

## Financial Expertise as an Arms Race\*

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## **Financial Expertise as an Arms Race**

### **Abstract**

We propose a model in which firms involved in trading securities overinvest in financial expertise. Intermediaries or traders in the model meet and bargain over a financial asset. Investment in financial expertise improves the ability of the intermediary to value an asset at short notice when responding to an opportunity to supply liquidity. These investments are made before the parties know about their role in the bargaining game, as proposer or responder, buyer or seller. A prisoner's dilemma arises because investments in expertise improve bargaining outcomes given the other party's expertise. Financial expertise deters opportunistic behavior by counterparties, even when the information acquired through expertise is rarely used in equilibrium and has no social benefit. These investments lead to breakdowns in trade, or liquidity crises, in response to random but infrequent increases in asset volatility.

# 1 Introduction

The financial sector attracts extremely qualified workers. Philippon and Reshef (2010) document that the phenomenal growth in financial services in recent decades has been associated with increases in employees' academic education, task complexity, and compensation, relative to other sectors of the economy. In this paper, we develop a model in which the acquisition of expertise by financial firms, such as hiring Ph.D. graduates to design and value financial instruments of ever increasing complexity, becomes an "arms race." By this phrase we mean two things:

- Investment in financial expertise confers an advantage on any one player (firm) in competing for a fixed surplus, and this advantage is neutralized in equilibrium by similar investment by his opponents.
- Investment in financial expertise is dangerous, in that it creates a risk of destruction of the surplus itself when there is an exogenous shock.

Our model shows that financial firms involved in trading assets with uncertain value may find it optimal to acquire socially undesirable levels of expertise and this might interfere with the efficient functioning of financial markets. In the model, traders (or financial intermediaries generally) acquire expertise in processing information about an asset. The resulting efficiency in acquiring information gives them an advantage in subsequent bargaining with competitors. Firms invest in expertise to the point where any additional investment would lead to breakdowns in trade because of adverse selection problems. We show that they will invest to this level even when there is some probability of a jump in volatility, and that when such a jump occurs levels of expertise that are benign under normal circumstances impede trade and become destructive of value. Thus, our model contributes to a better understanding of why, in recent financial crises, liquidity broke down in those parts of the financial sector where intermediaries were operating with very high levels of financial expertise.

For example, before the recent crisis financial firms had invested vast resources transforming relatively straight-forward securities, such as residential mortgages and credit-card debt, into complex instruments through securitization. They had then created trillions of dollars worth of derivative contracts based on these asset-backed securities. To facilitate this, financial firms hired legions of

highly trained and highly compensated experts to design, value, and hedge the complex securities and derivatives. Unfortunately, when housing prices fell and default rates rose, the complexity of the financial instruments, and the opacity of the over-the-counter markets where they traded, made it extremely difficult to identify where in the system the riskiest or most impaired liabilities were located. Estimates for the fundamental value of these financial instruments became highly uncertain and volatile. Of course, uncertainty per se does not interfere with trade, as long as the uncertainty is symmetric. As our model illustrates, however, when firms acquire high levels of financial expertise increases in uncertainty can lead to increases in asymmetric information. The very expertise firms had developed may have worked against them in the crises. Their relative advantage in valuing securities may have increased the asymmetric information they faced in dealing with relatively uninformed parties, who were in a position to take the opposite side of their trades. Our model provides an explanation for why so many financial intermediaries were so suddenly unwilling to trade with each other, despite the apparent gains to trade. The model also explains why financial intermediaries, whose business it is to facilitate or intermediate trade, would voluntarily acquire expertise, knowing it has the potential to create adverse selection that can impede trade, and thus destroy their business.

In most models with adverse selection in finance, some party is exogenously asymmetrically informed. If they could (publicly) avoid becoming informed, they would do so. For example, in the classic setting described in Myers and Majluf (1984), an owner-manager-entrepreneur wishes to finance investment in a new project by selling securities to outsiders who know less about the intrinsic value of his existing assets than he does. The positive Net Present Value of this new investment is common knowledge. The entrepreneur is assumed to have acquired his information through his past history managing the firm. This informational advantage, however, is an impediment to the entrepreneur in dealing with the financial markets, as it costs him gains to trade associated with the NPV of the new investment. If he could manage the firm's assets effectively without acquiring this information, he would do so in order to minimize frictions associated with financing. Similarly, used-car dealers would not choose to employ expert mechanics if they could manage the car dealership without them and thus avoid the costs of the lemons problem in dealing

with customers.

Given the obvious value of precommitting *not* to acquire information, why do we see financial firms, whose major business is to intermediate and facilitate trading, investing vast resources in expertise that speeds and improves their ability to acquire and process information about the assets they trade? In our model, the acquisition of expertise becomes a prisoner's dilemma. Given the expertise of others, it confers upon any one party an advantage in bargaining that protects him from opportunism by his counterparties. In the simplest version of the model, traders invest resources in expertise in anticipation of future trading encounters with other traders. In each such encounter, an uninformed trader with private value for the asset offers to buy or sell with a take-it-or-leave-it offer. His counterparty then observes a signal of the asset's value before accepting or rejecting the offer. The precision or informativeness of this signal is greater for traders who have invested in more financial expertise. The party with the bargaining advantage of making the initial move offers a better price to a counterparty with more expertise, in order to preserve the gains to trade that are common knowledge. At this better price, efficient trade occurs, but the responding party claims some of the gains to trade. The threat created by the acquisition of information ensures he is offered a better price, but given that offer, his equilibrium actions do not depend on his information. Looking forward, firms invest in expertise in anticipation of this advantage, but offsetting investments by other firms neutralizes the advantage in equilibrium. Under normal circumstances these investments are wasteful, but they do not interfere with efficient trade. The problem occurs if uncertainty about asset values jumps, and firms cannot immediately adjust their levels of expertise. At that point the adverse selection becomes too severe for efficient trade to be sustained. The central tradeoffs from this simple model survive in the more complex signalling game that arises when both parties come to a trading encounter with private information.

In the main version of our model, financial expertise, and the information experts acquire, are assumed to have no social value. Further, firms do not use the information their expertise obtains for them in equilibrium. The threat to use it ensures they get a better price, which renders their information superfluous. We do not mean to imply that highly trained and compensated financial professionals literally "do nothing useful" for their pay. Rather, these arguments illustrate that

part of their value to their firms, and thus part of their compensation, is due to their ability to deter others from opportunistic behavior. From a social perspective, financial experts might be viewed as overqualified for the routine activities associated with their work. By analogy, the most highly paid divorce lawyers might well neutralize each other’s impact on the division of their clients’ assets. In equilibrium, the tasks they perform might be performed as competently by lawyers with less experience, expertise, and reputation who would charge less, but those lawyers would not serve to deter the other party’s more expensive and experienced counsel. Indeed, we show that allowing for other benefits derived from financial expertise actually increases the likelihood that trade will break down in equilibrium.

The model in our paper is naturally interpreted as trading in an over-the-counter market, since trade involves bilateral bargaining rather than intermediation through a specialist or an exchange. Most of the complex securities associated with high levels of financial expertise are traded over the counter—including mortgage- and asset-backed securities, collateralized debt obligations (CDOs), credit default swaps (CDSs), currencies, and fixed-income products such as treasury, sovereign, corporate, and municipal debt. Several models of over-the-counter trading have been proposed in the literature, such as Duffie, Garleanu and Pedersen (2005) and Duffie, Garleanu and Pedersen (2007). In these models search frictions and relative bargaining power are the sources of illiquidity. The search frictions are taken as exogenous. Investments in “expertise” that reduced search frictions would be welfare enhancing, and would lead to greater gains to trade. In contrast, adverse selection is the central friction in our model. Investments in expertise are socially wasteful and put gains to trade at risk.

Other models such as Carlin (2009) and Carlin and Manso (2010) view financial complexity as increasing costs to counterparties. In these two papers, however, the financial intermediary directly manipulates search costs to consumers, so these costs are most naturally interpreted as hidden fees for mutual funds, bank accounts, credit cards, and other consumer financial products. Our intent is to model an arms race among equals—intermediaries trading with each other in the financial markets. We interpret financial expertise as a relative advantage in verifying the value of a common-value financial asset in an environment where the complexity of the security, or the

opacity of the trading venue, makes this costly.

Economists since Hirshleifer (1971) have recognized that in a competitive equilibrium, private incentives may lead agents to overinvest in information gathering activities that have redistributive consequences but no social value. Our model captures, in addition, the potential these investments have to create adverse selection, and thus destroy value beyond the resources invested directly in acquiring information. In addition, agents in our model behave strategically, rather than competitively, so we can capture the prisoner’s dilemma they face, which drives them to invest in expertise in gathering information.

The general notion that economic actors may over-invest in professional services that help them compete in a zero-sum game goes back at least to Ashenfelter and Bloom (1993), which empirically studies labor arbitration hearings and argues that outcomes are unaffected by legal representation, as long as both parties have lawyers. A party that is not represented, when his or her opponent has a lawyer, suffers from a significant disadvantage. In this setting, however, the investment in legal services is not destructive of value beyond the fees paid to the lawyers. In our setting, expertise in finance has the potential to cause breakdowns in trade since it creates adverse selection.

Baumol (1990) and Murphy, Shleifer, and Vishny (1991) draw parallels between legal and financial services in arguing that countries with large service sectors devoted to such “rent-seeking” activities grow less quickly than economies where talented individuals are attracted to more entrepreneurial careers. They do not directly model the source of rent extraction, as we do.

Other papers such as Hauswald and Marquez (2006) and Fishman and Parker (2010) show that banks or investors can overinvest in acquiring information, as they do in our model. The banks in Hauswald and Marquez (2006) acquire information about the credit worthiness of borrowers because it softens price competition between the banks as they compete for market share. Investors in Fishman and Parker (2010) acquire information about the value of multiple projects before choosing which projects to finance. Information can be socially useful in both of these settings in efficiently allocating capital. We model the interaction between financial intermediaries in their role as traders, where more expertise facilitates the (inefficient) acquisition of information about the assets to be traded and consequently improves bargaining positions. In our paper, expertise

leads to periodic breakdowns in trade that can naturally be interpreted as periods of illiquidity.

The paper is organized as follows. In the next section we describe the model in its simplest form. An uninformed trader, who demands liquidity, makes a take-it-or-leave-it offer to another trader, who can then observe a signal of the asset's value. That signal is more informative or precise if the trader has made investments in expertise. Section 3 studies the equilibria of the trading subgame where financial firms, with given levels of expertise, meet and bargain over the price of an asset. In Section 4 we evaluate the decision to invest in financial expertise, and prove our main results. Section 5 uses a parametric example to illustrate some of the features of the model. Section 6 studies how allowing for revenues unrelated to OTC trading but increasing in expertise affects the model's implications. In Section 7 we study the signalling game that arises when both parties to any one trading encounter come with private information from a signal. We show that the central tradeoffs from the simpler model survive in pooling equilibria based on credible off-equilibrium beliefs, where play proceeds much as in the simpler case. Section 8 concludes.

## 2 Model

There is a continuum of risk-neutral and infinitely-lived financial intermediaries or traders. In each period  $t, t = 1, \dots, \infty$ , trader  $i$  meets a random counterparty drawn from the set of potential traders, and they have the opportunity to exchange a financial security through bargaining in an ultimatum game. When they meet, agent  $i$  is assigned the role of "liquidity supplier" or "liquidity demander" with equal probability, and his counterparty assumes the other role. The liquidity demander can either be a buyer or seller, again with equal probability, and the liquidity supplier assumes the other role. At  $t = 0$  trader  $i$  can invest resources, denoted  $e_i$ , in financial expertise. This serves to increase the precision of information about the values of the assets he will be bargaining over when he must respond to future offers to buy or sell in his role as a liquidity supplier. The asset traded in any given encounter has a common-value component,  $v$ . The party demanding liquidity also has a private value for the asset that generates gains to trade. If he is a buyer his valuation of the object is  $v + 2\Delta$ , and if he is a seller his valuation is  $v - 2\Delta$ . The gains to trade are common knowledge and constant through time. The liquidity supplier simply values the asset at its common

value,  $v$ . The difference in private value can be interpreted as the result of a hedging need or from an opportunity to sell to or buy from a client at a favorable price.

