13	0.33	-0.77	-	-	-	-	-	0.55	0.54	0.48
B6	-	-	-	-	-	-	-0.97	-2.48	-	-	-	-	-	-	0.47	0.36
B7	-	-	-	-	-	-	-	-3.14	-	-	-	-	-	-	-	0.36

Keys: B0: Autoregressive; B1: Term spread, Corp. spread, Stock mkt returns; B2: Term spread, short rate; B3: Stock mkt volatility, Term spread volatility; B4: Stock mkt volatility, Term spread; B5: Vol of stock mkt vol, Short-rate; B6: Vol of stock mkt vol, Term spread; B7: Vol of stock mkt vol, Stock mkt vol, Term spread; B8: Vol of stock mkt vol, Stock mkt vol, Interaction, Term spread.

when the rolling estimation window is  $M = 120$  months; Panel B displays the results for  $M = 90$  months. In both cases, the naïve Block B0 (comprising lagged values of growth) is the one that performs best, at a predicting horizon of 3 months. Its performance, however, is comparable to those of Blocks B2 (term spread and short-term rate) and B4 (stock market volatility and term spread), with Block B4 performing marginally better than B2. For example, the GW decision rule would have led us to choose B4 against B2 54% of the

Table 8: (continued)

Panel B: Rolling estimation window = 90 months																
	Diebold-Mariano statistics								Giacomini-White conditional choices (frequencies)							
	B1	B2	B3	B4	B5	B6	B7	B8	B1	B2	B3	B4	B5	B6	B7	B8
Predicting horizon = 3 months																
B0	-0.83	-1.40	-3.74	-0.54	-2.29	-3.06	-3.91	-5.87	0.47	0.45	0.33	0.48	0.42	0.35	0.32	0.21
B1	-	-0.87	-2.50	0.38	-1.88	-2.24	-3.36	-5.91	-	0.46	0.37	0.52	0.43	0.39	0.32	0.21
B2	-	-	-1.75	1.14	-1.04	-1.29	-2.25	-4.47	-	-	0.39	0.51	0.47	0.43	0.39	0.29
B3	-	-	-	2.84	0.85	0.77	-0.18	-2.63	-	-	-	0.61	0.54	0.51	0.48	0.37
B4	-	-	-	-	-2.15	-2.73	-4.18	-6.10	-	-	-	-	0.40	0.39	0.33	0.23
B5	-	-	-	-	-	-0.27	-1.49	-4.30	-	-	-	-	-	0.46	0.45	0.29
B6	-	-	-	-	-	-	-1.42	-4.07	-	-	-	-	-	-	0.42	0.32
B7	-	-	-	-	-	-	-	-4.23	-	-	-	-	-	-	-	0.31
Predicting horizon = 6 months																
B0	1.51	0.46	-3.63	1.07	-1.28	-1.73	-2.61	-4.72	0.54	0.58	0.37	0.52	0.46	0.42	0.43	0.29
B1	-	-0.98	-4.14	-0.66	-2.95	-3.24	-3.96	-6.33	-	0.52	0.34	0.46	0.40	0.33	0.33	0.18
B2	-	-	-3.50	0.45	-1.85	-1.93	-2.42	-4.51	-	-	0.34	0.45	0.40	0.36	0.34	0.25
B3	-	-	-	4.09	1.95	2.16	1.83	-0.38	-	-	-	0.64	0.56	0.54	0.55	0.47
B4	-	-	-	-	-2.19	-2.84	-3.96	-6.14	-	-	-	-	0.42	0.36	0.37	0.23
B5	-	-	-	-	-	-0.20	-0.85	-2.87	-	-	-	-	-	0.46	0.48	0.34
B6	-	-	-	-	-	-	-0.75	-3.02	-	-	-	-	-	-	0.48	0.36
B7	-	-	-	-	-	-	-	-3.25	-	-	-	-	-	-	-	0.35
Predicting horizon = 1 year																
B0	2.38	1.18	-2.05	0.55	-0.09	0.43	-0.78	-2.42	0.61	0.58	0.41	0.54	0.51	0.49	0.51	0.35
B1	-	-0.91	-3.66	-2.54	-2.49	-2.41	-2.81	-3.77	-	0.48	0.34	0.37	0.42	0.41	0.37	0.25
B2	-	-	-2.90	-0.84	-1.66	-0.89	-1.76	-3.06	-	-	0.35	0.39	0.38	0.39	0.37	0.23
B3	-	-	-	2.60	1.81	2.49	1.54	-1.03	-	-	-	0.62	0.58	0.57	0.58	0.45
B4	-	-	-	-	-0.64	-0.19	-1.61	-3.14	-	-	-	-	0.51	0.46	0.43	0.28
B5	-	-	-	-	-	0.56	-0.56	-2.35	-	-	-	-	-	0.48	0.49	0.34
B6	-	-	-	-	-	-	-1.74	-3.07	-	-	-	-	-	-	0.45	0.28
B7	-	-	-	-	-	-	-	-2.72	-	-	-	-	-	-	-	0.28
Predicting horizon = 2 years																
B0	-0.04	0.20	-0.41	0.67	0.11	1.09	-0.48	-1.72	0.51	0.54	0.53	0.49	0.54	0.57	0.51	0.45
B1	-	0.24	-0.38	0.79	0.15	1.44	-0.43	-1.65	-	0.55	0.52	0.55	0.55	0.56	0.49	0.43
B2	-	-	-0.58	0.41	-0.11	0.92	-0.64	-1.69	-	-	0.51	0.51	0.51	0.52	0.45	0.42
B3	-	-	-	0.92	0.52	1.41	0.09	-1.54	-	-	-	0.51	0.49	0.53	0.47	0.42
B4	-	-	-	-	-0.53	0.55	-1.25	-2.18	-	-	-	-	0.46	0.53	0.42	0.39
B5	-	-	-	-	-	1.12	-0.65	-1.88	-	-	-	-	-	0.52	0.45	0.38
B6	-	-	-	-	-	-	-2.39	-2.57	-	-	-	-	-	-	0.41	0.35
B7	-	-	-	-	-	-	-	-2.24	-	-	-	-	-	-	-	0.41

*Keys:* B0: Autoregressive; B1: Term spread, Corp. spread, Stock mkt returns; B2: Term spread, short rate; B3: Stock mkt volatility, Term spread volatility; B4: Stock mkt volatility, Term spread; B5: Vol of stock mkt vol, Short-rate; B6: Vol of stock mkt vol, Term spread; B7: Vol of stock mkt vol, Stock mkt vol, Term spread; B8: Vol of stock mkt vol, Stock mkt vol, Interaction, Term spread.

