Online Appendix for
"Demand for Crash Insurance, Intermediary Constraints, and Risk Premia in Financial Markets"

Hui Chen Scott Joslin Sophie Ni*

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1 An Extension of the Dynamic Model

Our model presented in the paper captures a number of the key features we have found in the data. In particular, the model captures the fact that when equilibrium public buying is low, risk premia may be high as this may correspond to time when dealers are (or act as if they are) more risk averse. However, as in Chen, Joslin, and Tran (2012), wealth moves slowly between the public sector and dealers outside of disasters and only through crash insurance premiums. In this section, we generalize our main model to account for more general time variation in the relative wealth of the public and dealers.

Consider the case where the public and dealer not only view the disaster events differently, but also disagree about the future path of the likelihood of disasters. Specifically, consider the more general form of Equation (A9) where

$$\frac{d\mathbb{P}_D}{d\mathbb{P}_P} = \rho^{N_t} e^{(1-\rho)\int_0^t \lambda_s ds} \times e^{-\int_0^s \theta_s dW_s^\lambda - \int_0^t \theta_s^2 ds}. \tag{IA1}$$

*Chen: MIT Sloan and NBER (huichen@mit.edu). Joslin: USC Marshall (sjoslin@usc.edu). Ni: HKUST (sophieni@ust.hk)

and θ_s is some process satisfying Novikov's condition. For example, with an appropriate chose of θ_t, we may have that the dealer will believe that the dynamics of the λ_t are

$$d\lambda_t = \kappa^D(\bar{\lambda}^D - \lambda_t)dt + \sigma\sqrt{\lambda_t}dW_t^{\lambda,D},$$

where $W_t^{\lambda,D}$ is a standard Brownian motion under the dealer's beliefs.

An example we have in mind is that the dealer may believe that when the intensity is high, it will mean revert more quickly to the steady state than it actually will. When this is the case, the dealer will make bets with the public that the intensity will fall. This will cause the public's relative wealth to grow if the intensity continues to rise. Thus even if the dealers are becoming more risk averse as the intensity rises, there will be a greater demand for crash protection from the public and in equilibrium the net effect can be that the size of the insurance market increases. Without this additional trading incentive, the relative wealth of the public and dealers will be nearly constant over short horizons. This extension allows us to capture some patterns seen in the crisis. In Figure 1 of the paper, we saw that in the early stages of the crisis, the demand for crash insurance spiked and subsequently bottomed out as we reached the later stages.

The extended model can capture these types of features. To see this, we extend our base model with the additional assumption that the dealers believe that λ_t mean reverts ten times faster than the public (a half life of 0.48 years versus 4.8 years.) For simplicity, we assume that over a two year period the disaster intensity rises from its steady value of 1.7% at a rate of 1%/year to 3.7%. We initialize the public with a planner weight such that they initially represent 25% of consumption. We also model the implied risk aversion of the dealer to remain constant at $\gamma = 4$ in the beginning of the sample and then increase quadratically to $\gamma = 6.5$ at the end of the period. Figure IA1 plots the resulting market size (Panel A) and risk premium (Panel B), as measured by $\lambda^{\mathbb{Q}} - \lambda^{\mathbb{P}}$. Generally, the patterns we see are qualitatively similar to those found in Figure 1. The public begins buying more insurance as the dealers lose money on their λ bets. As the crisis deepens, the dealers start to become very risk averse and the market dries up to the point where the dealers even become buyers

