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Vincent Glode
University of Pennsylvania

Richard C. Green

Richard Lowery

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Financial Expertise as an Arms Race*

Vincent Glode
Wharton School
University of Pennsylvania

Richard C. Green
Tepper School of Business
Carnegie Mellon University

and

Richard Lowery
McCombs School of Business
University of Texas at Austin

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Financial Expertise as an Arms Race

Abstract

We show that firms intermediating trade have incentives to overinvest in financial expertise, and that these investments can be destabilizing. Financial expertise in our model improves firms' ability to accurately estimate value when responding to offers to buy or sell a security. Its presence creates adverse selection, but under normal circumstances this adverse selection works to the advantage of the expert. It deters opportunistic bargaining by counterparties. That advantage is neutralized in equilibrium, however, by offsetting investments competitors make. Moreover, when volatility rises the adverse selection created by expertise triggers breakdowns in liquidity, destroying gains to trade and thus the benefits that firms hope to gain through high levels of expertise.

1 Introduction

The financial sector attracts extremely qualified workers. Philippon and Reshef (2010) document that, when compared to other sectors of the economy, the growth in financial services in recent decades has been associated with increases in employees' academic education, task complexity, and compensation. This investment in financial expertise no doubt facilitates a range of important and productive roles financial intermediaries serve in modern economies. These include improving risk sharing, overcoming frictions that interfere with efficient trade, better risk management, and engineering securities that allow new clienteles to access capital markets.

Our paper points to incentives financial firms have to *over*invest in financial expertise and suggests these investments can have a destabilizing effect on financial markets. 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 three things:

- Investment in financial expertise confers an advantage on any one player (firm) when bargaining with counterparties in the trading process.
- This advantage is neutralized in equilibrium by offsetting investments made by competitors.
- Investment in financial expertise is destabilizing, in that it creates a risk of destruction of the gains to trade when there is an exogenous shock to the level of uncertainty in the economy.

In the model, traders (or financial intermediaries generally) acquire expertise in processing information about the values of assets traded. 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.

Financial expertise in the model is the ability to acquire more accurate information. This creates adverse selection. Under circumstances of high volatility in the model this causes trade to break down for the usual reasons. Knowing that an intermediary might be better informed leads others to avoid trading with him because they know they will end up buying only when the value is low (or selling when it is high). Ironically, however, adverse selection is also the source of the benefits to expertise. Under normal circumstances of lower volatility, knowledge that an intermediary might be better informed improves the terms of trade for this intermediary. It leads counterparties to offer the intermediary a price that he is more likely to accept regardless of his information. This imposes a natural limit on investments in expertise. While financial expertise deters opportunistic bargaining, firms do not wish to appear too informed. With too much expertise, the price concessions required to overcome adverse selection can swamp the gains to trade. The limits this imposes on optimal levels of expertise, however, are too high for efficient trade to be sustained under high volatility. Thus, our model contributes to a better understanding of why financial crises tend to have their origins in newer sectors of the financial industry, where highly specialized expertise is particularly important. It also suggests that the employment of experts should fall following a jump in uncertainty rises, which might otherwise seem counterintuitive. With greater uncertainty one might expect more, not less, need for financial expertise.

Before the recent crisis financial firms had built extensive capacity devoted to transforming relatively straight-forward securities, such as residential mortgages and credit-card debt, into complex instruments through securitization. They then created trillions of dollars worth of derivative contracts based on these asset-backed securities. To facilitate this, financial firms hired highly trained and highly compensated experts to design, value, hedge, and trade the complex securities and derivatives. In this environment, it was arguably more difficult to value the securities being traded, which in our model gives financial experts an advantage in trade. Unfortunately, when housing prices fell and default rates rose, the complexity of the financial instruments 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. 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 exacerbate the importance of asymmetric information. The very expertise firms had developed may have worked against them in the crises. Their 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 and supply liquidity. Our model provides an explanation for the sudden unwillingness of so many financial intermediaries 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. Of course, it seems quite clear to most observers that the financial firms with the most experts were, along with many non-experts, surprised and mystified by what was going on as the financial crisis unfolded. This is consistent with our model. When uncertainty rises in the model, the experts know less about underlying values than previously, but the importance of their relative advantage over others increases, and adverse selection disrupts trade.

In the main version of our model, the asset traded has an uncertain common, or intrinsic value. One of the two parties also ascribes private benefits to the asset, which creates known and exogenous gains to trade. Financial expertise, and the information experts acquire, reduce uncertainty about the common value when bargaining. Thus, expertise is assumed to have no intrinsic 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. Our assumption that financial expertise serves no broader purpose is not made in the interests of realism. Rather, it is intended to highlight a particular set of incentives and tensions that are likely to be particularly important in an industry where much of the competition is of a zero-sum nature. Similarly, 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, hiring the most highly paid divorce lawyers confers on any one party a huge unilateral advantage in bargaining, but if both parties hire similar lawyers they 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.

In most models with adverse selection in finance, some party is exogenously asymmetrically informed.[1] 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.

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. It confers upon any one party an advantage in bargaining that protects him from opportunism by his counterparties. Looking forward, firms invest in expertise in anticipation of this advantage, but investments by other firms neutralize 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.

To keep the analysis tractable, we model agents who are ex ante identical in terms of their ability to acquire expertise. We model competition between equals. The benefits expertise confers on a trader, however, and the limits to the acquisition of expertise the model articulates, still apply when some potential counterparties are uninformed or "noise traders."

[1] See the pioneering paper by Akerlof (1970) on adverse selection and more recent papers on its role in financial crises by Eisfeldt (2004), Kirabaeva (2009), Daley and Green (2010), and Kurlat (2010), among many others.

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 do not improve efficiency, and they 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. 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. That is, we take the complexity of valuation as given, and treat expertise as investment in talent and infrastructure that improves the speed, efficiency, or accuracy of ascertaining that value, rather than as the intentional obfuscation of useful information. Both forces could be at work in the financial industry, since the complexity of valuation and the transparency of information are clearly related.

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.