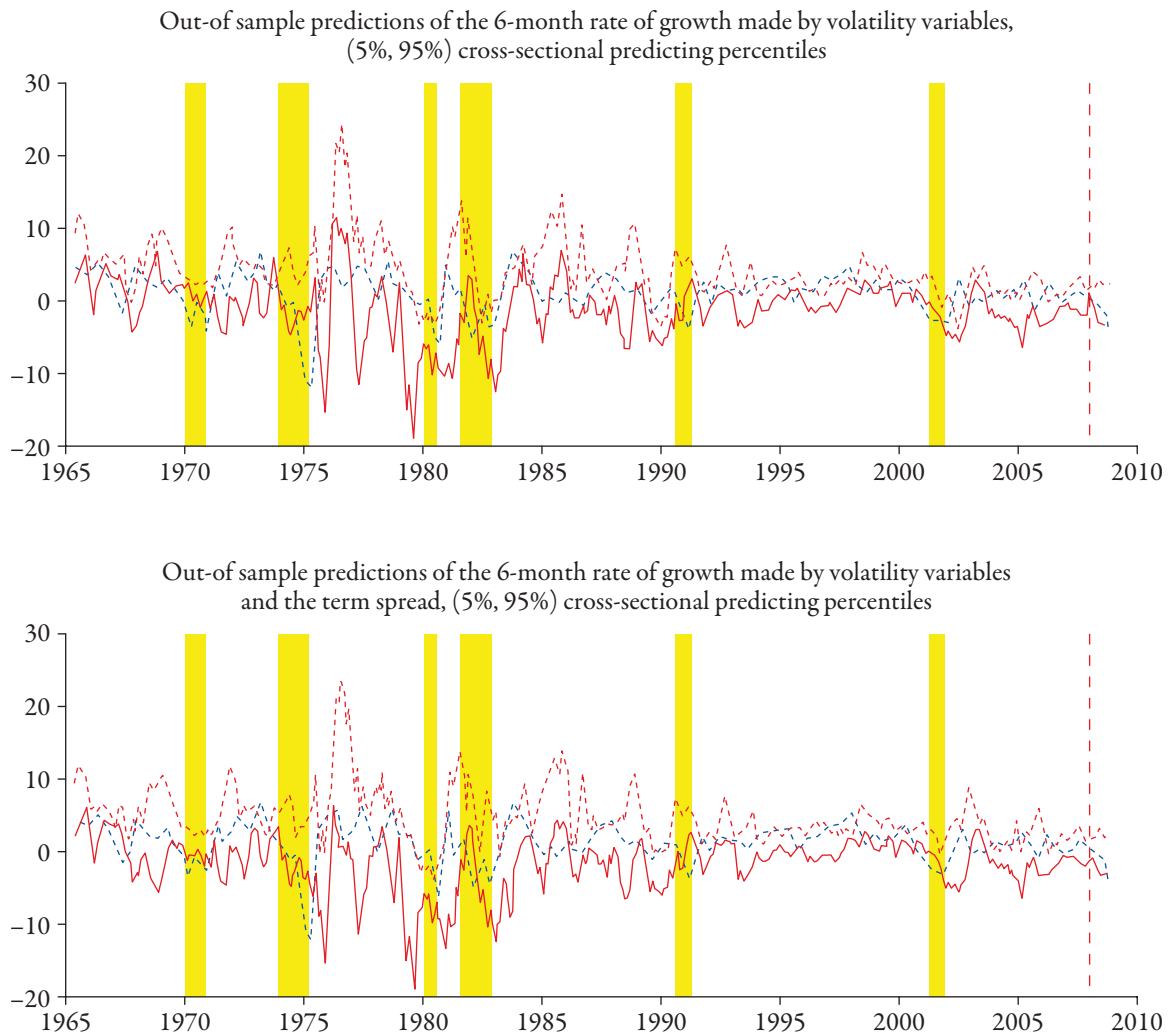
time, when  $M = 120$ , but only 51% of the time, when  $M = 90$ . At horizons of 6 and 12 months, the performances of the three blocks, B0, B2, and B4, are, again, comparable and the best. At the horizon of 24 months, B2 and B4 display the best relative performance, with the volatility-term spread block B4 performing better than the yield curve block B2, at least when  $M = 120$  months. In this case, for example, the GW rule tells us we would have chosen B4 over B2 65% of the time. When  $M = 90$ , however, B2 and B4 perform

Table 8: (continued)

Panel C: Combination forecasts								
	Diebold-Mariano statistics				Giacomini-White conditional choices (frequencies)			
	$M = 120$ months		$M = 90$ months		$M = 120$ months		$M = 90$ months	
	B-0, 1, 2	B-1, 2, 4	B1-0, 1, 2	B-1, 2, 4	B-0, 1, 2	B-1, 2, 4	B-0, 1, 2	B-1, 2, 4
Predicting horizon = 3 months								
B0	2.25	1.43	2.28	1.37	0.59	0.57	0.63	0.60
B1	3.72	3.24	4.05	3.41	0.68	0.57	0.73	0.69
B2	3.89	3.71	4.51	4.15	0.68	0.66	0.72	0.67
B3	4.06	3.65	4.89	4.22	0.69	0.66	0.75	0.71
B4	2.64	3.03	3.11	3.32	0.60	0.66	0.69	0.70
B5	3.64	3.45	4.32	4.16	0.65	0.65	0.67	0.67
B6	4.46	3.82	5.43	4.99	0.68	0.66	0.71	0.67
B7	4.42	4.63	6.05	5.92	0.72	0.74	0.77	0.77
B8	5.47	5.53	7.54	7.54	0.73	0.74	0.84	0.85
B-0, 1, 2	-	-0.71	-	-1.17	-	0.48	-	0.46
Predicting horizon = 6 months								
B0	2.78	2.80	3.89	3.54	0.63	0.64	0.67	0.67
B1	2.46	3.67	2.01	3.56	0.61	0.69	0.59	0.68
B2	2.55	3.16	2.77	3.72	0.55	0.60	0.57	0.62
B3	4.61	4.85	5.37	5.46	0.68	0.73	0.73	0.73
B4	1.48	2.79	2.40	4.03	0.55	0.62	0.59	0.71
B5	3.77	4.49	4.32	4.93	0.62	0.70	0.66	0.70
B6	3.48	4.05	5.17	5.78	0.63	0.64	0.68	0.73
B7	3.51	4.68	5.49	5.82	0.62	0.70	0.72	0.76
B8	4.56	5.37	7.42	7.85	0.71	0.75	0.86	0.91
B-0, 1, 2	-	1.76	-	1.96	-	0.63	-	0.61
Predicting horizon = 1 year								
B0	1.86	1.41	3.84	3.04	0.57	0.55	0.71	0.65
B1	3.09	3.24	0.31	1.16	0.68	0.71	0.54	0.57
B2	1.16	1.42	1.41	2.03	0.53	0.53	0.55	0.57
B3	3.02	3.30	4.36	4.74	0.62	0.64	0.69	0.73
B4	1.74	2.77	2.84	4.55	0.53	0.61	0.66	0.70
B5	2.06	2.51	2.73	3.63	0.58	0.61	0.60	0.61
B6	1.76	2.26	2.76	3.84	0.52	0.56	0.63	0.67
B7	2.14	2.58	3.54	4.02	0.55	0.59	0.63	0.68
B8	3.25	3.72	3.95	4.46	0.64	0.68	0.81	0.85
B-0, 1, 2	-	0.35	-	1.07	-	0.54	-	0.54
Predicting horizon = 2 years								
B0	2.39	3.32	2.29	2.09	0.62	0.72	0.62	0.59
B1	1.86	2.91	2.71	3.24	0.58	0.68	0.63	0.65
B2	1.47	2.12	1.51	1.99	0.57	0.65	0.57	0.58
B3	1.91	2.28	1.53	1.84	0.62	0.64	0.54	0.57
B4	-0.90	0.25	0.91	1.72	0.37	0.47	0.54	0.55
B5	0.47	0.93	1.34	1.83	0.47	0.53	0.56	0.57
B6	-0.82	-0.02	0.56	1.29	0.41	0.48	0.55	0.51
B7	0.11	0.83	2.10	2.60	0.45	0.49	0.60	0.61
B8	1.57	2.18	2.54	2.84	0.57	0.62	0.63	0.65
B-0, 1, 2	-	2.91	-	0.79	-	0.76	-	0.54

*Keys:* B0: Autoregressive; B1: Term spread, Corp. spread, Stock mkt returns; B2: Term spread, short rate; B3: Stock mkt volatility, Term spread volatility; B4: Stock mkt volatility, Term spread; B5: Vol of stock mkt vol, Short-rate; B6: Vol of stock mkt vol, Term spread; B7: Vol of stock mkt vol, Stock mkt vol, Term spread; B8: Vol of stock mkt vol, Stock mkt vol, Interaction, Term spread; B-0,1,2: Average of forecasts from Blocks B0, B1 and B2; B-1,2,4: Average of forecasts from Blocks B1, B2 and B4.

*Note:* This Table reports Diebold and Mariano (1995) (DM) test statistics for relative predictive accuracy of industrial production growth, obtained through the first nine predicting blocks in Table 4, or two selected combinations of them, and the fraction of time the Giacomini and White (2006) (GW) test of conditional predictive ability would have led to choose any one of these blocks, or the two selected combinations of them, against the others. The sample covers monthly data for the period from January 1957 to September 2008. The rolling estimation window,  $M$ , is set equal to 120 (Panel A) and 90 (Panel B), and forecasting horizons are 3 months, 6 months, 1 year and 2 years. Panel C reports DM statistics and GW frequencies for average forecasts of two selected combinations of blocks (Blocks B0, B1, B2, and Blocks B1, B2, B4), against all blocks, with rolling estimation window  $M = 120$  and 90 months, and forecasting horizons of 3 months, 6 months, 1 year and 2 years. A positive value for the DM test statistic indicates that the predicting block on the column has lower expected loss than the predicting block on the row. For GW, each figure indicates the frequency each predicting block on the column would be chosen against each predicting block on the row.



**Figure 5:** Linear predictions of economic activity.

*Note:* Out-of-sample forecasts of the six month industrial production growth. This figure depicts realized values for the six month industrial production growth, along with forecasts obtained through: (i) the predicting blocks B3 through B8 in Table 4, based on financial volatility variables such as the volatility of the term spread, stock market volatility, volatility of stock market volatility, an interaction term between stock volatility and volatility of stock volatility (top panel); and (ii) the predicting blocks B2 through B8 in Table 4, where the block B2 includes the short term rate and the term spread (bottom panel). The dashed line (in blue) is the realized value of six month industrial production growth. The solid lines are 5% and 95% percentiles of the cross sectional distribution of the predicting blocks. Predictions are obtained on rolling samples with size equal to 90 monthly observations. The sample covers monthly data for the period from January 1957 to September 2008. Shaded areas (in yellow) track NBER-dated recessions, and the vertical dashed line (in red) indicates the beginning of the latest NBER-dated recession.

roughly as B0, with B4 prevailing, but not significantly, over B2 (and other blocks). Finally, the volatility block B8 seems to perform quite poorly, at any horizon, and for any considered rolling window. Overall, it is only better than block B3. Equally disappointing is the volatility block B7, with the exception of the 24-month horizon. Thus, this first battery of tests suggests that among the best predicting blocks alternative to the naïve Block B0, the best are the yield curve block B2 and the volatility-term spread block B4.

