Imperfect Competition, Information Heterogeneity, and Financial Contagion

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Abstract

Financial contagion is the propagation of a shock to one security across fundamentally unrelated securities. In this paper, we examine how heterogeneity of insiders' information about fundamentals may induce financial contagion. We develop a model of multi-asset trading, populated by informed speculators facing a trade-off between the maximization of short versus long-term utility of their wealth, uninformed market-makers, and liquidity traders, in which assets' liquidation values depend on idiosyncratic and systematic risks. We show that, even when these insiders are risk-neutral and financially unconstrained, financial contagion can be an equilibrium outcome of a semi-strong efficient market, if and only if they receive heterogeneous information about those risks and strategically trade on it. Rational market-makers use the observed aggregate order flow to update their beliefs about assets' terminal payoffs. Imperfectly competitive speculators rebalance their portfolios to mask their information advantage. Asymmetric sharing of information among them prevents the market-makers from learning about their individual signals and trades with sufficient accuracy. Incorrect cross-inference about fundamentals and contagion then ensue. When used to analyze the transmission of shocks across countries, our model suggests that more adequate regulation of the process of generation and disclosure of information in emerging markets may reduce their vulnerability to international financial contagion.

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1 Introduction

Many recent financial crises, although of local origins (e.g., Mexico in 1994, Thailand in 1997, Russia in 1998, and Brazil in 1999), ultimately spilled over markets with little or no economic linkages to them. More generally, a growing body of empirical evidence suggests that excess price volatility and comovement are a pervasive feature of many capital markets during both tranquil and uncertain times. Thus, it should not be surprising that *financial contagion*, the propagation of a shock to one security or market across fundamentally unrelated securities or markets, has become one of the most intriguing asset pricing phenomena facing academics, practitioners, and policy-makers. At the same time, mutual funds have played an increasingly important role as a preferred investment vehicle in financial markets world-wide.[1] Accordingly, empirical research on portfolio flows has received much attention in the last decade, and the behavior of hedge funds, pension funds, and mutual funds in those crises actively scrutinized.[2] Yet, theoretical analysis of the impact of the actions of institutional investors on asset prices across fundamentally unrelated markets has only recently gained momentum.

A popular explanation of financial contagion, first introduced by King and Wadhwani (1990), is based on the idea that information asymmetry leads uninformed traders to incorrect updating of beliefs on the terminal payoffs of many assets following idiosyncratic shocks to a single asset. However, several such models (e.g., Fleming et al., 1998; Kodres and Pritsker, 2002) assume that private information is shared symmetrically among price-taking insiders. Most financial markets are instead characterized by the presence of strategic traders endowed with diverse, disparate information. This is especially true in emerging markets, where the process of generation, acquisition, and disclosure of information is not as standardized as in more developed economies, and where contagion has been observed more frequently. Information heterogeneity and imperfect competition among insiders represent a richer and more realistic view of a financial market that so far has not been employed to investigate excess price comovement.

In this paper, we develop a three-date, two-period model of multi-asset trading, populated by informed speculators not facing any borrowing or

[1]For instance, Bhattacharya and Nanda (1999) reported that total equity holdings by mutual funds account for more than 16% of the value of U.S. equities. Assets held by (mostly foreign) mutual funds in emerging markets represent smaller fractions of their market capitalization, because of greater ownership concentration and lower turnover (Borensztein and Gelos, 2000).

[2]E.g., Brown et al. (1998), Eichengreen and Mathieson (1998), Kaminsky et al. (2000, 2001), Disyatat and Gelos (2001), and Kim and Wei (2002).

short-selling constraints, uninformed market-makers, and liquidity traders, in which securities' terminal payoffs depend on idiosyncratic and systematic sources of risk. Calvo (1999) and Yuan (2000) explored the consequences of insiders being financially constrained for the propagation of liquidity shocks across equilibrium prices. Alternatively, Kyle and Xiong (2001) described financial contagion as a wealth effect induced by convergence traders' need to liquidate their positions in all assets in response to losses on a single asset. These arguments nevertheless ignore that market participants hit by a liquidity shock might prefer to sell highly liquid assets, like those in developed exchanges, instead of their holdings in emerging markets.[3] Our model also assumes that the insiders are imperfectly competitive, risk-neutral, and care about the interim as well as the terminal value of their portfolios, like the stylized money managers in Bhattacharya and Nanda (1999). In this setting, we show that excess price comovement is an equilibrium outcome, if and only if those speculators receive heterogeneous private information about the liquidation values of the assets and strategically trade on it.

This result constitutes the main contribution and empirical implication of the paper. The intuition for it is as follows. Informed trading activity by money managers potentially dissipates at least part of their informational advantage. In particular, because the real economy is fundamentally interconnected, the uninformed market-makers may use the observed demand for one asset to cross-infer the terminal payoffs of other assets. Therefore, the insiders trade cautiously and strategically across assets, rather than massively and independently in each asset, to minimize the resulting dispersion of information. Even so, the insiders have also an incentive to act noncooperatively, i.e., to compete more aggressively to exploit their perceived individual informational edge. When the insiders receive homogeneous information, this competition, in equilibrium, makes the aggregate order flow a sufficient statistic for rational dealers to learn about whether that observed demand is due to idiosyncratic or systematic shocks. Heterogeneity of their private signals instead induces each of the insiders to a quasi-monopolistic trading behavior, since part of his informational advantage is now known exclusively to him. Consequently, in equilibrium, the dealers learn more accurately about the average signal than about any private signal and individual trade. The ensuing incorrect cross-inference about fundamentals causes excess covariance among asset prices.

[3] See Kodres and Pritsker (2002). However, Schinasi and Smith (1999) observe that money managers' objective functions and portfolio leverage may sometimes force liquidation of the most risky assets, instead of the most liquid ones, in proximity of a financial crisis. In Allen and Gale (2000), financial intermediaries also withdraw from illiquid investments if unable to meet excess demand for liquidity.

