Liquidity Creation as Volatility Risk

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March, 2018

Motivation

1. A key function of the financial sector is liquidity creation: making assets cheaper to trade. It does so in different ways:
   - issuing safe securities against risky assets (Gorton Pennacchi, 1990)
   - making markets for trading risky assets (Kyle, 1985)

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2. Liquidity creation is fundamentally exposed to asymmetric information (Akerlof, 1970). From this, we show
   - that liquidity creation induces exposure to volatility risk (a negative beta to volatility shocks)
   - and since the variance risk premium is very high, liquidity creation earns a substantial premium

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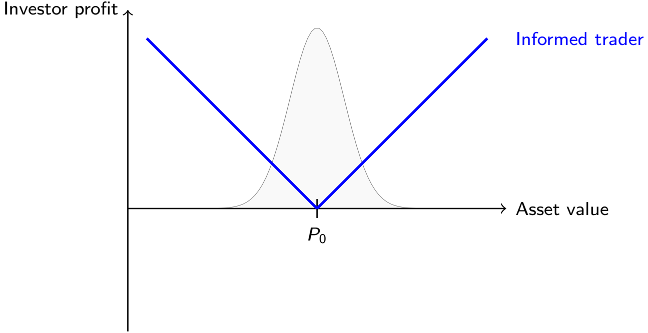
   - that liquidity creation induces exposure to volatility risk (a negative beta to volatility shocks)
   - and since the variance risk premium is very high, liquidity creation earns a substantial premium
3. Our results provide a new, asset-pricing perspective on the risks and returns to financial intermediation:
   - explains the level and variation of the liquidity premium in financial markets (Nagel, 2012)
   - explains how a surge in volatility can trigger a liquidity crunch (Brunnermeier, 2009)

Why is liquidity creation exposed to volatility risk?

1. Liquidity providers face liquidity-driven traders and informed traders who buy if price will rise, sell if it will fall
   - $\Rightarrow$ informed traders' payoff looks like a straddle (a call plus a put option)



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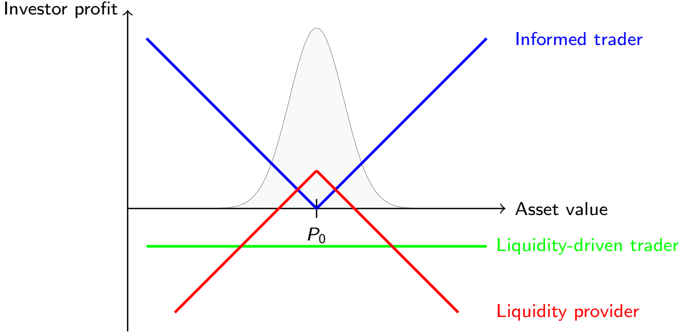
   - ⇒ liquidity providers are short the straddle



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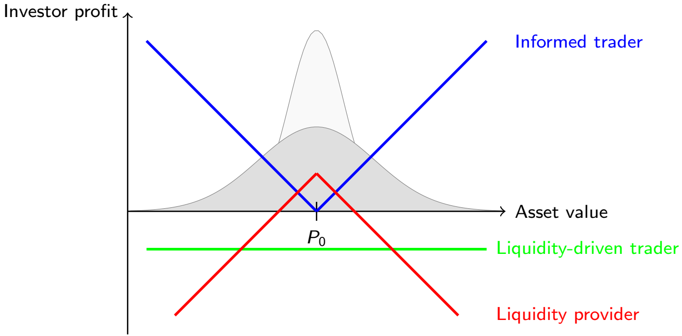
   - $\Rightarrow$ liquidity providers are short the straddle
   - $\Rightarrow$ negative exposure to volatility