The common value  $v$  is independently distributed through time. It can be high,  $v = v_h$ , or low,  $v = v_l$ , with equal probability. The distance between the two possible values is a measure of the uncertainty about that asset's value, or its volatility. We assume the common values are drawn from two possible regimes, high-volatility and low-volatility. The high-volatility regime is defined by more uncertainty concerning the common value—a larger distance between the possible outcomes,  $(v_h - v_l)$ . In the low-volatility regime,  $v_h - v_l = \sigma > 0$ , while in the high-volatility regime  $v_h - v_l = \theta\sigma$ , with  $\theta > 1$ . The high-volatility regime occurs infrequently, with probability  $\pi$ , compared to the low-volatility regime. Traders know, when they engage in bargaining, whether they are in the high or the low-volatility regime. They do not, however, know whether the value of the asset is high or low. Our central result is that, for any magnitude of volatility jump, if the probability of such jump is small enough, then traders will acquire the same level of expertise as if volatility is always low. Thus, liquidity will break down when volatility jumps.

We assume the party with private value for the asset (the liquidity demander) initiates trade, and acts as the first mover in an ultimatum game. He makes a take-it-or-leave-it offer to his counterparty at a price of  $p$ . The liquidity supplier responds by gathering information about the common value, and either accepting or rejecting the offer. Specifically, he observes a signal,  $s = H$  or  $s = L$ , that the value is high or low. The probability that each signal received by trader  $i$  is correct is  $\mu_i = \frac{1}{2} + e_i$ , where  $e_i \in [0, \frac{1}{2}]$  denotes his expertise, resulting from investments he has made at the initial date  $t = 0$ . The cost of resources that must be invested initially to attain expertise of  $e_i$  is  $c(e_i)$ . We assume this cost is positive, twice continuously differentiable, convex, and monotonically increasing ( $c'(e) > 0, c''(e) > 0$ ). Expertise, which can be viewed as both human capital and the infrastructure to support it, allows a trader or an institution to more accurately value a security when responding to an offer under time pressure.<sup>1</sup> Agents who do not acquire

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<sup>1</sup>Expertise includes the infrastructure (e.g., computers, databases) that helps employees to generate more profits for their firms when responding to trade offers under time pressure. For example, in an article titled “Fast Traders Face Off with Big Investors over ‘Gambling’”, the Wall Street Journal reported on June 29, 2010: “The showdown has led to an escalating arms race, with players on both sides plowing money into ever-more-powerful technology to trade effectively.”

expertise receive uninformative signals, with  $\mu_i = \frac{1}{2}$ .

If the liquidity supplier accepts an offer of  $p$  and trade takes place, the proposer receives

$$v + 2\Delta - p \tag{1}$$

or

$$p - (v - 2\Delta) \tag{2}$$

depending on whether he is buying or selling, respectively. The liquidity supplier's payoff is  $v - p$  or  $p - v$ . If no trade occurs both parties receive zero.

Some aspects of the model warrant comment at this point. First, we do not, at this point, allow the party demanding liquidity to acquire a signal about the value of the asset before making his offer. This simplifies the analysis, but allows us to describe the central intuition. It avoids the complications that arise when the first mover in the game has private information. In that case, the price he offers conveys information about his signal, resulting in a signalling game. We show in Section 7 that the central tradeoffs we describe here can be reproduced in the pooling equilibria of the trading game that rely on credibly updated off-equilibrium beliefs, as defined in Grossman and Perry (1986). Thus, the intuition we explore in this simpler setting carries over to the more complex environment. Traders have incentives to invest in expertise to the point where further investment would destroy gains to trade due to adverse selection under normal conditions of low volatility. In the simpler model this boundary is due to the incentives the responder has to act on his information. In the general case, it might also be associated with decisions made by the proposer.

Second, the benefits of expertise are modelled here as higher precision to a signal that the liquidity provider always obtains. This avoids the complications associated with a decision to acquire information that depends on the offered price. Again, this allows us to describe in a simple setting tradeoffs that also arise in more complex ones. Other models for the benefits conferred by expertise in trading encounters will also support an arms race. For example, one could allow the responder to pay a cost to observe the common value, as in model of bargaining in Dang (2008),

where this cost is decreasing in expertise.<sup>2</sup> This requires an analysis of the decision to pay the cost in the trading subgame, resulting in more possible outcomes and cases to consider than in the model we employ. One could also assume expertise simply increases the probability a trader knows the common value. This results in more cases to analyze, especially when the first mover can be informed, because traders then have private information both about whether they are informed and about the asset's value. In all these settings, however, the proposer will offer the responder a higher price to keep him from acquiring or responding to information and preserve gains to trade. This advantage in bargaining then leads to wasteful investment in expertise that can cause trade to break down when volatility jumps.

Finally, we give the liquidity demander all the bargaining power associated with the opportunity to make an ultimatum offer. Expertise, as we will see, protects the responding party from the opportunism of the proposer. Under alternative protocols, where the surplus is divided in some other way, the incentives we describe to acquire expertise should survive as long as the responding party is subject to some disadvantage.

More generally, this trading game is a relatively simple mechanism, in which the consequences of adverse selection are stark and straightforward to characterize. We can then highlight the trade-off between bargaining power gained with expertise and the increased risk of illiquidity, which is our central focus. The effects adverse selection has on trading outcomes in this setting, however, are similar to those in more complex and general mechanisms. Trade “breaks down” when parties bargaining are asymmetrically informed about valuations, even if it is common knowledge that there are gains to trade. For example, Myerson and Satterthwaite (1983) demonstrate that no bilateral trading mechanism (without external subsidies) achieves efficient ex-post outcomes. Incentive-compatible individually-rational mechanisms involve mixed strategies that with non-zero probability lead to inefficient allocations. Samuelson (1984) shows that when only the responder is informed, exchange occurs if and only if the proposer can successfully make a take-it-or-leave-it offer, as we assume he can in our model. Admati and Perry (1987) show in pure-strategy bargaining games that asymmetric information results in costly delays in bargaining. Thus, illiquidity, or the

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<sup>2</sup>This is shown formally in earlier versions of this paper, available from the authors on request.

loss of gains to trade in some circumstances, is a general feature of bilateral exchange mechanisms with asymmetric information. It is in no way unique to our setting.

We assume that all random variables are drawn independently across time, and that the trading histories of firms are not observable, consistent with the opacity of OTC markets. Levels of expertise, which are the result of investments made at  $t = 0$ , are known to all counterparties. These assumptions ensure that agent  $i$  plays the same trading game in each period, conditional on the expertise of his counterparty.

Information about the common value has no social value in this model. It simply serves to increase one's share of a fixed pie, unless it destroys value by shutting down trade due to adverse selection. Thus, investments in expertise, since they only serve to alter the precision of information, are socially wasteful. For now, we are abstracting from any broader benefits to expertise and information acquisition, such as improved risk sharing or better coordination of real investment due to more informative prices. This highlights the incentives to engage in an arms race in expertise, despite the costs of adverse selection it engenders. In Section 6, we consider how allowing for other revenues, unrelated to OTC trading but increasing in expertise, affects the model's implications.

### 3 The Trading Subgame

In this section we take the volatility in asset value and the precision of traders' signals as given, and analyze the bargaining problem that results.

In each bargaining subgame, the gains to trade are  $2\Delta$ . Under symmetric information, where the signal,  $s$ , received by the liquidity supplier is public, the proposer would simply make a take-it-or-leave-it offer of  $p = E(v \mid s)$ . The liquidity supplier would accept, and earn his reservation expected payoff of zero, while the proposer would capture the full surplus. Since each party moves first half the time, the expected surplus to each is  $\Delta$ .

Suppose, instead, the signal is private, and agent  $i$  is in the position of supplying liquidity. His signal is accurate with probability  $\mu_i = \frac{1}{2} + e_i$ . The party proposing a price now faces adverse selection. He must take into account that his counterparty may sell only if his signal is high, or buy only if it is low. We explicitly analyze the case where the demander of liquidity wishes to buy.

Proposition 1 summarizes the results of these arguments, and provides formulas for all possible cases.

The first mover (buyer) will always prefer to pay a lower price, given the liquidity supplier's (seller's) response. That response depends on his signal. For sufficiently high prices, where

$$p \geq E(v \mid s_i = H), \quad (3)$$

he will sell even if his signal tells him the asset is worth  $v_h$ . If the price is lower than  $E(v \mid s_i = H)$  he will reject the offer unless his signal is low, and so trade will only occur half the time at such a price. Let the lowest price at which agent  $i$  would accept with a low signal be denoted

$$\begin{aligned} p^* &= E(v \mid s_i = L) \\ &= (1 - \mu_i)v_h + \mu_i v_l, \end{aligned} \quad (4)$$

and the lowest price at which he will always accept be

$$\begin{aligned} p^{**} &= E(v \mid s_i = H) \\ &= \mu_i v_h + (1 - \mu_i)v_l. \end{aligned} \quad (5)$$

If the proposer offers the higher price,  $p^{**}$ , trade always occurs, but he shares some of the surplus with the seller because he is overpaying when the seller receives a low signal. The buyer's expected surplus is

$$\begin{aligned} E(v) + 2\Delta - p^{**} &= 2\Delta - (v_h - v_l) \left( \mu_i - \frac{1}{2} \right) \\ &= 2\Delta - (v_h - v_l)e_i. \end{aligned} \quad (6)$$

The seller's expected surplus at this price (unconditionally, across both possible realizations of his

signal) is

$$\begin{aligned}
E[p^{**} - E(v | s_i)] &= p^{**} - E(v) \\
&= (v_h - v_l)(\mu_i - \frac{1}{2}) \\
&= (v_h - v_l)e_i.
\end{aligned} \tag{7}$$

If the buyer offers  $p^*$ , which will only be accepted when the seller has received a low signal, his expected payoff is

$$\frac{1}{2}(2\Delta + E(v | s_i = L) - p^*) = \Delta, \tag{8}$$

and the expected surplus for the seller is his reservation price of zero.

The buyer's offer in the trading subgame will be the price that yields the higher expected payoff to him. Comparing (8) and (6), he will offer the higher price  $p^{**}$  if

$$2\Delta - (v_h - v_l)e_i \geq \Delta \tag{9}$$

or if

$$e_i \leq \frac{\Delta}{v_h - v_l}. \tag{10}$$

The tradeoffs from the proposer's perspective in this model are simple. If he pays a higher price, he preserves gains to trade but he must share some of those gains with the liquidity provider. As is evident in equations (6) and (7) the "bribe" the buyer must pay to keep the seller from responding to his information is increasing in the accuracy of that information—in his financial expertise. This drives the arms race in our model. If the liquidity provider's level of expertise is too high, however, condition (10) tells us that the buyer will switch to a lower price at which the seller earns no surplus and trade breaks down half the time due to adverse selection. This limits the arms race. The bound on expertise tightens if volatility rises relative to the gains to trade. Therefore, investments in expertise that still allow for efficient trade under normal circumstances might inhibit trade and destroy value when volatility is abnormally high.

Note that the higher the seller's expertise, the higher the price required to keep him from using

his information in responding to an offer, but given that he gets such an offer, the information in his signal is superfluous. In this sense, his expertise is not actually used in equilibrium aside from its role as a deterrent.

The proposition below summarizes the equilibrium for the subgame:

**Proposition 1** *In the trading subgame with an uninformed proposer, if the responder's level of expertise satisfies  $e_i \leq \frac{\Delta}{v_h - v_l}$ :*

- the proposer's expected payoff is

$$2\Delta - (v_h - v_l)e_i \tag{11}$$

- the responder's expected payoff is

$$(v_h - v_l)e_i \tag{12}$$

- the equilibrium price is  $E(v \mid s_i = H)$  if the proposer is buying and  $E(v \mid s_i = L)$  if the proposer is selling.