Consistent with this argument, Kallberg and Pasquariello (2004) found that, even after controlling for market volatility, a statistically and economically significant portion of excess comovement within the U.S. stock market can be explained by the dispersion of analysts' earnings forecasts, a proxy for information heterogeneity suggested by Diether et al. (2002). Kodres and Pritsker (2002) also argued for the role of portfolio rebalancing as a channel of financial contagion. In their model à la Grossman and Stiglitz (1980), it is risk aversion to induce competitive insiders to trade across assets. However, mean-variance portfolio selection may not describe adequately the decision process followed by institutional investors, especially in developing markets. Indeed, Nanda et al. (2000) and Das and Sundaram (2002) emphasized that compensation and principal-agent considerations are very important to understand observed investment policies of professional money managers; Disyatat and Gelos (2001) showed that mean-variance optimization fails to explain changes in portfolio weights for more than 600 emerging market mutual funds between January 1996 and December 2000.

In our framework, informed fund managers may move away from long-term profit-maximization to increase their short-term welfare. This behavior does not exacerbate the magnitude of contagion by real shocks, because more noise trading eventually brings forth more informative demand in the order flow. Despite this fact, shocks to uninformative trading due to positive feedback flows by final investors (e.g., in response to shifts in their preferences) can still result in financial contagion if those perturbations mislead the uninformed traders. We further show that more insiders and greater intensity of information heterogeneity within a market induce more incorrect inference about its liquidation values, hence making that market more vulnerable to external idiosyncratic shocks. These results have several policy implications. In particular, they suggest that the process of economic and financial integration and persistent asymmetric information sharing could explain why financial contagion has been occurring with greater frequency and magnitude in emerging markets. Therefore, the adoption of rigorous and uniform rules for the dissemination of corporate and macroeconomic information could strengthen their ability to withstand or avoid international spillover effects.

The paper is organized as follows. In Section 2 we outline the basic economy and derive its equilibrium. In Section 3 we define financial contagion and establish the main results of this study. Section 4 provides intuition on the channels of transmission of shocks across fundamentally unrelated markets with the help of a numerical example. Section 5 concludes. All proofs are in Appendix A unless otherwise noted.

2 The model

In this section we describe our basic model, which extends the K-trader, N-security generalization by Caballé and Krishnan (1994) of the single-trader, single-security model of Kyle (1985).

2.1 Structure and notation

The model is a three-date, two-period economy consisting of N risky assets and a riskless asset (the numeraire). Without loss of generality, the riskless rate is zero. Trading occurs only at the end of the first period ($t = 1$). At the end of the second period ($t = 2$), the payoffs of the risky assets, represented by a $N \times 1$ multivariate normally distributed (MND) random vector v, with mean $\overline{v}$ and nonsingular covariance matrix Σ_v, are realized. When Σ_v is either nondiagonal or block-diagonal (see Definition A1 in Appendix A), either some of the N assets or some assets in any subset (block) are fundamentally correlated to each other.

We model this fundamental interaction by assuming that v is characterized by the following linear factor structure:

$$v = u + \beta\vartheta, \tag{1}$$

where u is a $N \times 1$ unobservable random vector of idiosyncratic shocks, ϑ is a $F \times 1$ unobservable random vector of common factors, and β is a $N \times F$ matrix of factor loadings. One can think of u as representing company, industry, market, or country-specific sources of risk. The vector ϑ is instead a proxy for systematic sources of risk. We assume that u and ϑ are MND with means $\overline{u}$ and $\overline{\vartheta}$ and (diagonal and nonsingular) covariance matrices Σ_u and Σ_ϑ. Consequently, $\overline{v} = \overline{u} + \beta\overline{\vartheta}$ and $\Sigma_v = \Sigma_u + \beta\Sigma_\vartheta\beta'$ is also nonsingular and nondiagonal (unless $\beta = O$, where O is a zero matrix).[4]

2.2 Market participants and information

We consider a market with risk-neutral traders: Perfectly competitive market-makers (MMs), K privately informed mutual fund managers (MFs), and liquidity traders. Insiders do not observe current prices or trades. MMs do not receive any private information, but observe the aggregate order flow from all market participants. All traders know the structure of the economy and the

[4] The matrix $\left[\Sigma_u + \beta\Sigma_\vartheta\beta'\right]^{-1}$ always exists for any $N \times F$ matrix β if both Σ_u and Σ_ϑ are nonsingular (e.g., Maddala, 1987 p. 446). Hence, the nonsingularity of Σ_v does not impose any restriction on the factor loadings β.

decision process leading to order flow and prices. At time $t = 0$ there is no information asymmetry about v, and the prices of the risky assets are given by the unconditional means of their terminal payoffs: $P_0 = \overline{v}$. Sometime between $t = 0$ and $t = 1$ each MF k receives two sets of private and noisy signals S_{uk} and $S_{\vartheta k}$ of u and ϑ.