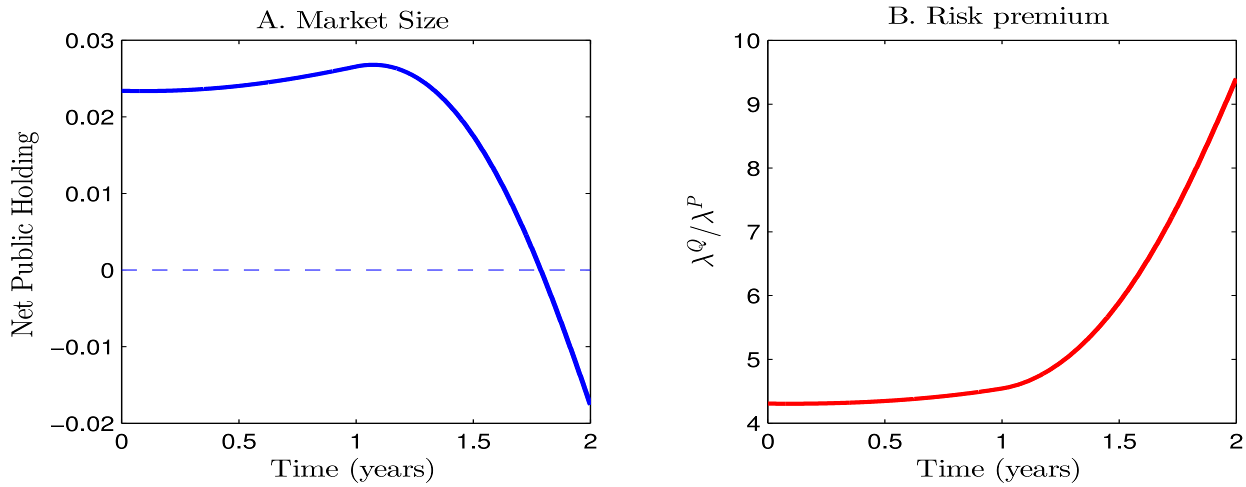

Figure IA1: **Dealer constraint and derivative supply.** This figure plots the equilibrium holding of crash insurance by the public investors (Panel A) and disaster risk premium (Panel B) for a hypothetical history where the intensity rises from 1.7% to 3.7% over a two year period. The public has an initial consumption fraction of 0.25. The dealer's relative risk aversion is initially $\gamma = 4$ and then rises in the second half quadratically to $\gamma = 6.5$.

of protection. Across this time period, the risk premium at first increases very slowly until the dealers are no longer willing to hold the risk and the premium begins to increase rapidly.

2 Additional Empirical Results

This section presents additional empirical results and robustness checks. For further information on the definition of variables, see Chen, Joslin, and Ni (2016).

- Figure IA2: Plot of the time series of $PNBO$, $b_{VP,t}$, and the constraint measure $I_{b_{VP,t}<0} \times PNBO_t$.
- Table IA1: A table of correlations between $PNBO$ and various macroeconomic and financial variables.
- Table IA2: A systematic analysis of the statistical significance for the return-forecasting regressions using $PBNO$ and $PNBON$, including Newey and West (1987) standard

errors with long lags, bootstrapped confidence intervals, and the test statistic of Muller (2014).

- Table IA3: Parameter estimates from estimation of the supply-demand system using the method of Rigobon (2003). For more details on the identification method, see Section 3.6 of Chen, Joslin, and Ni (2016).

- Table IA4: Return-forecasting regression with $PNBO_{1month}$ (and $PNBON_{1month}$), which is $PNBO$ constructed using only options with one month or less to maturity. Focusing on options with maturities of one month or less is another way to address the concern about the difference between quantity measure based on volume ($PNBO$) and open interest ($PNOI$).

- Table IA5: Sub-sample return-forecasting regressions with $PNOI$, the end-of-month public net open interest for DOTM SPX puts.

- Table IA6: Return-forecasting regression with PNB (and $PNBN$), which is the public net buy volume for DOTM SPX puts that include both open and close transactions. In contrast, $PNBO$ and $PNBON$ focus on open transactions.