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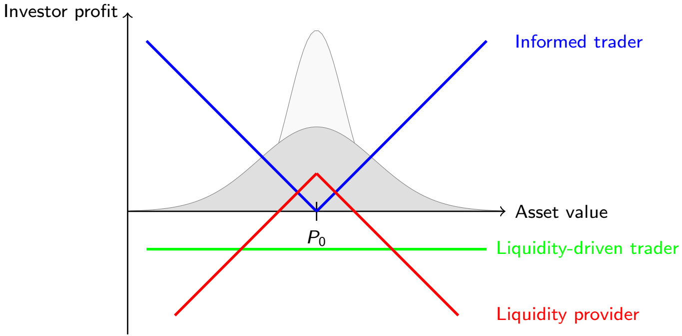
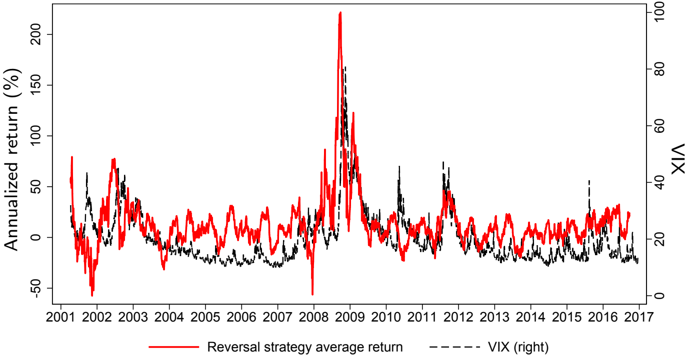


2. Volatility highly correlated across assets and with market volatility
   - ⇒ liquidity providers' volatility risk is undiversifiable

Liquidity creation and short-term reversals

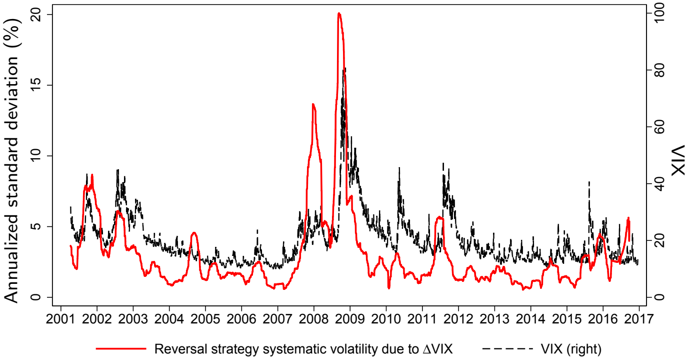
1. Use short-term reversals as proxy for return to liquidity provision (Lehman 1990)
   - daily decile sort by normalized return, largest 20% of stocks, buy low-return decile, sell high-return decile, hold for five days



2. Reversal premium is strongly increasing in VIX (Nagel, 2012)
   - seen in other markets, e.g. Treasuries during the 2008 financial crisis
   - consistent with volatility spikes inducing a liquidity crunch

Liquidity creation and short-term reversals

3. Regress reversal return on VIX changes (rolling window)
   - beta is negative: -14 bps for every 1 point increase in VIX; large relative to 27 bps average five-day return
   - annualized standard deviation of the fitted component captures the volatility risk of the reversal strategy



4. Volatility risk of reversal strategy is also strongly increasing in VIX
   - lines up with level and dynamics of reversal premium

Roadmap

1. Overview
2. Related literature
3. Model
4. Empirical results

Related literature

1. Liquidity and adverse selection: Akerlof (1970); Grossman and Stiglitz (1980); Kyle (1985); Glosten and Milgrom (1985); Gorton and Pennacchi (1990)
2. Macro finance and liquidity: Gromb and Vayanos (2002); Eisfeldt (2004); Brunnermeier and Pedersen (2008); Adrian and Shin (2010); Moreira and Savov (2017)
3. Asset prices and liquidity: Amihud and Mendelson (1986); Amihud (2002); Pástor and Stambaugh (2003); Acharya and Pedersen (2005); Nagel (2012)
4. The variance risk premium: Carr and Wu (2008); Bollerslev, Tauchen and Zhou (2009); Drechsler and Yaron (2010); Drechsler (2013); Dew-Becker, Giglio, Le, and Rodriguez (2017)