In the spirit of Admati (1985), it is assumed that those signals take the form $S_{uk} = u + \varepsilon_{uk}$, with $\varepsilon_{uk} \sim MND\left(\underline{0}, \Sigma_{\varepsilon_{uk}}\right)$ (where $\underline{0}$ is a zero vector), and $S_{\vartheta k} = \vartheta + \varepsilon_{\vartheta k}$, with $\varepsilon_{\vartheta k} \sim MND\left(\underline{0}, \Sigma_{\varepsilon_{\vartheta k}}\right)$.[5] For simplicity, we impose that u, ϑ, and all ε_{uk} and $\varepsilon_{\vartheta k}$ are mutually independent, that $\Sigma_{\varepsilon_{uk}} = \Sigma_{\varepsilon_u}$ and $\Sigma_{\varepsilon_{\vartheta k}} = \Sigma_{\varepsilon_\vartheta}$ (i.e., that the precision of each signal is identical across insiders), and that Σ_{ε_u} and $\Sigma_{\varepsilon_\vartheta}$ are diagonal. We can interpret the resulting *information heterogeneity* across the K MFs as arising from the use of diverse, disparate sources to learn about the same underlying variables affecting v. Significant and persistent differences in private information among traders are an ubiquitous feature of most financial markets, especially the ones of emerging economies, where the process of generation and acquisition of information is not as standardized as in more developed countries. It then follows (e.g., Greene, 1997 pp. 89-90) that the expectation of v by any MF k at $t = 1$, before trading with the MMs, is given by

$$E\left(v|S_{uk}, S_{\vartheta k}\right) \equiv E_1^k\left(v\right) = \overline{v} + \Sigma_u \Sigma_{S_u}^{-1}\left(S_{uk} - \overline{u}\right) + \beta \Sigma_\vartheta \Sigma_{S_\vartheta}^{-1}\left(S_{\vartheta k} - \overline{\vartheta}\right), \quad (2)$$

where $\Sigma_{S_u} = \Sigma_u + \Sigma_{\varepsilon_u}$ and $\Sigma_{S_\vartheta} = \Sigma_\vartheta + \Sigma_{\varepsilon_\vartheta}$. We define the informational advantage of that MF with respect to the uninformed traders about v by the random vector $\delta_k \equiv E_1^k\left(v\right) - \overline{v}$. It is clear that $\delta_k \sim MND\left(\underline{0}, \Sigma_\delta\right)$ for all k, with nonsingular $\Sigma_\delta = \Sigma_u \Sigma_{S_u}^{-1} \Sigma_u + \beta \Sigma_\vartheta \Sigma_{S_\vartheta}^{-1} \Sigma_\vartheta \beta'$. The above assumptions also imply that, for every pair of MFs k and i, with $i \neq k$, the random vectors δ_k and δ_i have a joint normal distribution and

$$cov\left(\delta_k, \delta_i\right) \equiv \Sigma_c = \Sigma_u \Sigma_{S_u}^{-1} \Sigma_u \Sigma_{S_u}^{-1} \Sigma_u + \beta \Sigma_\vartheta \Sigma_{S_\vartheta}^{-1} \Sigma_\vartheta \Sigma_{S_\vartheta}^{-1} \Sigma_\vartheta \beta', \quad (3)$$

where Σ_c is a symmetric positive definite (SPD) matrix.[6] Therefore, $E_1^k\left(\delta_i\right) = \Sigma_c \Sigma_\delta^{-1} \delta_k$. In general, it will be the case that $\Sigma_c \neq \Sigma_\delta$. Nonetheless, it ensues immediately from Eq. (2) that $cov\left(\delta_k, \delta_i\right) = \Sigma_\delta$ when $\delta_k = \delta$. Σ_c is instead equal to $\rho \Sigma_\delta$ (with $\rho \in (0, 1)$) and $E_1^k\left(\delta_i\right) = \rho \delta_k$ when all matrices Σ_u, Σ_{ε_u}, Σ_ϑ, and $\Sigma_{\varepsilon_\vartheta}$ are multiples of the corresponding identity matrix I such that $\Sigma_{S_u}^{-1} \Sigma_u = \rho I$ and $\Sigma_{S_\vartheta}^{-1} \Sigma_\vartheta = \rho I$.

At $t = 0$ each MF k has an inventory e_k of risky securities, and holds an amount $NAV_{0k} - e_k' P_0$ of the riskless asset. Clearly, NAV_{0k} represents the

[5] In other terms, it is possible that $S_{uk} \neq S_{ui}$ ($S_{\vartheta k} \neq S_{\vartheta i}$) only because of heterogeneous, but identically distributed noise terms $\varepsilon_{uk} \neq \varepsilon_{ui}$ ($\varepsilon_{\vartheta k} \neq \varepsilon_{\vartheta i}$).

[6] See Definition A2 in Appendix A.

initial Net Asset Value (NAV) of that MF's portfolio at $t = 0$, before trading occurs. We assume that the MFs do not face borrowing or short-selling constraints, to control for the liquidity channel of asymmetric contagion described in Section 1. The inventory of risky assets e_k is private information of that MF. We further assume that, from the perspective of the other market participants, each e_k is MND, with mean $\overline{e}$ and nonsingular covariance matrix Σ_e, and independent from v and any ε_{uk} and $\varepsilon_{\vartheta k}$. We define the informational advantage of each MF with respect to the uninformed traders about his initial holdings by the random vector $\delta_{ek} \equiv e_k - \overline{e}$. It follows that $\delta_{ek} \sim MND\left(\underline{0}, \Sigma_e\right)$. For simplicity, we impose that Σ_e is diagonal and $cov\left(\delta_{ek}, \delta_{ei}\right) = O$, so that $E_1^k\left(\delta_{ei}\right) = \underline{0}$ for each $i \neq k$.[7]

2.3 Market participants and trading

At $t = 1$ both MFs and liquidity traders submit their orders to the MMs, before the price vector P_1 has been set. Hence, the insiders submit market orders based on expected rather than actual prices. Liquidity traders are assumed to generate a vector of random demands z, independent from all δ_k and δ_{ek} and MND with mean $\overline{z}$ and nonsingular covariance matrix Σ_z. Again for simplicity, we assume that Σ_z is also diagonal.

