Market Response to Risk Shocks

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January 19, 2023

We analyze twenty billion NASDAQ order book messages for equity and government-bond exchange-traded funds to delineate how the market responds to an implied variance (VIX) impulse. We find that investors actively sell equities and buy government bonds on largely unchanged liquidity. Deeper analysis shows that the pattern we find for implied-variance (IV) impulses is entirely driven by changes in the variance risk premium. For IV impulses driven by changes in expected realized volatility, we find active *buying* of equities on worse liquidity. We rationalize the surprising patterns by adding risk shocks to a Grossman and Stiglitz (1980) model.

JEL Codes: G11, G12, G20
Keywords: Risk shocks, variance risk premium, market liquidity, intraday dynamics, big data, exchange-traded funds.

1 Introduction

Investors fly to safety at times of elevated risk.[1] They are on high-powered incentives to do so quickly if their liquidity demand exercises a negative externality as a result of a liquidity spiral (Pedersen, 2009; Brunnermeier, 2009). This channel could make markets fragile and, in the extreme, cause financial instability.[2]

We study if and how flight to safety and market fragility are intrinsically linked based on market dynamics at high frequencies. We analyze an exhaustive 2007-2021 sample of *all* NASDAQ trading messages for two exchange-traded funds (ETFs): SPY for the S&P 500 equity index and TLT for government bonds. For ease of exposition, we talk about asset classes instead of referring to ETF codes in the remainder of the manuscript.

To characterize market dynamics, we estimate generalized impulse response functions. The impulse is a surprise shock in *VIX* and the response variables for the ETFs include initiator net volume, midquote return, trading volume, bid-ask spread, order book depth, and the Amihud (2002) illiquidity ratio. We analyze how *VIX* shocks affect trading in equity and bond ETFs at a five-minute frequency.

Our most salient and robust finding is that *VIX* impulses lead to active selling of equities and active buying of government bonds, both contemporaneously and in the hour that follows the shock. Trading volume spikes while prices drop for equities and increase for government bonds, although only contemporaneously. These price responses revert partially in the subsequent hour, in spite of continued selling of equities and buying of bonds. Market liquidity also responds to *VIX* impulses, but magnitudes are negligible on all dimensions: bid-ask spread, depth, and ILLIQ.

To study the channel that drives the flight to safety dynamics, we decompose *VIX* changes into two canonical components:

1. changes in the variance risk premium (*VRP*), related to beliefs about higher crash state probabilities, skewness, or increases in risk aversion (Wang and Young, 2020), or

2. changes in expected realized volatility (*ERV*).

Although both components could, in principle, cause a flight to safety, we conjecture that *VRP*

[1] See, e.g., Longstaff (2004), Beber et al. (2009), Adrian et al. (2019), Baele et al. (2019).

[2] Central banks worry about market liquidity as part of their focus on liquidity risk management after the global financial crisis (BIS and IOSCO, 2012). The SEC worries about the ramifications of liquidity spirals as evidenced by their 2016 rule that requires each registered open-end management investment company, including open-end exchange-traded funds (ETFs), to establish a liquidity risk management program (SEC, 2016). European regulators share the worry but stopped short of imposing regulation (ESMA, 2019).

changes are the most likely triggers. This is in line with a strand of literature that finds time-varying variance risk premium being positively predictive of required returns (Campbell and Cochrane, 1999; Bekaert and Hoerova, 2014; Bollerslev et al., 2015).

To decompose five-minute *VIX* changes, we develop a high-frequency version of the methodology proposed by Bekaert and Hoerova (2014). We then study how both components relate to all trading variables, both contemporaneously, and subsequently the shock. The findings can be summarized as follows. First off, we find that the two components of *VIX* changes, *ERV* and *VRP*, are close to orthogonal at a five-minute frequency. This is a reassuring result because it allows us to identify potentially different market responses. This turns out to be the case as the responses to the two types of *VIX* shocks differ markedly. Shocking *VRP* leads to a market response that mirrors the response to *VIX* shocks: Flight to safety from equity towards government bonds. Shocking *ERV*, on the other hand, leads to active *buying* of equities and to fragile market liquidity, albeit only contemporaneously. The fragility shows through a sizeable jump in ILLIQ (18% on a one-standard deviation impulse). We find that the bid-ask spread widens and depth drops, but these changes are economically negligible.[3]

Reassuringly, we find that these patterns are consistent with institutional trading. For 2009 through 2013, we use standard Abel Noser data on institutional order flow to redo the impulse-response analysis. We find statistically significant institutional selling of equities on *VIX* and *VRP* shocks and significant *buying* on *ERV* shocks.

In summary, we find evidence relating *VIX* shocks to flight to safety and to market fragility, but these are due to separate channels. Shocks to the variance risk premium (*VRP*) seem to trigger active re-allocation from equities to government bonds, without impairing market liquidity. Shocks to the expected realize variance (*ERV*), do not seem to trigger active re-allocation, but they do impair market liquidity, at least contemporaneously. The surprising finding is the *active buying* of equities that accompanies this market fragility.

We rationalize these findings in the last part of the manuscript by adding risk shocks to the model proposed by Vayanos and Wang (2012), which, itself, is an extension of Grossman and Stiglitz (1980). We add two types of risk shocks to those seeking liquidity. Liquidity demanders either become more risk averse (*VRP* channel), or they enter a market with elevated expected

[3]These findings suggest that standard, readily observable liquidity metrics such as spread and depth are imprecise measures for the cost of executing large orders. A better proxy for their transaction cost might be the price elasticity of net volume. This is in line with Hendershott and Menkveld (2014) who have an orthogonality result for the size of the bid-ask spread and the elasticity of (midquote) price elasticity to market-maker inventory, which both are endogenously derived in a dynamic inventory control model. Price elasticity in their model is the extent to which a market maker skews the bid and ask quote to mean-revert out of non-zero inventory. This might be the more relevant liquidity metric for liquidity demanders who trade large orders. This price elasticity might be what ILLIQ picks up in our analysis.

variance (*ERV* channel). In the latter case, only the uninformed experience the increased uncertainty (i.e., the liquidity suppliers). This feature is in line with Grossman and Stiglitz (1980) where the uninformed bear additional uncertainty (simply because they know less).