- Table IA7: Return-forecasting using a supply/demand-regime indicator based on the price-quantity pair.[1] We implement the method by categorizing all the months in our sample into 4 groups based on a double sort on $PNBO$ (or $PNBON$) and VP: (i) weak supply (WS): when $PNBO$ is below sample median and VP is above sample median; (ii) strong supply (SS): when $PNBO$ is above median and VP is below median; (iii) weak demand (WD): when $PBNO$ and VP are both below median; (iv) strong demand (SD): when $PBNO$ and VP are both above median. We then regress future market excess returns on the four dummy variables (WS, SS, WD, SD) without an intercept. The expected excess returns one-month ahead is only significant in the WS regime, consistent with our interpretation that WS corresponds to periods of tight intermediary constraints.

[1]We thank an anonymous referee for this suggestion.

- Table IA8: Return prediction of PNBO when we use $b_{VP,t} + c_{VP,t}J_t < 0$ (instead of $b_{VP,t} < 0$) as an indicator of supply environment. The results are qualitatively similar to those using $b_{VP,t} < 0$.

- Table IA9: Sub-sample return-forecasting regressions with the log dividend-price ratio. These results show that the predictive power of $PNBO$ and $PNBON$ is concentrated in different sample periods compared to the dividend-price ratio.

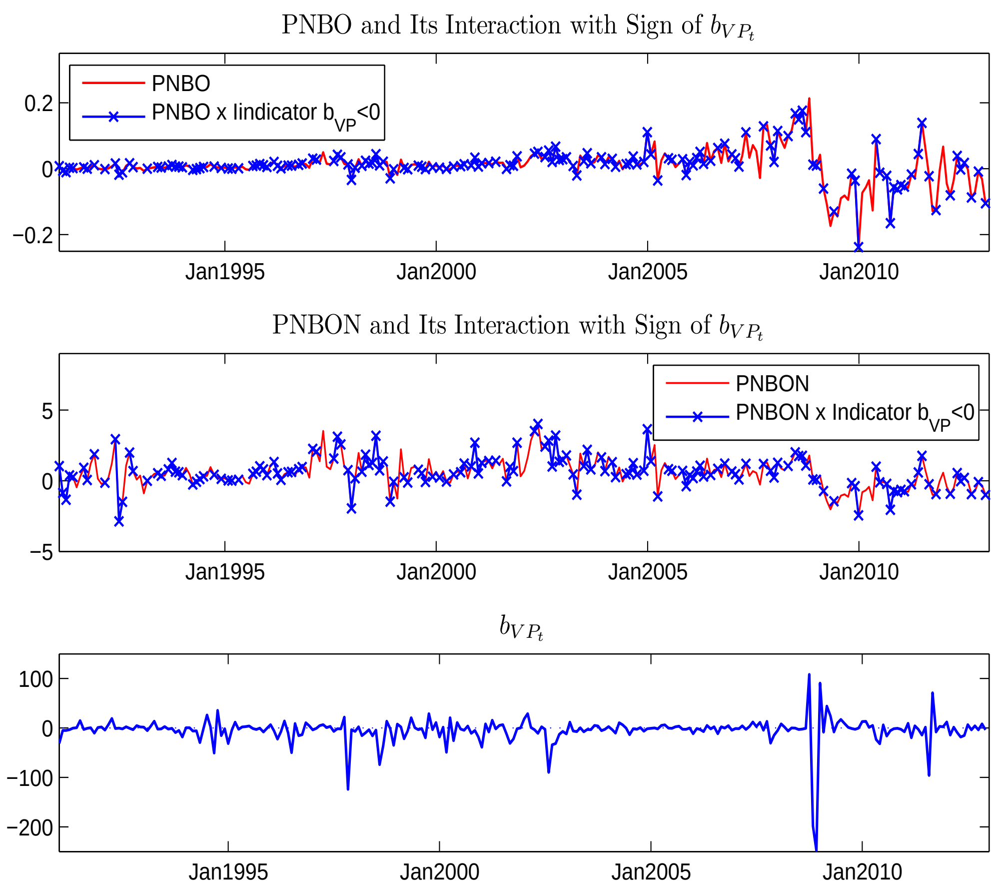

Figure IA2: **PNBO and its interaction with indicator of negative b_{VP}.**

Table IA1: **Correlations of PNBO with Other Variables**

PNBO: net open-buying volume of DOTM puts ($K/S <= 0.85$). PNBON: PNBO normalized by past 3-month average total options volume from public investors. IP: growth rate of industrial production. Unemploy: unemployment rate. $p-e$: log of price to earning ratio of SP500 stocks. $d-p$: the log of dividend yield of SP500 stocks. $\widehat{cay}$: consumption-wealth ratio. ΔLev: broker-dealer balance sheet growth of the financial intermediaries. IVSlope: the difference in the implied volatility between one-month DOTM and ATM SPX puts. Tail: tail risk measure computed from individual stock returns. VP: variance premium.

	1991 - 2012		**1991 - 2007**	
	$PNBO$	$PNBON$	$PNBO$	$PNBON$
IP	0.17*	-0.03	-0.01	-0.02