It is a stylized fact about speculative markets (especially emerging markets) that better-informed traders (especially if large enough) use their informational advantage to influence prices, instead of taking them as given. The latter, Grinblatt and Ross (1985) argue, would be "irrational" since prices respond to their actions. Here we posit that the MFs are imperfectly competitive: In equilibrium, they correctly anticipate the pricing rule and use this knowledge in formulating their orders, as in Kyle (1989). We further assume that each MF's optimal demand for risky assets, X_k, maximizes the expected value of the following separable utility function U_k of the NAV of his portfolio (i.e., of his wealth) at $t = 1$ and $t = 2$:

$$U_k = \gamma U\left(NAV_{1k}\right) + \left(1 - \gamma\right) U\left(NAV_{2k}\right), \tag{4}$$

where $\gamma \in [0, 1]$. NAV_{1k} is announced at the end of the first period, after the MMs set P_1, while NAV_{2k} is announced at the end of the second period, after v is realized. The MFs are risk-neutral: $U\left(NAV_{tk}\right) = NAV_{tk}$. Hence, the ratio $\frac{\gamma}{1-\gamma}$ can be interpreted as the MFs' intertemporal marginal rate of

[7] This last assumption can be relaxed to allow each MF to use his initial endowment to infer those of the other MFs. This may be realistic if we think of MFs as having similar customer bases, management styles, or benchmarks. If we impose that $cov\left(\delta_{ek}, \delta_{ei}\right) = \Sigma_{ee}$, then $E_1^k\left(\delta_{ei}\right) = \Sigma_{ee}\Sigma_e^{-1}\delta_{ek}$.

substitution (MRS) between short and long-term NAV. If $\gamma = 0$, each insider reduces to a (long-term) profit-maximizing speculator, as in Kyle (1985) and Caballé and Krishnan (1994). If $\gamma > 0$, the expected utility of each MF at $t = 1$, before trading occurs, is given by

$$\begin{aligned} E_1^k(U_k) &= NAV_{0k} + \gamma \left\{ e_k' \left[E_1^k(P_1) - P_0 \right] + X_k' \left[E_1^k(P_1) - E_1^k(P_1) \right] \right\} + \\ &\quad + (1-\gamma) \left\{ e_k' \left[E_1^k(v) - P_0 \right] + X_k' \left[E_1^k(v) - E_1^k(P_1) \right] \right\}. \end{aligned} \tag{5}$$

At both dates $t = 1$ and $t = 2$ the change in NAV with respect to NAV_{0k} depends on two components: The change in value of the existing inventory of the N risky assets and the profits from trading at $t = 1$. Because the MMs set P_1 after having observed the order flow, the value of the net position accumulated at $t = 1$ is equal to zero in NAV_{1k}.

This objective function, introduced by Bhattacharya and Nanda (1999) in a single-security framework, can be motivated by solvency issues, agency and reputation problems, or cash redemptions and injections affecting the interim life of (open-end) mutual funds. A popular argument in the financial press, in the wake of recent contagion events, is that institutional investors' "short-termism" helped fuel and spread crises of otherwise limited scale and scope. Excessive "long-termism" is frequently indicated as a culprit as well, for instance in many accounts of the collapse of Long Term Capital Management (LTCM).[8] Whether these considerations affect the likelihood and magnitude of financial contagion is an important question that the setting of Eq. (5) will allow us to address in this paper.

2.4 Equilibrium

In this economy, the risk-neutral, perfectly competitive MMs face a quantity-based signal extraction problem: At $t = 1$ they observe only the aggregate order flow for all securities $\omega_1 = \sum_{i=1}^{K} X_i + z$ and, with the information extracted from it, set the market-clearing price vector P_1: $P_1 = P_1(\omega_1)$.[9] Since $X_k = \arg\max E_1^k(U_k)$, we can think of the MFs' optimal trading strategies as functions of the realizations of δ_k and δ_{ek}: $X_k = X_k(\delta_k, \delta_{ek})$. We now show that a linear equilibrium for this economy exists. Consistently with Kyle (1985), we use the following standard definition of equilibrium.

[8] For an analysis of the LTCM debacle, see Edwards (1999).

[9] According to Calvo and Mendoza (2000), this modeling approach is especially relevant for emerging economies, in view of the short history of prices available for their domestic capital markets under financial integration. Because the MMs do not possess private information and hold their positions until liquidation (at $t = 2$), we may also envision them as uninformed long-term speculators, as in Froot et al. (1992).

Definition 1 *A Bayesian Nash equilibrium is a set of $K+1$ vector functions $X_1(\cdot), \ldots, X_K(\cdot)$, and $P_1(\cdot)$ such that the conditions below hold:*

1. ***Utility maximization:***

$$E_1^k\left[U_k\left(X_k(\delta_k,\delta_{ek}), P_1\left(\sum_{i=1}^{K} X_i(\delta_i,\delta_{ei})+z\right)\right)\right] \tag{6}$$
$$\geq E_1^k\left[U_k\left(Y_k(\delta_k,\delta_{ek}), P_1\left(Y_k(\delta_k,\delta_{ek})+\sum_{\substack{i=1\\ i\neq k}}^{K} X_i(\delta_i,\delta_{ei})+z\right)\right)\right]$$

for any alternative trading strategy $Y_k(\cdot)$ and for all $k=1,\ldots,K$;

2. ***Semi-strong market efficiency:***

$$P_1(\omega_1) = E(v|\omega_1). \tag{7}$$

Eq. (6) requires that the MFs' market orders X_k be optimal, given their information, before the MMs choose P_1. Eq. (7) is the result of competition among identical dealers driving to zero their expected long-term profits in each market, conditional on the signal they observed (ω_1), i.e., such that $\omega_1(n)\left[E(v(n)|\omega_1) - P_1(n)\right] = 0$ for $n=1,\ldots,N$. Caballé and Krishnan (1994) have shown how to explicitly characterize a symmetric linear equilibrium in a multi-security market with information asymmetry and risk-neutrality. The following proposition accomplishes this task for our economy.