Formal analysis of the two types of shocks in the model yields patterns that are consistent with the empirical findings. The results for the *VRP* channel are unsurprising. Investors who suddenly become more risk averse re-allocate risk to those who do not, hence the active selling of equities and buying of government bonds. Equity prices drop since the average investor becomes more risk-averse. Liquidity is unaffected, as the variance risk premium shocks are isomorphic to the endowment risk shocks that trigger trade in the core Grossman and Stiglitz (1980) model. This type of shocks does not affect liquidity which perfectly competitive liquidity providers offer. Liquidity is costly in this model because of information asymmetry and the adverse-selection costs. Variance risk premium or endowment risk shocks, however, do not change the level of information asymmetry.

The findings for the risk (*ERV*) channel yield novel insights into the observed market dynamics. Active buying of the risky asset is an equilibrium result. The uninformed experience the additional risk for the simple reason that they are *uninformed*. They understand that there is news, and they realize that others have access to it. They therefore prefer to reduce their risky asset holdings. The informed observe the news and, therefore, bear less posterior risk. They sell on bad news, they buy on good news, but asymmetrically so, because, *on average*, they are buyers in equilibrium. The reason is that the risk shock increases the wedge between the risk that the informed experience relative to the risk that the uninformed experience.

Not only does the risk shock cause net buying of equities, it also makes the transfer costly because of increased information asymmetry. The uninformed liquidity suppliers experience higher adverse-selection costs and liquidity thus deteriorates. The *ERV* therefore generates, on average, net buying by liquidity demanders on impaired liquidity supply, in line with our empirical findings.

Our findings that the root cause of risk shocks matters for how the market responds, add to a rapidly growing asset-pricing literature on the role of volatility. Ait-Sahalia et al. (2021), for example, motivate their model by quoting a New York Fed President who, in 2017, wondered: "You would think if uncertainty was high, you'd have a bit more volatility." In their paper, they rationalize asset-price dynamics by introducing two disconnected stochastic processes: One that drives (realized) volatility and another that drives risk (aversion). Models in the same spirit are Liu et al. (2004), Drechsler (2013), and Brenner and Izhakian (2018). Similarly, in our analysis, the effects of heightened uncertainty as measured by *VIX* shocks, depend on the underlying channel: Elevated variance risk premium or elevated expected realized variance.

The manuscript is organized as follows. Section 2 provides a deeper understanding of these findings by exploring a Grossman-Stiglitz model. Section 3 concludes.

2 A model to disentangle the responses

Our empirical results provide evidence relating a *VIX* impulse to flight to safety and to market fragility, but these are due to separate channels. Increases in the variance risk premium *VRP* trigger active re-allocation from equities to government bonds, without market liquidity becoming impaired. An increase in *ERV*, does *not* trigger a flight-to-safety but does seem to impair market liquidity, at least contemporaneously. The surprising finding is that *active buying* of equities accompanies this market fragility.

Inspired by Grossman and Stiglitz (1980), Vayanos and Wang (2012) propose a simple, unified model to study how a variety of frictions affect asset returns and market liquidity. We extend their model along two dimensions: i) we include variance risk premium shocks by letting some agents experience an increase in their coefficient of absolute risk aversion ("*VRP* channel"), and ii) we model a market with elevated expected variance ("*ERV* channel"). We compare the extended set of equilibrium results to rationalize our findings on how variance risk premium shocks or expected realized variance shocks affect prices due to initiator net volume and liquidity in form of price impact. We present the baseline model of Vayanos and Wang (2012) succinctly before introducing the model extensions.

2.1 Baseline model

The baseline model of Vayanos and Wang (2012) features three periods indexed by $t \in \{0, 1, 2\}$. The market consists of a riskless and a risky asset. The riskless asset is in supply of B shares and pays one unit of consumption in period 2. The risky asset is in supply of $\bar{\theta}$ shares and pays $D \sim N(\bar{D}, \sigma^2)$ units of consumption in period 2. Using the riskless asset as numéraire, let S_t be the risky asset's price in period t. By definition, $S_2 = D$.

There is a measure one of risk-averse agents with exponential utility function, who derive utility from consumption C in period 2:

$$U(C) = -\exp\left(-\alpha C\right), \tag{1}$$

where $\alpha > 0$ is the coefficient of absolute risk aversion. Agents are identical in period 0 and endowed with identical supply of the two assets.

We generate trade as follows: Just before period 1, a fraction π of the agents learns that they will receive an endowment $z(D - \bar{D})$ of the consumption good in period 2, with $z \sim N(0, \sigma_z^2)$, where z is independent of D. Since this endowment shock is perfectly correlated with D, the endowment creates hedging demand for the shocked agents in period 1. For $z > 0$, for example, the agents can hedge this risk by selling the risky asset. These agents therefore initiate trades in period 1 and are considered liquidity demanders. The remaining agents accommodate these trades and are considered liquidity suppliers.

2.2 Model extensions: Implied variance shocks

To analyze market responses to a *VIX* shock, we extend the baseline model. First, we introduce an initial period 0^- in which all investors are identical. At period 0 it gets revealed if the market participants will be hit with an endowment shock only or with one of two additional shocks.

We model an *VRP* shock by letting the fraction π of agents that receive the endowment shock simultaneously experience an increase in their risk aversion to $\alpha' > \alpha$.

Even absent of an endowment, the sudden risk aversion shock triggers re-allocations, which are absorbed by liquidity providers. The increase of the risk aversion of the investors does not affect the expected realized variance (under $\mathbb{P}$) but shifts the probability mass under the risk-neutral measure such that, as a response, *VRP* increases.

The second potential shock resembles increased an *ERV* shock for the (identical) agents in period 0, where it is common knowledge that liquidity demanders learn additional information in period 1 when observing a private signal:

$$s = D + \varepsilon, \tag{2}$$

where ε is normal with mean zero and variance σ_ε^2, and ε is independent of D and z. Note that we do not land in a no-trade theorem, since these agents also trade due to an endowment shock (Milgrom and Stokey, 1982). To consider the case of a period 0 *risk increase* from the baseline model σ^2 to $\sigma^{2\prime\prime} > \sigma^2$, we set:

$$\sigma_\varepsilon^2 = \frac{\sigma^2 \sigma''^2}{\sigma''^2 - \sigma^2}, \tag{3}$$

Given the joint normality of (D, ε) the posterior risk for liquidity demanders after observing the signal s in period 1 becomes:

$$\sigma^2(D|s) = \frac{\sigma_\varepsilon^2}{\sigma''^2 + \sigma_\varepsilon^2}\sigma''^2 = \sigma^2, \tag{4}$$

which is the baseline risk. The liquidity demander who received the signal in period 1 therefore experiences the same risk as the baseline model. The increased risk is experienced by the uninformed liquidity suppliers in period 1, and, therefore, by all agents in period 0 before they learn their type (i.e., liquidity demander or supplier). The uninformed experience the additional risk for the simple reason that they are *uninformed*. They heard there is news. They understand others have access to the news. Ergo, in equilibrium, they prefer to reduce their risky asset holdings. The informed have observed the news and, therefore, bear less posterior risk. An alternative interpretation of the *ERV* shock is that the more precise the signal (lower signal variance σ_ε^2), the higher the relative information asymmetry between liquidity demanders and providers.