Model setup

1. Add stochastic volatility to Kyle (1985) framework
   - three dates: 0, $t \in (0,1)$, and 1; N stocks traded at date 0
   - asset payoffs realized at date 1:

$$p_{i,1} = \overline{v}_i + \sigma_{i,1} v_i$$

   - volatility increasing in market volatility factor (e.g. Herskovic, Kelly, Lustig, Van Nieuwerburgh, 2016):

$$\sigma_{i,1} = k_{i,m}\sigma_{m,1} + \varepsilon_{\sigma_i}$$

2. Liquidity-driven ("noise") traders demand $z_i \sim N\left(0, \sigma_{z_i}^2\right)$
3. Informed trader observes v_i at date 0, demands y_i:

$$\max_{y_i} E_0^Q \left[y_i \left(p_{i,1} - p_{i,0} \right) \middle| v_i \right]$$

   - $E_0^Q[\cdot]$ is taken under the risk-adjusted probability measure Q

Equilibrium pricing

1. Liquidity providers see order flow $x_i = y_i + z_i$, set price to break even. Use same risk-adjusted measure Q as everyone else
   - no balance sheet frictions or market segmentation

$$p_{i,0} = E_0^Q \left[p_{i,1} \middle| x_i \right] = \overline{v}_i + \frac{x_i}{2\sigma_{z_i}} E_0^Q \left[\sigma_{i,1} \right]$$

   - sensitivity to order flow increasing in expected volatility because it captures the value of the informed trader's information

2. Let $\Delta p_{i,0} = (p_{i,0} - \overline{v}_i)$ be the date-0 price change. Then to clear market, the liquidity providers' position is

$$-x_i = -\Delta p_{i,0} \frac{2\sigma_{z_i}}{E_0^Q \left[\sigma_{i,1} \right]}$$

   $\Rightarrow$ liquidity providers hold a portfolio of reversals; they buy assets that went down in price and sell assets that went up

   - can use reversals as proxy for returns to liquidity provision

Volatility risk exposure

1. At date t, a shock to expected volatility causes price to move further in direction of order flow as informed trader's information becomes more valuable:

$$\Delta p_{i,t} \;=\; \frac{x_i}{2\sigma_{z_i}} \left(E_t^Q \left[\sigma_{i,1}\right] - E_0^Q \left[\sigma_{i,1}\right] \right)$$

2. Liquidity providers' payoff is

$$-x_i \Delta p_{i,t} \;=\; -\frac{x_i^2}{2\sigma_{z_i}} \left(E_t^Q \left[\sigma_{i,1}\right] - E_0^Q \left[\sigma_{i,1}\right] \right)$$

- since $x_i = \sigma_{z_i} v_i + z_i$, payoff resembles a short straddle in v_i

$\Rightarrow$ liquidity providers (reversals) have a negative exposure to volatility shocks on both long and short positions

- exposure is increasing in date-0 volume $|x_i|$

Volatility risk pricing

1. Liquidity providers' exposure to the market volatility factor σ_m is

$$\beta_{\sigma_m} = \sum_{i=1}^{N} \beta_{i,\sigma_m} = -\sum_{i=1}^{N} \frac{x_i^2}{2\sigma_{z_i}} k_{i,m} < 0$$

   - this exposure is undiversifiable
   - contrasts with inventory models which assume liquidity providers cannot fully diversify (e.g., Nagel 2012)

2. The expected payoff of liquidity providers from date 0 to 1 is

$$E_0^P\left[\sum_{i=1}^{N} -x_i \Delta p_{i,1}\right] = \beta_{\sigma_m}\left(E_0^P\left[\sigma_{m,1}\right] - E_0^Q\left[\sigma_{m,1}\right]\right)$$

   - the variance risk premium literature shows $E_0^Q\left[\sigma_{m,1}\right] \gg E_0^P\left[\sigma_{m,1}\right]$ (VIX $\gg$ realized volatility of S&P 500)
   - and since $\beta_{\sigma_m} < 0$, liquidity providers (reversals) earn a positive risk premium for bearing volatility risk