If instead  $e_i > \frac{\Delta}{v_h - v_l}$ :

- the proposer's expected payoff is  $\Delta$

- the responder's expected payoff is zero

- the equilibrium price is  $E(v \mid s_i = L)$  if the proposer is buying and  $E(v \mid s_i = H)$  if the proposer is selling.

**Proof:** The arguments in the text above prove the result for the case when the proposer is the buyer. The appendix provides analogous derivations when the proposer is the seller.

## 4 Investing in Expertise

It is evident from the previous section that if all traders invest in expertise below the bound  $\bar{e} \equiv \frac{\Delta}{v_h - v_l}$  then trade is efficient: it takes place with probability one. In this section we consider the equilibrium choices of expertise, and show that for reasonable cost functions for investment in expertise the equilibrium involves all traders investing to this boundary for the low-volatility regime. An arms race occurs. As a result, when volatility rises unexpectedly, liquidity breaks down.

We assume the common values are drawn from two possible regimes, high-volatility and low-volatility. In the normal, or low-volatility regime,  $v_h - v_l = \sigma$ . This regime occurs with probability  $1 - \pi$ . The high-volatility regime occurs infrequently, with probability  $\pi$ . The two possible values are then further apart:  $v_h - v_l = \theta\sigma$ , where  $\theta > 1$ . Traders know, when they engage in bargaining, whether they are in the high or the low-volatility regime.

To understand the incentives at work, consider agent's  $i$ 's best response assuming  $\pi = 0$ —that is, if there is just one volatility regime and  $v_h - v_l = \sigma$ . Suppose his counterparty is agent  $j$ , and  $e_j \leq \bar{e} = \frac{\Delta}{\sigma}$ . Then the analysis in the previous section tells us that agent  $i$ 's expected payoff in any subgame where he is the proposer is

$$2\Delta - \sigma e_j \tag{13}$$

and his payoff when he supplies liquidity is

$$\sigma e_i. \tag{14}$$

as long as  $e_i \leq \bar{e}$ . Each of these outcomes occur with probability one-half, so his ex ante expected payoff in such a subgame at the time when he invests in expertise, is, for  $e_i \leq \bar{e}$ ,

$$\Delta + \frac{1}{2}\sigma(e_i - e_j). \tag{15}$$

An agent's expected payoff in each period is increasing in the difference between his own expertise and that of his counterparty. In a Nash equilibrium, trader  $i$  takes the investment his counterparties make in expertise as given. His payoff increases linearly in his own expertise up to the boundary  $\bar{e}$ , where it drops discontinuously, and so if the marginal cost of investment in expertise does not rise too quickly, he will invest to that point. But then so will agent  $j$ , so that the advantage offered by expertise is neutralized in equilibrium. Whatever bargaining advantage the trader gains as a proposer through expertise, he loses as a responder to the expertise of others. Trade is efficient, and the expected surplus earned by any trader ex-ante is  $\Delta$ , half the total gains to trade. With one volatility regime, the only destruction due to expertise is the wasted resources of  $c(\bar{e})$  for each

trader.

The conditions on the cost function that ensure a symmetric equilibrium at the upper boundary with  $\pi = 0$  are straightforward. The expected payoff for agent  $i$  in any given trading encounter, assuming his counterparty is agent  $j$ , is:

$$\frac{1}{2}e_i\sigma\chi\left(e_i \leq \frac{\Delta}{\sigma}\right) + \frac{1}{2}\left[\Delta + (\Delta - e_j\sigma)\chi\left(e_j \leq \frac{\Delta}{\sigma}\right)\right], \quad (16)$$

where  $\chi(\cdot)$  is an indicator function. The first term represents the expected payoff for agent  $i$  when he is a responder, which occurs with probability  $\frac{1}{2}$ , and the second term represents his expected payoff when he is a proposer. As is obvious from the equation, his choice of  $e_i$  will be independent of his counterparties' choices of expertise,  $e_j, j \neq i$ . Hence, agent  $i$ 's optimal investment in expertise will maximize:

$$\frac{1}{2(1-\delta)}e_i\sigma\chi\left(e_i \leq \frac{\Delta}{\sigma}\right) - c(e_i). \quad (17)$$

This expression is the discounted sum of the portion of his periodic payoffs that depends on his own expertise less the initial cost of building expertise.

Assuming, as we do, that all agents face the same cost function  $c(\cdot)$ , all agents acquire  $\bar{e}$  of expertise if  $c'(\bar{e}) \leq \frac{1}{2(1-\delta)}\sigma$ . Otherwise all agents acquire  $\hat{e}$ , the level of expertise that satisfies:

$$c'(\hat{e}) = \frac{1}{2(1-\delta)}\sigma, \quad (18)$$

which is the first-order condition of equation (17). Furthermore, the strict convexity of the cost function ensures that no other expertise level can provide agent  $i$  with the same payoff as  $\bar{e}$  or  $\hat{e}$ , hence no mixed strategy equilibria will exist either. Therefore, the equilibrium above is unique.

Now, consider the same steps when volatility is stochastic. The expected periodic payoff for agent  $i$  is then given by:

$$\begin{aligned} & \frac{1}{2}\left[(1-\pi)e_i\sigma\chi\left(e_i \leq \frac{\Delta}{\sigma}\right) + \pi e_i\theta\sigma\chi\left(e_i \leq \frac{\Delta}{\theta\sigma}\right)\right] \\ & + \frac{1}{2}\left[\Delta + (1-\pi)(\Delta - e_j\sigma)\chi\left(e_j \leq \frac{\Delta}{\sigma}\right) + \pi(\Delta - e_j\theta\sigma)\chi\left(e_j \leq \frac{\Delta}{\theta\sigma}\right)\right]. \end{aligned} \quad (19)$$

As before, the first term represents the expected payoff for agent  $i$  when he is a responder and the second term in brackets represents his expected payoff when he is a proposer. The independence of optimal strategies is again obvious from this expression. The effects of changes in  $e_i$  do not depend on  $e_j$ . Trader  $i$ 's choice of  $e_i$  will be independent from his opponent's expertise level  $e_j$ . Hence, agent  $i$ 's optimal investment in expertise will maximize

$$\frac{1}{2(1-\delta)} \left[ (1-\pi)e_i\sigma\chi\left(e_i \leq \frac{\Delta}{\sigma}\right) + \pi e_i\theta\sigma\chi\left(e_i \leq \frac{\Delta}{\theta\sigma}\right) \right] - c(e_i). \quad (20)$$

When volatility is stochastic, there are four candidates for the equilibrium level of expertise:

1. the highest level of expertise that allows efficient trade in the low-volatility regime:  $\bar{e} \equiv \frac{\Delta}{\sigma}$ ,
2. the highest level of expertise that allows efficient trade in the high-volatility regime:  $\bar{e} \equiv \frac{\Delta}{\theta\sigma}$ ,
3. the level of expertise that satisfies the first-order condition in the low-volatility regime:  $\hat{e}_l$  such that,

$$\frac{1}{2(1-\delta)}(1-\pi)\sigma = c'(\hat{e}_l), \quad (21)$$

4. the level of expertise level that satisfies the first-order condition in the high-volatility regime:  $\hat{e}_h$  such that,

$$\frac{1}{2(1-\delta)} [(1-\pi)\sigma + \pi\theta\sigma] = c'(\hat{e}_h). \quad (22)$$

The next proposition shows that if expertise is relatively inexpensive (low marginal cost) in comparison to its discounted expected benefits in the low-volatility regime and  $\bar{e}$  is the equilibrium with  $\pi = 0$ , then the continuity of an agent's payoff function in  $\pi$  ensures that all agents acquiring  $\bar{e}$  in expertise remains the unique equilibrium whenever the high-volatility regime is sufficiently unlikely.

**Proposition 2** *Suppose that*

$$c'\left(\frac{\Delta}{\sigma}\right) < \frac{\sigma}{2(1-\delta)}, \quad (23)$$

so that  $\bar{e} = \frac{\Delta}{\sigma}$  is the unique equilibrium with a single, low-volatility regime (i.e., when  $\pi = 0$ ). Then, for any  $\theta > 1$ , there exists a  $\pi^\theta > 0$  such that, for any  $\pi < \pi^\theta$ ,  $\bar{e}$  remains the unique equilibrium in the choice of expertise.

The upper bound on  $\pi$  is then given by:

$$\pi^\theta = \min \left\{ 1 - \frac{2(1-\delta)}{\sigma} c' \left( \frac{\Delta}{\sigma} \right), \frac{(1 - \frac{1}{\theta}) \Delta - 2(1-\delta) [c(\frac{\Delta}{\sigma}) - c(\frac{\Delta}{\theta\sigma})]}{(2 - \frac{1}{\theta}) \Delta} \right\}. \quad (24)$$

**Proof:** Provided in the appendix.

The intuition behind the proof is that if  $\pi$  is less than the first term under the  $\min\{\cdot, \cdot\}$  operator in (24), then the marginal gains from expertise in the low-volatility regime (which now has a lower probability than one) still exceed the marginal cost of expertise. The convexity of the cost function then allows us to rule out the two candidate equilibrium levels of expertise associated with the first-order conditions holding with equality, and limit the comparison to  $\bar{e}$  and  $\bar{\bar{e}}$ . The second term under the  $\min\{\cdot, \cdot\}$  operator requires that the probability of the high-volatility regime is sufficiently low to ensure that the extra cost of investing the higher level of expertise,  $c(\bar{e}) - c(\bar{\bar{e}})$ , combined with the expected loss in gains to trade when volatility is high, do not offset the extra benefits associated with gaining a better price when responding to offers when volatility is low.

Hence, our model predicts that financial intermediaries might find optimal to acquire expertise even though it makes trade fragile in periods of high uncertainty. Acquiring expertise improves an intermediary's ability to assess an asset's value, and therefore it amplifies the possibility of an adverse selection problem. The threat of facing a better informed counterparty might force an intermediary to make him a better offer to ensure that trade takes place. But as volatility goes up, the value of information also goes up and the proposer becomes unable to make an offer that would be simultaneously viable for him and always accepted by the responder. In the high-volatility regime trade breaks down whenever the responder observes a high signal, which occurs half of the time. However, if the probability of the high-volatility regime is small enough, the gains to trade lost in the high-volatility regime are not as important as the increase in profits that added expertise, and the ensuing improved bargaining position, bring in the low-volatility regime. The intermediary finds it optimal to acquire the level of expertise that maximizes his expected profits in the more probable low-volatility regime, even though it leads to trade breakdowns and therefore lower profits

in the infrequent high-volatility regime. Each financial firm acts in its own best interests but, in equilibrium, trade breaks down with an unconditional probability of  $\frac{\pi}{2}$  and  $\pi\Delta$  of the expected gains to trade are destroyed.

## 5 Parameterization

In this section we parameterize our model, in order to better illustrate the model's implications. We assume the cost  $c(e)$  of acquiring a level of expertise  $e$  is given by  $c(e) = \frac{\kappa}{2}e^2$ . In this case, the threshold  $\pi^\theta$  becomes:

$$\pi^\theta = \min \left\{ 1 - 2(1 - \delta) \frac{\kappa\Delta}{\sigma^2}, \frac{(1 - \frac{1}{\theta}) - (1 - \delta) (1 - \frac{1}{\theta^2}) \kappa \frac{\Delta}{\sigma^2}}{(2 - \frac{1}{\theta})} \right\}. \quad (25)$$

Note that both arguments in the  $\min\{\cdot, \cdot\}$  operator are decreasing in  $\frac{\kappa\Delta}{\sigma^2}$ . If, instead, we take  $\pi$  as given, we can rewrite the two conditions ensuring that  $\bar{e}$  is the unique equilibrium in expertise as:

$$\frac{\kappa\Delta}{\sigma^2} < \min \left\{ \frac{1 - \pi}{2(1 - \delta)}, \frac{1 - 2\pi - \frac{(1-\pi)}{\theta}}{(1 - \delta) (1 - \frac{1}{\theta^2})} \right\}. \quad (26)$$

Thus, the arms race equilibrium, which of course puts gains to trade at risk, is more likely to occur when these gains to trade,  $\Delta$ , are low relative to the routine volatility,  $\sigma$ . Increasing the cost of acquiring expertise,  $\kappa$ , also works against the arms race equilibrium for obvious reasons.

