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Information Revelation and Market Incompleteness[†]

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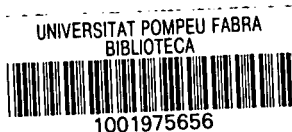
Abstract

This paper shows that the presence of private information in an economy can be a source of market incompleteness even when it is feasible to issue a set of securities that completely eliminates the informational asymmetries in equilibrium. We analyze a simple security design model in which a volume maximizing futures exchange chooses not only the characteristics of each individual contract but also the number of contracts. Agents have rational expectations and differ in information, endowments and, possibly, attitudes toward risk. The emergence of complete or incomplete markets in equilibrium depends on whether the *adverse selection effect* is stronger or weaker than the *Hirshleifer effect*, as new securities are issued and prices reveal more information. When the Hirshleifer effect dominates, the exchange chooses an incomplete set of financial contracts, and the equilibrium price is partially revealing.

1. Introduction

The eighties witnessed the development of an extensive literature on the existence and characterization of equilibrium in economies with incomplete financial markets (see the survey articles by Cass (1992), Duffie (1992), Geanakoplos (1990), and Magill and Shafer (1991)). In this literature, the set of financial instruments is exogenously given and assumed to be incomplete. There is now emerging a growing body of research on financial innovation and security design whose main goal is to endogenize the financial structure (for an overview, see Allen and Gale (1994) and Duffie and Rahi (1995)). This literature has identified several motives for innovation, such as the provision of new risk sharing opportunities, the desire to reduce transaction costs or increase liquidity, and the need to circumvent regulations. It has also studied the incentives of various types of innovators, from investment banks securitizing a pool of illiquid assets to exchanges introducing futures and options contracts.

Much of the security design literature takes the number of assets as given, focusing on characterizing an incomplete financial structure, rather than explaining the incompleteness itself. The papers by Demange and Laroque (1995a, 1995b), Duffie and Jackson (1989), Hara (1992), Ōhashi (1992, 1994), and Rahi (1995, 1996) fall in this category. Papers that do endogenize the number of assets do so by postulating an exogenously given cost of setting up or operating markets (Allen and Gale (1989, 1990, 1991), Cuny (1993), Pesendorfer (1995)). While market frictions and transaction costs are probably an important element in accounting for incomplete markets, taking them as exogenously given does not lead to a fully satisfactory explanation.

In this paper we eschew the frictions-based approach altogether, and argue that the presence of private information in an economy can be another source of market incompleteness. The connection between security design, asymmetric information, and trading in financial markets is a subtle one, and it is important to isolate its various facets. The efficacy of security markets in aggregating and transmitting private information depends on the characteristics of the financial structure, and especially on the number of tradable assets. Indeed, within the rational expectations paradigm, informational differences disappear in equilibrium (generically) when the price vector has a higher dimensionality than the space of private signals (see Radner (1979), Allen (1986)), *i.e.* when the number of securities is large enough.

At first glance, one would expect that from the point of view of information aggregation, a greater number of assets would be desirable, and hence created (given the right incentives).

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There is a strong case for this in a production economy in which privately held information impacts on real investment decisions. Rahi (1995) has analyzed a model which supports this intuition, although he is only concerned with the design of a given number of assets. In a pure exchange setting, one might still expect a higher volume of trade the lower the degree of informational asymmetry in equilibrium (Wang (1994)). In fact, a prevailing intuition in finance is that financial markets characterized by private information are much like the market for lemons *a la* Akerlof (1970). Less informed traders may be unwilling to trade, raising the possibility of even a market breakdown (Bhattacharya, Reny, and Spiegel (1995)). In the security design context, Rahi (1996) has shown that a privately informed entrepreneur, facing rational uninformed outside investors, issues a security that is not sensitive to her information, thus completely eliminating the adverse selection problem. (See also DeMarzo and Duffie (1995).)

However, there is another aspect of information revelation and trade which is been largely neglected in the finance literature. Markets prices may reveal "too much" information,[1] insofar as early resolution of uncertainty reduces the market's insurance capabilities: the more the information revealed by prices, the smaller is the amount of risk that remains to be shared in the market. Hirshleifer (1971) was the first to point out this fundamental aspect of the economics of information. We build on Hirshleifer's insight to identify conditions under which the solution to the security design problem involves incomplete markets. The choice of financial structure is determined by the amount of information revealed by prices via the interplay of the *adverse selection effect* and the *Hirshleifer effect*. In general, while the adverse selection effect makes it desirable to have a higher number of securities, and consequently lesser informational asymmetry across traders, the Hirshleifer effect favors a reduction in the number of assets, since the more is the information revealed, the greater are the insurance opportunities lost.

To formalize the discussion, we analyze a simple model in which agents differ in information, endowments, and possibly attitudes toward risk, but, because of the rational expectations assumption, may have homogeneous beliefs at the time of trade, depending on whether equilibrium prices are fully revealing or not. Given this *ex ante* heterogeneity, there is an incentive to set up an exchange on which agents can share their risks. In our model, the security designer is a volume maximizing futures exchange. This type of objective function is not new in the literature (see, for example, Duffie and Jackson (1989) and Rahi (1995))

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[1] For a welfare analysis of rational expectations equilibria, see Laffont (1985).

and we believe it a good assumption when confronted with practices in actual markets. For a more detailed discussion, see Black (1986) and Duffie and Rahi (1995). Saloner's (1984) model of the microstructure of futures markets, in which Bertrand competition in brokerage fees between floor traders leads to commonly set commission rates and equal shares of the trading volume, lends theoretical support for the volume maximizing objective.