Unemploy	-0.48**	-0.13*	-0.23**	-0.19**
$d-p$	-0.18**	-0.06	-0.28**	-0.21**
$\widehat{cay}$	0.00	-0.14*	-0.23**	-0.24**
ΔLev	0.50	0.54	0.46	0.46
IVSlope	-0.46**	-0.24**	-0.23**	-0.11*
Tail	-0.02	-0.27**	-0.21**	-0.22**
VP	-0.35**	-0.28**	-0.09	-0.16*
VIX	-0.07	0.10	0.01	-0.08

Table IA2: **Return Forecasts with $PNBO$, Statistical Significance**

This table provides additional results for the statistical significance of the return forecasting regressions using $PNBO$ and $PNBON$. $r_{t+j\to t+k}$ represents market excess return from $t+j$ to $t+k$ ($k > j \geq 0$). Standard errors in parentheses are computed based on Newey and West (1987) with 10 lags. Sq is the statistics based on **?**. The coefficient is significant at 5% if Sq larger than one. Sample period: 1991/01 – 2012/12. (***,**,*) denote significance at 1%, 5%, and 10%, respectively based on Newey and West (1987).

Return	b_r^-	$\sigma(b_r^-)$	Sq	Bootstrap 99% CI	b_r^-	$\sigma(b_r^-)$	Sq	Bootstrap 99% CI
	A: $r_{t+j\to t+k} = a_r + b_r^- I_{\{b_{VP,t}<0\}} PNBO_t + b_r^+ I_{\{b_{VP,t}\geq 0\}} PNBO_t + c_r I_{\{b_{VP,t}<0\}} + \epsilon_{t+j\to t+k}$							
	$PNBO$				$PNBON$			
$r_{t\to t+1}$	-22.04***	(9.12)	1.0	[-49.66, -2.91]	-0.97***	(0.32)	2.6	[-1.92, -0.07]
$r_{t+1\to t+2}$	-31.45***	(9.23)	1.1	[-57.74, -11.11]	-0.92***	(0.35)	1.4	[-1.86, -0.06]
$r_{t+2\to t+3}$	-31.31***	(8.86)	0.8	[-52.90, -11.02[	-0.78***	(0.36)	1.0	[-1.69, 0.05]
$r_{t+3\to t+4}$	-19.43***	(9.33)	0.4	[-46.94, 3.93]	-0.73***	(0.32)	0.7	[-1.64, 0.07]
$r_{t+1\to t+3}$	-84.75***	(21.95)	1.5	[-139.51, -46.01]	-2.67***	(0.66)	5.3	[-4.20, -1.35]
	B: $r_{t+j\to t+k} = a_r + b_r^- I_{\{J_t>\bar{J}\}} PNBO_t + b_r^+ I_{\{J_t<\bar{J}\}} PNBO_t + c_r I_{\{J_t>\bar{J}\}} + \epsilon_{t+j\to t+k}$							
	$PNBO$				$PNBON$			
$r_{t\to t+1}$	-33.69***	(7.48)	1.2	[-55.08, -14.84]	-1.11***	(0.33)	2.6	[-2.05, -0.16]
$r_{t+1\to t+2}$	-25.62***	(8.65)	0.6	[-50.36, -6.05]	-0.91***	(0.33)	1.2	[-1.83, 0.00]
$r_{t+2\to t+3}$	-28.22***	(7.02)	0.9	[-47.47, -8.42]	-1.06***	(0.44)	1.4	[-2.10, 0.01]
$r_{t+3\to t+4}$	-15.77***	(7.11)	0.3	[-33.89, 3.48]	-0.60**	(0.34)	0.7	[-1.52, 0.35]
$r_{t+1\to t+3}$	-87.49***	(18.83)	1.4	[-128.85, -53.43]	-3.08***	(0.88)	2.6	[-4.86, -1.26]