Figure 5, top panel, reports graphical evidence of how all the volatility blocks in Table 4, B3 through B8, help predict growth at the 6-month horizon. For each point in time, we calculate the 5% and the 95% percentiles of the cross-section of the growth forecasts

produced by these blocks, thus avoiding over-parametrization<sup>4</sup>. This cross-sectional range seems to track growth reasonably well, during the Great Moderation period. Its performance is almost identical, once we include B2 in the pool of predicting blocks, with the exception of the period immediately following the 2001 recession.

Next, we consider an experiment where we create two combination forecasts, which include: (i) B0, B1 and B2, denoted as Block B-0,1,2, and (ii) B1, B2, B4, denoted as Block B-1,2,4. The predictions of these two combinations are obtained as the arithmetic mean of the forecasts produced by each of the three blocks they are built upon, and as such, they are not plagued by over-parametrization issues. The motivation underlying these two combination forecasts is to investigate whether the information provided by Block B4 is better than that provided by the naïve block B0, once we condition on the two blocks B1 (which includes the term spread, corporate spread and stock returns) and B2. The reason for including B1, is that although this block is clearly outperformed by others, it does seem to provide some useful information at horizons of six months and one year. For example, at a horizon of one year, and for  $M = 90$ , it is even better than B4, although still worse than B2.

Table 8, Panel C, reports DM statistics and GW decision rules for these two combination forecasts. Overall, both blocks outperform the remaining ones, at all horizons and rolling estimation windows, although their relative performance is the best at six months and one year. There are, however, interesting exceptions: the performance of Block B-0,1,2 is only marginally better than B4 at six months, one year and two years horizons. For example, at two years, the GW decision rule says we would have chosen B-0,1,2 against B4 only 37% of the time, with  $M = 120$ . Likewise, the performance of Block B-0,1,2 is only marginally better than B2, at horizons of one and two years. The performance of Block B-1,2,4 is, instead, quite better than every single block, at horizons of six months and one year, and for all rolling windows,  $M$ . It is only at a three months horizon that Block B-1,2,4 performs only marginally better than the naïve B0, but still much better than blocks B2 or B4. At two years horizon, Block B-1,2,4 performs better than every single blocks, although its performance seems to deteriorate, for  $M = 120$ . Finally, Block B-0,1,2 is better than Block B-1,2,4 at three months, and worse than B-1,2,4 at six months. The two blocks are comparable at one and two years horizon, and B-1,2,4 is the best when  $M = 120$ .

To summarize, stock market volatility does help predict growth, especially at six months and one year, and when used in conjunction with other financial variables such as the term spread and the corporate spread. At shorter predicting horizons, stock market volatility does not seem to add important pieces of information on top of those already conveyed by traditional leading indicators.

### 6.2.2 Probabilities of Recessions, Coincident and Leading

Table 9 reports tests of predictive accuracy for Probit models of NBER-dated recessions, obtained with a rolling estimation window equal to  $M = 360$  months. We could

<sup>4</sup> This range does not rely on a single set of rolling regressions including all the variables in the six volatility blocks, B3 through B8. Rather, it relies on parameter estimates obtained by fitting six separate sets of rolling regressions.

**Table 9:** Out-of-sample tests of predictive accuracy for Probit-based models of recessions

Panel A: Test of predictive ability, coincident probabilities																
	Diebold-Mariano statistics								Giacomini-White conditional choices (frequencies)							
	B1	B2	B3	B4	B5	B6	B7	B8	B1	B2	B3	B4	B5	B6	B7	B8
Predicting horizon = 3 months																
B0	3.87	4.20	3.01	3.67	5.53	2.13	4.27	6.98	0.86	0.73	0.79	0.80	0.79	0.75	0.83	0.95
B1	-	-1.40	-1.57	-1.03	-0.58	-1.95	-0.49	1.03	-	0.21	0.32	0.43	0.34	0.22	0.50	0.58
B2	-	-	-1.19	0.70	1.59	-0.45	1.43	3.32	-	-	0.46	0.61	0.73	0.61	0.79	0.87
B3	-	-	-	0.84	1.22	-0.17	1.32	3.40	-	-	-	0.70	0.51	0.64	0.73	0.87
B4	-	-	-	-	0.50	-0.96	0.82	2.69	-	-	-	-	0.55	0.37	0.66	0.75
B5	-	-	-	-	-	-1.22	0.18	3.06	-	-	-	-	-	0.50	0.65	0.79
B6	-	-	-	-	-	-	1.83	3.05	-	-	-	-	-	-	0.63	0.80
B7	-	-	-	-	-	-	-	3.24	-	-	-	-	-	-	-	0.86
Predicting horizon = 6 months																
B0	1.66	5.89	1.71	3.79	6.87	2.07	6.05	7.73	0.75	0.87	0.70	0.85	0.87	0.82	0.95	0.97
B1	-	2.45	-0.07	2.42	1.62	1.00	3.20	3.85	-	0.82	0.38	0.85	0.51	0.70	0.95	0.97
B2	-	-	-1.72	0.65	0.43	-1.33	2.55	3.84	-	-	0.33	0.75	0.41	0.46	0.86	0.85
B3	-	-	-	1.96	2.43	0.60	2.92	4.02	-	-	-	0.78	0.67	0.67	0.90	0.94
B4	-	-	-	-	-0.16	-1.65	1.05	1.99	-	-	-	-	0.24	0.19	0.34	0.61
B5	-	-	-	-	-	-1.00	0.94	1.88	-	-	-	-	-	0.53	0.80	0.84
B6	-	-	-	-	-	-	2.58	3.04	-	-	-	-	-	-	0.86	0.90
B7	-	-	-	-	-	-	-	2.62	-	-	-	-	-	-	-	0.82
Predicting horizon = 1 year																
B0	1.40	2.30	-0.14	3.39	-0.41	0.74	3.13	3.34	0.75	0.74	0.54	0.83	0.47	0.77	0.86	0.86
B1	-	0.50	-0.94	1.78	-2.20	-0.80	1.39	1.48	-	0.49	0.42	0.63	0.19	0.30	0.55	0.57
B2	-	-	-1.37	2.31	-2.98	-1.73	1.71	1.93	-	-	0.43	0.80	0.23	0.23	0.67	0.65
B3	-	-	-	2.76	-0.12	0.58	2.68	2.86	-	-	-	0.77	0.47	0.61	0.92	0.91
B4	-	-	-	-	-3.74	-2.56	-0.29	0.05	-	-	-	-	0.14	0.22	0.43	0.54
B5	-	-	-	-	-	2.09	3.85	3.89	-	-	-	-	-	0.74	0.85	0.84
B6	-	-	-	-	-	-	2.42	2.54	-	-	-	-	-	-	0.70	0.76
B7	-	-	-	-	-	-	-	1.02	-	-	-	-	-	-	-	0.74
Predicting horizon = 2 years																
B0	1.23	-1.23	0.06	0.51	-0.68	-0.84	-0.84	-0.77	0.81	0.33	0.58	0.53	0.44	0.39	0.39	0.39
B1	-	-2.22	-0.37	-0.41	-1.38	-1.46	-1.46	-1.34	-	0.18	0.46	0.37	0.23	0.16	0.16	0.29
B2	-	-	0.76	1.50	0.44	0.06	0.06	-0.01	-	-	0.67	0.78	0.59	0.57	0.57	0.62
B3	-	-	-	0.29	-0.42	-0.58	-0.58	-0.60	-	-	-	0.35	0.37	0.33	0.33	0.43
B4	-	-	-	-	-0.83	-0.97	-0.97	-0.92	-	-	-	-	0.39	0.36	0.36	0.52
B5	-	-	-	-	-	-0.47	-0.47	-0.30	-	-	-	-	-	0.46	0.46	0.54
B6	-	-	-	-	-	-	0.01	-0.09	-	-	-	-	-	-	0.01	0.46
B7	-	-	-	-	-	-	-	-0.09	-	-	-	-	-	-	-	0.46