Data and empirical strategy

1. Form reversal portfolios to mimic returns to liquidity provision (Lehman, 1990)
   - sort daily into deciles by return, normalized by rolling standard deviation. Within each decile, weight by dollar volume (proxy for $|x_i|$)
   - split by size quintile, remove penny stocks, earnings announcements (large public information events), $\approx$ 100 stocks in each portfolio
   - sample period from 4/9/2001 to 12/31/2016 (3,958 days). Post decimalization, liquidity provision competitive (Bessembinder, 2003)
   - hold portfolios for one to five days (Nagel, 2012). Not HFT
   - reversal strategy buys low-return deciles, sells high-return deciles
2. Model predicts that the reversal strategy should
   - have a negative exposure to shocks to expected volatility
   - this exposure should explain the premium of the reversal strategy

Portfolio summary statistics

	Market cap (billions)				
	Lo-Hi	2-9	3-8	4-7	5-6
Small	**0.05**	0.05	0.05	0.05	0.05
2	**0.16**	0.16	0.17	0.17	0.17
3	**0.43**	0.44	0.44	0.44	0.44
4	**1.35**	1.37	1.37	1.37	1.37
Big	**49.57**	**54.15**	**56.02**	**56.02**	**55.40**

	Amihud illiquidity ($\times 10^6$)				
	Lo-Hi	2-9	3-8	4-7	5-6
Small	**33.60**	21.08	14.42	10.34	8.58
2	**5.73**	3.98	2.79	2.07	1.70
3	**1.36**	1.00	0.71	0.52	0.43
4	**0.30**	0.22	0.16	0.11	0.09
Big	**0.03**	**0.02**	**0.01**	**0.01**	**0.01**

1. **"Lo-Hi"** buys **Lo**west return decile, sells **Hi**ghest return decile
2. **"Big"** are the 20% **Big**gest stocks, $\approx$ 96.4% of market value
   - liquid, low transaction costs

Portfolio summary statistics

	Sorting-day returns (%)				
	Lo-Hi	2-9	3-8	4-7	5-6
Small	−**24.36**	−6.92	−4.21	−2.34	−0.74
2	−**17.54**	−6.05	−3.73	−2.07	−0.64
3	−**14.77**	−5.43	−3.34	−1.87	−0.60
4	−**11.97**	−4.70	−2.92	−1.64	−0.52
Big	**−7.45**	**−3.43**	**−2.13**	**−1.18**	**−0.38**

	Share turnover (%)				
	Lo-Hi	2-9	3-8	4-7	5-6
Small	**10.28**	7.37	6.71	6.28	6.07
2	**7.84**	4.45	3.85	3.60	3.42
3	**6.41**	3.11	2.63	2.46	2.36
4	**5.59**	2.76	2.44	2.25	2.21
Big	**3.28**	**2.13**	**1.99**	**1.89**	**1.83**

2. Reversal strategy has large negative sorting-day return (by design)
   - larger for small stocks since sorting is by normalized return
   - reversal associated with high share turnover, demand for liquidity

Average returns and CAPM alphas

$$R^p_{t,t+5} \;=\; \alpha^p + \sum_{s=1}^{5} \beta^p_s R^M_{t+s} + \epsilon^p_{t,t+5}$$

	5-day average return (%)				
	Lo-Hi	2–9	3–8	4–7	5–6
Small	**1.16**	0.56	0.21	0.05	0.04
2	**0.65**	0.30	0.17	0.03	−0.03
3	**0.35**	0.24	0.01	0.11	−0.01
4	**0.22**	0.23	0.13	0.06	0.01
Big	**0.27**	**0.25**	**0.18**	**0.11**	**0.05**

	5-day standard deviation (%)				
	Lo-Hi	2–9	3–8	4–7	5–6
Small	**10.54**	7.11	6.19	5.99	5.89
2	**6.44**	4.59	4.03	3.82	3.74
3	**5.11**	3.18	2.71	3.02	2.28
4	**3.88**	2.47	2.10	1.92	1.77
Big	**3.25**	**2.28**	**1.78**	**1.55**	**1.31**

	5-day CAPM alpha (%)				
	Lo-Hi	2–9	3–8	4–7	5–6
Small	**1.14**	0.55	0.20	0.04	0.04
2	**0.62**	0.30	0.16	0.02	−0.03
3	**0.34**	0.23	−0.00	0.10	−0.01
4	**0.20**	0.23	0.13	0.06	0.01
Big	**0.25**	**0.24**	**0.18**	**0.11**	**0.05**