Proposition 1 *There always exists a linear equilibrium given by the price function*

$$P_1 = P_0 + \frac{\sqrt{K}}{2}\Lambda\left[\omega_1 - \overline{z} - \left(\frac{\gamma}{1-\gamma}\right)K\overline{e}\right] = \tag{8}$$
$$= P_0 + H\sum_{i=1}^{K}\delta_i + \frac{\sqrt{K}}{4}\left(\frac{\gamma}{1-\gamma}\right)\Lambda\sum_{i=1}^{K}\delta_{ei} + \frac{\sqrt{K}}{2}\Lambda(z-\overline{z}) \tag{9}$$

and by the MF's demand strategy

$$X_k = \left(\frac{\gamma}{1-\gamma}\right)\overline{e} + C\delta_k + \frac{1}{2}\left(\frac{\gamma}{1-\gamma}\right)\delta_{ek}, \tag{10}$$

where $\Sigma_n = \Sigma_z + \frac{K}{4}\left(\frac{\gamma}{1-\gamma}\right)^2\Sigma_e$, $\Sigma_n^{1/2}$ and $\Psi^{1/2}$ are the unique SPD square roots of Σ_n and $\Psi = \Sigma_n^{1/2}\Gamma\Sigma_n^{1/2}$ (with the SPD matrix Γ defined in Appendix A), $\Lambda = \Sigma_n^{-1/2}\Psi^{1/2}\Sigma_n^{-1/2}$ is a SPD matrix, $H = \left[2I + (K-1)\Sigma_c\Sigma_\delta^{-1}\right]^{-1}$, and $C = \frac{2}{\sqrt{K}}\Lambda^{-1}H$.

Remark 1 *The linear equilibrium of Proposition 1 is the unique equilibrium for which Λ is symmetric. Moreover, that equilibrium is the unique linear equilibrium if either $K = 1$ (there is a single insider) or $\Sigma_n = \sigma_n^2 I$ (noise trading has identical variance and is uncorrelated across assets).*[10]

The optimal trading strategy of each MF depends on the information he receives about v and his inventory of risky assets. For $\gamma = 0$, X_k reduces to $C\delta_k$, the optimal informational demand schedule of Kyle (1985) and Caballé and Krishnan (1994), and $E(X_k) = \underline{0}$. For $\gamma > 0$, X_k results from the optimal resolution of a trade-off between short and long-term profits. Indeed, each MF now cares about the interim value of his portfolio as well. Hence, he trades more than he otherwise would ($E(X_k) = \frac{\gamma}{1-\gamma}\overline{e}$) to distort prices in the direction of his inventory e_k and so increase NAV_{1k}. In equilibrium, these efforts are successful: $cov(P_1, e_k) = \frac{\sqrt{K}}{4}\left(\frac{\gamma}{1-\gamma}\right)\Lambda\Sigma_e$ is SPD, so the expected change in the value of his inventory, $E\left[e_k'(P_1 - P_0)\right] = \frac{\sqrt{K}}{4}\left(\frac{\gamma}{1-\gamma}\right) tr(\Lambda\Sigma_e)$, is positive. This comes, however, at the cost of smaller expected terminal profits $\sum_{i=1}^{K} E\left[e_i'(v - P_0) + X_i'(v - P_1)\right] = \frac{\sqrt{K}}{2} tr(\Lambda\Sigma_z)$, since $X_k \neq C\delta_k$.

The MMs do not know how much of the order flow is due to MFs' informed trading. Thus, the equilibrium vector P_1 depends only on the portion of ω_1 that the MMs expect to be informative about v. The existence of noise trading is an important ingredient of the model: As emphasized by Admati (1985), a nonsingular Σ_n effectively provides camouflage for informed trades, since it prevents ω_1 from being a sufficient statistic for any combination of the MFs' private signals of v. Further, the imperfectly competitive insiders are aware of the impact of their trades on P_1 (via Λ) and, despite being risk neutral, trade cautiously ($|X_k(n)| < \infty$) to prevent ω_1 from fully dissipating their informational advantage. Hence, the expressions in Eqs. (8) to (10) represent a noisy rational expectations equilibrium.[11]

The matrix $\frac{2}{\sqrt{K}}\Lambda^{-1}$ in C is SPD (and nondiagonal, unless $\beta = O$) since so is Λ (see Theorem A1 in Appendix A) and, as in Kyle (1985), measures the depth of this multi-asset market. The equilibrium market depth reflects MMs' attempt to be compensated for the losses they anticipate from trading with insiders, as it affects their profits from liquidity and short-term trading. It follows immediately from the definition of Λ in Proposition 1 that

[10] It is straightforward to show that if $\Sigma_n = \sigma_n^2 I$, then $\Lambda = \frac{1}{\sigma_n}\Gamma^{1/2}$.

[11] In contrast, in the Gaussian setting with perfect competition of Admati (1985), where prices aggregate information across risk-averse traders, all private information is fully revealed when their risk aversion wanes.

$\lim_{K\to\infty}\Lambda = O$ and that the absolute market depth, $\frac{2}{\sqrt{K}}\left|\Lambda^{-1}\right|$,[12] increases with the number of MFs (K), their intertemporal MRS ($\frac{\gamma}{1-\gamma}$), and, more generally, the amount of noise trading (the diagonal matrix Σ_n): In these circumstances, the MMs perceive the threat of adverse selection as less serious, and penalize less their counterparts by increasing each market's liquidity.

The insiders' concern about the interim value of their holdings allows transactions to occur in this economy even in the absence of liquidity traders, as long as there is uncertainty about the original composition of the MFs' portfolios. Remark 2 generalizes Proposition 3 of Bhattacharya and Nanda (1999) to our multi-asset setting, and relates our Proposition 1 to the equilibrium with endowment shocks in Diamond and Verrecchia (1981).