*Keys:* B0: Autoregressive; B1: Term spread, Corp. spread, Stock mkt returns; B2: Term spread, short rate; B3: Stock mkt volatility, Term spread volatility; B4: Stock mkt volatility, Term spread; B5: Vol of stock mkt vol, Short-rate; B6: Vol of stock mkt vol, Term spread; B7: Vol of stock mkt vol, Stock mkt vol, Term spread; B8: Vol of stock mkt vol, Stock mkt vol, Interaction, Term spread.

not use significantly smaller windows, due to the low number of «one» events in the sample. Panel A reports results for coincident probabilities, computed as one-month ahead predictions, i.e.  $\text{Probit}_t^k(\text{Rec}_{t+1}|B_i)$  in Eq. (11), with  $k \in \{3, 6, 12, 24\}$ . At horizons of three and six months, the volatility Block B8 performs the best, although only marginally better than Block B1 at the three-month horizon. (Block B1, however, does not perform much better than the remaining blocks at this, or other, horizons.) At the

**Table 9:** (continued)

Panel B: Tests of predictive ability, multi-step ahead probabilities																
	Diebold-Mariano statistics								Giacomini-White conditional choices (frequencies)							
	B1	B2	B3	B4	B5	B6	B7	B8	B1	B2	B3	B4	B5	B6	B7	B8
Predicting horizon = 3 months																
B0	2.69	6.71	0.43	2.43	3.22	0.59	2.56	2.81	0.71	0.83	0.75	0.72	0.77	0.69	0.75	0.74
B1	-	1.11	-1.61	-0.11	-0.10	-2.11	-0.05	0.19	-	0.66	0.43	0.69	0.65	0.48	0.76	0.65
B2	-	-	-2.52	-1.52	-1.50	-2.86	-1.51	-0.96	-	-	0.46	0.41	0.71	0.25	0.36	0.42
B3	-	-	-	1.34	1.49	0.15	1.52	1.73	-	-	-	0.61	0.47	0.51	0.59	0.68
B4	-	-	-	-	-0.02	-1.54	0.13	0.47	-	-	-	-	0.57	0.30	0.42	0.37
B5	-	-	-	-	-	-1.27	0.08	0.30	-	-	-	-	-	0.30	0.37	0.47
B6	-	-	-	-	-	-	1.98	1.62	-	-	-	-	-	-	0.65	0.58
B7	-	-	-	-	-	-	-	0.38	-	-	-	-	-	-	-	0.34
Predicting horizon = 6 months																
B0	1.01	6.03	-0.02	1.62	4.97	0.55	2.07	2.20	0.66	0.85	0.65	0.77	0.85	0.67	0.81	0.80
B1	-	2.52	-0.79	0.90	1.32	-0.76	1.19	1.21	-	0.88	0.37	0.74	0.69	0.39	0.73	0.72
B2	-	-	-3.05	-1.46	-0.35	-3.27	-1.48	-1.08	-	-	0.33	0.44	0.65	0.11	0.47	0.46
B3	-	-	-	1.37	2.79	0.44	1.78	1.86	-	-	-	0.71	0.68	0.58	0.73	0.78
B4	-	-	-	-	0.81	-1.25	0.74	0.87	-	-	-	-	0.64	0.18	0.37	0.46
B5	-	-	-	-	-	-1.72	-0.68	-0.54	-	-	-	-	-	0.26	0.38	0.48
B6	-	-	-	-	-	-	1.68	1.45	-	-	-	-	-	-	0.70	0.71
B7	-	-	-	-	-	-	-	0.41	-	-	-	-	-	-	-	0.57
Predicting horizon = 1 year																
B0	0.57	2.04	-1.36	1.12	-0.62	0.92	1.51	1.56	0.61	0.69	0.45	0.74	0.43	0.64	0.73	0.77
B1	-	2.02	-1.58	0.96	-0.84	0.33	1.21	1.21	-	0.58	0.44	0.60	0.35	0.42	0.62	0.63
B2	-	-	-2.58	-0.46	-2.12	-1.42	0.07	0.20	-	-	0.36	0.62	0.29	0.34	0.63	0.65
B3	-	-	-	2.48	1.11	1.81	3.17	3.31	-	-	-	0.69	0.51	0.61	0.84	0.83
B4	-	-	-	-	-1.22	-0.62	0.75	0.79	-	-	-	-	0.28	0.39	0.45	0.56
B5	-	-	-	-	-	1.18	1.60	1.61	-	-	-	-	-	0.76	0.74	0.86
B6	-	-	-	-	-	-	0.99	1.10	-	-	-	-	-	-	0.63	0.66
B7	-	-	-	-	-	-	-	0.37	-	-	-	-	-	-	-	0.61
Predicting horizon =2 years																
B0	1.74	-0.74	-1.48	-0.78	0.23	-0.52	-0.51	-1.43	0.78	0.39	0.52	0.54	0.47	0.41	0.41	0.39
B1	-	-2.33	-1.71	-1.69	-1.22	-1.65	-1.65	-2.74	-	0.16	0.34	0.35	0.18	0.12	0.13	0.08
B2	-	-	-0.86	2.01	1.35	-0.09	-0.07	-1.36	-	-	0.55	0.55	0.45	0.42	0.40	0.41
B3	-	-	-	1.43	1.09	0.58	0.61	0.03	-	-	-	0.42	0.44	0.42	0.41	0.45
B4	-	-	-	-	0.54	-0.05	-0.03	-0.81	-	-	-	-	0.48	0.45	0.45	0.45
B5	-	-	-	-	-	-1.42	-1.02	-2.31	-	-	-	-	-	0.37	0.35	0.33
B6	-	-	-	-	-	-	0.11	-2.28	-	-	-	-	-	-	0.51	0.38
B7	-	-	-	-	-	-	-	-2.28	-	-	-	-	-	-	-	0.39

*Keys:* B0: Autoregressive; B1: Term spread, Corp. spread, Stock mkt returns; B2: Term spread, short rate; B3: Stock mkt volatility, Term spread volatility; B4: Stock mkt volatility, Term spread; B5: Vol of stock mkt vol, Short-rate; B6: Vol of stock mkt vol, Term spread; B7: Vol of stock mkt vol, Stock mkt vol, Term spread; B8: Vol of stock mkt vol, Stock mkt vol, Interaction, Term spread.

one year horizon, the performance of the volatility-term spread block B4 is quite comparable to that of B8, and both B4 and B8 significantly outperform the yield curve Block B2. At one year horizon, the volatility block B7 does also perform well, in comparison to all the other blocks except B4 and B8. At two years horizon, all blocks do not appear to perform significantly better than the naïve Block B0.



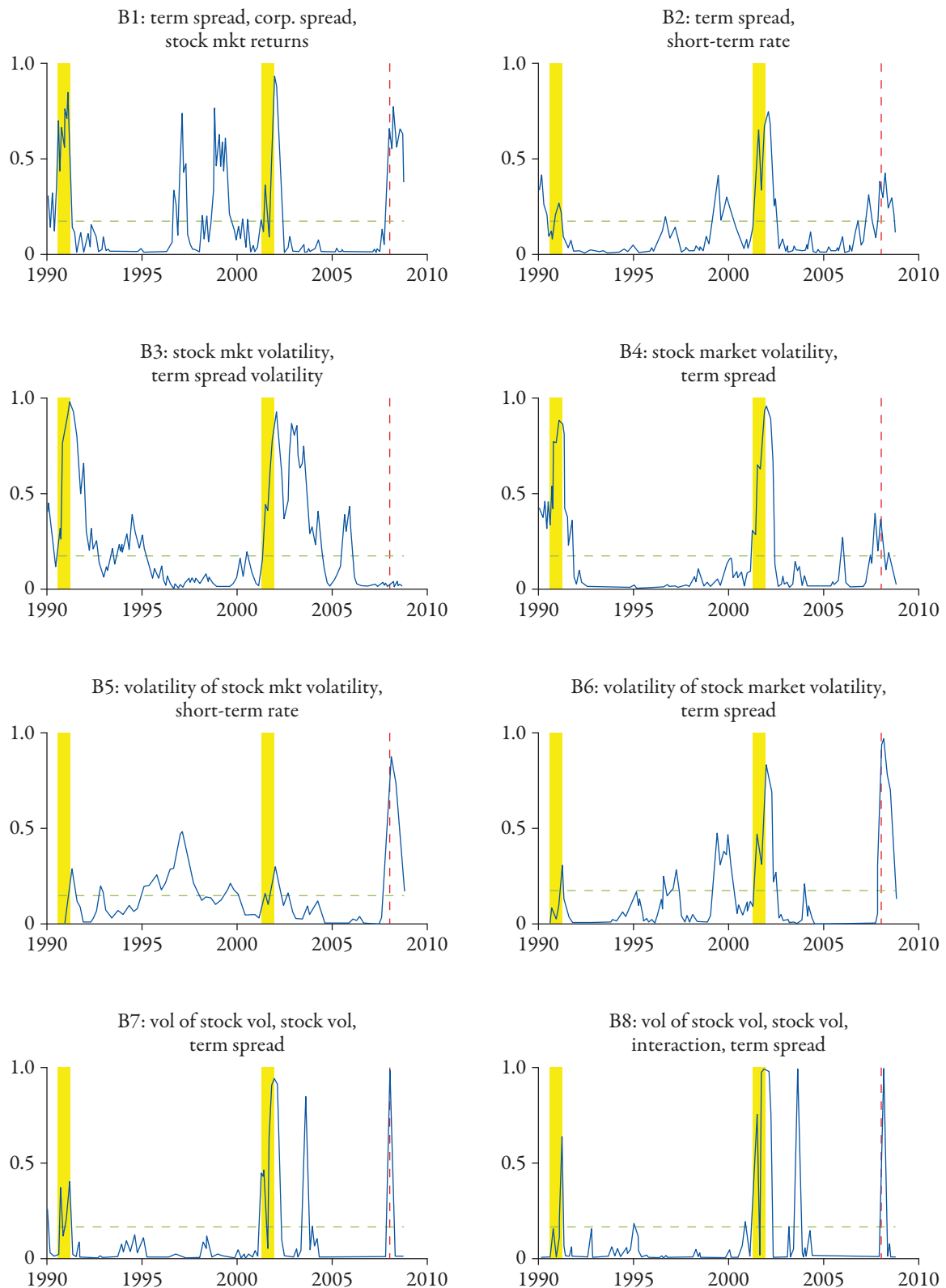
**Table 9:** Panel C: Frequencies of correctly identified NBER recessions and expansions