We model uncertainty in our economy by assuming the existence of several risk factors that affect agents' endowments. Agents are assumed to be rational in the von Neumann-Morgenstern sense. We introduce asymmetric information by assuming that a fraction of agents ("informed" traders) have access to a private signal that is correlated with some of the risk factors. We also assume that each agent privately observes the "size" (in a sense to be made precise) of his hedging needs. To summarize the informational structure: each agent has private information on the size of his hedging needs; the informed traders have superior information on the risk factors; everyone has rational expectations.

Given this set up, we can be more specific regarding the meaning of our hypothesis and the main result. The exchange can choose not only the characteristics of each individual security it issues, but also the number of securities. The greater the number of securities introduced, the more precise is the information conveyed by prices. This produces two opposing effects on the level of activity in the futures markets. On the one hand, there is (a reduction in) the adverse selection effect. Since the uninformed agents know the informed agents' private information better, they are more willing to participate in the market to share their initial risks. On the other hand, there is the Hirshleifer effect: the more the information revealed by prices, the smaller is the provision of insurance by markets. As more information is revealed, the riskiness of agents' endowments fall. Since the portion of risk that has already been revealed by prices cannot be traded away in the market, the size of the risk that can be shared is smaller. In the limit case in which the informed traders' private information is perfect (i.e. they know the true state that will occur in the future) and fully revealed by prices, no risk can be shared in the market. This was Hirshleifer's original example.

A way to measure the extent to which markets are used to share risk is to compute trading volume. In this sense, when the exchange maximizes trading volume, it is also maximizing the level of activity, or the provision of insurance, in the market. When the Hirshleifer effect outweighs the adverse selection effect, an incomplete financial structure entails a higher volume of trade (in a partially revealing equilibrium), than would be the

case with complete markets (and full revelation).

Before we proceed to formalize our argument, we would like to mention one earlier attempt to obtain incomplete markets endogenously in an economy with asymmetric information. Ōhashi (1995) provides an example of a futures exchange choosing a particular index contract in preference to a complete set of assets. He argues that full revelation in the latter case leads to a lower amount of speculative trade because of the symmetrization of agents' information in equilibrium. It appears to us that Ōhashi 's result depends crucially on the presence of noise traders (who are responsible for partial revelation in the case of a single contract). Indeed, homogeneity of beliefs should lead to a higher volume of trade due to the absence of adverse selection. Irrational noise traders are immune to the adverse selection effect. As far as speculative trade is concerned, it is well known that trade on the basis of informational differences alone is not viable (Milgrom and Stokey (1982)).

The rest of the paper is organized as follows. In Section 2 we set up the model. In Section 3 we compute the equilibrium for the case in which the exchange chooses a single futures contract which is an index of the risk factors. We study the complete markets case, with a contract corresponding to each factor, in Section 4. Section 5 is dedicated to comparing trading volume in the two economies and to precisely stating the conditions under which the exchange is better off issuing a single index contract. Finally, we reserve Section 7 for conclusions and for a discussion of some extensions of our model.

2. The Model

We use the exponential-normal framework described in the survey article by Duffie and Rahi (1995). The setting is a single-good economy with uncertainty and two types of asymmetrically informed agents with risky endowments. These agents have access to (possibly incomplete) futures markets that allow some risk-sharing and aggregation of information. The sequence of events is as follows: At the *ex ante* stage the collection of tradable futures contracts is determined by a futures exchange. At the *interim* stage agents observe their private signals and trade the available securities in a competitive rational expectations equilibrium. Finally, at the *ex post* stage, all uncertainty is resolved, the futures contracts are settled, and agents consume.

A trader of type i has a von Neumann-Morgenstern utility function with constant absolute risk aversion r_i. With this assumption, traders of a particular type can be aggregated into a representative agent. Therefore, we will henceforth refer to a type i agent simply as

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agent i. Let[2] $z := (z_1, z_2)^\top$ and $x := (x_1, x_2)^\top$ be independent normal random vectors,[3] with

$$z \sim N(0, I) \quad \text{and} \quad x \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho_x \\ \rho_x & 1 \end{pmatrix}\right]. \tag{1}$$

The initial endowment of agent i is $e_i := x_i k_i^\top z$, where $k_i := (k_{i1}, k_{i2})^\top$ is a coefficient vector in $\mathbb{R}^2$. Here x_i, assumed to be (privately) known to agent i at the time of trading, can be thought of as the size of agent i's hedging needs, and z an orthonormal basis for the agents' (normalized) endowments. By an appropriate choice of units we can normalize the variance of the x_i's to be one, so that ρ_x is their correlation coefficient. In addition to x_1 agent 1 observes a normally distributed private signal s correlated with the second risk factor z_2 (and independent of all other random variables).[4] We can take the signal s to be standard normal without loss of generality, and write

$$z_2 = \rho s + y, \tag{2}$$

where ρ is the correlation coefficient between z_2 and s, and y is a residual uncorrelated with s.