The general notion that economic actors may overinvest 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), Fishman and Parker (2010), Van Nieuwerburgh and Veldkamp (2010), and Bolton, Santos and Scheinkman (2011) propose settings in which banks and investors can overinvest in information acquisition, 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 banks that compete for market shares whereas investors in Fishman and Parker (2010) acquire information about the value of multiple projects before choosing which ones to finance. Information can, however, be socially useful in both of these settings in efficiently allocating capital. Investors in Van Nieuwerburgh and Veldkamp (2010) allocate their information acquisition resources across financial assets and make portfolio decision simultaneously. Investors tend to focus their information acquisition on a small set of assets they expect to include in their portfolio, leading to the appearance of portfolio underdiversification. Closer to our paper, Bolton, Santos and Scheinkman (2011) model a labor market for workers who can choose to become entrepreneurs or financiers. Compared to the social optimum, too many workers become financiers as workers do not account for the negative externality that informed screening by financiers has on the bargaining power of entrepreneurs, who are all assumed to be uninformed. 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.

The paper is organized as follows. In the next section we describe the model of trading interactions in its simplest form. Section 3 considers the decision to invest in financial expertise. In Section 4 we prove our main results, which illustrate the destabilizing effects of expertise. Section 5 uses a parametric example in a multiperiod setting 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 obtained through financial expertise. We show that the central tradeoffs from our basic model survive in a pooling equilibria based on credible off-equilibrium beliefs, where play proceeds much as in the simpler case. Section 8 concludes.

2 Financial Expertise as a Deterrent

In our model financial expertise is the ability to efficiently and accurately process information about a financial asset under time pressure in response to an offer to trade. It can be viewed as both human capital and technological infrastructure that supports it. Again, we emphasize that it is likely financial expertise has other roles and benefits to the firms that employ experts. We highlight this particular one here to show how it leads to incentives to overinvest in expertise that can be destabilizing.

This section develops a simple bargaining model that illustrates how expertise protects a trader from opportunistic bargaining by his counterparties, and results in more favorable terms of trade even though the information acquired through expertise is not used in equilibrium. It simply acts as a threat or deterrent. We begin with a very simple setting to illustrate the intuition. At the end of the section, we discuss which aspects of the problem are without loss of generality, and which will be addressed in later sections of the paper. The bargaining game here will, in later sections, be a subgame in a model that endogenizes the choice of expertise. For the moment, the levels of expertise the players bring to the bargaining process are taken as given.

Two risk-neutral traders, denoted i and j, come together to exchange a financial asset. The asset has both a common value component, v, and a private value component. One of the two parties is assigned the role of buyer, and we will assume for the moment that this is agent j. Agent i is the seller. The buyer's valuation of the asset is $v + 2\Delta$, while the seller's valuation is simply the common value v. The private value component, Δ, is the source of gains to trade. Without it, trade would break down in this setting due to the standard "no-trade theorem." The private value could be viewed as a hedging need, unique access to a customer who is willing to overpay for the asset, or any other source of value that is not shared by all parties. The gains to trade are common knowledge to both parties, but there is uncertainty about the common value. It is either high, v_h, or low, v_l, with equal probability. Notice that $v_h - v_l$ is a natural measure of the amount of uncertainty, or volatility, in this setting. It will play an important role in bounding the equilibrium levels of expertise, and unexpected jumps in this quantity are the source of the destabilizing effects of expertise that we explore in Section 4.

We give the buyer all the bargaining power in an ultimatum game. He makes a take-it-or-leave-it offer to buy the asset at a price p. We assume, at this point, that the buyer is uninformed about the value, v, and views the two possible outcomes as equally probable. This dramatically simplifies the analysis, while still allowing us to illustrate the central tradeoffs, because it eliminates the complications that arise when the first mover in the game is privately informed, creating a signalling game. We study the more general case in Section 7 and argue that the intuition we develop for the one-sided case survives in a robust class of equilibria.

The seller can use his expertise to obtain information about the asset's value before responding to the buyer's offer. Specifically, he receives a signal, $s_i \in \{H, L\}$, that the value of the asset is v_h or v_l. The accuracy of the signal depends on expertise. Specifically, the probability that his signal is correct is $\mu_i = \frac{1}{2} + e_i$, where $e_i \in [0, \frac{1}{2}]$ denotes his expertise. The expertise is the result of investments made at an earlier stage of the game, described in the next section.

Suppose the seller's signal is uninformative ($e_i = 0$ and $\mu_i = \frac{1}{2}$). Then we have an ultimatum game with symmetric information. The buyer offers $p = E(v)$, the lowest price the seller will accept. The buyer captures the entire surplus of 2Δ, and the seller earns no surplus. Trade always takes place in equilibrium, and the agent with the higher valuation always ends up with the asset—there is efficiency in allocations.

How does expertise, $e_i > 0$, help the agent responding to an offer in this game? If he is offered the unconditional value he will turn down that price whenever his signal is high. The gains to trade are then lost half the time, and at $p = E(v)$ the buyer is overpaying whenever trade does occur because he knows the seller has seen a low signal when he accepts.

The buyer, of course, will anticipate this. One possible response would be to offer the lowest price he can, given that the seller will walk away unless he has a low signal. This price is the seller's valuation, given a low signal:

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

At this price, trade breaks down whenever the seller gets a high signal. The seller receives zero expected surplus, and the buyer captures the gains to trade with probability one half, for an expected surplus of Δ.

An alternative for the buyer is to offer a price higher than the unconditional expectation, in hopes that the seller will accept regardless of his signal. The lowest price at which the seller will always accept will be:

$$\begin{aligned} p^{**} &= E(v \mid s_i = H) \\ &= \mu_i v_h + (1-\mu_i)v_l. \end{aligned} \tag{2}$$

If the buyer offers the higher price, p^{**}, trade always occurs, and the inefficient loss of gains to trade is avoided. He must share some of the surplus with the seller, however, to achieve this. The buyer's expected surplus is

$$\begin{aligned} E(v) + 2\Delta - p^{**} &= 2\Delta - (v_h - v_l)\left(\mu_i - \frac{1}{2}\right) \\ &= 2\Delta - (v_h - v_l)e_i. \end{aligned} \tag{3}$$

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

$$\begin{aligned} E[p^{**} - E(v \mid s_i)] &= p^{**} - E(v) \\ &= (v_h - v_l)(\mu_i - \frac{1}{2}) \\ &= (v_h - v_l)e_i. \end{aligned} \tag{4}$$

Thus, the seller's expertise allows him to extract a higher price from the buyer in this situation, even though the seller does not act on his information once the offer is made.