We introduce the additional period 0^- in order to track equilibrium price changes from 0^- to 0, that is when the type of the shock gets revealed. No trading occurs (because market participants are identical at that stage), thus only the valuation of the asset changes in response to the anticipated future market dynamics. It should be intuitively clear, that, after learning that the market will be hit by an *VRP* or *ERV* shock, the price of the asset will decrease as a direct reflection of the heightened implied volatility.

2.3 Equilibrium quantities and comparative statics

To investigate how equilibrium responses depend on *VRP* and *ERV* shocks, we focus on *initiator net volume,* which we define as the signed volume of liquidity demanders in period 1 and the *price impact* of the liquidity demanders' trades in period 1. We refer to price impact as λ, the coefficient of a regression of the price change between periods 0 and 1 on the signed volume of liquidity demanders in period 1. Intuitively, when λ is large, trades have large price impact, and we consider the market illiquid. Proposition 1 characterizes the relevant equilibrium quantities for the baseline model and the two distinct model extensions with *ERV* and *VRP* shocks, respectively.

Proposition 1. ***(Equilibrium quantities)****. The equilibrium quantities for the baseline model, the model with a* VRP *shock, and the model with an* ERV *shock are summarized below. The equilibrium quantities in the risk aversion-shock case are denoted by* VRP*, and the ones in the* *expected realized variance case are denoted by* ERV. *The initiator net volume results are:*

$$
\begin{aligned}
\nu &= -\pi\left(1-\pi\right)z, && (5)\\
\nu^{VRP} &= \nu - \pi\left(1-\frac{\bar{\alpha}}{\alpha'}\right)\left(\pi z+\bar{\theta}\right), && (6)\\
\nu^{ERV} &= \pi\frac{\left(1-b\right)\sigma''^{2}\bar{\theta}}{\sigma^{2}} + \pi\frac{\left(\beta_{s}-b\right)}{\alpha\sigma^{2}}\left(s-\bar{D}\right) - \pi\left(1-\frac{bc}{\alpha\sigma^{2}}\right)z && (7)
\end{aligned}
$$

where $\alpha' > \bar{\alpha} := \frac{1}{(1-\pi)\frac{1}{\alpha}+\pi\frac{1}{\alpha'}} > \alpha$ *and*

$$
\begin{aligned}
b &= \frac{\pi\sigma^{2}\left(D|S_{1}\right)\beta_{s} + \left(1-\pi\right)\sigma^{2}\beta_{\xi}}{\pi\sigma^{2}\left(D|S_{1}\right) + \left(1-\pi\right)\sigma^{2}} && (8)\\
c &= \alpha\sigma_{\varepsilon}^{2} && (9)\\
\beta_{s} &= 1-\frac{\sigma^{2}}{\sigma''^{2}}, && (10)\\
\beta_{\xi} &= \frac{\sigma''^{2}}{\sigma''^{2}+\sigma_{\varepsilon}^{2}+c^{2}\sigma_{z}^{2}}, && (11)\\
\sigma^{2}\left(D|S_{1}\right) &= \beta_{\xi}\left(\sigma_{\varepsilon}^{2}+c^{2}\sigma_{z}^{2}\right). && (12)
\end{aligned}
$$

The equilibrium price impacts are given by

$$
\begin{aligned}
\lambda &= \frac{\alpha\sigma^{2}}{1-\pi}, && (13)\\
\lambda^{VRP} &= \frac{\bar{\alpha}\sigma^{2}}{1-\pi+\pi\left(1-\frac{\bar{\alpha}}{\alpha'}\right)} && (14)\\
\lambda^{ERV} &= \frac{\alpha\sigma^{2}\left(D|S_{1}\right)}{\left(1-\pi\right)\left(1-\frac{\beta_{\xi}}{b}\right)}. && (15)
\end{aligned}
$$

Note that the expected interim liquidity shock equals to $z = E(z) = 0$ and, for the *ERV* model, the interim signal is $s = E(s) = \bar{D}$.

In expectation, trading decisions therefore do not reflect hedging needs due to endowment or information asymmetries, but only rely on either a change in the risk aversion for liquidity demanders or to an *ERV* shock for liquidity providers.

Corollary 1. ***(Initiator net volume)***. *The expected equilibrium quantities for initiator net volume, defined as the signed volume of liquidity demanders are such that*

$$
E\left(\nu^{VRP}\right) < E\left(\nu\right) = 0 < E\left(\nu^{ERV}\right) \qquad (16)
$$

Note first, that the expected initiator net volume for the baseline model is zero, $E(\nu) = 0$. Intuitively, this reflects that only the endowment of liquidity demanders, which is centered around zero, generates trading. In contrast, Corollary 1 shows that initiator net volume $E\left(\nu^{\text{VRP}}\right)$ is negative in response to a *VRP*: Upon realizing a shock in their preferences, liquidity demanders re-allocate their portfolio and dispose of the risky asset. The re-allocation results in initiated net selling of the risky asset and net buying of the numéraire (safe asset). In other words: After a *VRP* shock, liquidity demanders are net sellers of the risky asset (and they pay an additional liquidity premium to incentivize liquidity providers for holding more units of the risky asset).

For the *ERV* shock, receiving the signal triggers net initiated *buying* of the risky asset. Upon receiving the signal, liquidity demanders experience a reduction in future expected realized variance relative to liquidity providers. As a result, liquidity demanders re-allocate their portfolio by increasing their holdings of the risky asset. Liquidity providers learn that their uncertainty with respect to D did not get resolved and are willing to dispose of the asset.

Corollary 2. ***(Price impacts)****. The equilibrium quantities for price impact are such that*

$$0 < \lambda = \lambda^{VRP} < \lambda^{ERV} \tag{17}$$

Price impact is positive for each model, such that return responses reflect the direction of initiated net volume. Corollary 2 illustrates for the risk aversion shock, that, irrespective of the choice of α', the price impact λ^{VRP} remains the same as for the benchmark model, λ. Thus, risk aversion shocks do not imply that trades have larger price impact. For *ERV* shocks, on the other side, initiator net volume moves prices more relative to the benchmark case without any information asymmetries. Thus, although liquidity providers learn about the signal from observed order flow, their information is less precise as that of the liquidity demanders. Therefore, liquidity providers require a higher compensation relative to the benchmark model.