Given these primitives, we consider two different financial structures. In the first, the exchange issues a single index future contract that includes both risk factors, while in the second the exchange issues two sigled-factor securities. In the next two sections we separately analyze the equilibrium in each of these financial structures.

3. The One-Asset Economy

Suppose there is a single index futures contract with payoff f:

$$f = a^\top z + \epsilon, \tag{3}$$

where $a := (a_1, a_2) \in \mathbb{R}^2$, with $\|a\| = 1$, and ϵ is a normally distributed mean zero extraneous noise term independent of all other random variables. The norm condition on

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[2] Matrices, vectors, and vector-valued random variables are distinguished by boldface type. The symbol $^\top$ denotes transpose.

[3] All random variables are defined on a fixed probability space $(\Omega, \mathcal{F}, P)$. All normally distributed random variables belong to a linear space $\mathcal{N}$ of joint normally distributed random variables on Ω, endowed with an inner product in the usual way: For $g, h \in \mathcal{N}, (g|h) := \text{cov}(g, h)$.

[4] This is not as special as it seems since we can choose the basis z in such a way as to ensure that one of the risk factors is uncorrelated with s.

the coefficient vector $\mathbf{a}$ is merely a normalization of the size of the futures contract. The noise term ϵ can be thought of as uncertainty in the futures settlement technology, or simply as a modeling device. In fact, it plays no role in the one-asset economy, and is introduced here just to facilitate comparison with the two-asset case. We will comment on this in Section 5. For the present it suffices to note that the results of the paper hold regardless of the size of the noise, as long as it is nondegenerate. A futures position θ_i leaves agent i with net wealth

$$w_i := e_i + \theta_i(f - p), \tag{4}$$

where p is the asset price.

The information set of agent 1 is $\mathcal{I}_1 := (s, x_1, p)$, and that of agent 2 is $\mathcal{I}_2 := (x_2, p)$. Agent i faces the following optimization problem:

$$\max_{\theta_i \in \mathcal{M}_i} \quad E[-\exp(-r_i w_i)], \tag{5}$$

where w_i is given by (4), and $\mathcal{M}_i$ is the space of $\mathcal{I}_i$-measurable random variables. Conditional on $\mathcal{I}_i$, any choice of θ_i leaves net wealth w_i normally distributed.[5] Therefore, agent i's expected utility is

$$\begin{aligned}
E[-\exp(-r_i w_i)] &= -E\left[E[\exp(-r_i w_i)|\mathcal{I}_i]\right] \\
&= -E\left[\exp\left(-r_i\left[E(w_i|\mathcal{I}_i) - \frac{r_i}{2}\mathrm{Var}(w_i|\mathcal{I}_i)\right]\right)\right].
\end{aligned} \tag{6}$$

Let

$$\mathcal{E}_i := E(w_i|\mathcal{I}_i) - \frac{r_i}{2}\mathrm{Var}(w_i|\mathcal{I}_i). \tag{7}$$

The problem (5) reduces to choosing an asset position θ_i to maximize $\mathcal{E}_i$ pointwise for each realization of the information $\mathcal{I}_i$. From (4) and (7):

$$\mathcal{E}_i = E(e_i|\mathcal{I}_i) + \theta_i\left[E(f|\mathcal{I}_i) - p\right] - \frac{r_i}{2}\left[\mathrm{Var}(e_i|\mathcal{I}_i) + \theta_i^2\mathrm{Var}(f|\mathcal{I}_i) + 2\theta_i\mathrm{cov}(f, e_i|\mathcal{I}_i)\right]. \tag{8}$$

The solution to (5) is now easily obtained:

$$\theta_i = \frac{E(f|\mathcal{I}_i) - p - r_i\mathrm{cov}(f, e_i|\mathcal{I}_i)}{r_i\mathrm{Var}(f|\mathcal{I}_i)}. \tag{9}$$

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[5] Assuming that p is in $\mathcal{N}$, which will indeed be the case in the equilibrium we study.

We use "hats" and "tildes" to denote moments conditional on $\mathcal{I}_1$ and $\mathcal{I}_2$ respectively. For example, for random variables g and h, $\hat{E}_g := E(g|\mathcal{I}_1)$, and $\tilde{V}_{gh} := \text{cov}(g,h|\mathcal{I}_2)$. Then[6]

$$\theta_1 = \frac{\mathbf{a}^\top \hat{\mathbf{E}}_{\mathbf{z}} - p - r_1 x_1 \mathbf{a}^\top \hat{\mathbf{V}}_{\mathbf{z}} \mathbf{k}_1}{r_1(\mathbf{a}^\top \hat{\mathbf{V}}_{\mathbf{z}} \mathbf{a} + V_\epsilon)} \tag{10}$$

$$\theta_2 = \frac{\mathbf{a}^\top \tilde{\mathbf{E}}_{\mathbf{z}} - p - r_2 x_2 \mathbf{a}^\top \tilde{\mathbf{V}}_{\mathbf{z}} \mathbf{k}_2}{r_2(\mathbf{a}^\top \tilde{\mathbf{V}}_{\mathbf{z}} \mathbf{a} + V_\epsilon)} \tag{11}$$