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

$$\frac{1}{2}(2\Delta + E(v \mid s_i = L) - p^*) = \Delta, \tag{5}$$

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

It is obvious that p^* and p^{**} are the only candidate equilibrium offers, since the buyer strictly prefers a lower price, given the probability the seller accepts. The buyer's choice between these two prices will be the one that yields the higher expected payoff to him. Comparing (5) and (3), he will offer the higher price p^{**} if

$$2\Delta - (v_h - v_l)e_i \geq \Delta \tag{6}$$

or if

$$e_i \leq \frac{\Delta}{v_h - v_l}. \tag{7}$$

Remarks: The tradeoffs from the buyer's perspective in this model are straightforward. 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 (3) and (4) 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 seller's level of expertise is too high, however, condition (7) tells us that the buyer will switch to a lower offer 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, $v_h - v_l$, rises relative to the gains to trade, Δ. 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 as long as $e_i \leq \bar{e}$. Above that boundary the effects of adverse selection outweigh the gains to trade, and liquidity breaks down.

The appendix shows that exactly analogous expressions to those above hold when the first mover is a seller, and the buyer observes a signal before accepting or rejecting the offer. The same bound on expertise, (7), ensures efficient trade takes place in the trading game. The only difference is that the price required to ensure trade always takes place is the buyer's valuation given a *low* signal. Thus, the same conditions on expertise must hold under a variety of protocols. We can assume nature randomly assigns one agent to be the buyer and one to be the seller, and then the buyer always makes the ultimatum offer, or we can assume nature randomly assigns the opportunity to make the offer to either the buyer or the seller. What is important for the subsequent analysis is that at the point where agents invest in expertise, they are uncertain about whether they will be making an offer or responding to it. It is natural to think of the responder as a supplier of liquidity to the proposer, who needs liquidity because of some external opportunity or imperative. We can think, then, of intermediaries engaged in trading financial assets as sometimes in need of liquidity and sometimes being called upon to supply it on short notice.

In the game we have described to this point, traders are bargaining over a fixed surplus of 2Δ, and the only role of expertise is to increase their share of this surplus. Thus, we are *assuming* expertise has no social value, not proving it. We do this to highlight the incentives financial intermediaries who are engaged in this type of trading have to *over*invest in financial expertise by showing they do so even when it has no social value. In the actual economy, as opposed to in our abstract model, financial expertise surely does have social value. It is easy to imagine ways in which the gains to trade in our model, Δ, might be enhanced through financial expertise. Greater expertise in search could help match higher value buyers with lower value sellers. Better financial engineering could assist in identifying opportunities to more efficiently share risk or to avoid taxes. The ability to bring information to trading decisions quickly could improve price efficiency and in this way lead to better coordinated investment and operating decisions by firms. Still, if the incentives we highlight are present along with these benefits of expertise, one would expect excessive investment in expertise by firms, and, as we will go on to show, this investment will be destabilizing. Section 6 provides a simple generalization of our model that shows how the incentives we study can coexist with other benefits of expertise.

We have modeled a game where intermediaries with expertise are trading with other intermediaries with expertise. In actual financial markets much of their trade is surely with uninformed non-experts—what financial models often refer to as "noise traders." Note that the model of the trading process to this point highlights the value of expertise even when dealing with inexpert counterparties. The threat implicit in the expert's knowledge ensures price concessions when responding to an offer from an uninformed trader seeking liquidity. Of course, in the model the incentives to acquire expertise are symmetric, but it is easy to imagine that for some market participants their infrequent needs to trade in complex securities requiring expertise to evaluate would mean the marginal costs of additional investment would lead them to acquire much lower levels of expertise.

One way to think of the gains to trade in our model is that it ultimately derives from such noise traders. An intermediary identifies a third party with inelastic demand or an urgent need to trade, and then seeks liquidity from another intermediary in order to meet that third party's needs. Obviously, financial intermediaries trading in OTC markets would prefer to obtain liquidity from naive noise traders when they can, rather than from sophisticated counterparties they know will drive a harder bargain. As long as there are some times when they must resort to trading with each other when seeking or supplying liquidity, however, the deterrent role of expertise we highlight will be relevant. Hedge funds, trading desks of Wall Street firms, and institutional investors all have incentives to build expertise to deter aggressive bargaining by counterparties.

More broadly, 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 tradeoff between bargaining power gained with expertise and the increased risk of illiquidity. 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 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.

3 Investing in Expertise

It is evident from the previous section that if all traders come to the bargaining process with expertise below the bound $\bar{e} \equiv \frac{\Delta}{v_h - v_l}$ then trade is efficient: it takes place with probability one and the party with the higher value obtains the asset. In this section we consider the equilibrium choices of expertise, and provide conditions under which the unique equilibrium involves all traders investing up to this boundary. An arms race occurs. In the next section, we will allow the volatility to vary stochastically, and show that the same levels of expertise are still the equilibrium. As a result, when volatility rises suddenly, liquidity breaks down.

We now treat the trading game described above as a second stage in a two-stage game. In the first stage traders acquire expertise. 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 ($c'(e) > 0, c''(e) > 0$). At the point where they invest in expertise, agents are uncertain about their role in the trading subgame—whether they will be buying or selling, proposing a price or responding to an offer. This is intended to capture the notion that firms routinely engaged in trading in financial markets are at times seeking liquidity and at other times able to supply it. At times they have a (potential) bargaining advantage, and at other times they must respond quickly to offers from others, which puts them at a disadvantage in bargaining. The previous section showed how expertise can be viewed as a deterrent in the latter situation.

Consider agent's i's best response assuming that his counterparty is agent j, and $e_j \le \bar{e} = \frac{\Delta}{v_h - v_l}$. Then the analysis in the previous section tells us that agent i's expected payoff in any subgame where he is the buyer (or more generally the proposer) is

$$2\Delta - (v_h - v_l)e_j \tag{8}$$

and his payoff when selling is

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

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

$$\Delta + \frac{1}{2}(v_h - v_l)(e_i - e_j). \tag{10}$$

Evidently, the effect of a trader's choice of expertise is independent of that of his opponent. More expertise increases his payoff when he is a seller and has no effect on his payoff when he is a buyer. That depends on his opponent's expertise, but in a Nash equilibrium trader i takes his counterparties' actions as given. His payoff increases linearly in his own expertise up to the boundary $\bar{e}$, where it drops discontinuously because above that point the adverse selection disrupts trade. 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 seller through expertise, he loses as a buyer to the expertise of his counterparty. Trade is efficient, and the expected surplus earned by any trader ex-ante is Δ, half the total gains to trade. The only destruction of value 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 are straightforward. The expected payoff for agent i in any given trading encounter, assuming his counterparty is agent j, is:

$$\frac{1}{2}e_i(v_h - v_l)I\left(e_i \leq \frac{\Delta}{(v_h - v_l)}\right) + \frac{1}{2}\left[\Delta + (\Delta - e_j(v_h - v_l))I\left(e_j \leq \frac{\Delta}{(v_h - v_l)}\right)\right], \tag{11}$$

where $I(\cdot)$ 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 counterparty's choice of expertise, $e_j, j \neq i$. Hence, agent i's optimal investment in expertise will maximize:

$$\frac{1}{2}e_i(v_h - v_l)I\left(e_i \leq \frac{\Delta}{(v_h - v_l)}\right) - c(e_i). \tag{12}$$

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

$$c'(\hat{e}) = \frac{1}{2}(v_h - v_l), \tag{13}$$

which is the first-order condition of equation (12). 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 is unique.