Table IA3: **Supply-demand estimation**

This table reports parameter estimates from estimation of the supply-demand system given by

$$\text{Demand: } VP_t = b + \beta \cdot PNBO_t + \epsilon_t, \quad \text{and}$$
$$\text{Supply: } PNBO_t = a + \alpha \cdot VP_t + \eta_t.$$

The η and ϵ are uncorrelated with regime-dependent volatilities. Regimes are given by the crisis period (regime 1: December 2007 to May 2009) and non-crisis period (regime 2). Standard errors are computed by bootstrap. Sample period: 1991/01 – 2012/12. (***,**,*) denote significance at 1%, 5%, and 10%, respectively.

b	21.6***	(1.2)
β	-297.2	(444.0)
$\sigma_{\epsilon,1}$	41.9**	(19.9)
$\sigma_{\epsilon,2}$	17.5***	(3.3)
a	-0.031	(0.130)
α	0.002	(0.004)
$\sigma_{\eta,1}$	0.170	(0.210)
$\sigma_{\eta,2}$	0.060	(0.070)

Table IA4: **Return Forecasts with One-month** $PNBO$

This table reports the results of the return forecasting regressions using one month $PNBO$ and $PNBON$. $r_{t+j\to t+k}$ represents market excess return from $t+j$ to $t+k$ ($k > j \geq 0$). Standard errors in parentheses are computed based on Hodrick (1992). Sample period: 1991/01 – 2012/12. (***,**,*) denote significance at 1%, 5%, and 10%, respectively.

$$r_{t+j\to t+k} = a_r + b_r^- I_{\{b_{VP,t}<0\}} PNBO_t + b_r^+ I_{\{b_{VP,t}\geq 0\}} PNBO_t + c_r I_{\{b_{VP,t}<0\}} + \epsilon_{t+j\to t+k}$$

Return	b_r	c_r	R^2	b_r	c_r	R^2
	$PNBO_{1month}$			$PNBON_{1month}$		
$r_{t\to t+1}$	-29.92**	-12.78	7.0	-0.96	-0.99	2.9
	(15.18)	(9.20)		(0.82)	(0.72)	
$r_{t+1\to t+2}$	-18.78	-23.98*	4.3	-0.24	-1.70***	2.4
	(11.51)	(13.20)		(0.67)	(0.82)	
$r_{t+2\to t+3}$	-21.20***	-14.33	3.8	-1.39***	-1.04	3.7
	(10.30)	(12.09)		(0.67)	(0.84)	
$r_{t+3\to t+4}$	-22.67***	-24.90	5.4	-1.39***	-2.16***	6.2
	(10.34)	(14.01)		(0.60)	(0.92)	
$r_{t\to t+3}$	-69.90***	-51.06***	11.8	-2.60*	-3.73***	5.9
	(27.46)	(19.80)		(1.45)	(1.49)	