DEFINITION 1. *A linear rational expectations equilibrium for the one-asset economy is a 3-tuple of random variables (θ_1, θ_2, p), such that p is of the form:*

$$p = \alpha_1 x_1 + \alpha_2 x_2 + \beta s, \qquad (\alpha_1, \alpha_2, \beta) \in I\!R^3; \tag{12}$$

given this price function, θ_i solves the utility maximization problem (5) for $i = 1, 2$; and markets clear for every realization of private information:

$$\theta_1 + \theta_2 = 0. \tag{13}$$

In the Appendix we show that there exists a unique linear rational expectations equilibrium. In general this equilibrium is partially revealing. Agent 2 cannot unravel the information signal s (which is relevant to both his endowment and the asset payoff) by observing the equilibrium price. Given that he knows the size of his own endowment, x_2, he can only infer a linear combination of agent 1's private signals, x_1 and s.

Let

$$\mu := \frac{a_2}{a_1}, \qquad \bar{\mathbf{a}} := \frac{1}{a_1}\mathbf{a} = \begin{pmatrix} 1 \\ \mu \end{pmatrix}. \tag{14}$$

Given our normalization $\|\mathbf{a}\| = 1$, the ratio μ is the only security design parameter.

4. The Two-Asset Economy

Now suppose there is a separate market for each risk factor. The security payoff vector is:

$$\mathbf{f} = \mathbf{z} + \epsilon, \tag{15}$$

where $\epsilon := (\epsilon_1, \epsilon_2)^\top \sim N(0, V_\epsilon I)$. We denote the futures position of agent i by $\Theta_i := (\theta_{i1}, \theta_{i2})^\top$. The futures price vector is $\mathbf{p}$. Then the net wealth of agent i is given by

$$w_i := e_i + \Theta_i^\top(\mathbf{f} - \mathbf{p}), \tag{16}$$

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[6] We use the following notational convention for covariance matrices: $(\mathbf{V_g})_{ij} := \text{cov}(g_i, g_j)$, $(\mathbf{V_{gh}})_{ij} := \text{cov}(g_i, h_j)$, and, for univariate g, the j'th component of the column vector $\mathbf{V_{gh}}$ is $\text{cov}(g, h_j)$.

and she solves

$$\max_{\Theta_i \in \mathcal{M}_i^2} \quad E[-\exp(-r_i w_i)]. \tag{17}$$

As before, conditional on agent i's information set $\mathcal{I}_i$, any choice of portfolio leaves net wealth normally distributed, so that the optimization problem (17) is equivalent to pointwise maximization of the mean-variance criterion (7). In this case,

$$\mathcal{E}_i = E(e_i|\mathcal{I}_i) + \Theta_i^\mathsf{T}\Big[E(\mathbf{f}|\mathcal{I}_i) - \mathbf{p}\Big] - \frac{r_i}{2}\Big[\mathrm{Var}(e_i|\mathcal{I}_i) + \Theta_i^\mathsf{T}\mathrm{Var}(\mathbf{f}|\mathcal{I}_i)\Theta_i + 2\Theta_i^\mathsf{T}\mathrm{cov}(\mathbf{f}, e_i|\mathcal{I}_i)\Big]. \tag{18}$$

The optimal portfolio is, therefore, given by

$$\Theta_i = \frac{1}{r_i}\mathrm{Var}(\mathbf{f}|\mathcal{I}_i)^{-1}\left[E(\mathbf{f}|\mathcal{I}_i) - \mathbf{p} - r_i\mathrm{cov}(\mathbf{f}, e_i|\mathcal{I}_i)\right]. \tag{19}$$

DEFINITION 2. *A linear rational expectations equilibrium for the two-asset economy is a 3-tuple of $I\!\!R^2$-valued random variables $(\Theta_1, \Theta_2, \mathbf{p})$, such that $\mathbf{p}$ is of the form:*

$$\mathbf{p} = \alpha\mathbf{x} + \beta s, \tag{20}$$

where α is a 2×2 nonsingular matrix and β is a 2×1 matrix; given this price function, Θ_i solves the utility maximization problem (17) for $i = 1, 2$; and markets clear for every realization of private information:

$$\Theta_1 + \Theta_2 = 0. \tag{21}$$

Such an equilibrium is fully revealing: In equilibrium $\mathcal{I}_1 = \mathcal{I}_2 = (s, x_1, x_2)$. The next lemma asserts the existence of such an equilibrium and gives the agents' equilibrium portfolio.

LEMMA 4.1. *There exists a unique linear rational expectations equilibrium for the two-asset economy. The equilibrium price function is*

$$\mathbf{p} = \hat{\mathbf{E}}_\mathbf{f} - \frac{r_1 r_2}{r_1 + r_2} \cdot \left[\hat{\mathbf{V}}_{\mathbf{f}e_1} + \hat{\mathbf{V}}_{\mathbf{f}e_2}\right], \tag{22}$$

and the equilibrium asset demands are

$$\Theta_i = \frac{1}{r_1 + r_2} \cdot \hat{\mathbf{V}}_\mathbf{f}^{-1}\left[r_j\hat{\mathbf{V}}_{\mathbf{f}e_j} - r_i\hat{\mathbf{V}}_{\mathbf{f}e_i}\right], \qquad i = 1, 2, \quad j \neq i. \tag{23}$$

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Proof. Substituting the optimal portfolios from (19) in the market clearing condition (21), we can solve for the price function. Substituting this price function back into (19) gives us the equilibrium asset demands. ∎

Now we can compare trading volume in both economies.