Remarks: We describe the competition to accumulate expertise as an "arms race" because, as in the military setting, there is a unilateral incentive for each agent to acquire expertise in order to enforce better bargaining outcomes, but these advantages are neutralized in equilibrium by offsetting investments by the other agents. In the basic setting that we have described thus far, the marginal benefits of additional expertise do not depend on the opponents' expertise. In most military situations, this would not be the case. There, any one state's incentives to acquire additional arms falls once it has an arsenal sufficiently superior to its opponents to dictate outcomes. The benefits of additional expertise do interact with the opponents level of expertise in the model with two-sided private information we develop in Section 7, and in this respect it might be viewed as more closely conforming to an “arms race” in the classic sense.

4 The Destabilizing Effects of Expertise

To this point, we have considered only a setting where investments in expertise are wasteful, but have no consequences for trade or market liquidity. This is analogous to an arms race that achieves mutual deterrence, and never leads to a war.

Consider, however, that the bound on expertise that ensures efficient trade in the bargaining subgame is decreasing in $v_h - v_l$. Suppose firms invest in expertise in anticipation of the benefits to them under normal circumstances of relatively low volatility. Then, any jump in volatility will lead to breakdowns in trade or illiquidity due to adverse selection, if firms cannot costlessly and immediately adjust their expertise in response. We provide conditions in this section under which this is the equilibrium outcome.

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 π. 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.

Now, consider the same steps as in the previous section when volatility is stochastic. The expected periodic payoff for agent i in the trading subgame is given by:

$$\begin{aligned} &\frac{1}{2}\left[(1-\pi)e_i\sigma I\left(e_i \leq \frac{\Delta}{\sigma}\right) + \pi e_i\theta\sigma I\left(e_i \leq \frac{\Delta}{\theta\sigma}\right)\right] \\ &\quad + \quad \frac{1}{2}\left[\Delta + (1-\pi)(\Delta - e_j\sigma)I\left(e_j \leq \frac{\Delta}{\sigma)}\right) + \pi(\Delta - e_j\theta\sigma)I\left(e_j \leq \frac{\Delta}{\theta\sigma}\right)\right]. \end{aligned} \tag{14}$$

As before, the first term represents the expected payoff for agent i when he is a responder (seller) and the second term in brackets represents his expected payoff when he is a proposer (buyer). 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

$$\frac{1}{2}\left[(1-\pi)e_i\sigma I\left(e_i \leq \frac{\Delta}{\sigma}\right) + \pi e_i \theta\sigma I\left(e_i \leq \frac{\Delta}{\theta\sigma}\right)\right] - c(e_i). \tag{15}$$

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: $\bar{\bar{e}} \equiv \frac{\Delta}{\theta\sigma}$,

3. the level of expertise that satisfies the first-order condition in the low-volatility regime: $\hat{e}_l$ such that,
$$\frac{1}{2}(1-\pi)\sigma = c'(\hat{e}_l), \tag{16}$$

4. the level of expertise level that satisfies the first-order condition in the high-volatility regime: $\hat{e}_h$ such that,
$$\frac{1}{2}\left[(1-\pi)\sigma + \pi\theta\sigma\right] = c'(\hat{e}_h). \tag{17}$$

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

Proposition 1 *Suppose that*
$$c'\left(\frac{\Delta}{\sigma}\right) < \frac{\sigma}{2}, \tag{18}$$
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 π is then given by:

$$\pi^\theta = \min\left\{1 - \frac{2}{\sigma}c'\left(\frac{\Delta}{\sigma}\right), \frac{\left(1-\frac{1}{\theta}\right)\Delta - 2\left[c\left(\frac{\Delta}{\sigma}\right) - c\left(\frac{\Delta}{\theta\sigma}\right)\right]}{\left(2-\frac{1}{\theta}\right)\Delta}\right\}. \tag{19}$$

Proof: Provided in the appendix.

The intuition behind the proof is that if π is less than the first term under the $\min\{\cdot,\cdot\}$ operator in (19), 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 under low volatility.

Remarks: Our model predicts that financial intermediaries might find it 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 buyer becomes unable to make an offer that would be simultaneously viable for him and always accepted by the seller. In the high-volatility regime trade breaks down whenever the responder observes a high signal, which occurs half of the time. If the probability of the high-volatility regime is small enough, however, 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.

Of course, it is often the case that decisions that are good for one state might be bad for another.

Similarly, information theorists have long understood that although pooling can be sustained, despite adverse selection, in settings where the differences between outcomes are small, trade will break down when this difference is large. What is novel in our model is that the degree of adverse selection is a choice. Both the acquisition of expertise and the limits are endogenous responses. The benefit of becoming informed is that, when called upon to supply liquidity, the supplier's share of the surplus stemming from his counterparty's private value is increasing in the supplier's expertise. The cost of becoming too informed is the increasing risk that, as the asymmetric information problem worsens, the counterparty will only offer the lemons price, which leaves the liquidity supplier with zero surplus. Large liquidity suppliers might want to appear informed to their counterparties since the implicit threat improves their bargaining position. This is the mechanisms that motivates the acquisition of expertise. On the other hand, the same intermediaries might want to avoid appearing to be too informed relative to their counterparties, or else traders will avoid them. That is the mechanism that constrains expertise in the model. Facing this tradeoff, intermediaries acquire the capacity to become informed, even though it puts their business at risk.