	5-day CAPM alpha t-statistic				
	Lo-Hi	2–9	3–8	4–7	5–6
Small	**6.57**	4.88	1.97	0.44	0.39
2	**5.83**	3.96	2.43	0.33	−0.50
3	**3.85**	4.31	−0.03	2.25	−0.14
4	**3.13**	5.54	3.82	2.00	0.31
Big	**4.51**	**6.48**	**6.24**	**4.35**	**2.50**

1. Large-stock reversal strategy has an average annual return of 13.6% $(= 0.27\% \times 252/5)$, volatility 23%, Sharpe ratio 0.59
   - small-stock reversal returns are larger but more volatile
   - CAPM alphas $\approx$ average returns $\Rightarrow$ CAPM cannot price reversals

Predicting reversals with VIX

$$R^p_{t,t+5} \;=\; \alpha^p + \beta^p VIX_t + \epsilon^p_{t,t+5}$$

	5-day return VIX loading ($\times 10^2$)				
	Lo-Hi	2–9	3–8	4–7	5–6
Small	**3.53**	3.48	3.51	2.72	0.16
2	**7.01**	3.14	2.68	1.40	−0.27
3	**4.84**	2.98	1.16	0.93	−0.10
4	**2.94**	2.33	1.52	−0.04	0.44
Big	**5.37**	**3.69**	**1.74**	**0.67**	**0.08**

	5-day return VIX t-statistic				
	Lo-Hi	2–9	3–8	4–7	5–6
Small	**1.95**	2.62	2.55	2.16	0.13
2	**3.70**	2.77	3.66	2.05	−0.34
3	**4.03**	3.42	1.60	1.59	−0.21
4	**2.80**	3.70	2.83	−0.11	1.24
Big	**3.98**	**4.64**	**3.26**	**1.70**	**0.22**

	5-day return VIX R^2 (%)				
	Lo-Hi	2–9	3–8	4–7	5–6
Small	**0.09**	0.19	0.26	0.16	0.00
2	**0.95**	0.37	0.35	0.11	0.00
3	**0.72**	0.70	0.15	0.08	0.00
4	**0.46**	0.71	0.42	0.00	0.05
Big	**2.18**	**2.11**	**0.77**	**0.15**	**0.00**

1. *VIX* predicts reversal returns (Nagel, 2012), even for large stocks
   - very high R^2 for large stocks
   - consistent with model because when VIX is high, premium for volatility risk rises (Drechsler and Yaron, 2010)

Volatility risk exposure

$$R^p_{t,t+5} = \alpha_p + \sum_{s=1}^{5} \beta_s^{p,VIX} \Delta VIX_{t+s} + \epsilon^p_{t,t+5}$$

	5-day ΔVIX beta				
	Lo-Hi	2–9	3–8	4–7	5–6
Small	−**0.81**	−0.49	−0.57	−0.26	−0.31
2	−**0.82**	−0.34	−0.24	−0.31	0.03
3	−**0.57**	−0.26	−0.36	−0.32	−0.01
4	−**0.54**	−0.26	−0.18	0.01	−0.04
Big	−**0.64**	−**0.34**	−**0.09**	−**0.01**	−**0.01**

	5-day ΔVIX beta *t*-statistic				
	Lo-Hi	2–9	3–8	4–7	5–6
Small	−**2.66**	−3.29	−3.02	−1.31	−1.78
2	−**3.47**	−2.21	−1.82	−2.39	0.25
3	−**3.63**	−2.52	−3.82	−4.16	−0.09
4	−**4.30**	−2.78	−2.70	0.13	−0.93
Big	−**4.28**	−**3.09**	−**1.34**	−**0.25**	−**0.31**

1. Reversal strategy has a large negative beta to VIX innovations
   - large-stock reversal drops by 64 bps per 5-point VIX increase (1.3 standard deviations); large relative to average return (27 bps)