Table IA5: **Return Forecasts with $PNOI$: Sub-sample Results**

This table reports the sub-sample results of the return forecasting regressions using $PNOI$ and $PNOIN$. $PNOI$ is the end-of-month public net open interest for deep-out-of-the-money ($K/S \leq 0.85$) puts. $PNOIN$ is $PNOI$ normalized by the sum of public long and short open interest. $I_{\{b_{VP,t}<0\}}$ is an indicator of negative coefficient on daily $PNBO$ regressing on VP. VP is the variance premium based on Bekaert and Hoerova (2014). J is monthly average of the daily physical jump risk measure by Andersen, Bollerslev, and Diebold (2007). $\bar{J}$ is the median of monthly J_t for the full sample. Standard errors (σ) in parentheses are computed based on Hodrick (1992). (***,**,*) denote significance at 1%, 5%, and 10%, respectively. Sample period: 1991/01 – 2012/12.

$$r_{t\to t+3} = a_r + b_r \ PNOI_t + \epsilon_{t\to t+3}$$

Sub-sample	b_r	$\sigma(b_r)$	R^2	b_r	$\sigma(b_r)$	R^2	obs
	$PNOI$			$PNOIN$			
$b_{VP,t} < 0, J_t \geq \bar{J}$	-78.60**	(35.56)	23.9	-9.25**	(3.78)	11.0	80
$b_{VP,t} < 0, J_t < \bar{J}$	-42.12***	(14.59)	14.2	-6.77***	(2.57)	13.1	79
$b_{VP,t} \geq 0, J_t \geq \bar{J}$	-22.79	(19.35)	3.4	-1.25	(3.14)	0.0	52
$b_{VP,t} \geq 0, J_t < \bar{J}$	-11.03	(14.70)	1.7	-2.23	(2.87)	1.8	53

Table IA6: **Return Forecasts with PNB**

This table reports the results of the return forecasting regressions using PNB and $PNBN$. PNB: public net buy volume for DOTM puts (including both open and close transactions). $PNBN$: PNB normalized by the monthly average public total SPX options volume over the past three months. $r_{t+j\to t+k}$ represents market excess return from $t+j$ to $t+k$ ($k > j \geq 0$). Standard errors in parentheses are computed based on Hodrick (1992). Sample period: 1991/01 – 2012/12. (***,**,*) denote significance at 1%, 5%, and 10%, respectively.

$$r_{t+j\to t+k} = a_r + b_r^- I_{\{b_{VP,t}<0\}} PNB_t + b_r^+ I_{\{b_{VP,t}\geq 0\}} PNB_t + c_r I_{\{b_{VP,t}<0\}} + \epsilon_{t+j\to t+k}$$

Return	b_r^-	b_r^+	R^2	b_r^-	b_r^+	R^2
	PNB			$PNBN$		
$r_{t\to t+1}$	-21.71***	7.09	5.8	-0.86***	0.20	4.0
	(10.75)	(6.05)		(0.36)	(0.37)	
$r_{t+1\to t+2}$	-24.21***	-7.29	6.2	-0.60*	-0.52	2.2
	(9.55)	(8.01)		(0.33)	(0.39)	
$r_{t+2\to t+3}$	-11.34	-15.18	3.0	-0.79***	-0.57	3.6
	(8.65)	(9.30)		(0.36)	(0.37)	
$r_{t+3\to t+4}$	-3.71	-11.46	1.0	0.04	-0.44	0.6
	(7.98)	(11.78)		(0.33)	(0.40)	
$r_{t\to t+3}$	-57.22***	-15.35	10.1	-2.25***	-0.89	6.6
	(21.75)	(14.34)		(0.75)	(0.70)	

Table IA7: **Return Forecasts with $PNBO$-VP Pair**

This table reports the sub-sample results of the return forecasting regressions using $PNBO$ and $PNBON$. $r_{t+j\to t+k}$ represents market excess return from $t+j$ to $t+k$ ($k > j \geq 0$). Standard errors (σ) in parentheses are computed based on Hodrick (1992). Sample period: 1991/01 – 2012/12. (***,**,*) denote significance at 1%, 5%, and 10%, respectively.