These tradeoffs make the relationship between expertise, market instability, and uncertainty ambiguous, but by considering them we might still gain some insights into why liquidity crises emerged in particular sectors of the financial industry. On one hand, high levels of uncertainty, $(v_h - v_l)$, make expertise more valuable as a threat at the margin, as is apparent from equation (10). On the other hand, the very power of expertise with higher levels of uncertainty makes the adverse selection more problematic, so that the bound on the equilibrium level of expertise, in (7), is tighter with more uncertainty. Note that when uncertainty is low investment in expertise will be limited to the technological cost of greater investment, captured in the model by the marginal cost condition (13), and the level of expertise will be below the threshold at which adverse selection interferes with trade. When this is the case, a jump in volatility must be much larger to trigger a drop in liquidity. For an arms race in expertise to lead to breakdowns in liquidity, therefore, we must have two forces at work. Valuation must be sufficiently complex and uncertain to warrant investments in expertise to begin with, and to raise the level of investment to the point that liquidity is at risk. Second, volatility or uncertainty must jump in response to an exogenous shock. Recent financial crises appear to share the required characteristics. For example, the LTCM default and the crisis in the mortgage-backed and credit default swap markets all involved new strategies, technologies, or types of securities where the expert knowledge of some traders might have given financial firms a big advantage. They also involved surprises that raised uncertainty about intrinsic valuations: the Russian default and a national fall in housing prices.

In this model, the choice of expertise is made at an initial date, before the volatility state is known. Our results then highlight the fact that expertise becomes costly for firms when, for exogenous reasons, volatility increases. In the actual financial industry, of course, firms can and do adjust their "expertise" in response to changing conditions, as the layoffs following the recent financial crisis make very clear. The incentives we focus on would presumably survive as long as there were adjustment costs that would keep firms' response from being complete and instantaneous.

In this respect, the empirical implications of our model stand in marked contrast to other explanations for the value of financial expertise. Typically, other views of expertise would imply that it has greater value when more uncertainty is present. For example, more uncertainty would seem to create more need to reallocate risk, and greater opportunities for financial firms to create value by facilitating this process. Indeed, it is often said that Wall Street "makes money off of volatility." Yet we consistently see dramatic contractions in hiring and employment of professional employees in the financial sector following financial crises. These are also periods with both abnormally high volatility and the destruction of liquidity, despite apparent benefits to trade and a greater need to reallocate risk.

Our model offers a way to reconcile these seemly contradictory phenomena. The one theoretically coherent explanation for an unwillingness to trade in periods of high volatility is increased adverse selection. Our model explains how expertise might exacerbate this problem. At the same time, the experts in our model do profit from volatility under normal conditions. Without some uncertainty in our model expertise has no value in trading interactions. Accordingly, in light of the incentives our model highlights, it should not be surprising that financial firms build expertise through periods of moderate volatility, knowing this puts their business in jeopardy should uncertainty suddenly increase, and then contract in response to shocks that raise uncertainty.

The breakdown in trade triggered by a jump in volatility is due to the increase in the importance of the liquidity supplier's private information in the presence of more uncertainty. It may seem to some readers implausible that the liquidity problems we observe during financial crises could be due to financial intermediaries knowing too much, when it appeared to many observers they the large financial intermediaries were themselves surprised and mystified by what was happening. Keep in mind, however, that the experts in our model *are* more mystified when volatility jumps. There is more uncertainty in the environment. They are just less mystified than their counterparties.

5 Parameterization

In this section we parameterize our model, in order to better illustrate its implications. The earlier sections developed the model as a two-stage game with one trading encounter. This illustrates the central qualitative tradeoffs, but the model is quantitatively more sensible if we view investments in expertise as made in anticipation of many trading interactions.

Accordingly, we assume there is a continuum of risk-neutral and infinitely-lived financial intermediaries or traders. In each period t, $t = 1, \ldots, \infty$, trader i meets a random counterparty drawn from the set of potential traders, and they bargain through the ultimatum game described in earlier sections. When they meet, agent i is assigned the role of buyer (proposer) or seller (responder) with equal probability, and his counterparty assumes the other role. Nature then determines the volatility regime, low with probability $1 - \pi$ or high with probability π. This is common knowledge to the traders. The common value, v, is drawn independently through time. At $t = 0$ trader i can invest resources, $c(e_i)$, to acquire in financial expertise e_i, which is fixed through time. The expertise is known to all parties at all times. Trading history, however, is anonymous to abstract from the effects of reputation building and the complications this would create in the game. Thus, a specific trader knows in any given encounter if he is dealing with a major investment bank or a municipal pension fund. He does not know the outcomes of his counterparty's recent trades. Future expected payoffs are discounted at rate δ. This setting preserves the simplicity of the two-stage game, while allowing for more reasonable relative magnitudes of initial investment and periodic trading profits.

We specify the cost $c(e)$ of acquiring a level of expertise e as given by $c(e) = \frac{\kappa}{2}e^2$. In this case, the threshold π^θ becomes:

$$\pi^\theta = \min\left\{1 - 2(1-\delta)\frac{\kappa\Delta}{\sigma^2}, \frac{\left(1-\frac{1}{\theta}\right) - (1-\delta)\left(1-\frac{1}{\theta^2}\right)\kappa\frac{\Delta}{\sigma^2}}{\left(2-\frac{1}{\theta}\right)}\right\}. \tag{20}$$

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

$$\frac{\kappa\Delta}{\sigma^2} < \min\left\{\frac{1-\pi}{2(1-\delta)}, \frac{1-2\pi-\frac{(1-\pi)}{\theta}}{(1-\delta)\left(1-\frac{1}{\theta^2}\right)}\right\}. \tag{21}$$

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

Figure 1 plots the maximum probability for the high-volatility regime, π^θ, that supports the arms-race equilibrium with trade breakdowns as a function of the magnitude of the jump, θ. 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 π^θ and θ is increasing in this figure because a higher θ increases the differential in payoffs between $\bar{e}$ and $\bar{\bar{e}}$, in the low volatility regime, at a higher rate than the differential in costs of expertise. Essentially, when θ 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 Δ is allowed to vary. When Δ is small enough for the inequality in (21) to hold ($\Delta < 3.55$), the equilibrium level of expertise is equal to $\bar{e}$, which is increasing in Δ. Once Δ becomes large enough, however, and (21) is violated ($\Delta \geq 3.55$), expertise drops discretely from $\bar{e} = \frac{\Delta}{\sigma}$ to $\bar{\bar{e}} = \frac{\Delta}{\theta\sigma}$, which is also increasing in Δ 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.