Volatility risk exposure, controlling for the market

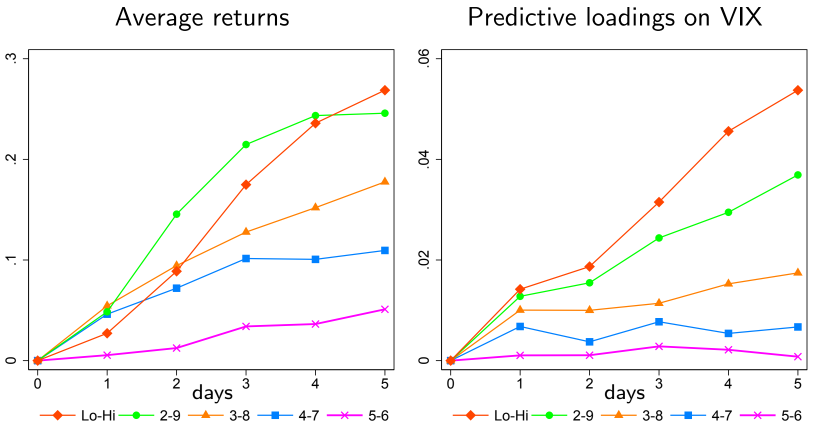
$$R^p_{t,t+5} \;=\; \alpha_p + \sum_{s=1}^{5} \beta_s^{p,VIX} \Delta VIX_{t+s} + \sum_{s=1}^{5} \beta_s^{p,M} R^M_{t+s} + \epsilon^p_{t,t+5}$$

	5-day ΔVIX beta				
	Lo-Hi	2–9	3–8	4–7	5–6
Small	−**0.75**	−0.60	−0.80	−0.13	−0.46
2	−**0.65**	−0.44	−0.35	−0.04	−0.08
3	−**0.62**	−0.12	−0.25	−0.14	−0.14
4	−**0.33**	−0.30	−0.34	0.04	−0.01
Big	**−0.71**	**−0.37**	**−0.18**	**0.05**	**−0.13**

	5-day ΔVIX beta *t*-statistic				
	Lo-Hi	2–9	3–8	4–7	5–6
Small	−**1.53**	−2.40	−2.43	−0.43	−1.75
2	−**1.87**	−1.75	−1.78	−0.20	−0.47
3	−**2.23**	−0.72	−1.71	−0.85	−1.26
4	−**1.41**	−2.28	−3.00	0.48	−0.13
Big	**−3.33**	**−2.42**	**−1.46**	**0.62**	**−1.62**

2. Reversal strategy negative ΔVIX beta unaffected by controlling for market return

Reversal strategy dynamics



1. Average returns increase steadily with horizon, line up with predictive loadings

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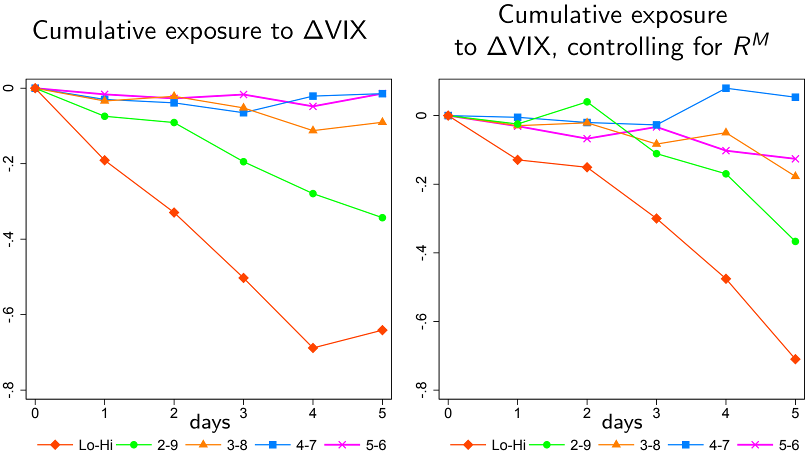


2. ΔVIX betas increase steadily with horizon, line up with average returns and predictive loadings