5. Trading Volume

The expected volume of trade in the one-asset economy is $V := E(|\theta_1| + |\theta_2|)$, while in the two-asset economy it is $V^* := E(\sum_{i,j} |\theta_{ij}|)$. Trading volume depends on the heterogeneity in agents' endowments. Let

$$h_j := r_1 k_{1j} x_1 - r_2 k_{2j} x_2, \qquad j = 1, 2. \tag{24}$$

The random variable h_j is the *ex ante* risk adjusted heterogeneity in agents' endowments of factor j.

LEMMA 5.1. *The equilibrium expected trading volume in the two-asset economy is*

$$V^* = 2\sqrt{\frac{2}{\pi}} \cdot \frac{1}{r_1 + r_2} \cdot \left[\frac{\text{sdev}(h_1)}{1 + V_\epsilon} + V_y \frac{\text{sdev}(h_2)}{V_y + V_\epsilon} \right].$$

Proof. It is straightforward to deduce from the Lemma 4.1 that

$$\theta_{11} = -\frac{h_1}{(r_1 + r_2)(1 + V_\epsilon)},$$

$$\theta_{12} = -\frac{V_y h_2}{(r_1 + r_2)(V_y + V_\epsilon)}.$$

In equilibrium $|\theta_{1j}| = |\theta_{2j}|$, $j = 1, 2$. Furthermore, if $X \sim N(0, \sigma^2)$, then $E(|X|) = (2/\pi)^{\frac{1}{2}} \sigma$. The result follows. ∎

The expression for total volume in the lemma is the sum of two terms, corresponding respectively to the volume of trade in the two markets. The relevant informational parameter is V_y, which measures the residual uncertainty regarding z_2 (for both agents, since equilibrium is fully revealing). Indeed, V_y parametrizes the Hirshleifer effect. Volume in the second market is monotonically increasing in this parameter. It is zero when V_y is zero (or, equivalently, when $\rho = 1$), which is the "pure" Hirshleifer effect, *i.e.* the complete

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elimination of trade when there is perfect information. The noise in the second market ϵ_2 ensures that trading volume in this market is continuous with respect to V_y. Without the noise term we get a discontinuity at $V_y = 0$. This discontinuity disappears when ϵ_2 is nondegenerate, no matter how small its variance is.

Volume in the one-asset case, on the other hand, is not susceptible to such a transparent analysis, since equilibrium is not fully revealing in general. A useful benchmark, however, is when $\mu = V_y = 0$, i.e. when the informed agent has perfect information on the second risk factor and the asset payoff in the one-asset economy depends only on the first risk factor. The two economies are essentially identical in this case, with no trading on account of factor 2. In particular, we have:

LEMMA 5.2. *If* $\mu = V_y = 0$,

$$V = V^* = 2\sqrt{\frac{2}{\pi}} \cdot \frac{\text{sdev}(h_1)}{(r_1 + r_2)(1 + V_\epsilon)}.$$

Proof. Immediate from Lemma 5.1 and Lemma A.2 (in the Appendix). ∎

Now we perturb the one-asset economy, starting from the benchmark.

LEMMA 5.3.
$$\left(\frac{\partial V}{\partial \mu}\right)_{\mu=0, V_y=0} = -2\sqrt{\frac{2}{\pi}} \cdot \frac{\text{cov}(h_1, r_2 k_{22} x_2)}{(r_1 + r_2)(1 + V_\epsilon)\,\text{sdev}(h_1)}.$$

Proof. Immediate from Lemma A.2. ∎

Putting a small positive weight on the second risk factor increases trading volume if (and only if) $\text{cov}(h_1, r_2 k_{22} x_2)$ is negative. To interpret this result, note that agent 1 has no hedging need (at the *interim* stage) with respect to factor 2, since she has perfect information regarding this factor. However, with an index futures contract the equilibrium is partially revealing, so that agent 2 would want to trade factor 2. Since the two factors cannot be traded separately, the question is whether or not trading motivated by factor 2 risk goes in the same direction as that which is already taking place on account of factor 1. If h_1, the *ex ante* heterogeneity in factor 1, is high, agent 2 takes a long position in the asset on average. If, in addition, his *ex ante* risk adjusted endowment of factor 2 is negatively

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correlated with h_1, he would want (on average) to buy the asset in order to increase his exposure to factor 2. On the other hand, if his factor 2 endowment is positively correlated with h_1, his desire to take a short position in factor 2 and a long position in factor 1 would tend to coincide, reducing the size of his position in the index.