Predicting block	Coincident probabilities							
	3 months		6 months		1 Year		2 Years	
	Rec	Exp	Rec	Exp	Rec	Exp	Rec	Exp
B0	0.61	0.78	0.39	0.64	0.50	0.70	0.28	0.66
B1	0.94	0.86	0.89	0.73	0.72	0.80	0.00	0.76
B2	0.28	0.87	0.50	0.91	0.67	0.82	0.56	0.54
B3	0.83	0.88	0.83	0.76	0.94	0.63	0.94	0.72
B4	0.78	0.85	1.00	0.85	1.00	0.87	0.89	0.77
B5	0.50	0.95	0.44	0.97	0.22	0.68	0.50	0.64
B6	0.78	0.81	0.50	0.83	0.56	0.79	0.61	0.57
B7	0.61	0.89	0.56	0.96	0.72	0.93	0.61	0.57
B8	0.56	0.96	0.67	0.98	0.61	0.94	0.44	0.58
	Multi-step ahead probabilities							
B0	1.00	0.74	0.88	0.72	1.00	0.62	0.88	0.53
B1	0.66	0.80	0.89	0.74	0.00	0.77	0.00	0.77
B2	0.55	0.88	0.44	0.91	0.00	0.85	0.11	0.57
B3	0.44	0.78	0.22	0.69	0.66	0.54	0.00	0.59
B4	0.66	0.79	0.55	0.82	0.22	0.83	0.00	0.65
B5	0.44	0.83	0.00	0.88	0.00	0.61	1.00	0.55
B6	1.00	0.77	0.33	0.76	0.33	0.80	1.00	0.47
B7	0.66	0.83	0.22	0.88	0.00	0.87	1.00	0.47
B8	0.55	0.83	0.22	0.88	0.33	0.88	0.44	0.43

*Keys:* B0: Autoregressive; B1: Term spread, Corp. spread, Stock mkt returns; B2: Term spread, short rate; B3: Stock mkt volatility, Term spread volatility; B4: Stock mkt volatility, Term spread; B5: Vol of stock mkt vol, Short-rate; B6: Vol of stock mkt vol, Term spread; B7: Vol of stock mkt vol, Stock mkt vol, Term spread; B8: Vol of stock mkt vol, Stock mkt vol, Interaction, Term spread.

*Note:* Panel A of this Table reports Diebold and Mariano (1995) (DM) test statistics for relative predictive accuracy of the first nine predicting blocks in Table 4 about probabilities of NBER recessions, and the fraction of time the Giacomini and White (2006) (GW) test of conditional predictive ability would have led to choose any one of these blocks against the others. The sample covers monthly data for the period from January 1957 to September 2008. The rolling estimation window,  $M$ , is set equal to 360 months. Panel A reports DM statistics and GW frequencies related to «coincident» probability estimates, defined as one-month ahead projections of Probit models estimated at forecasting horizons of 3 months, 6 months, 1 year and 2 years. Panel B reports DM statistics and GW frequencies related to «multi-step ahead» probability estimates, defined as projections of Probit models 3 months, 6 months, 1 year and 2 years ahead. A positive value for the DM test statistic indicates that the predicting block on the column has lower expected loss than the predicting block on the row. For GW, each figure indicates the frequency each predicting block on the column would be chosen against each predicting block on the row. Panel C reports the frequencies of correctly identified NBER recessions and expansions, for out-of-sample forecasts of probabilities of NBER expansions and recessions, both coincident and multi-step ahead. A correctly identified recession (resp., expansion) occurs when the probability of recession (resp., expansion) predicted by a given block exceeds (resp., does not exceed) 16.22%, which is the fraction of time the US economy spent in recession in the sample, according to NBER dating. For each predicting horizon (3 and 6 months, 1 Year and 2 Years), the columns labeled Rec and Exp report frequencies of correctly identified recessions and expansions.

Figure 6 depicts coincident probabilities predicted by all blocks from B1 through B8, at one year horizon, i.e.  $\text{Probit}_t^k(\text{Rec}_{t+1}|Bi)$  in Eq. (11), with  $k = 12$ , along with the horizontal line drawn at 16.22%, which is the fraction of time the US spent in recession over the entire sample period. The picture confirms, qualitatively, the message conveyed by our previous discussion: the volatility-term spread block B4 and the volatility block B8 would have performed quite well at signaling the last three recessions. At the same time, B8 does produce a sizeable and wrong warning flag of a recession in 2003, which the volatility-term spread block B4 does not. The 2001 recession deserves additional discussion. As documented by Stock and Watson (2003b), this recession took forecasters by surprise. The predicting block B4 would have helped signal this downturn: the coincident probability of an imminent recession predicted by Block B4 was larger than 16.22%, even before the 2001 recession. Note that the two volatility blocks, B7 and B8, also point to a recession, in 2001, but they both deliver one false recession signal in