Remark 2 *When $\gamma > 0$ and the vectors e_k are private information, there is trading in equilibrium even in the absence of liquidity shocks z.*[13]

The deviation of each MF's trade from $C\delta_k$ does not depend on Λ: In equilibrium, the MMs discount their knowledge of MFs' behavior into P_1, while the MFs discount their knowledge of the process by which MMs set P_1 into X_k. Consequently, although $var\left(X_k\right) = \frac{1}{K}\Sigma_n + \frac{1}{4}\left(\frac{\gamma}{1-\gamma}\right)^2\Sigma_e$ is a function of γ, Σ_e, and Σ_z, the unconditional variance of P_1, given by the SPD matrix

$$var\left(P_1\right) = H\left[K\Sigma_\delta + K\left(K-1\right)\Sigma_c\right]H' + \frac{K}{4}\Lambda\Sigma_n\Lambda = KH\Sigma_\delta, \tag{11}$$

is not, as in Kyle (1985): More noise trading offers more hiding opportunities to insiders, brings forth more aggressive informative trading, and eventually does not destabilize prices in equilibrium.

3 Excess covariance

The identification of empirical regularities in episodes of domestic and international financial turmoil is currently at the center of an intense debate in the literature.[14] Nonetheless, a consensus emerged that not only periods

[12] In this paper, we use the absolute value of a matrix to denote the matrix of the absolute values of its elements.

[13] The proof is straightforward from Proposition 1. When $\gamma = 1$, ω_1 does not contain any information about v, hence $\Lambda = O$ and $E\left(v|\omega_1\right) = \overline{v}$. Semi-strong market efficiency then imposes that $P_1 = P_0$ in equilibrium.

[14] An incomplete list includes Shiller (1989), King and Wadhwani (1990), Pindyck and Rotemberg (1990, 1993), King et al. (1994), Karolyi and Stulz (1996), Baig and Goldfajn (1999), Bekaert and Harvey (2000), Connolly and Wang (2000), Barberis et al. (2002), Boyer et al. (2002), Corsetti et al. (2002), Forbes and Rigobon (2002), Kallberg et al. (2002), and Kallberg and Pasquariello (2004).

of uncertainty but also more tranquil times are generally accompanied by excess volatility and comovement among asset prices within and across both developed and emerging financial markets. We define such excess covariance as covariance beyond the degree justified by economic fundamentals, and financial contagion as the circumstance of its occurrence. In this section we propose a novel explanation for these phenomena that uses two realistic market frictions, imperfect competition among insiders and heterogeneity of their information endowments, in the context of our stylized economy.

3.1 Cautious trading and information

One of the main features of the model of Section 2 is that the insiders, albeit risk-neutral, exploit their private information cautiously, to avoid dissipating their informational advantage with their trades. For a given amount of noise trading Σ_n, the intensity of competition among insiders affects their ability to maintain the informativeness of the order flow as low as possible. Intuitively, this intensity depends not only on the number of MFs (K) but also on the degree of heterogeneity of their private information. We measure such degree by the matrix H (defined in Proposition 1). Insiders receive the same or similar (i.e., not heterogeneous enough) private information if $S_{uk} = S_u$ and $S_{\vartheta k} = S_\vartheta$, so $cov(\delta_k, \delta_i) = \Sigma_\delta$, or if $S_{uk} \neq S_{ui}$ and $S_{\vartheta k} \neq S_{\vartheta i}$ but $cov(\delta_k, \delta_i) = \rho\Sigma_\delta$ (with $\rho \in (0,1)$), for any $i \neq k$.[15] In those cases, $H = \frac{1}{2+\rho(K-1)} I$, with $\rho \in (0,1]$. Conversely, the more Σ_c is distant from $\rho\Sigma_\delta$, the more heterogeneous is their information, and the more $H \neq \frac{1}{2+\rho(K-1)} I$. For the remainder of the paper we refer to the former as *information homogeneity*, and to the latter as (enough) *information heterogeneity* among insiders. We then have the following corollary.[16]

Corollary 1 *In equilibrium, if there is only one MF ($K = 1$), then* $\Lambda_{K=1} = \Sigma_n^{-1/2}\left(\Sigma_n^{1/2}\Sigma_\delta\Sigma_n^{1/2}\right)^{1/2}\Sigma_n^{-1/2}$. *If instead there are many homogeneously informed MFs ($K > 1$), then* $\Lambda_{K>1} = \frac{2}{2+\rho(K-1)}\Sigma_n^{-1/2}\left(\Sigma_n^{1/2}\Sigma_\delta\Sigma_n^{1/2}\right)^{1/2}\Sigma_n^{-1/2}$.

[15] In particular, when $\Sigma_c = \rho\Sigma_\delta$ each MF k expects the information endowments of the other insiders to be a fraction of (thus perfectly correlated to) his own (i.e., $E_1^k(\delta_i) = \rho\delta_k$); moreover, the higher is ρ, the closer is $cov(\delta_k, \delta_i)$ to $var(\delta_k)$ (and $E_1^k(\delta_i)$ to δ_k), hence the greater is the similarity between δ_k and δ_i.

[16] Similar results and intuition for the case of a single risky asset have been provided by Admati and Pfleiderer (1988) in a one-period framework, by Holden and Subrahmanyam (1992) and Foster and Viswanathan (1996) in a multi-period game, and by Back et al. (2000) in a continuous-time setting.

This implies that, for each $n = 1, \ldots, N$,

$$\Lambda(n,n)_{K=1} \geq \Lambda(n,n) \geq \Lambda(n,n)_{K>1}, \tag{12}$$

with a strict inequality holding for at least some n.