Let us assume that $\text{cov}(h_1, r_2 k_{22} x_2)$ is nonzero.[7] Then trading an index always generates higher volume than in the benchmark case. In the benchmark case, however, the market for the second asset is inactive in the two-asset economy. This raises a conceptual difficulty in that we have agent 2 inferring agent 1's information from a price in a market in which no trade takes place. If, on the other hand, agent 1's information about the second factor is not perfect there will be trading in both markets, and the total volume may well exceed that with the index. At the benchmark, we have

LEMMA 5.4.

$$\left(\frac{\partial V^*}{\partial V_y}\right)_{\mu=0, V_y=0} = 2\sqrt{\frac{2}{\pi}} \cdot \frac{\text{sdev}(h_2)}{(r_1 + r_2)V_\epsilon}.$$

Proof. Immediate from Lemma 5.1. ∎

Thus the volume of trade in the two-asset economy goes up (from the benchmark) in the absence of perfect information about factor 2. But volume is continuous in the precision of the informed agent's signal. Provided this signal is sufficiently precise, trading volume in the one-asset economy will be higher than with trading the factors separately. Let us regard the volume of trade (in either economy) as a function of μ and V_y, defined on $(-\infty, \infty) \times [0, 1]$.

THEOREM 5.5. *There exists a neighborhood of* $(0,0)$ *such that* $V > V^*$, *for all* (μ, V_y) *in this neighborhood satisfying*

$$\text{sgn}(\mu) = -\text{sgn}[\text{cov}(h_1, r_2 k_{22} x_2)], \tag{25}$$

and

$$\frac{|\mu|}{V_y} > \frac{1 + V_\epsilon}{V_\epsilon} \cdot \frac{\text{sdev}(h_1)\,\text{sdev}(h_2)}{|\text{cov}(h_1, r_2 k_{22} x_2)|}. \tag{26}$$

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[7] Note that $\text{cov}(h_1, r_2 k_{22} x_2) = r_2 k_{22}(r_1 k_{11} \rho_x - r_2 k_{21})$, so that the assumed condition holds for an open dense subset of agents' endowments parametrized by $(\mathbf{k}_1, \mathbf{k}_2)$.

Proof. Note first that

$$\left(\frac{\partial V}{\partial V_y}\right)_{\mu=0, V_y=0} = \left(\frac{\partial V^*}{\partial \mu}\right)_{\mu=0, V_y=0} = 0.$$

Therefore, evaluated at the benchmark,

$$d(V - V^*) = \frac{\partial V}{\partial \mu} d\mu - \frac{\partial V^*}{\partial V_y} dV_y.$$

The result now follows from Lemmas 5.3 and 5.4. ∎

The reason for condition (25) is apparent from the previous discussion: Volume in the index is amplified if agents want to trade factors in the same direction. The second condition (26) simply requires that the weight on factor 2 in the index be sufficiently high relative to the residual hedging need in the second asset in the two-asset economy that arises when $V_y > 0$.

An index contract entails a smaller Hirshleifer effect than the two-asset financial structure, since the index does not allow full revelation of private information about endowments. At the same time partial revelation means that the adverse selection effect, which in absent in the two-asset case, comes into play as well. If private information about endowments is very precise (V_y is small), an appropriately chosen index contract reduces the Hirshleifer effect (relative to the two-asset case) by more than it increases the adverse selection effect, where we measure the size of these effects by their impact on the volume of trade. The above theorem is just a formalization of this statement.

6. Welfare

**** To be completed

7. Conclusion

We have shown that the presence of information asymmetrically distributed among agents with rational expectations can be a source of market incompleteness. This result does not depend on the existence of frictions, such as transaction costs or restrictions on short sales. Our analysis of the role of prices in conveying information, as new securities are issued, identifies two main countervailing forces that are relevant for assessing the use of insurance markets. First, the *adverse selection effect* suggests that the greater the number

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of securities issued, the better, since the equilibrium price is more informative and uninformed traders will be more willing to use the market to share risks. Second, the *Hirshleifer effect* favors restricting the number of securities, since the less informative prices are, the greater is the amount of unexplained risk and, therefore, the larger the risk that can be shared through markets. Hence, the emergence of complete or incomplete markets in equilibrium is a question of which of these two effects dominates. When the Hirshleifer effect is strong enough, endogenous incomplete markets arise and the equilibrium price is partially revealing.

There are several natural extensions our model. First, our approach in this paper is minimalist in the sense that we use a simple model structure in which our conjecture is true. The first extension would consist of checking how robust our results are when some of the assumptions are relaxed, while keeping the present parameterized Gaussian economy. The second extension would relate to asking the same type of question in a general equilibrium model with a general specification of the state space, preferences, and endowments. We believe that the first extension is straightforward, but the second one quite ambitious. Note that in order to compute trading volume, we need closed form solutions for the agents' equilibrium demands. In particular, we need to compute equilibrium demands in an economy in which the equilibrium price is partially revealing. It is well known that such constructions are difficult as soon as we deviate from the Gaussian framework.

Another, perhaps more important, extension would be to do welfare analysis in the present economy. While most of the asymmetric information finance literature uses the noisy rational expectations approach, our model has the virtue of assuming that all agents are fully rational. This is an obvious advantage when it comes to welfare analysis. In particular, we are interested in finding out who profits, the informed or the uninformed traders, for each possible choice of financial structure by the exchange. For instance, we would like to know whether the choice of an incomplete market structure, because of a strong Hirshleifer effect, benefits the informed traders, the uninformed traders, or both, when compared with the complete markets case. This analysis is interesting in its own right but also because it opens a new set of issues. For example, since not all the active traders in a particular market are members (or owners) of the exchange, one issue we would like to study is the theoretical link between the exchange's ownership and its security design policy. All these are problems we are currently working on and we believe we will be able to provide some results not only on the normative, but also on the positive side.