Remarks: Note that to keep the model tractable, and avoid having to deal with an extremely complicated dynamic game, we have specified that trading is anonymous so that there is no opportunity for building a reputation. This is clearly an important limitation. Professional participants in OTC markets surely do differ in the reputations, as well as in the expertise they bring to bear in their dealings with others. First, we note that there is nothing "disreputable" in what the traders in our model are doing. They are simply bargaining. In equilibrium, nobody is misled or exploited on average. It is also not at all clear in which direction allowing for reputation would lead. On one hand, building a reputation for tough bargaining, even at the risk of losing gains to trade, has a benefit in repeated interactions much like expertise in our model, and would serve to exacerbate the risk of periodic breakdowns in liquidity. On the other hand, a reputation for fair dealing would mitigate the need for, and value of, expertise as a deterrent.

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 (14) 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 $\widetilde{e}$ ($> \bar{e}$) that satisfies:

$$\frac{1}{1-\delta}r'(\widetilde{e}) = c'(\widetilde{e}). \tag{22}$$

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 $\frac{1}{1-\delta}[r(\widetilde{e}) - r(\bar{e})]$ 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 $[c(\bar{e}) - c(\widetilde{e})]$. 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,

$$\begin{aligned} \psi_L^L &\equiv \Pr\{s_s = L \mid s_b = L\} \\ &= \mu_b\mu_s + (1-\mu_b)(1-\mu_s) \end{aligned} \tag{23}$$

$$\begin{aligned} \phi_{LL}^l &\equiv \Pr\{v = v_l \mid s_b = L, s_s = L\} \\ &= \frac{\mu_b\mu_s}{\mu_b\mu_s + (1-\mu_b)(1-\mu_s)}, \end{aligned} \tag{24}$$

and for the high-signal buyer,

$$\begin{aligned} \psi_L^H &= \Pr\{s_s = L \mid s_b = H\} \\ &= \mu_b(1-\mu_s) + \mu_s(1-\mu_b) \end{aligned} \tag{25}$$

$$\begin{aligned} \phi_{HL}^l &= \Pr\{v = v_l \mid s_b = H, s_s = L\} \\ &= \frac{\mu_s(1-\mu_b)}{\mu_b(1-\mu_s) + \mu_s(1-\mu_b)}. \end{aligned} \tag{26}$$

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 2:

$$p^{**} = \mu_s v_h + (1 - \mu_s) v_l. \tag{27}$$

- 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 (4) is $(v_h - v_l)\left(\mu_s - \frac{1}{2}\right)$. 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:

$$\begin{aligned} E(v \mid s_b = L) + 2\Delta - p^{**} &= 2\Delta + (v_h - v_l)(1 - \mu_b - \mu_s) \\ &= 2\Delta - (v_h - v_l)(e_b + e_s). \end{aligned} \tag{28}$$

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 (3). 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, ψ_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:

$$\begin{aligned} &\psi_L^L[E(v \mid s_b = L, s_s = L) + 2\Delta - p^*] \\ &\quad = \psi_L^L[(1 - \phi_{LL}^l)v_h + \phi_{LL}^l v_l + 2\Delta - (1 - \mu_s)v_h - \mu_s v_l] \\ &\quad = \psi_L^L[2\Delta - (v_h - v_l)(\phi_{LL}^l - \mu_s)]. \end{aligned} \tag{29}$$

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 Δ, as in the case of an uninformed buyer, equation (5).

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

$$2\Delta + (v_h - v_l)(1 - \mu_b - \mu_s) \geq \psi_L^L[2\Delta - (v_h - v_l)(\phi_{LL}^l - \mu_s)]. \tag{30}$$

Substituting for the conditional probabilities from equations (23) and (24), and for the signal precisions, $\mu_i = \frac{1}{2} + e_i$, we find after some simplification that the condition above is equivalent to:

$$\frac{2\Delta}{v_h - v_l} \geq \frac{\frac{e_b}{2} + e_s + 2e_b e_s^2}{\frac{1}{2} - 2e_b e_s}. \tag{31}$$

Note that as expertise rises from zero to its maximum value of $\frac{1}{2}$ the numerator on the right-hand side of condition (31) 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 (7) when the buyer is uninformed.

The next lemma shows that the incentive compatibility constraint in condition (31) 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 (31) is satisfied, it is also incentive compatible for the high-signal buyer.*

Also, condition (31) 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 (31) as:

$$2\Delta - \frac{\frac{e_b}{2} + e_s + 2e_b e_s^2}{\frac{1}{2} - 2e_b e_s}(v_h - v_l) \geq 0, \tag{32}$$

and since

$$\frac{\frac{e_b}{2} + e_s + 2e_b e_s^2}{\frac{1}{2} - 2e_b e_s} = \frac{e_b + 2e_s + 4e_b e_s^2}{1 - 4e_b e_s} \geq e_b + 2e_s + 4e_b e_s^2 \geq e_b + e_s, \tag{33}$$

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 (31). 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 $E(v \mid s_b = H)$ or $E(v \mid s_b = L)$ with equal probability, or

$$2\Delta + (v_h - v_l)\left(\frac{1-\mu_s-\mu_b}{2} + \frac{\mu_b-\mu_s}{2}\right) = 2\Delta - (v_h - v_l)e_s. \tag{34}$$

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

$$(v_h - v_l)e_s. \tag{35}$$

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

$$\Delta + \frac{1}{2}(v_h - v_l)(e_i - e_j). \tag{36}$$

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. Notice, however, that for each agent the bound on expertise differs from the one derived earlier in that it now depends on the opponent's level of expertise. For example, taking the seller's expertise level e_s as given, efficient trade will be possible in equilibrium as long as the buyer's expertise level satisfies:

$$e_b \leq \frac{\frac{\Delta}{v_h - v_l} - e_s}{\frac{1}{2} + 2e_s^2 + \frac{4\Delta}{v_h - v_l} e_s}. \tag{37}$$

For a pooling equilibrium to exist, the buyer cannot be tempted to deviate from the pooling offer p^{**} after receiving a low signal. But the expected payoff the low-value buyer collects from playing the pooling strategy will decrease in the seller's expertise (which increases the pooling price) and also in his own expertise (which makes him even more sure that he will end up buying a low-value asset).

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.[2] 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 (31), which ensures pooling is an equilibrium with agnostic beliefs. The

[2] 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.

proof of the proposition is provided in appendix.