Multiple homogeneously informed insiders, acting noncooperatively, have an incentive to trade more aggressively than a monopolist MF would in the setting of Kyle (1985): $\left|\sum_{i=1}^{K} X_i\right| > |X_{K=1}|$ when $\Sigma_c = \rho\Sigma_\delta$.[17] This "quasi-competitive" behavior occurs because imperfectly competitive MFs cannot collude to use their similar signals more parsimoniously. Consequently, ω_1 becomes more revealing about v. Thus, MMs fear less adverse selection and reduce the compensation they require for it by increasing each market's liquidity: $\Lambda(n,n)_{K>1} \leq \Lambda(n,n)_{K=1}$.

Heterogeneously informed MFs compete less aggressively with each other. Indeed, when information is less correlated, each insider has some monopoly on his private signal, because part of it is known exclusively to him. Hence, he exploits his informational advantage more carefully, by submitting smaller orders, to reveal less of it. We define this behavior as "quasi-monopolistic." The diversity in S_{uk} and $S_{\vartheta k}$ and the less aggressive MFs' market orders make ω_1 more informative about their average knowledge of v (since ε_{uk} and $\varepsilon_{\vartheta k}$ are mutually independent and identically distributed) but less informative about each individual signal, i.e., less revealing of each insider's trading activity. This induces the MMs to feel more vulnerable to adverse selection, so to reduce all markets' depth: $\Lambda(n,n) \geq \Lambda(n,n)_{K>1}$.

The trading activity of a monopolist insider is the least aggressive: Unthreatened by competing MFs, he can exploit fully his private signals by trading cautiously to avoid dispersing his informational advantage. This makes ω_1 the least informative about v, and the perceived risk of adverse selection the highest for the MMs. The lowest degree of depth in each market ensues: $\Lambda(n,n)_{K=1} \geq \Lambda(n,n)$.

3.2 Strategic trading and contagion

We are now ready to address the issue of financial contagion using the results of Section 3.1. This is the topic of Proposition 2.

Proposition 2 *In equilibrium, $var(P_1)_{K=1} = \frac{1}{2}\Sigma_\delta$, while $var(P_1)_{K>1} = \frac{K}{2+\rho(K-1)}\Sigma_\delta$. This implies that, for each $n, j = 1, \ldots, N$,*

$$|var(P_1)(n,j)| \geq \left|var(P_1)_{K>1}(n,j)\right| \geq |var(P_1)_{K=1}(n,j)|, \tag{13}$$

[17] It can in fact be shown that $|\Lambda_{K=1}(n,j)| \geq \frac{\sqrt{K}}{2}|\Lambda_{K>1}(n,j)|$ and $|C_{K=1}(n,j)| \leq |C_{K>1}(n,j)|$ for any $n, j = 1, \ldots, N$.

with a strict inequality holding for at least one $n = j$*.*

To interpret Eq. (13) we refer to the expression for $var(P_1)$, $KH\Sigma_\delta$ in Eq. (11). We can think of Σ_δ, the variance of δ_k, as reflecting the true covariance structure of the economy (Σ_u and $\beta\Sigma_\vartheta\beta'$), adjusted for the relative precision of the signals of u and ϑ ($\Sigma_u\Sigma_{S_u}^{-1}$ and $\Sigma_\vartheta\Sigma_{S_\vartheta}^{-1}$). For example, if $\Sigma_v(n,j)$ is equal to zero, then so is $\Sigma_\delta(n,j)$. Therefore, H controls for the amount of private information about v incorporated in P_1, consistent with Eq. (9). When $K = 1$, $H = \frac{1}{2}I$ and $var(P_1) = \frac{1}{2}\Sigma_\delta$, as in Kyle (1985). When there are many homogeneously informed insiders, $H = \frac{1}{2+\rho(K-1)}I$ and $var(P_1) = \frac{K}{2+\rho(K-1)}\Sigma_\delta$. In both cases, H is diagonal, so $var(P_1)$ mimics the fundamental covariance structure Σ_v embedded in Σ_δ.[18] If the MFs are heterogeneously informed ($H \neq \frac{1}{2+\rho(K-1)}I$), excess covariance instead arises in our economy. According to Proposition 2, $var(P_1)$ departs from Σ_v when H is nondiagonal: For example, $var(P_1)(n,j)$ may be different from zero although $\Sigma_v(n,j) = 0$. Motivated by this discussion, we measure the degree of excess covariance by the absolute difference between $var(P_1)$ and the corresponding $var(P_1)_{K>1}$, $EC = \left|K\left[H - \frac{1}{2+\rho(K-1)}I\right]\Sigma_\delta\right|$. The following corollary then summarizes these findings.

Corollary 2 *There is financial contagion in equilibrium if and only if* $K > 1$ *and* $H \neq \frac{1}{2+\rho(K-1)}I$*. The intensity of noise trading has no impact on* EC*.*

Proposition 2 and Corollary 2 state the main result of this study. Excess price volatility and comovement depend on the intensity of competition and information heterogeneity among MFs. Indeed, even in a setting with risk-neutrality and absence of financial constraints, contagion is an equilibrium outcome if and only if strategic insiders' private signals are heterogeneous.

What is the intuition behind this result? When Σ_v is nondiagonal or block-diagonal, rational MMs use the order flow for each asset ($\omega_1(n)$) to cross-infer new information about the terminal payoffs of other assets. Imperfectly competitive MFs, aware of this learning process, do not trade on each of the assets independently, but choose each $X_k(n)$ strategically to minimize the amount of information divulged by their market orders.[19] We call this trading activity "strategic portfolio diversification." The MMs account for the MFs' expected strategic trading when updating their priors on v

[18] Nonetheless, $var(P_1)$ is only a fraction of Σ_δ since the order flow is only partially revealing about the insiders' private information.

[19] Therefore, both the matrices Λ in Eq. (8) for P_1 and C in Eq. (10) for X_k are nondiagonal or block-diagonal as well.

from ω_1. Their ability to do so partially or in full determines whether excess comovement arises in our economy.