**Figure 6:** Probabilities of recession predicted by Probit models: out-of-sample, coincident projections.

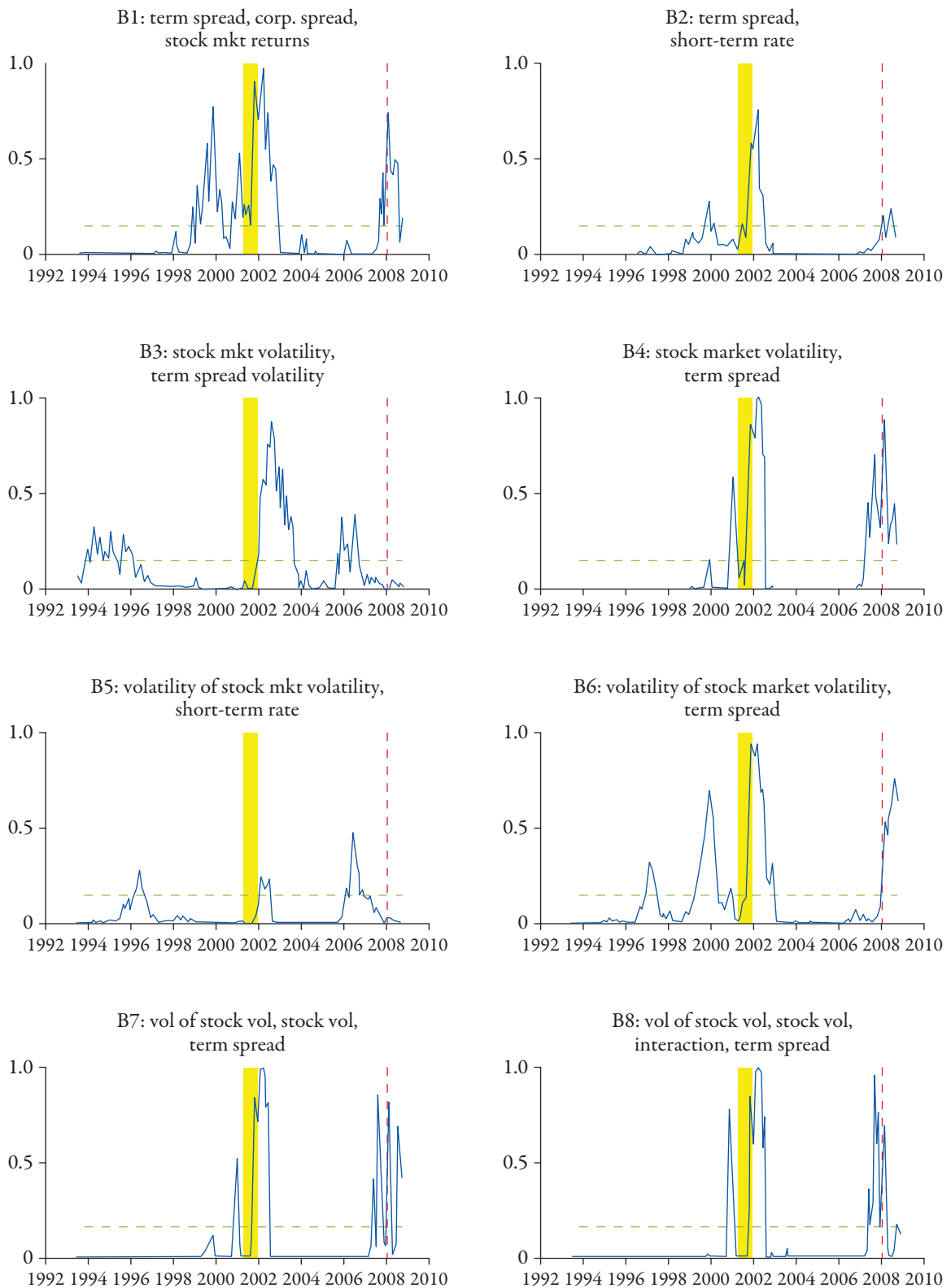
*Note:* Out-of sample forecasts of NBER-recession probabilities one-month ahead, obtained through Probit models estimated on rolling samples with size equal to 360 monthly observations, using the predicting blocks in Table 4, B1 through B8, and estimation window equal to twelve months. The horizontal dashed line (in green) is drawn at a value equal to 16.22%, which is the fraction of time the US economy spent in recession in the sample, according to NBER dating. The sample covers monthly data for the period from January 1957 to September 2008. Shaded areas (in yellow) track NBER-dated recessions, and the vertical dashed line (in red) indicates the beginning of the latest NBER-dated recession.

2003. Finally, on top of B4, the additional volatility blocks, B5 through B8, would have signaled the 2007 recession. Block B4 would also have signaled the 1990-1991 recession, which the yield curve block B2 could not really, a difficulty shared by many recession forecasts of the time, as documented for example by Stock and Watson (1993). Useless to mention, the block comprising stock returns, Block B1, is literally able to forecast five of the last three recessions, as in the old adage.

Panel B of Table 9 reports results for the more challenging task of multi-step ahead predictions, computed as  $\text{Probit}_t(\text{Rec}_{t+k}|B_i)$  in Eq. (10). In this exercise, the only recession we can cover is the 2001 recession. Therefore, our tests are simply gauging the ability of the predicting blocks to anticipate expansion periods. Overall, it is Block B2 which does better, at all horizons except two years. (At two year horizon, however, all blocks perform similarly as the naïve Block B0.) This conclusion is corroborated by Panel C of Table 9, which shows the frequency of correctly identified recessions and expansions, for both coincident and multi-step ahead probabilities: B2 does indeed roughly produce the highest frequencies of correctly identified expansion, among all blocks.

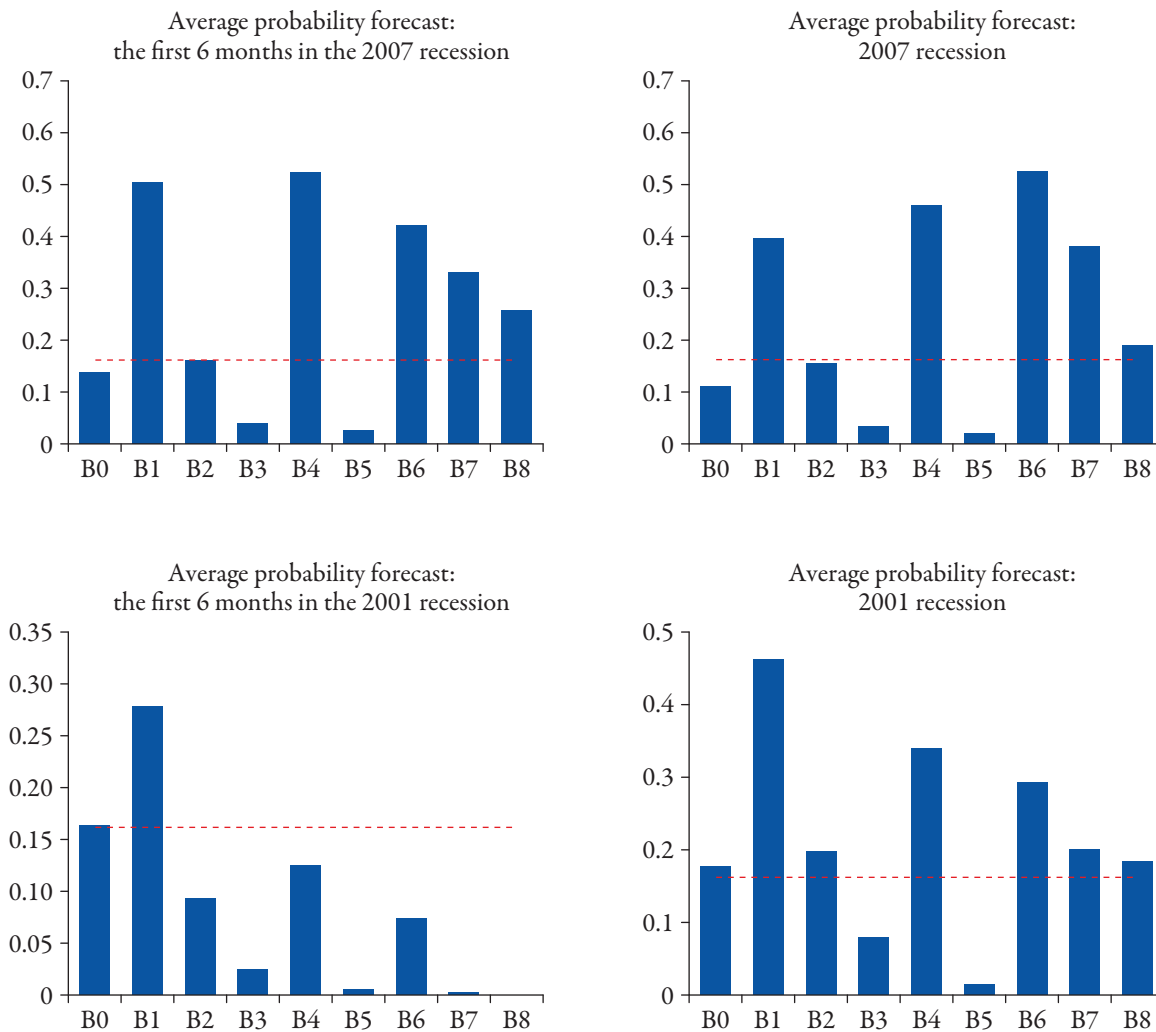
Figure 7 reports multi-step probability predictions, computed as  $\text{Probit}_t(\text{Rec}_{t+k}|B_i)$  in Eq. (10), for  $k = 6$  months. Once again, predicting blocks with volatility variables would have produced significant warning flags for the 2007 recession, with the exception of Blocks B3 and B5. Particularly informative is the volatility-term spread block B4, which also helps anticipate the 2001 recession. Figure 8 complements Figure 7, in that it reports the average probability forecasts the nine blocks in Table 4 would have produced, for the two recessions occurred in 2001 and in 2007. We consider (i) the average probability for the first six months of any such recession, which would necessarily have produced up to six months before the two recessions actually occurred, and (ii) the average probability over the whole recessions, assuming September 2008 is still part of a NBER recession event. Figure 8 reveals that as regards the 2007 recession, the yield curve block B2 does not simply work, as it fails to predict a probability of recession larger than the threshold 16.22%. Instead, all volatility blocks (excluding B3 and B5) seem to perform reasonably well. In particular, Block B4 is the one that best anticipates the 2007 recession, six months ahead. Over the whole recession, the average probability is the highest for the volatility Block B6 (comprising the volatility of stock market volatility and the term spread), although statistically not significantly better than that produced by Block B4. (Standard errors for the average probabilities are available upon request.)