Pricing the reversal strategy: Fama-Macbeth regressions

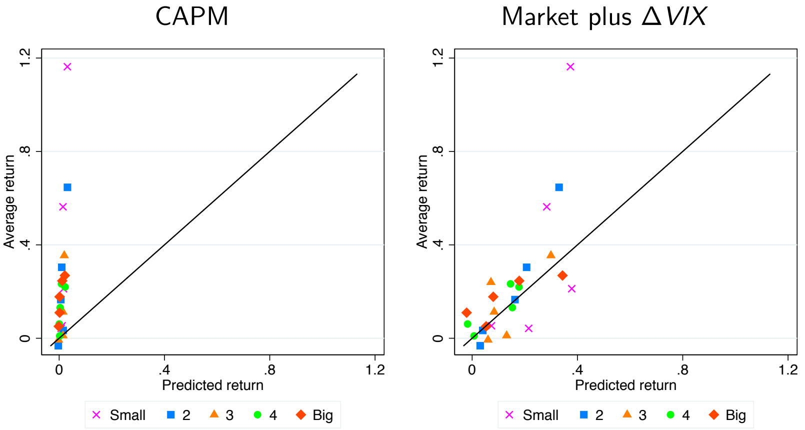
	Factor premia					
	Market	*t*-stat.	Δ VIX	*t*-stat.	R.m.s.	*p*-value
(1)	0.03	2.06			0.18	0.00
(2)	**0.05**	**3.04**	**−0.49**	**−8.57**	**0.14**	**0.00**

	CAPM pricing error				
	Lo-Hi	2–9	3–8	4–7	5–6
Small	**1.13**	0.55	0.20	0.04	0.03
2	**0.61**	0.29	0.16	0.02	−0.03
3	**0.33**	0.23	−0.00	0.10	−0.00
4	**0.20**	0.22	0.13	0.06	0.01
Big	**0.25**	**0.23**	**0.18**	**0.11**	**0.05**

	Market plus ΔVIX pricing error				
	Lo-Hi	2–9	3–8	4–7	5–6
Small	**0.79**	0.28	−0.17	−0.02	−0.17
2	**0.32**	0.10	0.00	−0.01	−0.06
3	**0.06**	0.17	−0.12	0.03	−0.07
4	**0.04**	0.09	−0.02	0.08	0.00
Big	**−0.07**	**0.07**	**0.10**	**0.13**	**−0.00**

1. Fama-Macbeth regressions: ΔVIX factor explains reversal returns of large and medium stocks. Large and significant premium

Pricing the reversal strategy: Fama-Macbeth regressions



1. Fama-Macbeth regressions: ΔVIX factor explains reversal returns of large and medium stocks. Large and significant premium

Is the implied price of volatility risk consistent with other markets?

1. Volatility risk is traded directly in option markets
   - VIX itself is the price of a basket of options that replicates the realized variance of the S&P 500 over next 30 days
   - However, ΔVIX is not a return because basket changes daily

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2. We replicate the VIX using S&P 500 options (99.83% accuracy) and use the change in the price of a given basket to get a VIX return
   - can go shorter than 30 days by using VIXN, the near-term component of VIX ($\approx$ 22 days). VIXN return
   - this gets us closer to the relevant horizon for liquidity providers

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2. We replicate the VIX using S&P 500 options (99.83% accuracy) and use the change in the price of a given basket to get a VIX return
   - can go shorter than 30 days by using VIXN, the near-term component of VIX ($\approx$ 22 days). VIXN return
   - this gets us closer to the relevant horizon for liquidity providers
3. Average daily VIX return is -1.54%, VIXN return is -2.01%
   - consistent with variance risk premium literature (Carr and Wu, 2008; Bollerslev, Tauchen, and Zhou, 2009)

Option-implied prices of volatility risk

	$\mathbf{R^{VIX}}$	$\mathbf{R^{VIXN}}$
ΔVIX	**6.938*** (0.106)**	
ΔVIXN		**5.696*** (0.120)**
Constant	−1.511*** (0.184)	−1.986*** (0.264)
Obs.	3,788	3,787
R^2	0.529	0.372

1. Implied price of risk: −22 bps for ΔVIX and −35 bps for $\Delta VIXN$
   - we use R^{VIX} and R^{VIXN} as test assets instead of factors because their ex-post variation is dominated by the day's realized variance
   - model predicts that liquidity providers are exposed to shocks to expected variance, which is captured by ΔVIX and $\Delta VIXN$