Return	r_{t+1}	$r_{t\to t+3}$	r_{t+1}	$r_{t\to t+3}$
	$PNBO$		$PNBON$	
WS (Weak Supply)	2.52***	5.22***	2.01***	4.90***
	(0.60)	(1.01)	(0.61)	(1.07)
SS (Strong Supply)	-0.07	1.05	-0.20	1.21
	(0.51)	(0.90)	(0.52)	(0.91)
WD (Weak Demand)	0.47	2.52***	0.58	2.35***
	(0.36)	(0.57)	(0.35)	(0.57)
SD (Strong Demand)	-0.44	-1.39	0.06	-1.00
	(0.66)	(1.31)	(0.64)	(1.26)
R^2	5.5	7.9	2.5	6.0

Table IA8: **Return Forecasts with** $PNBO$

$r_{t+j\to t+k}$ represents market excess return from month $t+j$ to $t+k$ ($k > j \geq 0$). (***,**,*) denote significance at 1%, 5%, and 10%, respectively.

$$r_{t+j\to t+k} = a_r + b_r^- \ I_{\{b_{VP,t}+c_{VP,t}J_t<0\}} \, PNBO_t + b_r^+ \ I_{\{b_{VP,t}+c_{VP,t}J_t<\geq 0\}} \, PNBO_t \\ + c_r \ I_{\{b_{VP,t}+c_{VP,t}J_t<0\}} + \epsilon_{t+j\to t+k}$$

Return	b_r^-	b_r^+	R^2	b_r^-	b_r^+	R^2
	$PNBO$			$PNBON$		
$r_{t\to t+1}$	-18.00***	-19.46	6.0	-0.90***	-0.55	4.3
	(8.83)	(11.31)		(0.40)	(0.48)	
$r_{t+1\to t+2}$	-32.24***	3.80	8.6	-0.96***	0.35	4.5
	(11.28)	(5.83)		(0.37)	(0.33)	
$r_{t+2\to t+3}$	-29.00***	-11.17	8.4	-0.71**	-0.66	3.5
	(11.26)	(10.16)		(0.36)	(0.47)	
$r_{t+3\to t+4}$	-17.47	-9.43	3.8	-0.69*	-0.32	2.7
	(10.75)	(10.56)		(0.36)	(0.43)	
$r_{t\to t+3}$	-79.17***	-26.86	18.1	-2.57***	-0.86	9.0
	(24.52)	(19.11)		(0.67)	(0.92)	

Table IA9: **Return Forecasts with Log Dividend-Price Ratio: Sub-sample Results**

This table reports the sub-sample results of the return forecasting regressions using the log dividend-price ratio $(d-p)$. $r_{t\to t+k}$ represents market excess return from month t to $t+k$. Standard errors (σ) in parentheses are computed based on Hodrick (1992). Sample period: 1991/01 - 2012/12. (***,**,*) denote significance at 1%, 5%, and 10%, respectively.

Sub-sample	b_r	$\sigma(b_r)$	R^2	b_r	$\sigma(b_r)$	R^2	obs
	$r_{t\to t+k} = a_r + b_r\ (d_t - p_t) + \epsilon_{t\to t+k}$						
	3 months			12 months			
$b_{VP,t} < 0, J_t \geq \bar{J}$	1.21	(4.69)	0.1	15.67	(11.09)	7.5	80
$b_{VP,t} < 0, J_t < \bar{J}$	6.68*	(3.76)	8.5	21.54*	(12.39)	17.1	79
$b_{VP,t} \geq 0, J_t \geq \bar{J}$	8.07**	(4.08)	9.4	24.97**	(12.17)	19.4	52
$b_{VP,t} \geq 0, J_t < \bar{J}$	4.42	(3.60)	4.6	29.71**	(12.30)	22.1	53

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