Figure 1 plots the maximum probability for the high-volatility regime,  $\pi^\theta$ , that supports the arms-race equilibrium with trade breakdowns as a function of the magnitude of the jump,  $\theta$ . The parameter values used in this figure are  $\sigma = 1$  (base volatility is a free normalization),  $\Delta = 0.2$  (gains to trade),  $\delta = 0.9$  (discount factor), and  $\kappa = 10$  (marginal cost of acquiring expertise). The lesson to be drawn from this figure is that the probability of a jump to the high volatility regime, with a loss of half the gains to trade, can be quite substantial. It ranges from around 5% when the jump in volatility is 10%, to around 15% when that jump is 50%. The relationship between  $\pi^\theta$  and  $\theta$  is increasing in this figure because a higher  $\theta$  increases the differential in payoffs between  $\bar{e}$  and  $\bar{e}$ , in the low volatility regime, at a higher rate than the differential in costs of expertise. Essentially,

when  $\theta$  increases and the volatility levels in the two regimes get farther from each other, the loss in profits in the low-volatility regime that goes with lowering expertise to preserve efficient trade in the high-volatility regime increases. Saving the gains to trade in the high-volatility regime becomes costlier in terms of bargaining position in the low-volatility regime.

Figure 2 shows the relationship between the equilibrium level of expertise and the gains to trade when we set  $\theta = 1.2$ , and  $\pi = 0.05$  and  $\Delta$  is allowed to vary. When  $\Delta$  is small enough for the inequality in (26) to hold ( $\Delta < 3.55$ ), the equilibrium level of expertise is equal to  $\bar{e}$ , which is increasing in  $\Delta$ . Once  $\Delta$  becomes large enough, however, and (26) is violated ( $\Delta \geq 3.55$ ), expertise drops discretely from  $\bar{e} = \frac{\Delta}{\sigma}$  to  $\bar{e} = \frac{\Delta}{\theta\sigma}$ , which is also increasing in  $\Delta$  but at a lower rate.

Intuitively, when gains to trade are small enough relative to the volatility in asset value, intermediaries are willing to acquire high levels of expertise even though this expertise leads to some trade breakdowns when volatility is high. On the other hand, when gains to trade get larger, the potential losses due to trade breakdowns become too important and intermediaries prefer to dial down on expertise to ensure that trade takes place even when volatility is high.

## 6 Other Benefits from Financial Expertise

The simple model we analyzed so far focuses on the role of expertise in valuing and trading securities in an over-the-counter setting. Abstracting away all other benefits from financial expertise yields stark and intuitive results about the incentives of financial firms to acquire expertise before trading with other firms. Of course, in reality financial expertise has other benefits, and produces revenues, that are unrelated to trading, but that affect firms' decisions to acquire expertise.

So here we assume that, in addition to earning revenues from the trading game we model, a firm with expertise  $e$  earns in each period a revenue  $r(e)$  unrelated to trading activities. This revenue is assumed to be positive, increasing and weakly concave in expertise and represents, for example, compensation for investment banking activities or for improving a client's risk-management processes. The expected periodic payoff for firm  $i$  is the payoff we had in equation (19) for the simple model plus  $r(e_i)$ .

Adding other revenues to the benefits of expertise makes the acquisition of expertise more

attractive for the financial firms in our model. Since it is unrelated to trading payoffs, adding  $r(e)$ , where  $r'(e) > 0$ , is equivalent to reducing the cost of expertise  $c(e)$  by  $\frac{1}{1-\delta}r(e)$ . Therefore, the earlier conditions required for expertise  $\bar{e}$  to be optimal are easier to satisfy when  $r(e)$  enters the payoff function.

The novelty from adding  $r(e)$  is that, in some circumstances, firms will not stop at  $\bar{e}$  when acquiring expertise. If  $r(e)$  increases sufficiently quickly in the region where  $e > \bar{e}$ , the unique equilibrium will then be an arms race in expertise where all firms acquire a level of expertise  $\tilde{e}$  ( $> \bar{e}$ ) that satisfies:

$$\frac{1}{1-\delta}r'(\tilde{e}) = c'(\tilde{e}). \quad (27)$$

In such settings, the marginal benefits of expertise are so high that firms continue to acquire expertise well past the previous equilibrium level  $\bar{e}$  even though it implies that trade breaks down half of the time in the low-volatility regime as well as in the high-volatility regime. The extra revenues  $\frac{1}{1-\delta}[r(\tilde{e}) - r(\bar{e})]$  from the higher expertise are larger than the expected loss in gains to trade in the low-volatility regime  $\frac{1}{1-\delta}\pi\Delta$  plus the cost savings  $[c(\bar{e}) - c(\tilde{e})]$ . Hence, firms maximize their total payoff, net of the cost of expertise, by picking the same level of expertise they would pick if expertise did not affect what happens in the trading game.

To summarize, accounting for other revenues generated by financial expertise strengthens the incentives of financial firms to acquire expertise and breakdowns in trade are then as frequent, if not more, than in our earlier model without such revenues. Hence, for simplicity, we continue to abstract away from these revenues in the remaining of the paper.

## 7 The Signalling Game with Two-Sided Asymmetric Information

In the previous sections we treated financial expertise as a capacity to accurately assess the value of an asset under time pressure in response to an offer to trade. We assumed that the intermediaries or traders use this expertise in their role as liquidity suppliers. The party making the offer to trade was the source of private benefits, but did not receive an informative signal. This simplified the analysis, since the first mover's offer did not convey private information, while still allowing us to

illustrate the incentives that create an arms race. Intermediaries have private incentives to invest in expertise as a deterrent in bargaining, even though it risks the social surplus generated by trade.

Our goal in this section is to show that these tradeoffs survive in the signalling game that arises when expertise informs the actions of both the proposer and responder in any given trading encounter. When the proposing party is informed, his offer influences the beliefs of the responder, and thus his willingness to accept. As is typically the case in such settings, there are many equilibria. Our approach is to show, first, that only pooling equilibria, where proposers with high signals offer the same price as proposers with with low signals, support efficient trade. Second, we show that in the trading subgame a pooling equilibrium exists in which the first mover offers the same price as he would if he were uninformed, and play proceeds as in the previous sections. The conditions under which any pooling equilibrium exists restrict the level of expertise of the traders in terms of the volatility and the ex-ante expected payoffs in the pooling equilibrium to the traders are the same as in the subgame with an uninformed first mover. They are linear and increasing in their own expertise. Finally, we show that if play in the trading subgames proceeds in a manner in which beliefs are “credibly updated,” as defined by Grossman and Perry (1986), and in which gains to trade are preserved through efficient trade whenever possible, traders will increase their expertise in anticipation of this and volatility jumps will lead to breakdowns in trade, as in earlier sections.

## 7.1 The Trading Subgame

Again, we develop in detail the case where the first mover wishes to buy, and the responding, liquidity supplier takes the role of a potential seller. As should be clear from previous sections, this is without loss of generality.

Let  $s_b \in \{H, L\}$  denote the buyer’s signal and  $s_s \in \{H, L\}$  that of the seller. We take as given  $\mu_s = \frac{1}{2} + e_s$  and  $\mu_b = \frac{1}{2} + e_b$  the probabilities, which increase with expertise, that the signals are correct. We must now also consider the following quantities for the low-signal buyer,

$$\begin{aligned} \psi_L^L &\equiv \Pr\{s_s = L \mid s_b = L\} \\ &= \mu_b \mu_s + (1 - \mu_b)(1 - \mu_s) \end{aligned} \tag{28}$$

$$\begin{aligned}
\phi_{LL}^l &\equiv \Pr\{v = v_l \mid s_b = L, s_s = L\} \\
&= \frac{\mu_b \mu_s}{\mu_b \mu_s + (1 - \mu_b)(1 - \mu_s)},
\end{aligned} \tag{29}$$

and for the high-signal buyer,

$$\begin{aligned}
\psi_L^H &= \Pr\{s_s = L \mid s_b = H\} \\
&= \mu_b(1 - \mu_s) + \mu_s(1 - \mu_b)
\end{aligned} \tag{30}$$

$$\begin{aligned}
\phi_{HL}^l &= \Pr\{v = v_l \mid s_b = H, s_s = L\} \\
&= \frac{\mu_s(1 - \mu_b)}{\mu_b(1 - \mu_s) + \mu_s(1 - \mu_b)}.
\end{aligned} \tag{31}$$

It is straightforward to demonstrate the following result.

**Lemma 1** *The only equilibria in which efficient trade always occurs are pooling equilibria in which the high-signal and low-signal proposers offer the same price, which is accepted by the seller.*

**Proof:** Suppose there is an equilibrium in which different types of proposers offer different prices. In such an equilibrium, for trade to be efficient, the responder needs to accept all of the proposer's offers. If the proposer anticipates such a response, then he should offer the price that is favorable to himself (lower if he buys, higher if he sells), regardless of his signal, a contradiction. ■

The next question, then, is whether pooling equilibria that support efficient trade exist. We first construct a pooling equilibrium with very simple off-equilibrium beliefs. These beliefs are agnostic, in that they treat any offer below the pooling price as equally likely to come from either type of buyer. We use this case to illustrate the nature of pooling equilibria, and explain intuitively why their existence imposes a bound on the level of expertise in terms of the amount of volatility relative to the gains to trade. We then go on to provide a more formal analysis of efficient pooling equilibria, where we focus on perfect sequential equilibria as proposed by Grossman and Perry

(1986). A similar bound on expertise must be satisfied for efficient perfect sequential equilibria to exist in the trading subgame. This bound then serves as a basis for our analysis of the arms race in expertise, and its potential to destroy gains to trade when volatility rises.

We conjecture an equilibrium of the following sort:

- Buyers of both types offer the lowest price at which the seller, knowing nothing about the buyer's signal, would accept regardless of the seller's signal. This is, of course, the same price buyers offer when they are uninformed, as in Section 3:

$$p^{**} = \mu_s v_h + (1 - \mu_s) v_l. \tag{32}$$

- Sellers believe any offer of a lower price is uninformative, equally likely to come from either type.

Given that both buyer types offer  $p^{**}$ , when the seller accepts he receives the same unconditional expected payoff as he obtains with an uninformed buyer, which from equation (7) is  $(v_h - v_l) (\mu_s - \frac{1}{2})$ . Since the seller accepts this price regardless of his signal, the buyer learns nothing about the seller's signal.

To verify that pooling at  $p^{**}$  is an equilibrium, we must check that it satisfies the participation constraints and the incentive compatibility constraints for both the high- and low-signal buyers. First note that satisfying the participation constraint for the low-signal buyer guarantees that the participation constraint for the high-signal buyer is satisfied. Both buyers pay the same price for the asset, but the expected value of the asset is weakly higher after seeing a high signal than a low signal. Also note that there is no incentive for either type of buyer to defect from the proposed equilibrium by offering a price higher than  $p^{**}$ , regardless of the seller's beliefs. At best, the seller would always accept, which he will do at  $p^{**}$  in any case, and the buyer will pay more. It remains, therefore, to verify that neither buyer will defect to a lower price.