To conclude, the theoretical framework provides the following main insights, in line with our empirical findings:

1. Risk aversion shocks trigger net selling of the risky asset and simultaneously net buying of government bonds as a response to re-allocations triggered by the shift in preferences. Liquidity remains largely unaffected.

2. *ERV* shocks generate positive initiator net volume because they resemble a relative increase in risk for liquidity providers that did not receive a signal.

3. Price impact increases in response to *ERV* shocks.

3 Conclusion

I Proofs and Lemmas

I Model

Proof. (Proposition 1) For ease of exposition, we derive the equilibrium quantities provided in Proposition 1 individually within the Lemmas below: Lemma 1 summaries price impact and net initiator volume for the baseline model, Lemma 2 derives the equivalent quantities for the risk aversion shock model and Lemma 3 concludes with the equilibrium quantities from the risk model. □

Proof. (Corollary 1) Follows directly from Proposition 1, Equations (5) - (7). Setting $z = 0$ and $s = \bar{D}$ we get $\nu = 0$, $\nu' = -\pi\left(1 - \frac{\bar{\alpha}}{\alpha'}\right)\bar{\theta} < 0$ and $\nu'' = \pi\frac{(1-b)\sigma''^2\bar{\theta}}{\sigma^2}$. It holds that $(1-b) > 0$ because $0 < \beta_s < 1$ and $0 < \beta_\xi < 1$ by definition for σ''^2 such that $0 < b < 1$. □

Proof. (Corollary 2) Follows from Proposition 1, Equations (13) - (15). First, $\lambda > 0$ for $\pi < 1$ is trivial. Then, note that

$$\lambda'' = \frac{\bar{\alpha}\sigma^2}{1 - \pi + \pi\left(1 - \frac{\bar{\alpha}}{\alpha'}\right)} = \frac{\bar{\alpha}\sigma^2}{1 - \pi\frac{\bar{\alpha}}{\alpha'}} = \frac{\sigma^2}{\frac{1}{\bar{\alpha}} - \frac{\pi}{\alpha'}} = \frac{\alpha\sigma^2}{1-\pi} = \lambda \tag{A1}$$

where in the second-to-last term we made use of $\bar{\alpha} := \frac{1}{(1-\pi)\frac{1}{\alpha} + \pi\frac{1}{\alpha'}}$. The final statement, $\lambda < \lambda^{\text{ERV}}$, resembles the statement in Proposition 3.4 in Vayanos and Wang (2012). □

For ease of exposition, we start by presenting the equilibrium quantities of the baseline model as of see Section 2 of (Vayanos and Wang, 2012) (henceforth abbreviated to VW12). We always denote liquidity demanders with subscript d and liquidity suppliers with subscript s.

Lemma 1. *(Baseline model) Equilibrium quantities of the baseline model are*

$$\nu = -\pi(1-\pi)z$$
$$\lambda = \frac{\alpha\sigma^2}{1-\pi}.$$

Proof. (Lemma 1) VW12 provide all proofs. Specifically, the following quantities are of relevance:

Agents' demand functions for the risky asset in period 1 are $\theta_1^s = \frac{\bar{D}-S_1}{\alpha\sigma^2}$ and $\theta_1^d = \frac{\bar{D}-S_1}{\alpha\sigma^2} - z$ where market clearing implies that the period 1 equilibrium price is $S_1 = \bar{D} - \alpha\sigma^2\left(\bar{\theta} + \pi z\right)$.

Total initiator net volume as of VW12, Equation (2.15) is:

$$\nu = \pi\left(\frac{\bar{D} - S_1}{\alpha\sigma^2} - z - \bar{\theta}\right) = -\pi\left(1-\pi\right)z. \tag{A2}$$

The price in period 0 which includes the equilibrium discount for anticipated illiquidity is:

$$S_0 = S_0\left(\bar{\theta}, \alpha, \sigma^2, \pi, \bar{D}, \sigma_z^2\right) = \bar{D} - \alpha\sigma^2\bar{\theta} - \frac{\pi M}{1-\pi+\pi M}\Delta_1\bar{\theta}, \tag{A3}$$

where

$$M = \exp\left(\tfrac{1}{2}\alpha\Delta_2\bar{\theta}^2\right)\sqrt{\frac{1+\Delta_0\pi^2}{1+\Delta_0\left(1-\pi\right)^2 - \alpha^2\sigma^2\sigma_z^2}}, \tag{A4}$$

$$\Delta_0 = \alpha^2\sigma^2\sigma_z^2, \tag{A5}$$

$$\Delta_1 = \frac{\alpha\sigma^2\Delta_0\pi}{1+\Delta_0\left(1-\pi\right)^2 - \alpha^2\sigma^2\sigma_z^2}, \tag{A6}$$

$$\Delta_2 = \frac{\alpha\sigma^2\Delta_0}{1+\Delta_0\left(1-\pi\right)^2 - \alpha^2\sigma^2\sigma_z^2}. \tag{A7}$$

The price impact of the total initiator net volume is:

$$\lambda = \frac{\mathrm{Cov}\left(S_1 - S_0, \nu\right)}{\mathrm{Var}\left(\nu\right)} = \frac{\mathrm{Cov}\left(\alpha\sigma^2\pi z, \pi\left(1-\pi\right)z\right)}{\sigma_z^2\pi^2\left(1-\pi\right)^2} = \frac{\alpha\sigma^2}{1-\pi} \tag{A8}$$

□

Lemma 2. *(Risk aversion shock) Equilibrium quantities of the model with a risk aversion shock are*

$$\nu' = \nu - \pi\left(1 - \frac{\bar{\alpha}}{\alpha'}\right)\left(\pi z + \bar{\theta}\right),$$
$$\lambda' = \frac{\bar{\alpha}\sigma^2}{1-\pi+\pi\left(1-\frac{\bar{\alpha}}{\alpha'}\right)}$$

Proof. (Lemma 2) A risk aversion shock is added to the baseline model by letting the fraction π of agents experiences a change of risk aversion from α to α'. The optimal holding of these agents after experiencing the shock becomes (VW12, Equation 2.4b):

$$\theta_1^{d\prime} = \frac{\bar{D} - S_1'}{\alpha'\sigma^2} - z, \tag{A9}$$

where a prime is added to equilibrium quantities that change. The holdings for the liquidity providers remain like in the baseline model (WV12, Eq. 2.4a):

$$\theta_1^{s\prime} = \frac{\bar{D} - S_1'}{\alpha\sigma^2}. \tag{A10}$$

Market clearing requires that demand equals supply such that

$$\pi\theta_1^{d\prime} + (1-\pi)\,\theta_1^{s\prime} = \bar{\theta}. \tag{A11}$$

Plugging in delivers the period 1 price:

$$S_1' = \bar{D} - \bar{\alpha}\sigma^2\left(\bar{\theta} + \pi z\right), \tag{A12}$$

where

$$\bar{\alpha} = \frac{1}{(1-\pi)\,\frac{1}{\alpha} + \pi\frac{1}{\alpha'}}. \tag{A13}$$

Note that the inverse of the economy's risk aversion coefficient in period 1, $1/\bar{\alpha}$, is the weighted average of the inverted risk aversion coefficients of the two types of agents.