Proposition 2 *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*

$$\frac{2\Delta}{v_h - v_l} \geq \frac{e_s + e_b}{\frac{1}{2} - 2e_s e_b}. \tag{38}$$

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 $(v_h - v_l)$, 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.[3] 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

[3]This restriction can be motivated by a strong form of forward induction closely related to the updating rule imposed in Grossman and Perry (1986).

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.,

$$e^* = \frac{\sigma}{4\Delta}\left[\sqrt{1+\frac{4\Delta^2}{\sigma^2}}-1\right], \tag{39}$$

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 (38) in Proposition 2, a perfect sequential equilibrium exists and is unique in a sufficiently small neighborhood of the symmetric expertise level e^* where the boundary in (38) 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 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 3 *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* $p^h \equiv E\left[v|s_s = H, s_b = H\right]$*.*
- *The low type buyer offers* $p^l \equiv E\left[v|s_s = L, s_b = L\right]$*.*
- *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* $2\Delta\left[\frac{1}{4} - e_b e_s\right]$.

To summarize, when the condition in Proposition 2 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 3, $\psi_L^H \Delta$ 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 2 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

Symmetry of the trading game: The arguments in the text derive expressions 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 1:

If

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

then

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

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

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

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

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

and

$$\frac{1}{2}\left[(1-\pi)\sigma + \pi\theta\sigma\right] > c'(\bar{\bar{e}}). \tag{A9}$$

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 $\bar{\bar{e}}$ which maximizes the payoff without triggering breakdowns in trade in the high-volatility regime.

Comparing payoffs from the two levels of expertise, $\bar{e}$ will be preferred if:

$$\frac{1}{2}(1-\pi)\bar{e}\sigma - c(\bar{e}) \geq \frac{1}{2}\left[(1-\pi)\bar{\bar{e}}\sigma + \pi\bar{\bar{e}}\theta\sigma\right] - c(\bar{\bar{e}}). \tag{A10}$$

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 (18) in the Proposition. Thus, even if we allow for a small but positive probability π 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 yields:

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

which can be written as:

$$\frac{\left[\bar{e}-\bar{\bar{e}}\right]\sigma - 2\left[c(\bar{e})-c(\bar{\bar{e}})\right]}{\left[\bar{e}+(\theta-1)\bar{\bar{e}}\right]\sigma} \geq \pi. \tag{A12}$$

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

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

and

$$\frac{1}{2}(1-\pi)\bar{e}\sigma - c(\bar{e}) \geq \frac{1}{2}\left[(1-\pi)\bar{\bar{e}}\sigma + \pi\bar{\bar{e}}\theta\sigma\right] - c(\bar{\bar{e}}). \tag{A14}$$

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

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

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

which, when substituting for the values of $\bar{e}$ and $\bar{\bar{e}}$, is equal to expression (19) 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

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

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 Δ 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 ϕ_{HL}^l is less than or greater than μ_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 (25) and (26) for the conditional probabilities, rewriting the precisions in terms of expertise and simplifying then yields:

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

The above will never bind if pooling is incentive compatible for the low-signal buyer. Comparison of (A19) with the IC constraint for the low-signal type, (31), reveals that for $0 < e_s, e_b < \frac{1}{2}$, the denominator of (31) is always lower, and the numerator is always higher, than for (A19).∎

Proof of Proposition 2:

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 $E\left[v|s_s = L, s_b = L\right]$. 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:

$$2\Delta + E\left[v|s_b = L\right] - p^{**} \geq \psi_L^L 2\Delta, \tag{A20}$$

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) $E\left[v|s_s = L, s_b = L\right]$. 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 $E\left[v|s_s = L, s_b = L\right]$ 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 $E\left[v|s_s = L, s_b = L\right]$ 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 3 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 $E\left[v|s_s=H,s_b=H\right]$. If $p^h \in \left(E\left[v|s_s=H,s_b=L\right], E\left[v|s_s=H,s_b=H\right]\right)$, 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 $E\left[v|s_s=L,s_b=H\right]$ when his signal is low and $E\left[v|s_s=H,s_b=H\right]$ 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 $E\left[v|s_s=H,s_b=L\right]=E\left[v|s_s=L,s_b=H\right]$ at (e^*,e^*). Thus, p^h must be either $E\left[v|s_s=H,s_b=H\right]$ or $E\left[v|s_s=L,s_b=H\right]$. The buyer will prefer to make an offer of $E\left[v|s_s=H,s_b=H\right]$ whenever

$$1+E\left[v|s_b=H\right]-E\left[v|s_s=H,s_b=H\right]>\psi_H^L. \tag{A21}$$

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

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

which holds for all $(v_h-v_l)>0$. Hence, the buyer will prefer $p^h=E\left[v|s_s=H,s_b=H\right]$ in the neighborhood around (e^*,e^*). Since the high type seller can reject any offer below $E\left[v|s_s=H,s_b=H\right]$ 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 $p^{l'} \in \left(E\left[v|s_s=L,s_b=L\right], E\left[v|s_s=H,s_b=L\right]\right)$. The high type seller will reject, regardless of his beliefs about the seller's type. Now, for $p^{l'} \in \left(E\left[v|s_s=H,s_b=L\right], E\left[v|s_s=H\right]\right)$, 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 α_h as the probability that the high type seller accepts $p^{l'}$, we need:

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

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 α_h gives a payoff to the low type buyer who offers $p^{l'}$ of:

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

while adhering to the equilibrium strategy of offering p^l gives a payoff of ψ_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. Deviations to prices above $E\left[v|s_s = H\right]$ cannot come from a low type buyer even if both seller types accept. Around (e^*, e^*), the buyer would prefer to adhere to the low offer p^l than deviate to $E\left[v|s_s = H\right]$. Thus, the seller can credibly commit to reject 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 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 $p^l = E\left[v|s_s = L, s_b = L\right]$. 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 $E\left[v|s_s = H\right]$ 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 $p^h = E\left[v|s_s = H, s_b = H\right]$. Hence, in order to establish uniqueness, we need to consider all sequential equilibria where the low type offers $p^l > E\left[v|s_s = L, s_b = L\right]$ or the high type offers p^h with probability less than one. First, consider any sequential equilibrium where the low type offers $p^l > E\left[v|s_s = L, s_b = L\right]$ (or the low type offers $p^l = E\left[v|s_s = L, s_b = L\right]$ but the low type seller mixes over accepting or rejecting p^l). Consider an off-equilibrium offer infinitesimally above $E\left[v|s_s = L, s_b = L\right]$. 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^*):

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

Suppose 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 class of equilibria to check. There may 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:

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

The value for α_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 α_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 ψ_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 $\frac{1}{4} - e_b e_s$. ∎

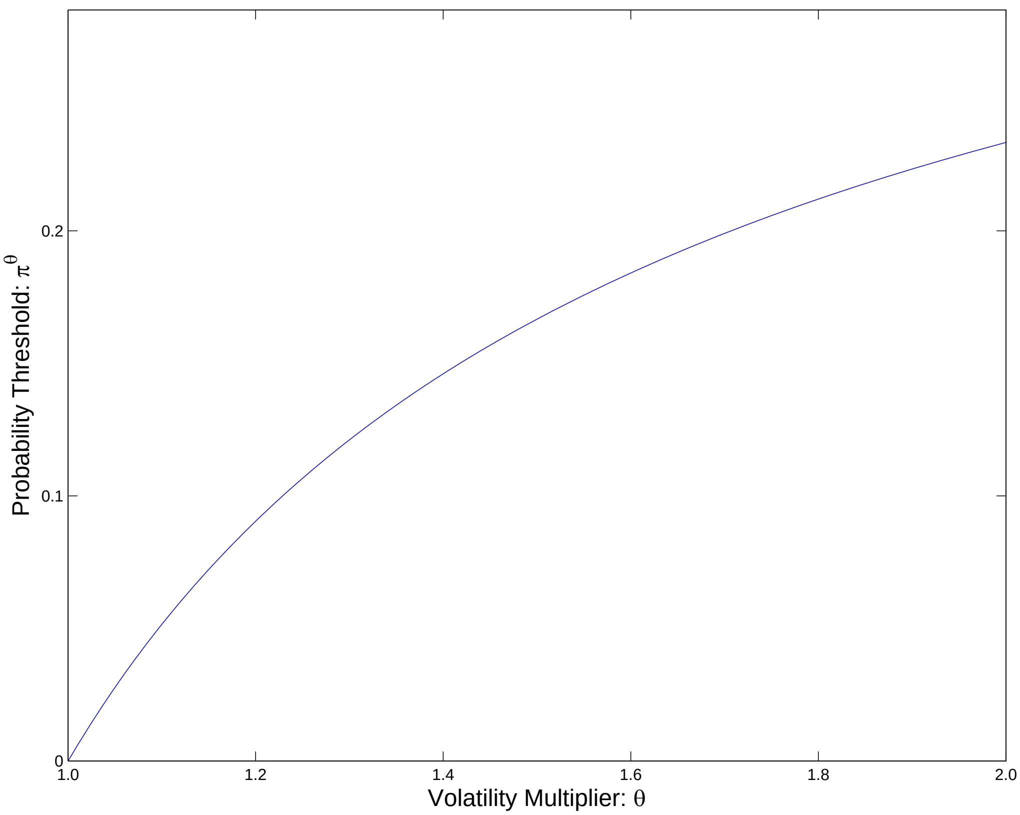

Figure 1: Bounds on π. The plot shows the maximum value of the probability of the high-volatility regime π, against the increase in the volatility θ. For values of π below this bound, agents in the model invest in expertise to the maximum level, $\bar{e}$, even though this leads to breakdowns in trade when the high-volatility regime occurs. Figure is generated using a discount rate $\delta = 0.9$, ex-ante gain to trade $\Delta = 0.2$, a cost parameter $\kappa = 10$, and a low volatility $\sigma = 1$.

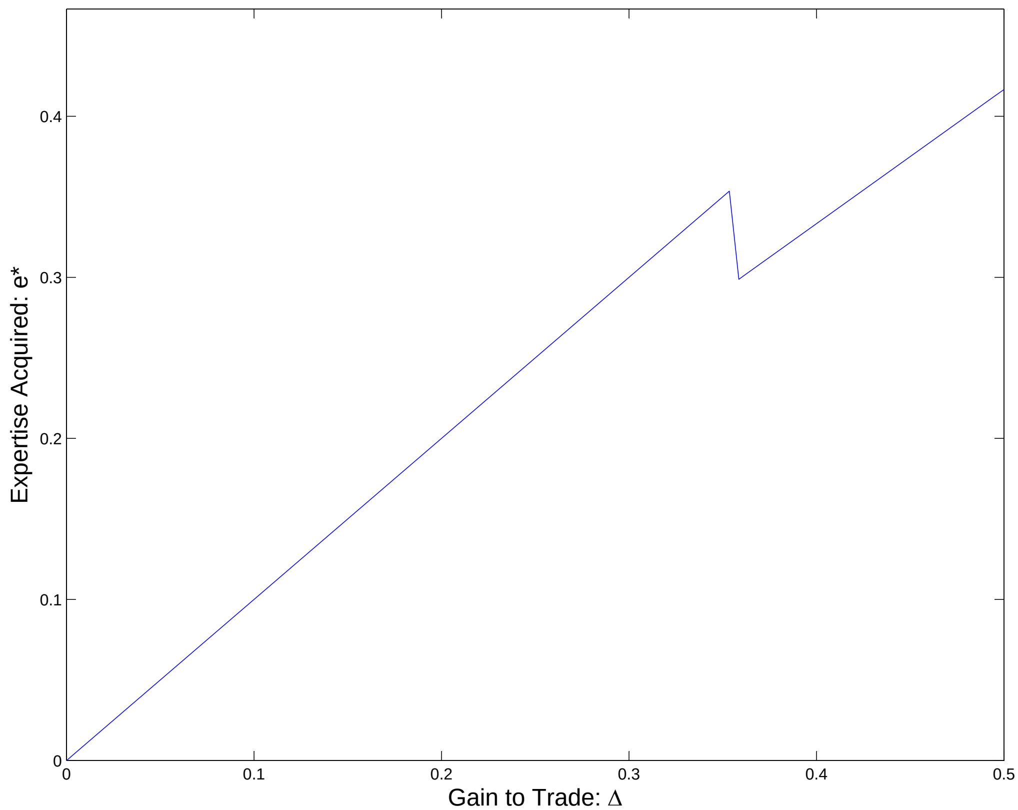

Figure 2: Expertise as a function of ex-ante gain to trade Δ. The plot shows the relationship between the equilibrium level of expertise and the ex-ante gain to trade. Figure is generated using a discount rate $\delta = 0.9$, a cost parameter $\kappa = 10$, a low volatility $\sigma = 1$, a jump in volatility $\theta = 1.2$, and a probability of such jump $\pi = 0.05$.