The payoff to a low-signal buyer from offering  $p^{**}$  is:

$$\begin{aligned} E(v \mid s_b = L) + 2\Delta - p^{**} &= 2\Delta + (v_h - v_l)(1 - \mu_b - \mu_s) \\ &= 2\Delta - (v_h - v_l)(e_b + e_s). \end{aligned} \quad (33)$$

This payoff needs to be at least zero for pooling at  $p^{**}$  to be an equilibrium. As long as the signals are informative (positive expertise), the buyer must surrender some of his surplus to the seller to induce him to accept the offer. With  $\mu_b = \frac{1}{2}$  and  $e_b = 0$ , this is the same expression as we obtained with an uninformed buyer, equation (6). The buyer's expected payoff in this case is lower because his signal is low, and he knows he is overpaying by more relative to the common value.

If the buyer offers a price  $p < p^{**}$ , the seller views this as uninformative about the buyer's signal. The seller will therefore only accept the offer if his own signal is low, and will earn zero surplus. Given this response, the buyer should offer the lowest price possible, which is  $p^* = E(v \mid s_s = L)$ . Now, however, the probability that the seller accepts,  $\psi_L^L$ , depends on the buyer's signal and its precision, and the information conveyed by this acceptance confirms the buyer's signal. The buyer's expected payoff is therefore:

$$\begin{aligned} &\psi_L^L[E(v \mid s_b = L, s_s = L) + 2\Delta - p^*] \\ &= \psi_L^L[(1 - \phi_{LL}^L)v_h + \phi_{LL}^L v_l + 2\Delta - (1 - \mu_s)v_h - \mu_s v_l] \\ &= \psi_L^L[2\Delta - (v_h - v_l)(\phi_{LL}^L - \mu_s)]. \end{aligned} \quad (34)$$

In this expression, the buyer loses surplus, conditional on a trade occurring, as long as both signals are more informative than that of the seller alone. The buyer is overpaying ex-post, because the seller's acceptance confirms his signal. As the signals become less informative, the buyer's payoff at this price approaches  $\Delta$ , as in the case of an uninformed buyer, equation (8).

Comparing these payoffs, the low-signal buyer will not deviate to a lower price as long as

$$2\Delta + (v_h - v_l)(1 - \mu_b - \mu_s) \geq \psi_L^L[2\Delta - (v_h - v_l)(\phi_{LL}^L - \mu_s)]. \quad (35)$$

Substituting for the conditional probabilities from equations (28) and (29), and for the signal precisions,  $\mu_i = \frac{1}{2} + e_i$ , we find after some simplification that the condition above is equivalent to:

$$\frac{2\Delta}{v_h - v_l} \geq \frac{\frac{e_b}{2} + e_s + 2e_b e_s^2}{\frac{1}{2} - 2e_b e_s}. \quad (36)$$

Note that as expertise rises from zero to its maximum value of  $\frac{1}{2}$  the numerator on the right-hand side of condition (36) approaches unity, while the denominator approaches zero. Thus, for fixed gains to trade relative to volatility, the incentive compatibility condition bounds the level of expertise, as in equation (10) when the buyer is uninformed.

The next lemma shows that the incentive compatibility constraint in condition (36) is the critical one. The proof is provided in the appendix.

**Lemma 2** *If pooling is incentive compatible for the low-signal buyer, and condition (36) is satisfied, it is also incentive compatible for the high-signal buyer.*

Also, condition (36) implies that the participation constraint for the low-signal buyer (and, therefore, for the high-signal buyer) will be satisfied. To see this, we can rewrite condition (36) as:

$$2\Delta - \frac{\frac{e_b}{2} + e_s + 2e_b e_s^2}{\frac{1}{2} - 2e_b e_s} (v_h - v_l) \geq 0, \quad (37)$$

and since

$$\frac{\frac{e_b}{2} + e_s + 2e_b e_s^2}{\frac{1}{2} - 2e_b e_s} = \frac{e_b + 2e_s + 4e_b e_s^2}{1 - 4e_b e_s} \geq e_b + 2e_s + 4e_b e_s^2 \geq e_b + e_s, \quad (38)$$

then the incentive compatibility for the low-signal buyer guarantees that both the high- and low-signal buyers get a payoff of at least zero. Thus, the only critical constraint on the parameters that support a pooling equilibrium with efficient trade is given by condition (36). This constraint will be violated when volatility (relative to gains to trade) is too high or when traders' expertise is too high.

Now consider the ex-ante expected payoffs to the buyer and seller from the trading subgame, in the pooling equilibrium, before knowing their signals. The buyer receives  $2\Delta - p^{**}$  plus  $E(v |$

$s_b = H$ ) or  $E(v | s_b = L)$  with equal probability, or

$$2\Delta + (v_h - v_l) \left( \frac{1 - \mu_s - \mu_b}{2} + \frac{\mu_b - \mu_s}{2} \right) = 2\Delta - (v_h - v_l)e_s. \quad (39)$$

Since trade always takes place, the seller receives the remaining surplus of

$$(v_h - v_l)e_s. \quad (40)$$

Not surprisingly, since trade always occurs, and at the same prices as when the buyer is uninformed, the ex-ante payoffs are the same. Agent  $i$ , then, before knowing whether he or his opponent, agent  $j$ , is buyer or seller, earns an expected payoff of

$$\Delta + \frac{1}{2}(v_h - v_l)(e_i - e_j). \quad (41)$$

Taking as given his opponents' levels of expertise, trader  $i$  will increase his expected payoff in any given trading encounter by increasing his expertise. The incentives to invest in expertise are similar to those in the simpler case of one-sided asymmetric information.

To summarize, in an equilibrium preserving efficient trade in the trading subgame, where both parties receive private signals, expertise plays the same role it does in the simpler setting analyzed earlier. It deters opportunistic offers by the party initiating the trade, but the private incentives agents have to invest in expertise are limited by an incentive compatibility condition, and this bound decreases when volatility rises. Thus, just as before, investments in expertise made in anticipation of efficient trade in the subgame could put gains to trade at risk if volatility jumps.

There exist other pooling equilibria in the subgame that are based on different off-equilibrium beliefs and that preserve the gains to trade. The next proposition shows that if we restrict players to update their beliefs credibly, as in the definition of perfect sequential equilibria in Grossman and Perry (1986), the only equilibria with efficient trade that survive in the trading subgame will be pooling equilibria at a price of  $p^{**}$ . A perfect sequential equilibrium is described by Grossman and Perry (1986) as an equilibrium “supported by beliefs  $p$  which prevent a player from deviating to an

unreached node, when there is no belief  $q$  which, when assigned to the node, makes it optimal for a deviation to occur with probability  $q$ .” Intuitively speaking, this concept ensures that, whenever possible, the off-equilibrium beliefs associated with a deviation by the buyer are updated following Bayes’ rule given the best response(s) of the seller if he has such beliefs. The result will help to restrict the behavior we should expect to take place when traders meet. There is at most one type of pooling equilibria that is perfect sequential.<sup>3</sup> Since the price offered in these equilibria is the same as in the case with agnostic beliefs, equilibrium play will proceed as described above, and as in previous sections with one-sided asymmetric information. We also derive the boundary for the existence of an efficient, perfect sequential equilibrium in the trading subgame. Since the low type buyer might find profitable to deviate to an offer slightly above  $E[v|s_s = L, s_b = L]$  when the seller’s beliefs are credibly updated, the refinement proposed by Grossman and Perry (1986) produces a tighter condition than (36), which ensures pooling is an equilibrium with agnostic beliefs. The proof of the proposition is provided in appendix.

**Proposition 3** *The only equilibria that involve efficient trade in the trading subgame and that are perfect sequential as defined in Grossman and Perry (1986) are pooling equilibria at  $p^{**}$ . Such efficient perfect sequential equilibria exist if and only if*

$$\frac{2\Delta}{v_h - v_l} \geq \frac{e_s + e_b}{\frac{1}{2} - 2e_s e_b}. \quad (42)$$

From the above expression for the threshold for the existence of a perfect sequential, efficient equilibrium, we can immediately obtain the following results. First, there is a unique symmetric expertise pair  $e^* = \frac{v_h - v_l}{4\Delta} \left[ \sqrt{1 + \frac{4\Delta^2}{(v_h - v_l)^2}} - 1 \right]$  that satisfies the above threshold with equality. This expertise level is greater than zero whenever  $\frac{v_h - v_l}{\Delta} \in (0, +\infty)$ . Second, regardless of whether expertise is symmetric, a slight increase in expertise by one player crossing this boundary implies that the efficient, perfect sequential equilibrium ceases to exist, whether that player is a buyer a seller. Finally, since the left-hand side of the condition in the proposition is decreasing in  $(v_h - v_l)$ ,

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<sup>3</sup>Formally, since beliefs will be unrestricted following certain off equilibrium path actions that are always unappealing to both types, there are multiple equilibria, but they are outcome equivalent. We maintain the convention of using uniqueness in this sense.

an increase in volatility eliminates the efficient, perfect sequential equilibrium where traders have invested in expertise up to the boundary.

As before, the ex-ante payoffs to the agents, anticipating the pooling equilibrium in the trading game, before they know their roles as buyer or seller, will be the same as when asymmetric information is one-sided,  $\Delta + \frac{1}{2}(v_h - v_l)(e_i - e_j)$ .

## 7.2 Choice of Expertise

We now investigate the possible equilibrium choices for expertise at  $t = 0$ , assuming that the costs of expertise are low and high-volatility states are rare. If all traders anticipate that in the low-volatility regime play in the trading subgame will proceed according to a pooling equilibrium at  $p^{**}$ , then their expected payoffs will be linear in their own expertise and they will invest in expertise. However, at some boundary in expertise, any increase in expertise will prevent efficient trade from taking place and will destroy some of the gains to trade. The equilibrium in expertise associated with that boundary will involve efficient trade in low-volatility regimes and breakdowns in liquidity in the high-volatility regimes, regardless of the size of the jump in volatility, just as in the setup with one-sided asymmetric information.

There will, however, be other types of equilibria. The multiplicity of possible beliefs and equilibria in the trading subgame when both parties have private information induce multiple equilibria in the choice of expertise. In these equilibria, play along the equilibrium path proceeds in the subgame according to the pooling equilibrium, but additional investment in expertise is deterred by beliefs about the opponents' strategic choices in response to an out-of-equilibrium increase in expertise.

Specifically, suppose all traders have low levels of expertise. Any trader can then improve his discounted expected payoffs by raising his investment in expertise as long as he anticipates pooling equilibrium outcomes in the trading subgame (in the low volatility regime). An arms race will then occur. If instead he anticipates that the response of his opponents to such an increase in his expertise will be to play either the strategies associated with separating equilibria in the trading subgame, which are inefficient, or to play efficient equilibria that provides the non-deviating player with a larger share of the surplus, the resulting decrease in his expected payoff may be sufficient to

discourage such a deviation from the lower, equilibrium level of expertise.

For this reason, we impose the perfect sequential equilibrium refinement defined in Grossman and Perry (1986) on the expertise acquisition game and eliminate equilibria that rely on off-equilibrium threats with incredible beliefs. We further require that players anticipate that, if both efficient and inefficient perfect sequential equilibria exist, the efficient equilibrium will prevail.<sup>4</sup> We confine attention to the more interesting case where the costs of expertise rise sufficiently fast above the symmetric point on the threshold so that large increases in expertise are too costly to be profitable. Formally, we will show that when both traders invest up to the symmetric threshold  $e^*$ , neither trader has an incentive to deviate to a marginally higher level of expertise where trade breaks down with positive probability. We also consider only the most efficient symmetric equilibrium (that is, the equilibrium in which trade always takes place in the low-volatility state and expertise investment is minimized). Under these restrictions, we obtain a unique prediction for investment in expertise, and small, infrequent increases in volatility will lead to breakdowns in trade in the high-volatility state.