APPENDIX

It is useful first to calculate some conditional moments for the one-asset economy. Recall that "hats" and "tildes" denote moments with respect to the information sets of agents 1 and 2 respectively. Using (1) and (2), and the standard theory of the multivariate normal distribution (see, for example, Anderson (1984), Ch. 1):

$$\hat{\mathbf{E}}_z = \begin{pmatrix} 0 \\ \rho s \end{pmatrix}, \qquad \hat{\mathbf{V}}_z = \begin{pmatrix} 1 & 0 \\ 0 & 1 - \rho^2 \end{pmatrix} \tag{27}$$

$$\tilde{\mathbf{E}}_z = \begin{pmatrix} 0 \\ \frac{\beta \rho [p - (\alpha_1 \rho_x + \alpha_2) x_2]}{\alpha_1^2 (1 - \rho_x^2) + \beta^2} \end{pmatrix}, \qquad \tilde{\mathbf{V}}_z = \hat{\mathbf{V}}_z + \begin{pmatrix} 0 & 0 \\ 0 & \frac{\alpha_1^2 \rho^2 (1 - \rho_x^2)}{\alpha_1^2 (1 - \rho_x^2) + \beta^2} \end{pmatrix} \tag{28}$$

For convenience in handling long algebraic expressions we define:

$$D := (r_1 + r_2)(\mathbf{a}^\top \hat{\mathbf{V}}_z \mathbf{a} + V_\epsilon)[r_1^2 (1 - \rho_x^2)(\mathbf{a}^\top \hat{\mathbf{V}}_z \mathbf{k}_1)^2 + a_2^2 \rho^2] + r_1^2 r_2 a_2^2 \rho^2 (1 - \rho_x^2)(\mathbf{a}^\top \hat{\mathbf{V}}_z \mathbf{k}_1)^2,$$

$$\overline{D} := (r_1 + r_2)[\bar{\mathbf{a}}^\top \hat{\mathbf{V}}_z \bar{\mathbf{a}} + (1 + \mu^2) V_\epsilon][r_1^2 (1 - \rho_x^2)(\bar{\mathbf{a}}^\top \hat{\mathbf{V}}_z \mathbf{k}_1)^2 + \mu^2 \rho^2]$$
$$\quad + r_1^2 r_2 \mu^2 \rho^2 (1 - \rho_x^2)(\bar{\mathbf{a}}^\top \hat{\mathbf{V}}_z \mathbf{k}_1)^2,$$

$$Q := r_1^2 r_2 (1 - \rho_x^2) \mathbf{a}^\top \mathbf{k}_2 (\mathbf{a}^\top \hat{\mathbf{V}}_z \mathbf{k}_1)^2 + a_2^2 \rho^2 [r_2 \mathbf{a}^\top \hat{\mathbf{V}}_z \mathbf{k}_2 - r_1 \rho_x \mathbf{a}^\top \hat{\mathbf{V}}_z \mathbf{k}_1],$$

$$\overline{Q} := r_1^2 r_2 (1 - \rho_x^2) \bar{\mathbf{a}}^\top \mathbf{k}_2 (\bar{\mathbf{a}}^\top \hat{\mathbf{V}}_z \mathbf{k}_1)^2 + \mu^2 \rho^2 [r_2 \bar{\mathbf{a}}^\top \hat{\mathbf{V}}_z \mathbf{k}_2 - r_1 \rho_x \bar{\mathbf{a}}^\top \hat{\mathbf{V}}_z \mathbf{k}_1],$$

$$R := r_1 (\mathbf{a}^\top \hat{\mathbf{V}}_z \mathbf{a} + V_\epsilon)[\alpha_1^2 (1 - \rho_x^2) + \beta^2 - a_2 \beta \rho] + r_2 (\mathbf{a}^\top \hat{\mathbf{V}}_z \mathbf{a} + V_\epsilon)[\alpha_1^2 (1 - \rho_x^2) + \beta^2]$$
$$\quad + r_2 a_2^2 \alpha_1^2 \rho^2 (1 - \rho_x^2).$$

LEMMA A.1. *There exists a unique linear rational expectations equilibrium for the one-asset economy with*

$$\alpha_1 = r_1 \mathbf{a}^\top \hat{\mathbf{V}}_z \mathbf{k}_1 \left[r_1^3 (1 - \rho_x^2)(\mathbf{a}^\top \hat{\mathbf{V}}_z \mathbf{a} + V_\epsilon)(\mathbf{a}^\top \hat{\mathbf{V}}_z \mathbf{k}_1)^2 D^{-1} - 1 \right],$$

$$\alpha_2 = -r_1 (\mathbf{a}^\top \hat{\mathbf{V}}_z \mathbf{a} + V_\epsilon) Q D^{-1},$$

$$\beta = -\frac{a_2 \rho \alpha_1}{r_1 \mathbf{a}^\top \hat{\mathbf{V}}_z \mathbf{k}_1}.$$