Total initiator net volume becomes

$$\begin{aligned}
\nu' &= \pi\left(\theta_1^{d\prime} - \bar{\theta}\right) = \pi\left(\frac{\bar{D} - S_1'}{\alpha'\sigma^2} - z - \bar{\theta}\right) \\
&= \pi\left(\frac{\bar{\alpha}}{\alpha'}\left(\bar{\theta} + \pi z\right) - z - \bar{\theta}\right) = \pi\left(\left(\frac{\bar{\alpha}}{\alpha'} - 1\right)\left(\bar{\theta} + \pi z\right)\right) - \pi z\,(1-\pi) \\
&= \nu - \pi\left(1 - \frac{\bar{\alpha}}{\alpha'}\right)\left(\pi z + \bar{\theta}\right).
\end{aligned} \tag{A14}$$

Notice how for a sudden risk aversion shock, $\alpha' > \alpha$, initiator net volume becomes negative even in the absence of an endowment shock, and it becomes more sensitive to endowment shocks. If one sets the interim liquidity shock to its expectation, $z = 0$, initiator net volume in the baseline model becomes zero but turns negative for $\alpha' > \alpha$. In other words: After a risk aversion shock, liquidity demanders are net sellers of the risky asset, and they pay an additional liquidity premium of size $(\alpha' - \bar{\alpha})\,\sigma^2\bar{\theta} > 0$ to incentivize liquidity providers for holding more units of the risky asset.

Expected utility liquidity supplier. To extract the period 0 price we follow the same steps as VW12 and update their equations as follows. First, note that $W_1 = W_0 + \theta_0 \left(S'_1 - S'_0\right) = W_0 + \theta_0 \left(\bar{D} - S'_0\right) - \bar{\alpha}\sigma^2\theta_0 \left(\bar{\theta} + \pi z\right)$. The expected utility of the liquidity supplier in period 1 becomes (VW12, Equation 2.8):

$$= -E\left(\exp\left(-\alpha\left[W_1 + \theta_1^{s\prime}\left(D - S'_1\right)\right]\right)\right) \tag{A15}$$

$$= -\exp\left(-\alpha\left[W_1 + \theta_1^{s\prime}\left(\bar{D} - S'_1\right) - \frac{1}{2}\alpha\sigma^2\left(\theta_1^{s\prime}\right)^2\right]\right) \tag{A16}$$

$$= -\exp\left(-\alpha\left[W_0 + \theta_0\left(\bar{D} - S'_0\right) - \bar{\alpha}\sigma^2\theta_0\left(\bar{\theta} + \pi z\right) + \tfrac{1}{2}\tfrac{\bar{\alpha}^2}{\alpha}\sigma^2\left(\bar{\theta} + \pi z\right)^2\right]\right). \tag{A17}$$

With the help of VW12 Lemma A.1, we compute the expected utility of a liquidity supplier *before* observing z (VW12, Equation A.2). The updated variables to be used when applying Lemma A.1 are (only changed variables are mentioned):

$$A' = W_0 + \theta_0\left(\bar{D} - S'_0\right) - \bar{\alpha}\sigma^2\theta_0\bar{\theta} + \tfrac{1}{2}\tfrac{\bar{\alpha}^2}{\alpha}\sigma^2\bar{\theta}^2, \tag{A18}$$

$$B' = \sigma^2\pi\left(\tfrac{\bar{\alpha}^2}{\alpha}\bar{\theta} - \bar{\alpha}\theta_0\right), \tag{A19}$$

$$C' = \tfrac{\bar{\alpha}^2}{\alpha}\sigma^2\pi^2. \tag{A20}$$

The expected utility of a liquidity supplier becomes:

$$U^{s\prime} = -\exp\left(-\alpha F^s\right)\frac{1}{\sqrt{1 + \bar{\alpha}^2\sigma^2\sigma_z^2\pi^2}}, \tag{A21}$$

where

$$F^{s\prime} = W_0 + \theta_0\left(\bar{D} - S'_0\right) - \bar{\alpha}\sigma^2\theta_0\bar{\theta} + \tfrac{1}{2}\tfrac{\bar{\alpha}^2}{\alpha}\sigma^2\bar{\theta}^2 - \alpha\frac{\sigma^4\sigma_z^2\pi^2\left(\tfrac{\bar{\alpha}^2}{\alpha}\bar{\theta} - \bar{\alpha}\theta_0\right)^2}{2\left(1 + \bar{\alpha}^2\sigma^2\sigma_z^2\pi^2\right)} \tag{A22}$$

Expected utility liquidity demander. Following the same steps, we work towards computing the expected utility of a liquidity demander prior to observing z (VW12, Equation A.4). Then, the expected utility of the liquidity demander in period 1 is:

$$-\exp\left(-\alpha\left[W'_1 + \theta_1^{d\prime}\left(\bar{D} - S'_1\right) - \tfrac{1}{2}\alpha'\sigma^2\left(\theta_1^{d\prime} + z\right)^2\right]\right), \tag{A23}$$

where the adjusted alpha α' is used to compute the expected utility of period 2 risk. Notice how any remaining uncertainty with respect to period 1 price (due to z) is being evaluated with the unadjusted risk aversion α because this uncertainty will be experienced from period 0 to period 1 where agents have not yet learned their type (demander or supplier) and risk aversion therefore is alpha for both.