Under the restrictions described above, investment up to the threshold that applies in the low-volatility regime, i.e.,

$$e^* = \frac{\sigma}{4\Delta} \left[ \sqrt{1 + \frac{4\Delta^2}{\sigma^2}} - 1 \right], \quad (43)$$

will be the unique prediction of our model if we can show that, for any expertise pair  $\{e_i, e_j\}$  that violates the threshold (42) in Proposition 3, a perfect sequential equilibrium exists and is unique in a sufficiently small neighborhood of the symmetric expertise level  $e^*$  where the boundary in (42) is violated by an increase in expertise. Note that uniqueness is not necessary but is sufficient to rule out a deviation above  $e^*$ . If there is a perfect sequential equilibrium following a small deviation in expertise above  $e^*$  and that equilibrium is unique, then the deviator has to expect lower payoffs than at  $e^*$ . This is because for a small deviation payoffs accrue almost symmetrically to the deviator and non-deviator and total payoffs are discretely less than they would be if neither player had deviated as trade breaks down with positive probability. If there were multiple perfect

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<sup>4</sup>This restriction can be motivated by a strong form of forward induction closely related to the updating rule imposed in Grossman and Perry (1986).

sequential equilibria, it would be necessary to check whether one player could anticipate higher payoffs following a deviation by expecting the perfect sequential equilibrium most favorable to the seller when he is the seller or to the buyer when he is the buyer. Furthermore, if there is no perfect sequential equilibrium, any sequential equilibrium of the trading subgame could be anticipated, including those that are efficient but not perfect sequential. The next proposition establishes the existence and uniqueness of the perfect sequential equilibrium slightly above  $e^*$  where the efficient trading equilibrium does not exist, and thus completes the argument.

**Proposition 4** *The unique perfect sequential equilibrium in a neighborhood around  $(e^*, e^*)$  with at least one  $e_i > e^*$ , involves the following actions:*

- *The high type buyer offers  $p^h \equiv E[v|s_s = H, s_b = H]$ .*
- *The low type buyer offers  $p^l \equiv E[v|s_s = L, s_b = L]$ .*
- *Both seller types accept  $p^h$  when offered.*
- *The low type seller always accepts  $p^l$  when offered.*
- *The high type seller always rejects  $p^l$  when offered.*
- *Trade breaks down with probability  $\frac{1}{4} - e_b e_s$ , destroying a surplus of  $2\Delta [\frac{1}{4} - e_b e_s]$ .*

To summarize, when the condition in Proposition 3 is violated, efficient trade cannot take place in the trading game with low volatility if beliefs are credibly updated. Instead, trade takes place as in Proposition 4,  $\psi_L^H \Delta$  of the gains to trade are lost, and the ex-ante payoffs to the agents before they know their roles as buyer or seller, are smaller than if the condition in Proposition 3 is not violated. So as long as the costs of expertise do not rise too quickly and the high volatility is not too frequent, the equilibrium outcome of the expertise game that survive the credible updating criterion of Grossman and Perry (1986) here will have traders investing in expertise up to the point where any further investment would lead to breakdowns in trade in the low-volatility regime, as in earlier sections where only the responder is informed. And as long as the costs of acquiring expertise are not too flat, we have shown that this is the unique prediction for expertise investment

in a symmetric equilibrium. Infrequent, small shocks to volatility will still lead to breakdowns in trade.

## 8 Conclusion

The model in this paper illustrates the incentives for financial market participants to overinvest in financial expertise. Expertise in finance increases the speed and efficiency with which traders and intermediaries can determine the value of assets when they are negotiating with potential counterparties. The lower costs give them advantages in negotiation, even when the information acquisition has no value to society, and even when it can create adverse selection that disrupts trade if uncertainty about the volatility of fundamental values increases too quickly or unexpectedly to allow intermediaries to adjust or scale back their investment in expertise. If jumps in volatility are sufficiently infrequent, the gains to trade lost in the high-volatility regime will not be as important as the increase in profits that added expertise, and the ensuing improved bargaining position, bring in the low-volatility regime. The intermediary will find optimal to acquire expertise that increases expected profits in the more probable low-volatility regime, even though the advantage gained is neutralized by similar investments by counterparties in equilibrium, and even though expertise decreases profits because of trade breakdowns when volatility jumps.

Some extensions to the model may warrant additional research. Financial expertise might also allow intermediaries to decrease the precision of information acquired by their counterparties, as well as increasing the precision of their own information. Investment in expertise permits firms to create, and make markets in, more complex financial instruments. In our notation, we can view the precision of information about intrinsic value for agent  $i$  as  $\mu(e_i, e_j)$ , which decreases in  $i$ 's own expertise and increases in that of his counterparty. The logic of our analysis suggests firms benefit from increasing the relative costs of their counterparties. The tension between the incentives to decrease others' signal precision, which would reduce adverse selection, and increase one's own signal precision, which increases it, may help us better understand innovation and evolution in financial markets.

In our model, intermediaries invest in expertise only once, and the volatility states are drawn

independently through time. This illustrates the consequences shocks to volatility have for liquidity. If volatility is persistent through time, and intermediaries can adjust, with some adjustment costs, their level of expertise in response to changing volatility, then shocks to volatility will still lead to breakdowns in liquidity, but they will also trigger contractions in “expertise” which can be interpreted as employment of financial professionals. Such a model might be informative about the nature of employment cycles in financial services.

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## Appendix

### A Proofs

**Proof of Proposition 1:** The arguments in the text prove the proposition for the case where the proposer buys. If the proposer sells, the highest price at which he can ensure acceptance of his offer for any signal is

$$p^{**} = E(v \mid s_i = L) \tag{A1}$$

and his payoff is

$$\begin{aligned} p^{**} - [E(v) - 2\Delta] &= 2\Delta - (v_h - v_l) \left( \mu_i - \frac{1}{2} \right) \\ &= 2\Delta - (v_h - v_l)e_i. \end{aligned} \tag{A2}$$

The highest price at which trade will occur at least half the time is

$$p^* = E(v \mid s_i = H) \tag{A3}$$

and the seller's payoff is

$$\frac{1}{2}(p^* - [E(v \mid s_i = H) - 2\Delta]) = \Delta \tag{A4}$$

Comparing these expressions for the seller's payoff to those for the buyer's payoffs in the text reveals they are identical. A comparison of the payoffs at price  $p^{**}$  and  $p^*$  then yields the same inequality for the level of expertise. ■

**Proof of Proposition 2:**

If

$$\frac{1}{2(1-\delta)}(1-\pi)\sigma \geq c'(\bar{e}). \tag{A5}$$

then

$$\pi \leq 1 - \frac{2(1-\delta)}{\sigma}c'(\bar{e}). \tag{A6}$$

Noting that  $\bar{e} = \frac{\Delta}{\sigma}$ , this inequality follows from the first terms under the  $\min\{\cdot, \cdot\}$  operator in the expression for  $\pi^\theta$  in the proposition.

This also implies, by the convexity of the cost function, and  $\bar{e} > \bar{e}$  the three following conditions:

$$\frac{1}{2(1-\delta)} [(1-\pi)\sigma + \pi\theta\sigma] > c'(\bar{e}), \tag{A7}$$

$$\frac{1}{2(1-\delta)}(1-\pi)\sigma > c'(\bar{e}), \tag{A8}$$

and

$$\frac{1}{2(1-\delta)} [(1-\pi)\sigma + \pi\theta\sigma] > c'(\bar{e}). \quad (\text{A9})$$

Thus, we can rule out as candidate equilibria levels of expertise where the first-order conditions hold with equality,  $\hat{e}_h$  and  $\hat{e}_l$ , and focus only on whether agents will prefer  $\bar{e}$  which maximizes the payoff in the low-volatility regime, but leads to breakdowns in trade with probability 0.5 in the high-volatility regime or they will prefer the expertise level  $\bar{e}$  which maximizes the payoff without triggering breakdowns in trade in the high-volatility regime.

Comparing the expected payoffs associated with the two levels of expertise,  $\bar{e}$  will be preferred whenever:

$$\frac{1}{2(1-\delta)}(1-\pi)\bar{e}\sigma - c(\bar{e}) \geq \frac{1}{2(1-\delta)} [(1-\pi)\bar{\bar{e}}\sigma + \pi\bar{\bar{e}}\theta\sigma] - c(\bar{\bar{e}}). \quad (\text{A10})$$

Notice that due to the convexity of  $c(\cdot)$ , when we set  $\pi = 0$  this inequality is satisfied and non-binding whenever the inequality required for  $\bar{e}$  to be the equilibrium expertise level when  $\pi = 0$  is satisfied, i.e., condition (23) in the Proposition. Thus, even if we allow for a small but positive probability  $\pi$  of high volatility, the second term on the left-hand side of (A12) above will be small and will not violate the inequality.

Multiplying both sides of the inequality by  $2(1-\delta)$  yields:

$$(1-\pi)\bar{e}\sigma - 2(1-\delta)c(\bar{e}) \geq (1-\pi)\bar{\bar{e}}\sigma + \pi\bar{\bar{e}}\theta\sigma - 2(1-\delta)c(\bar{\bar{e}}), \quad (\text{A11})$$

which can be written as:

$$\frac{[\bar{e} - \bar{\bar{e}}]\sigma - 2(1-\delta)[c(\bar{e}) - c(\bar{\bar{e}})]}{[\bar{e} + (\theta - 1)\bar{\bar{e}}]\sigma} \geq \pi. \quad (\text{A12})$$

In summary, the following two conditions ensure that  $\bar{e}$  remains the unique equilibrium in expertise:

$$\frac{1}{2(1-\delta)}(1-\pi)\sigma \geq c'(\bar{e}), \quad (\text{A13})$$

and

$$\frac{1}{2(1-\delta)}(1-\pi)\bar{e}\sigma - c(\bar{e}) \geq \frac{1}{2(1-\delta)} [(1-\pi)\bar{\bar{e}}\sigma + \pi\bar{\bar{e}}\theta\sigma] - c(\bar{\bar{e}}). \quad (\text{A14})$$

And since both conditions are continuous in  $\pi$ , then we know that if these conditions are not binding when  $\pi = 0$ , they will not bind for small enough positive  $\pi$ .

Combining these requires  $\pi < \pi^\theta$ , where:

$$\pi^\theta = \min \left\{ 1 - \frac{2(1-\delta)}{\sigma} c'(\bar{e}), \frac{[\bar{e} - \bar{\bar{e}}]\sigma - 2(1-\delta)[c(\bar{e}) - c(\bar{\bar{e}})]}{[\bar{e} + (\theta - 1)\bar{\bar{e}}]\sigma} \right\}, \quad (\text{A15})$$

which, when substituting for the values of  $\bar{e}$  and  $\bar{\bar{e}}$ , is equal to expression (24) in the Proposition. ■

**Proof of Lemma 2:**

For a buyer with a high signal, the expected payoff from offering  $p^{**}$ , given that it is always accepted by the responding seller, is

$$\begin{aligned} E(v \mid s_b = H) + 2\Delta - p^{**} &= 2\Delta + (v_h - v_l)(\mu_b - \mu_s) \\ &= 2\Delta - (v_h - v_l)(e_s - e_b) \end{aligned} \quad (\text{A16})$$

In this case, the buyer may be overpaying or underpaying at  $p^{**}$ , depending on whose signal is more accurate.

The same buyer's expected payoff if he offers  $p^*$  reflects the conditional probability that the seller has a low signal, which is required for him to accept a low offer, and the value of the asset conditional on the seller revealing a low signal through his decision:

$$\begin{aligned} \psi_L^H [E(v \mid s_b = H, s_s = L) + 2\Delta - p^*] \\ &= \psi_L^H [(1 - \phi_{HL}^l)v_h + \phi_{HL}^l v_l + 2\Delta - (1 - \mu_s)v_h - \mu_s v_l] \\ &= \psi_L^H [2\Delta - (v_h - v_l)(\phi_{HL}^l - \mu_s)] \end{aligned} \quad (\text{A17})$$

As before, this expression goes to  $\Delta$  as expertise goes to zero, and the signals become uninformative. Even at this lower price, the buyer may overpay conditional on trade occurring, depending on the accuracy of his signal relative to that of the seller. This determines whether  $\phi_{HL}^l$  is less than or greater than  $\mu_s$ .