The 2001 recession would have been harder to predict. For each predicting block, the average recession probability for the 2001 recession is approximately half that delivered for the 2007 recession. The block that best anticipates this recession six months ahead is Block B1, with an average probability of only about 27%. This same block produces the highest average probability over the entire recession episode (48%), and is followed by Block B4 (32%). With the exception of Block B5, the remaining volatility blocks would also have produced significant warning flags of a recession, a few months after its inception, as Figure 8 reveals. Instead, the yield curve block B2 would have been uninformative about this recession episode.



**Figure 7:** Probabilities of recession predicted by Probit models: out-of-sample, six month projections.

*Note:* Out-of sample forecasts of NBER-recession probabilities six-month ahead, obtained through Probit models estimated on rolling samples with size equal to 360 monthly observations, using the first nine predicting blocks in Table 4, and estimation window equal to six months. The horizontal dashed line (in green) is drawn at a value equal to 16.22%, which is the fraction of time the US economy spent in recession in the sample, according to NBER dating. The sample covers monthly data for the period from January 1957 to September 2008. Shaded areas (in yellow) track NBER-dated recessions, and the vertical dashed line (in red) indicates the beginning of the latest NBER-dated recession.



**Figure 8:** A tale of two recessions, 2001 and 2007: average probabilities of recessions predicted by Probit models, out-of-sample, six month projections.

*Note:* This figure reports out-of-sample, average probability forecasts produced by the nine blocks of Table 4 six months earlier, and related to the two recession episodes occurred in 2001 and in 2007. The graphs on the first column report the average projections for the first six months since the inception of each recession. The graphs on the second column report the average projections for the whole recession episodes. Keys: B0: Past six month industrial production growth; B1: Term spread, Corp. spread, Stock mkt returns; B2: Term spread, short rate; B3: Stock mkt volatility, Term spread volatility; B4: Stock mkt volatility, Term spread; B5: Vol of stock mkt vol, Short-rate; B6: Vol of stock mkt vol, Term spread; B7: Vol of stock mkt vol, Stock mkt vol, Term spread; B8: Vol of stock mkt vol, Stock mkt vol, Interaction, Term spread.

### 6.2.3 Controls

We control the previous results with one block including the volatility of selected macro-economic variables, and a second block, containing standard indexes of leading indicators:

Block B9: *Volatilities of: oil return, industrial production growth, inflation, metal return.* These volatilities are shown to spike around recessions and, therefore, stand as a natural alternative to the financial volatility blocks analyzed throughout the paper.

Block B10: *Oil return, index of leading indicators (growth), inflation, dividend yield.*

Table 10 reports results related to linear predictions. At three months horizon, Blocks B9 and B10 are outperformed by all the other blocks, for all rolling estimation windows

**Table 10:** Out-of-sample tests of predictive accuracy for control predictors, linear models

		B0	B1	B2	B3	B4	B5	B6	B7	B8	B9
Predicting horizon = 3 months											
Diebold-Mariano statistics											
$M = 120$	B9	-3.33	-3.56	-3.59	-1.36	-3.72	-2.96	-2.26	-2.50	-1.51	
	B10	-2.28	-2.61	-2.24	-0.39	-2.48	-1.67	-1.10	-1.26	-0.30	1.17
$M = 90$	B9	-3.99	-3.77	-3.56	-3.57	-3.79	-3.54	-3.54	-2.38	-1.05	
	B10	-3.50	-2.66	-2.69	-2.41	-2.42	-2.43	-2.21	-1.01	0.12	1.11
Giacomini-White conditional choices (frequencies)											
$M = 120$	B9	0.37	0.36	0.33	0.40	0.31	0.39	0.42	0.38	0.45	
	B10	0.25	0.29	0.33	0.44	0.30	0.38	0.46	0.40	0.46	0.52
$M = 90$	B9	0.26	0.31	0.30	0.25	0.24	0.34	0.30	0.34	0.46	
	B10	0.33	0.31	0.31	0.36	0.30	0.35	0.32	0.42	0.47	0.58
Predicting horizon = 6 months											
Diebold-Mariano statistics											
$M = 120$	B9	-0.78	-1.79	-1.45	0.95	-1.52	-1.35	-0.81	-0.54	-0.21	
	B10	-2.07	-2.90	-2.65	-0.01	-2.84	-2.39	-1.91	-1.93	-1.64	-1.27
$M = 90$	B9	-0.91	-2.71	-2.97	-0.69	-1.24	-1.84	-1.81	-0.27	-0.01	
	B10	-1.77	-3.37	-3.76	-1.71	-2.13	-2.59	-2.37	-1.11	-0.94	-0.93
Giacomini-White conditional choices (frequencies)											
$M = 120$	B9	0.49	0.39	0.45	0.47	0.40	0.40	0.50	0.49	0.50	
	B10	0.37	0.30	0.33	0.49	0.30	0.43	0.46	0.42	0.40	0.38
$M = 90$	B9	0.46	0.34	0.33	0.42	0.42	0.37	0.39	0.41	0.44	
	B10	0.41	0.32	0.27	0.38	0.35	0.37	0.38	0.42	0.39	0.47
Predicting horizon = 1 year											
Diebold-Mariano statistics											
$M = 120$	B9	-1.42	-1.44	-1.57	-0.66	-1.57	-1.68	-1.88	-1.51	-0.69	
	B10	-3.49	-4.17	-4.41	-2.66	-3.25	-5.09	-5.05	-4.81	-3.48	-2.20
$M = 90$	B9	-1.01	-1.88	-2.50	-0.63	0.37	-2.44	-1.78	-0.47	-0.64	
	B10	-1.44	-2.76	-3.66	-1.34	-0.08	-3.76	-2.70	-1.33	-1.51	-0.95
Giacomini-White conditional choices (frequencies)											
$M = 120$	B9	0.43	0.44	0.41	0.43	0.38	0.37	0.38	0.37	0.41	
	B10	0.28	0.26	0.24	0.35	0.26	0.20	0.21	0.20	0.21	0.34
$M = 90$	B9	0.48	0.41	0.36	0.37	0.57	0.33	0.36	0.43	0.43	
	B10	0.46	0.36	0.26	0.32	0.51	0.30	0.33	0.39	0.36	0.38
Predicting horizon = 2 years											
Diebold-Mariano statistics											
$M = 120$	B9	-2.04	-1.15	-0.90	-0.44	-2.64	-1.06	-2.90	-1.65	-0.61	
	B10	-2.70	-1.50	-1.04	-0.64	-2.29	-1.01	-1.99	-1.29	-0.61	-0.27
$M = 90$	B9	-1.37	-1.11	-2.01	-1.44	-2.32	-2.47	-1.13	-1.17	-0.51	
	B10	-1.22	-0.59	-0.91	-0.73	-1.25	-1.05	-0.45	-0.37	0.05	0.33
Giacomini-White conditional choices (frequencies)											
$M = 120$	B9	0.39	0.50	0.42	0.48	0.34	0.41	0.29	0.34	0.41	
	B10	0.26	0.40	0.40	0.38	0.30	0.40	0.33	0.36	0.39	0.43
$M = 90$	B9	0.43	0.42	0.39	0.39	0.36	0.36	0.42	0.41	0.45	
	B10	0.40	0.46	0.41	0.46	0.45	0.41	0.42	0.45	0.51	0.52

*Keys:* B0: Autoregressive; B1: Term spread, Corp. spread, Stock mkt returns; B2: Term spread, short rate; B3: Stock mkt volatility, Term spread volatility; B4: Stock mkt volatility, Term spread; B5: Vol of stock mkt vol, Short-rate; B6: Vol of stock mkt vol, Term spread; B7: Vol of stock mkt vol, Stock mkt vol, Term spread; B8: Vol of stock mkt vol, Stock mkt vol, Interaction, Term spread; B9: volatilities of: oil return, industrial production growth, inflation, metal return; B10: oil return, index of leading indicators (growth), inflation, dividend yield.

*Note:* This table reports Diebold and Mariano (1995) (DM) test statistics for relative predictive accuracy of industrial production growth, obtained through the last two predicting blocks in Table 4 (Blocks B9 and B10), and the fraction of time the Giacomini and White (2006) (GW) test of conditional predictive ability would have led to choose any one of these two blocks, against all the remaining blocks. The sample covers monthly data for the period from January 1957 to September 2008. The rolling estimation window,  $M$ , is set equal to 120 and 90, and forecasting horizons are 3 months, 6 months, 1 year and 2 years. A negative value for the DM test statistic indicates that the predicting block on the column has lower expected loss than the predicting block on the row. For GW, each figure indicates the frequency each predicting block on the row would be chosen against each predicting block on the column.