Inserting the equilibrium expressions for $\theta_1^{d\prime}$ from (A9) and S_1' from (A12), yields:

$$-\exp\left(-\alpha\left[W_0+\theta_0\left(\bar{D}-S_0'\right)-\bar{\alpha}\sigma^2\left(\theta_0+z\right)\left(\bar{\theta}+\pi z\right)+\frac{1}{2}\frac{\bar{\alpha}^2}{\alpha'}\sigma^2\left(\bar{\theta}+\pi z\right)^2\right]\right), \tag{A24}$$

where z is the only addition to the expression for the liquidity supplier in Equation (A17). The expected utility *before* observing z becomes is computed from Lemma A.1 (VW12) with the following updated variables:

$$A' = W_0+\theta_0\left(\bar{D}-S_0'\right)-\bar{\alpha}\sigma^2\theta_0\bar{\theta}+\frac{1}{2}\frac{\bar{\alpha}^2}{\alpha}\sigma^2\bar{\theta}^2, \tag{A25}$$

$$B' = \sigma^2\pi\left(\frac{\bar{\alpha}^2}{\alpha'}\bar{\theta}-\bar{\alpha}\theta_0\right)-\bar{\alpha}\sigma^2\bar{\theta}, \tag{A26}$$

$$C' = \bar{\alpha}\sigma^2\left(\frac{\bar{\alpha}}{\alpha'}\pi^2-2\pi\right), \tag{A27}$$

where A', B', and C' are the same as the expressions for the liquidity supplier, except for the addition of the last term for B' and C' (which is the result of the additional z in Equation (A24)).

The expected utility of a liquidity demander becomes:

$$U^{d\prime} = -\exp\left(-\alpha F^{d\prime}\right)\frac{1}{\sqrt{1+\alpha\bar{\alpha}\sigma^2\sigma_z^2\left(\frac{\bar{\alpha}}{\alpha'}\pi^2-2\pi\right)}}, \tag{A28}$$

where

$$\begin{aligned} F^{d\prime} = {} & W_0+\theta_0\left(\bar{D}-S_0'\right)-\bar{\alpha}\sigma^2\theta_0\bar{\theta}+\frac{1}{2}\frac{\bar{\alpha}^2}{\alpha}\sigma^2\bar{\theta}^2 \\ & -\alpha\frac{\sigma_z^2\left(\sigma^2\pi\left(\frac{\bar{\alpha}^2}{\alpha'}\bar{\theta}-\bar{\alpha}\theta_0\right)-\bar{\alpha}\sigma^2\bar{\theta}\right)^2}{2\left(1+\alpha\bar{\alpha}\sigma^2\sigma_z^2\left(\frac{\bar{\alpha}}{\alpha'}\pi^2-2\pi\right)\right)}. \end{aligned} \tag{A29}$$

Equilibrium price at time 0. The period 0 agents chooses θ_0 to maximize:

$$U' = (1-\pi)\,U^{s\prime}+\pi U^{d\prime} \tag{A30}$$

The associated first-order condition is:

$$
\begin{aligned}
&(1-\pi)\exp\left(-\alpha F^{s\prime}\right)\left(-\alpha\frac{dF^{s\prime}}{d\theta_0}\right)\frac{1}{\sqrt{1+\bar{\alpha}^2\sigma^2\sigma_z^2\pi^2}}\\
&+\pi\exp\left(-\alpha F^{d}\right)\left(-\alpha\frac{dF^{d\prime}}{d\theta_0}\right)\frac{1}{\sqrt{1+\alpha\bar{\alpha}\sigma^2\sigma_z^2\left(\frac{\bar{\alpha}}{\alpha'}\pi^2-2\pi\right)}}=0
\end{aligned}
\tag{A31}
$$

Let us compute the various parts of this equation and evaluate them in equilibrium (i.e., at $\theta_0=\bar{\theta}$):

$$
\frac{dF^{s\prime}}{d\theta_0}=\bar{D}-S_0'-\bar{\alpha}\sigma^2\bar{\theta}+\frac{\bar{\alpha}^2\sigma^4\sigma_z^2\pi^2\left(\bar{\alpha}-\alpha\right)}{1+\bar{\alpha}^2\sigma^2\sigma_z^2\pi^2}\bar{\theta}
\tag{A32}
$$

$$
\begin{aligned}
F^{s\prime}=&\,W_0+\left(\bar{D}-S_0'\right)\bar{\theta}-\bar{\alpha}\sigma^2\bar{\theta}^2+\tfrac{1}{2}\tfrac{\bar{\alpha}^2}{\alpha}\sigma^2\bar{\theta}^2+\\
&-\alpha\frac{\sigma^4\sigma_z^2\pi^2\bar{\alpha}^2\left(\frac{\bar{\alpha}}{\alpha}-1\right)^2}{2\left(1+\bar{\alpha}^2\sigma^2\sigma_z^2\pi^2\right)}\bar{\theta}^2
\end{aligned}
\tag{A33}
$$

$$
\frac{dF^{d\prime}}{d\theta_0}=\bar{D}-S_0'-\bar{\alpha}\sigma^2\bar{\theta}+\alpha\frac{\bar{\alpha}\sigma^2\sigma_z^2\pi\left(\sigma^2\pi\left(\frac{\bar{\alpha}^2}{\alpha'}-\bar{\alpha}\right)-\bar{\alpha}\sigma^2\right)}{1+\alpha\bar{\alpha}\sigma^2\sigma_z^2\left(\frac{\bar{\alpha}}{\alpha'}\pi^2-2\pi\right)}\bar{\theta}
\tag{A34}
$$

$$
F^{d\prime}=W_0+\left(\bar{D}-S_0'\right)\bar{\theta}-\bar{\alpha}\sigma^2\bar{\theta}^2+\tfrac{1}{2}\tfrac{\bar{\alpha}^2}{\alpha}\sigma^2\bar{\theta}^2
\tag{A35}
$$

$$
-\alpha\frac{\sigma_z^2\left(\sigma^2\pi\left(\frac{\bar{\alpha}^2}{\alpha'}-\bar{\alpha}\right)-\bar{\alpha}\sigma^2\right)^2}{2\left(1+\alpha\bar{\alpha}\sigma^2\sigma_z^2\left(\frac{\bar{\alpha}}{\alpha'}\pi^2-2\pi\right)\right)}\bar{\theta}^2
\tag{A36}
$$