Pooling will be incentive compatible for the high-signal buyer if

$$2\Delta + (v_h - v_l)(\mu_b - \mu_s) \geq \psi_L^H [2\Delta - (v_h - v_l)(\phi_{HL}^l - \mu_s)] \quad (\text{A18})$$

Substituting from (30) and (31) for the conditional probabilities, rewriting the precisions in terms of expertise and simplifying then yields:

$$\begin{aligned} \frac{2\Delta}{v_h - v_l} &\geq \frac{(1 - \mu_s)\mu_b\mu_s + \mu_s^2(1 - \mu_b) - \mu_s(1 - \mu_b) - \mu_b + \mu_s}{1 - \mu_b(1 - \mu_s) + \mu_s(1 - \mu_b)} \\ &= \frac{e_s - 2e_s^2e_b - \frac{e_b}{2}}{\frac{1}{2} + 2e_b e_s} \end{aligned} \quad (\text{A19})$$

This constraint will never bind if pooling is incentive compatible for the low-signal buyer. Comparison of (A19) with the incentive compatibility constraint for the low-signal type, (36), reveals that for  $0 < e_s, e_b < \frac{1}{2}$ , the denominator of (36) is always lower, and the numerator is always higher, than for (A19). ■

### Proof of Proposition 3:

Here, we consider all the possible prices that could trigger an equilibrium with efficient trade in the trading subgame and check if they can be sustained by beliefs that satisfy the credible updating

rule of Grossman and Perry (1986). Since a pooling equilibrium involves both types of buyers offering the same price, the minimal price that a seller will always accept is  $p^{**} = \mu_s v_h + (1 - \mu_s) v_l$ . Prices below  $p^{**}$  cannot sustain an efficient equilibrium in the subgame.

Now, consider an efficient equilibrium with price  $p > p^{**}$ . Consider a deviation to some  $p' \in (p^{**}, p)$ . We compare the strategy-belief combinations for the seller. If the seller has a strategy of rejecting  $p'$  regardless of his signal, neither type of buyer will deviate from  $p$ , so the seller's beliefs are unrestricted, but the deviation is unattractive. If the seller always accepts, both types of buyers prefer to deviate and the seller's (credibly updated) posterior belief is that the deviation is equally likely to come from both types of buyers. Given these beliefs, the seller's best response is to accept. If the seller chooses to accept only when he is the low type, either only the low type buyer wants to deviate to  $p'$  or both types want to deviate to  $p'$ . Thus, the seller must believe that  $p'$  comes from the low type at least as often as from the high type, and therefore his best response is to accept  $p'$  with probability 1. Thus, both buyer types will deviate to  $p'$  when beliefs are credibly updated, and a pooling equilibrium at  $p > p^{**}$  cannot be a perfect sequential equilibrium in the subgame.

We now show that if the boundary in the proposition is violated, the buyer will have a profitable deviation when beliefs are credibly updated, and that if the boundary is not violated, there exists perfect sequential equilibria with pooling at  $p^{**}$ . First, it is immediate that no type of buyers will deviate to a price higher than  $p^{**}$ . Now, suppose the low type buyer deviates to an offer infinitesimally above  $E[v|s_s = L, s_b = L]$ . Conjecture that this offer is accepted by the low type seller and rejected by the high type seller. The low type buyer will prefer to adhere to the pooling price  $p^{**}$  that is accepted by both types of seller only if:

$$2\Delta + E[v|s_b = L] - p^{**} \geq \psi_L^L 2\Delta, \quad (\text{A20})$$

which can be rewritten as the threshold in the proposition.

If this condition does not hold and as conjectured the seller accepts the deviation when his signal is low and rejects it when his signal is high, the low type buyer will prefer to deviate to the offer (infinitesimally above)  $E[v|s_s = L, s_b = L]$ . If the high type buyer does not prefer this deviation over offering the pooling price that is always accepted (which will be true around the threshold in the proposition), then the credibly updated belief is that the deviation comes from the low type only and the low type seller's best response is then to accept the deviation. This makes deviating to an offer slightly above  $E[v|s_s = L, s_b = L]$  profitable for the low type buyer. And since neither type of buyer can prefer to make an offer the seller always rejects, conjecturing that the seller always rejects a deviation will not generate different credible beliefs. Hence, the only set of credible beliefs in the case where the high type buyer does not want to deviate is that the deviation comes from the low type only. If both the high and low type buyers prefer the low offer when only the low type seller accepts, then there is some price above  $E[v|s_s = L, s_b = L]$  such that the high type buyer prefers to adhere to the pooling price when he expects the high type seller to reject and the low

type seller to accept, while the low type seller prefers to deviate. For any given possible deviation, it is impossible for the high type buyer to prefer to deviate from the pooling equilibrium while the low type buyer prefers to adhere. This is an immediate consequence of the fact that the increased payoff for the deviation conditional on trade is identical for both players, but the probability of trade is reduced more for the high type seller than for the low type seller. A deviation to this price then implies that the low type seller must accept since the offer exceeds  $E[v|s_s = L, s_b = L]$ , so the deviation is preferred by the low type buyer. Thus, if the posited condition does not hold, the pooling equilibrium at  $p^{**}$  is not perfect sequential.

Now, if the condition in the proposition does hold, a deviation to  $E[v|s_s = L, s_b = L]$  will not be preferred by either type of buyer when expecting the seller to accept if and only if his signal is low. Furthermore, it is immediate that no high type seller will accept an offer of  $p < E[v|s_s = H, s_b = L]$ . Since the low type buyer does not prefer a deviation to  $E[v|s_s = L, s_b = L]$  when only the low type seller accepts, no type of buyer cannot prefer an offer of  $p > E[v|s_s = L, s_b = L]$  when only the low type seller accepts. Thus, credible updating does not restrict beliefs for deviations to prices less than  $E[v|s_s = H, s_b = L]$ . Thus, it remains to show that no deviation to a price  $p \in [E[v|s_s = H, s_b = L], p^{**})$  is preferred by a buyer given that beliefs are credibly updated whenever possible. For such deviation to be attractive to the buyer, we need the high type seller to accept it with positive probability. If the high type seller always accepts the deviation, regardless of his own signal, then both types have an incentive to deviate to  $p$ . And since  $p < p^{**}$ , the high type seller will always reject given credibly updated beliefs. Therefore, the buyer cannot anticipate that the seller will always accept, regardless of his signal. This leaves only the possibility that the high type seller is indifferent between accepting and rejecting the offer. Indifference implies that the seller believes that the offer is more likely to come from the low type buyer than from the high type buyer (since  $p < p^{**}$ ). This is possible since the probability that the high type seller accepts can be chosen to make the high type buyer indifferent between adhering and deviating, while the low type buyer strictly prefers to deviate. Given these beliefs, however, it is still a best response of the high type seller to always reject the offer after the deviation, which makes deviating unprofitable for both types. The requirement for perfect sequential equilibria is that, whenever possible, beliefs are credible following a deviation, and that the responding player plays *some* best response to these beliefs, not necessarily the best response that generates these beliefs. So, the seller can reject any price  $p \in [E[v|s_s = H, s_b = L], p^{**})$  while updating his beliefs credibly. Thus, the threshold presented is both necessary and sufficient for a pooling offer of  $p^{**}$  to trigger a perfect sequential equilibrium in the trading subgame. ■

**Proof of Proposition 4** Because we confine attention to a neighborhood around  $(e^*, e^*)$ , we can evaluate all prices and payoffs at  $(e^*, e^*)$  and rely on a basic continuity argument for  $\mu_i = \frac{1}{2} + e_i$ . For notational simplicity, we normalize  $2\Delta = 1$ , which is without loss of generality. We first show that the posited equilibrium is, in fact, a perfect sequential equilibrium.

We start by showing that, in any equilibrium with two prices (say  $p_h$  and  $p_l$ , where  $p_h > p_l$ ), the high type buyer must offer  $p_h = E[v|s_s = H, s_b = H]$  with positive probability. If  $p^h > E[v|s_s = H, s_b = H]$ , both seller types will sell regardless of their off equilibrium path beliefs, so  $p^h$  cannot exceed  $E[v|s_s = H, s_b = H]$ . If  $p^h \in (E[v|s_s = H, s_b = L], E[v|s_s = H, s_b = H])$ , then the low-type buyer will never want to offer  $p^h$  and the seller must therefore believe that the value of the asset is  $E[v|s_s = L, s_b = H]$  when his signal is low and  $E[v|s_s = H, s_b = H]$  when his signal is high. The seller thus strictly prefers to reject the offer when he is the high type and accept the offer when he is the low type, given that  $E[v|s_s = H, s_b = L] = E[v|s_s = L, s_b = H]$  at  $(e^*, e^*)$ . Thus,  $p^h$  must be either  $E[v|s_s = H, s_b = H]$  or  $E[v|s_s = L, s_b = H]$ . The buyer will prefer to make an offer of  $E[v|s_s = H, s_b = H]$  whenever

$$1 + E[v|s_b = H] - E[v|s_s = H, s_b = H] > \psi_H^L. \quad (\text{A21})$$

Directly comparing the payoff to each offer at  $(e^*, e^*)$  gives the condition:

$$\frac{1}{2} \left( 2 + (v_h - v_l)^2 - \frac{(v_h - v_l)^3}{\sqrt{1 + (v_h - v_l)^2}} \right) > \frac{(v_h - v_l)(2 + (v_h - v_l)^2 - (v_h - v_l)\sqrt{1 + (v_h - v_l)^2})}{2\sqrt{1 + (v_h - v_l)^2}} \quad (\text{A22})$$

which holds for all  $(v_h - v_l) > 0$ . Hence, the buyer will prefer  $p^h = E[v|s_s = H, s_b = H]$  in the neighborhood around  $(e^*, e^*)$ . Since the high type seller can reject any offer below  $E[v|s_s = H, s_b = H]$  if he believes the offer only comes from a high type buyer, the posited equilibrium is confirmed to be a sequential equilibrium. In order to check that it is perfect sequential, it remains to show that there is no price the low type buyer can deviate to such that the seller is forced to update his beliefs to accept when he is the high type.

Consider a deviation to a low price of  $p^l \in (E[v|s_s = L, s_b = L], E[v|s_s = H, s_b = L])$ . The high type seller will reject, regardless of his beliefs about the seller's type. Now, for  $p^l \in (E[v|s_s = H, s_b = L], E[v|s_s = H])$ , the high type seller will accept only if he believes the low type buyer makes the offer sufficiently frequently relative to the high type buyer. If the high type seller accepts with probability 1, then the high type buyer has an incentive to deviate to a low offer and beliefs must be updated such that the offer comes from the high type with at least probability  $\frac{1}{2}$ . The offer should then be rejected by the high type seller. Therefore, the high type seller cannot accept with probability 1. If the high type seller mixes to make the high type buyer indifferent, defining  $\alpha_h$  as the probability that the high type seller accepts  $p^l$ , we need:

$$\begin{aligned} 1 + E[v|s_b = H] - p^h &= \psi_H^L \left( 1 + E[v|s_s = L, s_b = H] - p^l \right) \\ &+ \psi_H^H \alpha_h \left( 1 + E[v|s_s = H, s_b = H] - p^l \right). \end{aligned} \quad (\text{A23})$$

Now we check if the low type buyer would prefer the deviation to  $p^l$  over what he would get in the

equilibrium we propose. Solving for  $\alpha_h$  gives a payoff to the low type buyer who offers  $p^l$  of:

$$\begin{aligned} & \psi_L^L \left( 1 + E[v|s_s = L, s_b = L] - p^l \right) + \\ & \psi_L^H \left( \frac{1 + E[v|s_b = H] - p^h - \psi_H^L \left( 1 + E[v|s_s = L, s_b = H] - p^l \right)}{\psi_H^H \left( 1 + E[v|s_s = H, s_b = H] - p^l \right)} \right) \left( 1 + E[v|s_s = H, s_b = L] - p^l \right), \end{aligned} \quad (\text{A24})$$

while adhering to the equilibrium strategy of offering  $p^l$  gives a payoff of  $\psi_L^L$ . Simple (but tedious) calculations show that, around  $(e^*, e^*)$ , the payoff to the low type buyer from offering  $p^l$  exceeds the payoff from offering  $p^l$ . Thus, the deviation to  $p^l$  must be assumed to come from the high type, and must therefore be rejected. Finally, deviations to prices above  $E[v|s_s = H]$  cannot come from a low type buyer even if both seller types accept since, around  $(e^*, e^*)$ , the buyer would prefer to adhere to the low offer  $p^l$  than deviate to  $E[v|s_s = H]$ . Thus, the seller can credibly commit to rejecting such offers.