**Table 11:** Out-of-sample tests of predictive accuracy for control predictors, Probit-based recessions models

Panel A: Tests of predictive ability										
	B0	B1	B2	B3	B4	B5	B6	B7	B8	B9
Predicting horizon = 3 months										
Diebold-Mariano statistics										
B9	1.29	-0.53	-1.32	0.80	-0.48	-0.46	0.54	-0.52	-0.65	
B10	3.94	-0.29	-2.17	1.82	-0.14	-0.14	1.32	-0.23	-0.49	0.42
Giacomini-White conditional choices (frequencies)										
B9	0.86	0.63	0.58	0.75	0.60	0.59	0.68	0.65	0.57	
B10	0.79	0.41	0.34	0.55	0.31	0.39	0.58	0.31	0.30	0.23
Predicting horizon = 6 months										
Diebold-Mariano statistics										
B9	-0.14	-0.69	-2.29	-0.12	-1.18	-2.03	-0.44	-1.42	-1.50	
B10	-0.30	-1.15	-4.27	-0.23	-1.81	-3.42	-0.72	-2.36	-2.52	-0.02
Giacomini-White conditional choices (frequencies)										
B9	0.81	0.58	0.42	0.59	0.42	0.34	0.68	0.42	0.40	
B10	0.62	0.31	0.17	0.44	0.21	0.11	0.30	0.14	0.15	0.19
Predicting horizon = 1 year										
Diebold-Mariano statistics										
B9	-0.98	-0.99	-1.66	0.28	-1.42	-0.67	-1.17	-1.67	-1.74	
B10	-0.10	-0.72	-2.52	1.41	-1.75	0.16	-1.29	-2.04	-2.04	0.66
Giacomini-White conditional choices (frequencies)										
B9	0.73	0.60	0.58	0.56	0.58	0.75	0.66	0.50	0.52	
B10	0.55	0.41	0.33	0.62	0.27	0.67	0.44	0.29	0.26	0.34
Predicting horizon = 2 years										
Diebold-Mariano statistics										
B9	2.60	1.01	2.27	2.06	2.21	1.67	1.84	1.84	2.49	
B10	-0.14	-0.97	0.32	1.78	0.42	-0.23	0.24	0.24	0.88	-1.43
Giacomini-White conditional choices (frequencies)										
B9	0.84	0.71	0.81	0.79	0.84	0.84	0.84	0.84	0.85	
B10	0.65	0.55	0.73	0.67	0.67	0.68	0.65	0.65	0.68	0.46
Panel B: Frequencies of correctly identified NBER recessions and expansions										
Predicting block	3 months		6 months		1 year		2 years			
	Rec	Exp	Rec	Exp	Rec	Exp	Rec	Exp		
B9	0.55	0.81	0.33	0.77	0.11	0.71	0.00	0.84		
B10	0.33	0.87	0.00	0.71	0.00	0.76	0.00	0.76		

*Keys:* B0: Autoregressive; B1: Term spread, Corp. spread, Stock mkt returns; B2: Term spread, short rate; B3: Stock mkt volatility, Term spread volatility; B4: Stock mkt volatility, Term spread; B5: Vol of stock mkt vol, Short-rate; B6: Vol of stock mkt vol, Term spread; B7: Vol of stock mkt vol, Stock mkt vol, Term spread; B8: Vol of stock mkt vol, Stock mkt vol, Interaction, Term spread; B9: volatilities of: oil return, industrial production growth, inflation, metal return; B10: oil return, index of leading indicators (growth), inflation, dividend yield.

*Note:* Panel A of this Table reports Diebold and Mariano (1995) (DM) test statistics for relative predictive accuracy of the last two predicting blocks in Table 4 (Blocks B9 and B10) about probabilities of NBER recessions, and the fraction of time the Giacomini and White (2006) (GW) test of conditional predictive ability would have led to choose any one of these two blocks against the other blocks. Probabilities are «multi-step ahead» probability estimates, defined as projections of Probit models 3 months, 6 months, 1 year and 2 years ahead. The sample covers monthly data for the period from January 1957 to September 2008. The rolling estimation window,  $M$ , is set equal to 360 months. A negative value for the DM test statistic indicates that the predicting block on the column has lower expected loss than the predicting block on the row. For GW, each figure indicates the frequency each predicting block on the row would be chosen against each predicting block on the column. Panel B reports the frequencies of correctly identified NBER recessions and expansions, for out-of-sample «multi-step ahead» forecasts of probabilities of NBER expansions and recessions. A correctly identified recession (resp., expansion) occurs when the probability of recession (resp., expansion) predicted by a given block exceeds (resp., does not exceed) 16.22%, which is the fraction of time the US economy spent in recession in the sample, according to NBER dating. For each predicting horizon (3 and 6 months, 1 Year and 2 Years), the columns labeled Rec and Exp report frequencies of correctly identified recessions and expansions.

$M$ , although the outperformance is only quite marginal for Block B8. At longer horizons (six months and one year), Block B9 (but not Block B10) seems to be quite comparable to Block B2 and all the volatility blocks, and both Blocks B9 and B10 are worse than B4 at a one year horizon.

Table 11 reports results for multi-step probabilities generated by Probit models. Again, the main difficulty here is that these tests only cover a single recession episode, that occurred in 2001. Overall, the two blocks B2 and B4 seem to perform better than both B9 and B10, although their best relative performance occurs at the horizons of six months and one year. At two year horizon, Block B9 outperforms all the remaining blocks.

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## 7 Conclusion

The key idea underlying this paper is simple: if financial volatility is countercyclical, it might encode information about developments in the business cycle. Our conclusion, based on an array of measurement methods, is that stock volatility does indeed help predict the business cycle. We rely on predictions of both industrial production growth and NBER-dated recessions, utilizing in-sample projections and submitting our findings to reality checks and other out-of-sample experiments. We control the significance of these predicting relations by looking at alternative predicting blocks of economic activity which include (i) traditional leading indicators, (ii) financial variables such as the term spread or the corporate spread, (iii) additional volatility variables, such as the volatility of the term spread, the volatility of stock market volatility or the volatility of real aggregates. We find that combining stock volatility with the term spread leads to a predicting block of economic activity, which tracks, and anticipates, the business cycle reasonably well. For instance, this predicting block would have considerably helped predict at least the last three recessions, with no «false positive» signals.

While we have outlined a few theoretical explanations for these findings, we still lack a systematic explanation of them. Bloom (2009) and Bloom, Floetotto and Jaimovich (2009) certainly constitute important advances into the issue of how uncertainty shocks stand as a valid propagation mechanism. The next and intriguing step is to integrate financial volatility into a plausible propagation mechanism that includes realistically calibrated asset prices.

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## 8 Appendix

### 8.1. Derivation of Eq. (1)

We derive the expressions for the asset price, real production and asset volatility reported in Eq. (1). In this economy, managers are risk-neutral, and maximize the value of the firm. Therefore, the share price of the firm is the firm's maximized value, viz

$$(A.1) \quad P(s) = \max_{Q \geq 0} E(D^{-1}(Q)Q - C(Q) | s)$$



The production chosen by the firm equals,

$$Q(s) = \operatorname{argmax}_{Q \geq 0} E((\alpha + \tilde{v} - \lambda Q)Q - zQ | s) = \max \left\{ \frac{a - z + E(\tilde{v} | s)}{2\lambda}, 0 \right\},$$

where, by the Projection Theorem,  $E(\tilde{v} | s) = \theta s$ , with  $\theta = \frac{\sigma^2}{\sigma^2 + \sigma_\epsilon^2}$ . By replacing this solution back into Eq. (A.1), we find the price function in Eq. (1). Finally, the expression for return volatility in Eq. (1), follows by computing the right hand side of the following definition,

$$\operatorname{Vol}(s) \equiv \sqrt{E \left[ \left( \frac{D^{-1}(Q(s))Q(s) - C(Q(s))}{P(s)} - 1 \right)^2 | s \right]},$$

holding for all  $s : a - z + E(\tilde{v} | s)$ , i.e. for all  $s > \hat{s}$ , where  $\hat{s} = -\frac{a - z}{\theta}$ .

## 8.2 Details on the Monte Carlo Experiment in Table 1

The Monte Carlo results summarized in Table 1 of Section 2.1 are obtained as follows. First, we set  $\sigma = \sigma_\epsilon = a - z = 1$ , and  $\lambda = 5$ . Then, we draw 500 values from the signals distribution. For each draw, we compute prices, production and volatility from Eq. (1). We only retain prices, production and return volatility when economic activity takes place, i.e. when  $s > \hat{s}$ . Return volatility blows up as  $s$  approaches  $\hat{s}$ , and we only consider signal realizations that are 5% larger than the cutoff  $\hat{s}$ . For each Monte Carlo repetition, we compute the values of constants, regression slopes and centered  $R^2$ . Table 1, then, reports OLS estimates, t-stats, and  $R^2$  averaged over all the Monte Carlo repetitions.

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