Let us simplify notation in the spirit of VW12:

$$
\frac{dF^{d\prime}}{d\theta_0}=\frac{dF^{s\prime}}{d\theta_0}-\Delta_1'\bar{\theta},
\tag{A37}
$$

$$
F^{d\prime}=F^{s\prime}-\tfrac{1}{2}\Delta_2'\bar{\theta}^2,
\tag{A38}
$$

where

$$
\Delta_1'=\frac{\bar{\alpha}^2\sigma^4\sigma_z^2\pi^2\left(\bar{\alpha}-\alpha\right)}{1+\bar{\alpha}^2\sigma^2\sigma_z^2\pi^2}-\alpha\frac{\bar{\alpha}\sigma^2\sigma_z^2\pi\left(\bar{\alpha}\sigma^2-\sigma^2\pi\left(\frac{\bar{\alpha}^2}{\alpha'}-\bar{\alpha}\right)\right)}{1+\alpha\bar{\alpha}\sigma^2\sigma_z^2\left(\frac{\bar{\alpha}}{\alpha'}\pi^2-2\pi\right)},
\tag{A39}
$$

$$
\Delta_2'=\alpha\frac{\sigma_z^2\left(\sigma^2\pi\left(\frac{\bar{\alpha}^2}{\alpha'}-\bar{\alpha}\right)-\bar{\alpha}\sigma^2\right)^2}{1+\alpha\bar{\alpha}\sigma^2\sigma_z^2\left(\frac{\bar{\alpha}}{\alpha'}\pi^2-2\pi\right)}-\alpha\frac{\sigma^4\sigma_z^2\pi^2\bar{\alpha}^2\left(\frac{\bar{\alpha}}{\alpha}-1\right)^2}{1+\bar{\alpha}^2\sigma^2\sigma_z^2\pi^2},
\tag{A40}
$$

so that, inserting (A37) and (A38) into (A31) yields (notice how, among others, the factor $\exp\left(-\alpha F^{s\prime}\right)$ drops out which avoids ending up with a non-linear equation in S_0):

$$\frac{dF^{s\prime}}{d\theta_0}\left(\frac{1-\pi}{\sqrt{1+\bar{\alpha}^2\sigma^2\sigma_z^2\pi^2}}+\frac{\pi\exp\left(\frac{1}{2}\alpha'\Delta_2'\bar{\theta}^2\right)}{\sqrt{1+\alpha\bar{\alpha}\sigma^2\sigma_z^2\left(\frac{\bar{\alpha}}{\alpha'}\pi^2-2\pi\right)}}\right)= \frac{\pi\exp\left(\frac{1}{2}\alpha\Delta_2'\bar{\theta}^2\right)}{\sqrt{1+\alpha\bar{\alpha}\sigma^2\sigma_z^2\left(\frac{\bar{\alpha}}{\alpha'}\pi^2-2\pi\right)}}\Delta_1'\bar{\theta}, \tag{A41}$$

which can be simplified to

$$\frac{dF^{s\prime}}{d\theta_0}\left(1-\pi+\pi M'\right)=\pi M'\Delta_1'\bar{\theta}, \tag{A42}$$

where

$$M' = \exp\left(\tfrac{1}{2}\alpha'\Delta_2'\bar{\theta}^2\right)\sqrt{\frac{1+\bar{\alpha}^2\sigma^2\sigma_z^2\pi^2}{1+\alpha\bar{\alpha}\sigma^2\sigma_z^2\left(\frac{\bar{\alpha}}{\alpha'}\pi^2-2\pi\right)}}. \tag{A43}$$

Inserting (A32) in (A42) yields:

$$\boxed{S_0'} = \bar{D}-\bar{\alpha}\sigma^2\bar{\theta}+\frac{\bar{\alpha}^2\sigma^4\sigma_z^2\pi^2\left(\bar{\alpha}-\alpha\right)}{1+\bar{\alpha}^2\sigma^2\sigma_z^2\pi^2}\bar{\theta}-\frac{\pi M'}{1-\pi+\pi M'}\Delta_1'\bar{\theta} \tag{A44}$$

$$= \bar{D}+\left(\alpha\sigma^2\bar{\theta}-\alpha\sigma^2\bar{\theta}\right)-\bar{\alpha}\sigma^2\bar{\theta}+\frac{\bar{\alpha}^2\sigma^2\sigma_z^2\pi^2}{1+\bar{\alpha}^2\sigma^2\sigma_z^2\pi^2}\left(\bar{\alpha}-\alpha\right)\sigma^2\bar{\theta}-\frac{\pi M'}{1-\pi+\pi M'}\Delta_1'\bar{\theta} \tag{A45}$$

$$= \bar{D}-\alpha\sigma^2\bar{\theta}-\left(\bar{\alpha}-\alpha\right)\sigma^2\bar{\theta}+\frac{\bar{\alpha}^2\sigma^2\sigma_z^2\pi^2}{1+\bar{\alpha}^2\sigma^2\sigma_z^2\pi^2}\left(\bar{\alpha}-\alpha\right)\sigma^2\bar{\theta}-\frac{\pi M'}{1-\pi+\pi M'}\Delta_1'\bar{\theta} \tag{A46}$$

$$= \bar{D}-\alpha\sigma^2\bar{\theta}+\left(\frac{\bar{\alpha}^2\sigma^2\sigma_z^2\pi^2}{1+\bar{\alpha}^2\sigma^2\sigma_z^2\pi^2}-1\right)\left(\bar{\alpha}-\alpha\right)\sigma^2\bar{\theta}-\frac{\pi M'}{1-\pi+\pi M'}\Delta_1'\bar{\theta} \tag{A47}$$

$$= \bar{D}-\alpha\sigma^2\bar{\theta}-\frac{\left(\bar{\alpha}-\alpha\right)\sigma^2\bar{\theta}}{1+\bar{\alpha}^2\sigma^2\sigma_z^2\pi^2}-\frac{\pi M'}{1-\pi+\pi M'}\Delta_1'\bar{\theta} \tag{A48}$$

Notice that this expression closely resembles VW12 Equation (2.10) with the exception that the third term is an additional one.