To summarize, if the high type seller rejects a deviation, such deviation cannot be preferred by the low type buyer over the equilibrium strategy. If the high type seller always accepts a deviation, then it becomes profitable for the high type buyer to deviate, and beliefs should be updated such that the high type seller rejects, making the beliefs that support always accepting not credible. Finally, if the high type seller mixes after a deviation, any frequency of accepting that makes the high type buyer indifferent between deviating and not deviating (which is necessary for the high type seller to have beliefs that lead him to mix) makes the low type seller prefer to adhere to  $p^l = E[v|s_s = L, s_b = L]$ . Therefore, the seller must believe the deviation comes only from the high type and he rejects the deviation with probability 1. Since any off-equilibrium offer that is greater or equal to  $E[v|s_s = H]$  can at best make the low type buyer indifferent between adhering and deviating, even if the offer is accepted by both types of seller after the deviation, this establishes that the equilibrium posited is perfect sequential.

We have already shown that any perfect sequential equilibrium with two prices must rely on a high price of  $p^h = E[v|s_s = H, s_b = H]$ . Hence, in order to establish uniqueness, we need to consider all sequential equilibria where the low type offers  $p^l > E[v|s_s = L, s_b = L]$  or the high type offers  $p^h$  with probability less than one. First, consider any sequential equilibrium where the low type offers  $p^l > E[v|s_s = L, s_b = L]$  (or the low type offers  $p^l = E[v|s_s = L, s_b = L]$  but the low type seller mixes over accepting or rejecting  $p^l$ ). Consider an off-equilibrium offer infinitesimally above  $E[v|s_s = L, s_b = L]$ . The set of buyer types that could benefit from such a deviation is either the low type or both types. Consider first the case where only the low type benefits. Then, the low type seller will accept and the high type seller will reject. The low type buyer will prefer such

deviation to offering  $p_l$  but the high type buyer will not, since around  $(e^*, e^*)$ :

$$\begin{aligned} & 1 + E[v|s_b = H] - E[v|s_s = H, s_b = H] \\ & > \psi_H^L(1 + E[v|s_s = L, s_b = H] - E[v|s_s = L, s_b = L]). \end{aligned} \quad (\text{A25})$$

Now, consider the case where both buyer types prefer the deviation. From the expression above, we would need the high type seller to accept the offer slightly above  $E[v|s_s = L, s_b = L]$  with positive probability. But the offer is below  $E[v|s_s = H, s_b = L]$ , hence the high type seller will reject an offer slightly above  $E[v|s_s = L, s_b = L]$  regardless of his beliefs about the buyer's type. The only consistent beliefs following a deviation to an offer slightly above  $E[v|s_s = L, s_b = L]$  are that such deviation can only come from the low type and the offer will therefore be accepted by the low type seller with probability 1, making the sequential equilibrium proposed not perfect sequential.

There remains one final class of equilibria to check. In some cases, there will exist sequential equilibria where the low type buyer offers a price  $p^l \geq E[v|s_s = H, s_b = L]$  while the high type buyer mixes between  $p^l$  and  $p^h = E[v|s_s = H, s_b = H]$ . Both types of seller will accept the offer  $p^h$ , the low type seller will accept the offer  $p^l$  and the high type seller will mix between accepting and rejecting an offer  $p^l$ . In any such equilibrium, the payoff to the low type buyer for adhering is given by:

$$\psi_L^L(1 + E[v|s_s = L, s_b = L] - p_l) + \psi_L^H\alpha_h(1 + E[v|s_s = H, s_b = L] - p_l). \quad (\text{A26})$$

The value for  $\alpha_h$  is given by the requirement that the high type buyer be indifferent between offering  $p^h$  and  $p^l$ :

$$\begin{aligned} 1 + E[v|s_b = H] - E[v|s_s = H, s_b = H] &= \psi_H^L(1 + E[v|s_s = L, s_b = H] - p_l) \\ &+ \psi_H^H\alpha_h(1 + E[v|s_b = H, s_s = H] - p_l). \end{aligned}$$

Substituting the implied  $\alpha_h$  into the payoff function and noting that the payoff for deviating to an offer slightly above  $E[v|s_s = L, s_b = L]$  is still  $\psi_L^L$  in any perfect sequential equilibrium, it follows that at  $(e^*, e^*)$  the low type buyer strictly prefers to deviate to the lower offer in anticipation of the low type seller accepting.

Now, consider the possibility that more than two prices are used. By the same logic as above, at least one of the prices offered by the low type must be  $E[v|s_s = L, s_b = L]$ . But, for any price offered by the low type above  $E[v|s_s = L, s_b = L]$ , an offer lower than this offer but slightly higher than  $E[v|s_s = L, s_b = L]$  will be accepted by the low type by the arguments above, and will be a profitable deviation. Thus, this cannot be a perfect sequential equilibrium.

Finally, in the perfect sequential equilibrium proposed in the proposition, trade breaks down

whenever the buyer receives a low signal and the seller receives a high signal. This takes place with probability  $\frac{\psi_L^H}{2}$ , which can be rewritten as  $\frac{1}{4} - e_b e_s$ . ■

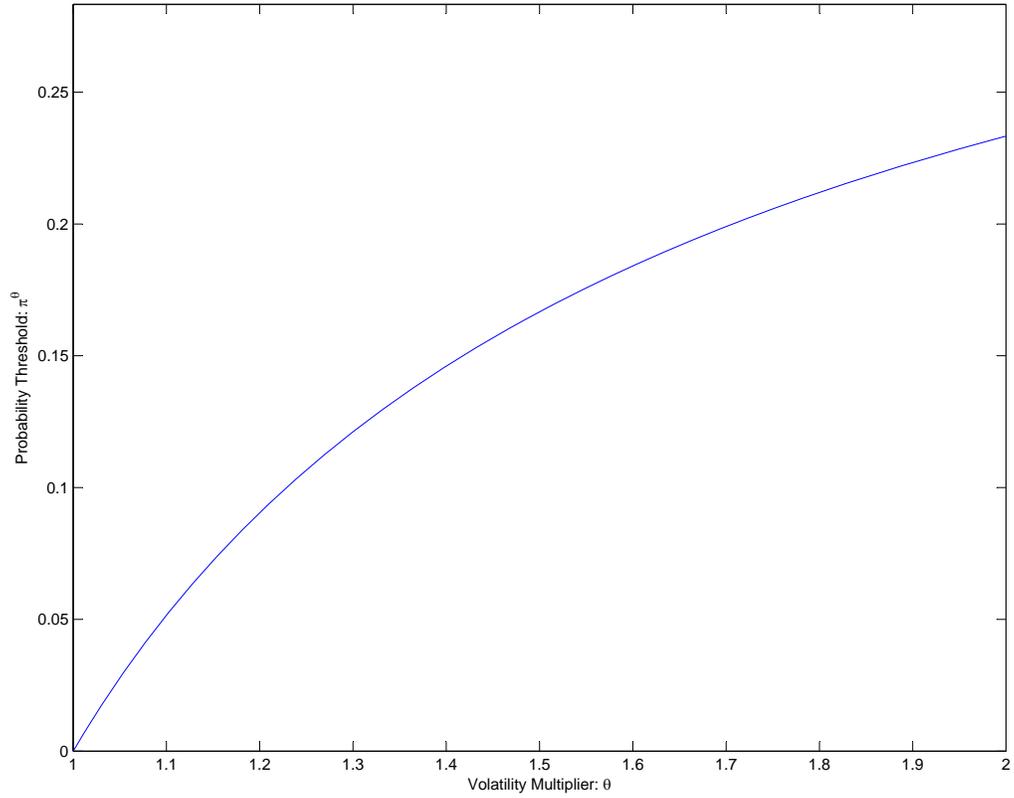


Figure 1: Bounds on  $\pi$ . The plot shows the maximum value of the probability of the high-volatility regime, against the increase in the volatility. For values of  $\pi$  below this bound, agents in the model invest in expertise to the maximum level,  $\bar{e}$ , even though this leads to breakdowns in trade when the high-volatility regime occurs. Figure is generated by setting:  $\delta = 0.9$ ,  $\Delta = 1$ ,  $\kappa = 10$ , and  $\sigma = 0.2$ .

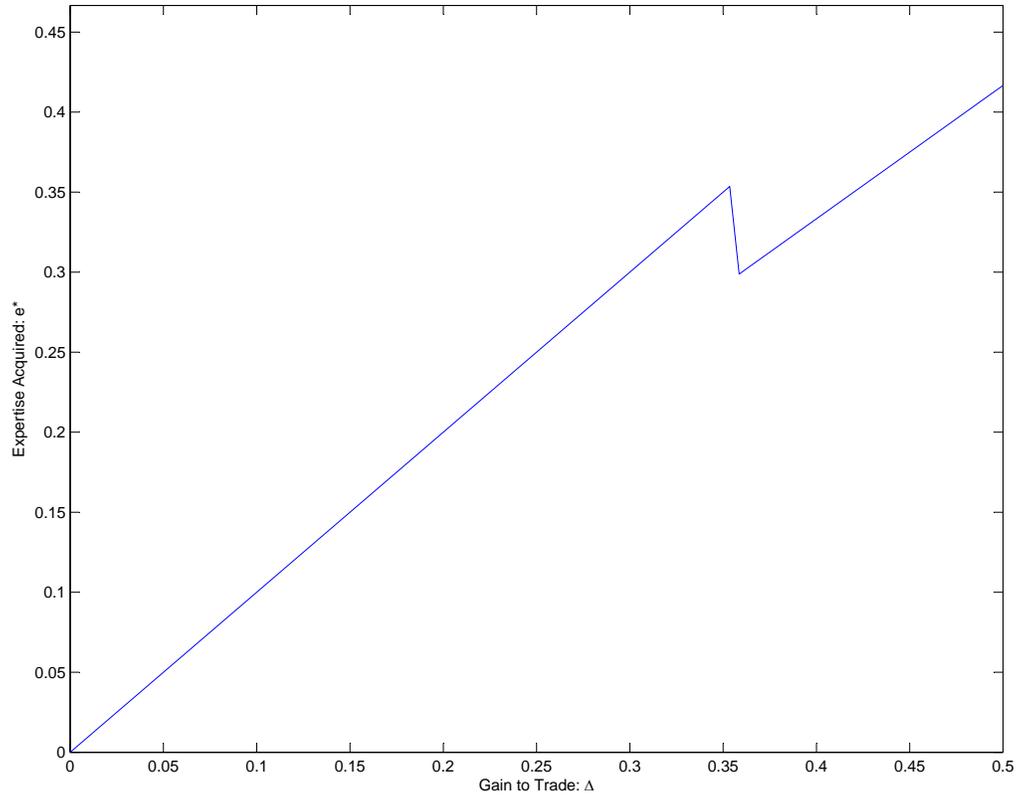


Figure 2: Expertise as a function of gains to trade  $\Delta$ . The plot shows the relationship between the equilibrium level of expertise and the gains to trade. Figure is generated by setting:  $\delta = 0.9$ ,  $\kappa = 10$ ,  $\sigma = 0.2$ ,  $\theta = 1.2$ , and  $\pi = 0.05$ .