The equilibrium asset position of agent 1 is:

$$\theta_1 = (1 + \mu^2)^{\frac{1}{2}} \overline{D}^{-1} \left[r_1^2 (1 - \rho_x^2)(\bar{\mathbf{a}}^\top \hat{\mathbf{V}}_z \mathbf{k}_1)^2 (\mu \rho s - r_1 x_1 \bar{\mathbf{a}}^\top \hat{\mathbf{V}}_z \mathbf{k}_1) + \overline{Q} x_2 \right]. \tag{29}$$

Proof. Substituting (27) and (28) in (10) and (11), and using the market clearing condition (13), we obtain the equilibrium price function in terms of α_1, α_2, and β:

$$p = a_2\rho\Big[r_2(\mathbf{a}^\top\hat{\mathbf{V}}_z\mathbf{a} + V_\epsilon)[\alpha_1^2(1 - \rho_x^2) + \beta^2] + r_2a_2^2\alpha_1^1\rho^2(1 - \rho_x^2)\Big]R^{-1}s$$
$$- r_1\mathbf{a}^\top\hat{\mathbf{V}}_z\mathbf{k}_1\Big[r_2(\mathbf{a}^\top\hat{\mathbf{V}}_z\mathbf{a} + V_\epsilon)[\alpha_1^2(1 - \rho_x^2) + \beta^2] + r_2a_2^2\alpha_1^1\rho^2(1 - \rho_x^2)\Big]R^{-1}x_1$$
$$- r_1(\mathbf{a}^\top\hat{\mathbf{V}}_z\mathbf{a} + V_\epsilon)\Big[a_2\beta\rho(\alpha_1\rho_x + \alpha_2) + r_2\mathbf{a}^\top\hat{\mathbf{V}}_z\mathbf{k}_2[\alpha_1^2(1 - \rho_x^2) + \beta^2]$$
$$+ r_2a_2k_{22}\alpha_1^2\rho^2(1 - \rho_x^2)\Big]R^{-1}x_2.$$

Now we can solve for α_1, α_2, and β by comparing coefficients with (12). (A standard trick here is to first solve for the ratios $\frac{\alpha_1}{\beta}$ and $\frac{\alpha_2}{\beta}$.) The futures position θ_1 is obtained by substituting the conditional expectations (27) and the price function we have just calculated in (10). ∎

LEMMA A.2. *The equilibrium expected trading volume in the one-asset economy is*

$$\mathcal{V} = 2[(2/\pi)(1 + \mu^2)]^{\frac{1}{2}}\overline{D}^{-1}\Big[r_1^4(1 - \rho_x^2)^2(\overline{\mathbf{a}}^\top\hat{\mathbf{V}}_z\mathbf{k}_1)^4[\mu^2\rho^2 + r_1^2(\overline{\mathbf{a}}^\top\hat{\mathbf{V}}_z\mathbf{k}_1)^2]$$
$$+ \overline{Q}^2 - 2r_1^3\rho_x(1 - \rho_x^2)(\overline{\mathbf{a}}^\top\hat{\mathbf{V}}_z\mathbf{k}_1)^3\overline{Q}\Big]^{\frac{1}{2}}. \tag{30}$$

Proof. In equilibrium $|\theta_1| = |\theta_2|$. Furthermore, if $X \sim N(0, \sigma^2)$, then $E(|X|) = (2/\pi)^{\frac{1}{2}}\sigma$. The result now follows from (29). ∎

LEMMA A.3. *Suppose $\mathbf{A}$ is a symmetric $n \times n$ matrix and $\mathbf{w}$ is an n-dimensional normal variate: $\mathbf{w} \sim N(\mathbf{0}, \Sigma)$, Σ positive definite. Then $E[\exp(\mathbf{w}^\top\mathbf{A}\mathbf{w})$ is well-defined if and only if $(\mathbf{I} - 2\Sigma\mathbf{A})$ is positive definite, and*

$$E[\exp(\mathbf{w}^\top\mathbf{A}\mathbf{w}) = |\mathbf{I} - 2\Sigma\mathbf{A}|^{-\frac{1}{2}}.$$

Proof.

$$E[\exp(\mathbf{w}^\top\mathbf{A}\mathbf{w})] = \int_{R^n} \exp(\mathbf{w}^\top\mathbf{A}\mathbf{w})(2\pi)^{-\frac{n}{2}}|\Sigma|^{-\frac{1}{2}}\exp(-\frac{1}{2}\mathbf{w}^\top\Sigma^{-1}\mathbf{w})\,d\mathbf{w}$$
$$= \int_{R^n} (2\pi)^{-\frac{n}{2}}|\Sigma|^{-\frac{1}{2}}\exp[-\frac{1}{2}\mathbf{w}^\top(\Sigma^{-1} - 2\mathbf{A})\mathbf{w}]\,d\mathbf{w}$$
$$= |\Sigma|^{-\frac{1}{2}}|(\Sigma^{-1} - 2\mathbf{A})^{-1}|^{\frac{1}{2}}$$
$$= |\mathbf{I} - 2\Sigma\mathbf{A}|^{-\frac{1}{2}}. \quad∎$$

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