Price impact. With the expression for initiator net volume and equilibrium prices, we can now compute the price impact λ^{VRP} that liquidity demanders pay for their demand:

$$\lambda' = \frac{\operatorname{Cov}\left(S_1'-S_0', \nu'\right)}{\operatorname{Var}\left(\nu'\right)}. \tag{A49}$$

Inserting (A12), (A14), and (A44) into this expression we get:

$$\operatorname{Var}(\nu') = \operatorname{Var}\left(-z\pi\left(1-\pi\frac{\bar{\alpha}}{\alpha'}\right)\right) = \sigma_z^2\pi^2\left(1-\pi\frac{\bar{\alpha}}{\alpha'}\right)^2 \tag{A50}$$

$$\lambda' = \frac{\bar{\alpha}\sigma^2}{1-\pi\frac{\bar{\alpha}}{\alpha'}} = \frac{\sigma^2}{\frac{1}{\bar{\alpha}}-\frac{\pi}{\alpha'}} = \frac{\alpha\sigma^2}{1-\pi}. \tag{A51}$$

□

Lemma 3. *(Risk shock) Equilibrium quantities of the model with a risk shock are*

$$\begin{aligned}
\nu'' &= \pi\frac{(1-b)\,\sigma''^2\bar{\theta}}{\sigma^2} + \pi\frac{(\beta_s-b)}{\alpha\sigma^2}\left(s-\bar{D}\right) - \pi\left(1-\frac{bc}{\alpha\sigma^2}\right)z \\
\lambda'' &= \frac{\alpha\sigma^2\,(D|S_1)}{(1-\pi)\left(1-\frac{\beta_\xi}{b}\right)}
\end{aligned}$$

where $\alpha' > \bar{\alpha} := \frac{1}{(1-\pi)\frac{1}{\alpha}+\pi\frac{1}{\alpha'}} > \alpha$ *and*

$$\begin{aligned}
b &= \frac{\pi\sigma^2\,(D|S_1)\,\beta_s + (1-\pi)\,\sigma^2\beta_\xi}{\pi\sigma^2\,(D|S_1) + (1-\pi)\,\sigma^2} \\
c &= \alpha\sigma_\varepsilon^2 \\
\beta_s &= 1-\frac{\sigma^2}{\sigma''^2}, \\
\beta_\xi &= \frac{\sigma''^2}{\sigma''^2+\sigma_\varepsilon^2+c^2\sigma_z^2}, \\
\sigma^2\,(D|S_1) &= \beta_\xi\left(\sigma_\varepsilon^2+c^2\sigma_z^2\right).
\end{aligned}$$

Proof. (Lemma 3)

We model the case of increased risk as one where dividend risk is increased for the (identical) agents in period 0, and it is common knowledge that liquidity demanders learn the additional information in period 1 when observing a private signal:

$$s = D + \varepsilon, \tag{A52}$$

where ε is normal with mean zero and variance σ_ε^2, and is independent of D and z. Note that we do not land in a no-trade theorem, since these agents also trade due to an endowment shock (Milgrom and Stokey, 1982). The equilibrium quantities are presented in this subsection and denoted with a double prime. These quantities are developed in VW12 Sec. 3 where the baseline case corresponds to the no-information case discussed in VW12 Sec. 3.2). To consider the case of a period 0 risk *increase* from the baseline model σ^2 to $\sigma^{2\prime\prime} > \sigma^2$, we set:

$$\sigma_\varepsilon^2 = \frac{\sigma^2 \sigma''^2}{\sigma''^2 - \sigma^2}, \tag{A53}$$

so that the posterior risk for liquidity demanders after observing the signal s in period 1 becomes (VW12 Equation 3.2b):

$$\sigma^2 (D|s) = \frac{\sigma_\varepsilon^2}{\sigma''^2 + \sigma_\varepsilon^2} \sigma''^2 = \sigma^2, \tag{A54}$$

which is the baseline risk. The liquidity demander who received the signal in period 1 therefore experiences the same risk as the baseline model. The increased risk is experienced by the uninformed liquidity suppliers in period 1, and, therefore, by all agents in period 0 before they learn their type (i.e., liquidity demander or supplier).

With this reparametrization the equilibrium quantities are taken straight from VW12 Sec. 3 by, in their expressions, using:

$$\sigma^2 = \sigma''^2. \tag{A55}$$

The equilibrium price in period 1 is:

$$S_1 = a + b\left(s - \bar{D} - cz\right), \tag{A56}$$

with

$$a = \bar{D} - \alpha (1 - b) \sigma^2 \bar{\theta}, \tag{A57}$$

$$b = \frac{\pi \sigma^2 (D|S_1) \beta_s + (1 - \pi) \sigma^2 \beta_\xi}{\pi \sigma^2 (D|S_1) + (1 - \pi) \sigma^2}, \tag{A58}$$

$$c = \alpha \sigma_\varepsilon^2 \tag{A59}$$

$$\beta_s = \frac{\sigma''^2}{\sigma''^2 + \sigma_\varepsilon^2}, \tag{A60}$$

$$\beta_\xi = \frac{\sigma''^2}{\sigma''^2 + \sigma_\varepsilon^2 + c^2 \sigma_z^2}, \tag{A61}$$

$$\sigma^2 (D|S_1) = \beta_\xi \left(\sigma_\varepsilon^2 + c^2 \sigma_z^2\right). \tag{A62}$$

The initiator net volume due to liquidity demanders is:

$$
\begin{aligned}
\nu'' &= \pi\left(\theta_1^d - \bar{\theta}\right) = -(1-\pi)\left(\theta_1^s - \bar{\theta}\right) \\
&= -(1-\pi)\left(\frac{\bar{D} + \beta_\xi/b\left(S_1'' - a\right) - S_1''}{a\sigma^2(D|S_1)} - \bar{\theta}\right)
\end{aligned} \tag{A63}
$$

The period 0 price is

$$
\boxed{S_0''} = \bar{D} - \alpha\sigma''^2\bar{\theta} - \frac{\pi M''}{1-\pi+\pi M''}\Delta_1''\bar{\theta}, \tag{A64}
$$

where M is given by (A4) with the deltas replaced by:

$$
\Delta_0'' = \frac{\left(b-\beta_\xi\right)^2\left(\sigma''^2 + \sigma_\varepsilon^2 + c^2\sigma_z^2\right)}{\sigma^2\left(D|S_1\right)\pi^2}, \tag{A65}
$$

$$
\Delta_1'' = \frac{\alpha^3 b\sigma''^2\left(\sigma''^2 + \sigma_\varepsilon^2\right)\sigma_z^2}{1+\Delta_0''\left(1-\pi\right)^2 - \alpha^2\sigma''^2\sigma_z^2}, \tag{A66}
$$

$$
\Delta_2'' = \frac{\alpha^3\sigma''^4\sigma_z^2\left(1+\frac{(\beta_s-b)^2\left(\sigma''^2+\sigma_\varepsilon^2\right)}{\sigma^2}\right)}{1+\Delta_0''\left(1-\pi\right)^2 - \alpha^2\sigma''^2\sigma_z^2}. \tag{A67}
$$

The price impact is:

$$
\lambda'' = \frac{\alpha\sigma^2\left(D|S_1\right)}{(1-\pi)\left(1-\frac{\beta_\xi}{b}\right)}. \tag{A68}
$$

□

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