Pricing the reversal strategy: option-implied price of risk

	Pricing error using VIX return				
	Lo-Hi	2–9	3–8	4–7	5–6
Small	**0.99**	0.44	0.04	0.02	−0.05
2	**0.50**	0.21	0.09	0.01	−0.04
3	**0.22**	0.21	−0.05	0.07	−0.03
4	**0.14**	0.17	0.06	0.07	0.01
Big	**0.11**	**0.16**	**0.14**	**0.12**	**0.03**

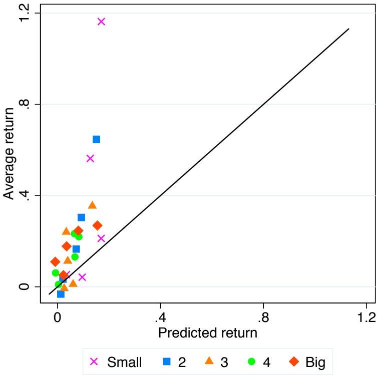
	Pricing error using VIXN return				
	Lo-Hi	2–9	3–8	4–7	5–6
Small	**0.87**	0.34	0.04	−0.04	−0.09
2	**0.42**	0.16	0.07	−0.00	−0.05
3	**0.12**	0.12	−0.08	0.04	−0.03
4	**0.05**	0.10	0.01	0.07	−0.01
Big	**0.01**	**0.13**	**0.11**	**0.11**	**0.03**

1. The option-implied price of ΔVIX explains most of the reversal return among large stocks (pricing error falls from 25 bps to 11 bps)
2. The near-term $\Delta VIXN$ fully explains it (pricing error is just 1 bp)

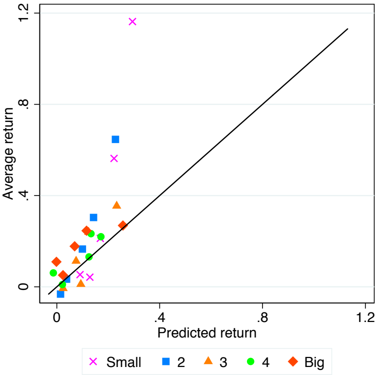
   $\Rightarrow$ Near-term volatility risk priced the same in reversals and options

Pricing the reversal strategy: option-implied price of risk

Market plus ΔVIX



Market plus $\Delta VIXN$



1. Option-implied price of $\Delta VIXN$ explains reversal returns of large and medium stocks

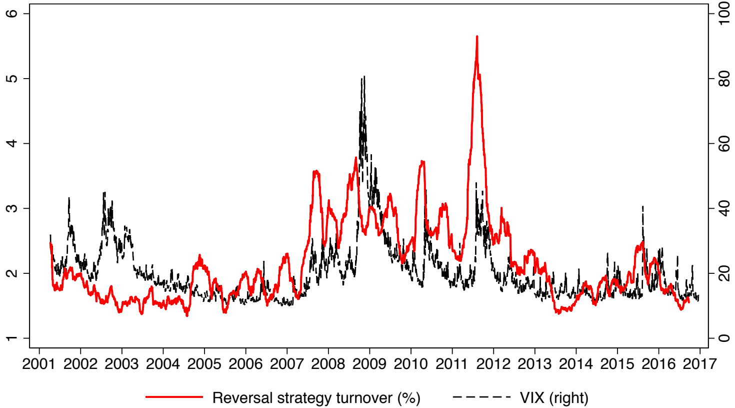
   $\Rightarrow$ the returns to liquidity provision reflect broad economic risks instead of intermediation frictions (segmented markets)

Takeaways

1. Liquidity creation is a key function of the financial sector
2. Exposure to asymmetric information $\Rightarrow$ exposure to volatility risk
   - liquidity providers implicitly short a straddle
3. Volatility risk commands a high premium in financial markets
   - explains the level and variation of liquidity premium
4. A new, asset-pricing perspective on the risks and returns to financial intermediation

APPENDIX

Reversal strategy turnover



1. Reversal strategy turnover increasing in VIX
   - higher quantity and premium ⇒ shift in liquidity demand curve
   - goes against financial constraints theories, which work through shifts in supply curve (e.g., VaR constraint)