When there is only one or many homogeneously informed MFs, their strategic trading activity is correctly anticipated by the MMs, resulting in no excess comovement ($var\left(P_1\right) = \frac{K}{2+\rho(K-1)}\Sigma_\delta$ and $EC = O$). The presence of only one insider limits MMs' uncertainty surrounding his strategy in ω_1. A larger number of homogeneously informed MFs does not increase this uncertainty. In fact, their trades are either identical or expected to be perfectly correlated, since so are their informational endowments ($\delta_k = \delta$ or $E_1^k\left(\delta_i\right) = \rho\delta_k$). Their resulting quasi-competitive behavior makes ω_1 a sufficient statistic for the MMs to avoid incorrect cross-inference about v in P_1. Heterogeneous information instead induces the insiders to quasi-monopolistic trading, since part of each MF's informational advantage is known exclusively to him. Indeed, their market orders are expected to be less than perfectly correlated ($E_1^k\left(\delta_i\right) \neq \rho\delta_k$). Consequently, in equilibrium, the MMs learn less accurately about any private signal and any individual trading activity. The ensuing incorrect cross-inference on v causes excess covariance among asset prices ($var\left(P_1\right) = KH\Sigma_\delta$ and $EC\left(n,j\right) > 0$).[20]

The intensity of financial contagion does not depend on the amount of liquidity and short-term trading (i.e., on Σ_z, γ, or Σ_e), since more noise in the order flow leaves its information content (and the MMs' cross-inference) unchanged in equilibrium. This result suggests that short-term trading behavior, often accused to exacerbate the propagation of shocks across assets or markets, does not play any role in explaining excess covariance in our model. Noise trading is nonetheless what prevents ω_1 from becoming a sufficient statistic for S_{uk} and $S_{\vartheta k}$ in the first place. Hence, Σ_n controls for the degree of information asymmetry in this economy. Then, Corollary 2 implies that changes in the intensity of information asymmetry *per se* do not affect the vulnerability of an asset to financial contagion unless they lead to more asymmetric information sharing among insiders. When $\Sigma_c \neq \rho\Sigma_\delta$, if we define $\Sigma_c^* = \alpha\Sigma_c + (1-\alpha)\,\rho\Sigma_\delta$, assume that $cov\left(\delta_k, \delta_i\right) = \Sigma_c^*$ for any $i \neq k$, and consequently substitute Σ_c with Σ_c^* in H, we can interpret the parameter $\alpha \in [0,1]$ as a proxy for the degree of information heterogeneity among the MFs. The following remark ensues.

Remark 3 *Each $EC\left(n,j\right) > 0$ is increasing in K and α. Furthermore,*

[20] Consistently with this interpretation, Grinblatt and Ross (1985) show that the impact of the actions of an insider behaving like a Stackelberg leader on the noisy rational expectations equilibrium of a two-period economy with one risky security and other perfectly competitive traders is significant only when all agents have less than perfectly correlated private information.

$\lim_{K\to\infty} var\left(P_1\right) = \Sigma_\delta \left(\Sigma_c^*\right)^{-1} \Sigma_\delta$ *if* $H \neq \frac{1}{2+\rho(K-1)}I$, *while* $\lim_{K\to\infty} var\left(P_1\right) = \frac{1}{\rho}\Sigma_\delta$ *if* $H = \frac{1}{2+\rho(K-1)}I$. *Therefore,* $\lim_{K\to\infty} EC = \left|\left[\Sigma_\delta \left(\Sigma_c^*\right)^{-1} - \frac{1}{\rho}I\right]\Sigma_\delta\right|$.

Ceteris paribus, more (heterogeneously informed) insiders or greater dispersion of their signals raise the amount of uncorrelated strategic trading in ω_1, so inducing more incorrect cross-inference by the MMs and greater excess covariance (toward $\left|\left[\Sigma_\delta \left(\Sigma_c^*\right)^{-1} - \frac{1}{\rho}I\right]\Sigma_\delta\right|$).[21]

3.3 A no-contagion condition

Information asymmetry among traders is a necessary (albeit not sufficient) ingredient for excess covariance in our economy, as it allows for inference errors in the signal extraction process by the uninformed dealers. In the previous subsection, we have established a necessary and sufficient condition (information heterogeneity) under which financial contagion may occur in equilibrium. We now state another necessary (but not sufficient) condition that, if violated, rules out any comovement between fundamentally unrelated assets, similarly to Kodres and Pritsker (2002).

Proposition 3 *If Σ_v is diagonal or block-diagonal, then there may be financial contagion across assets within a block, but not among blocks of assets.*

Proposition 3 is an important underpinning of our analysis. When there is no fundamental link across assets, the order flow in one security (or block of securities) cannot reveal any information about the terminal payoffs of other securities (or blocks of securities). In those cases, neither cross-inference is possible in the MMs' belief updating process, nor is MFs' strategic portfolio diversification effective in limiting the informativeness of ω_1. Hence, financial contagion cannot occur. This result suggests that the trend toward a more integrated world economy, by magnifying the significance of global factors in explaining local returns (e.g., Bekaert, Harvey, and Ng, 2002) and so providing a motivation for cross-inference, might have increased the likelihood of contagion among international financial markets.

4 International financial contagion

The structure of the economy in Eq. (1) is general enough to allow us to analyze excess comovement across the broadest possible classes of assets. Many

[21] Vice versa, the more homogeneously informed MFs are in the market, the more informative ω_1 becomes about their strategies, the smaller is $|\Lambda|$ (toward O), and the closer $var\left(P_1\right)$ gets to $\frac{1}{\rho}\Sigma_\delta$.

empirical studies (e.g., King et al., 1994; Karolyi and Stulz, 1996; Connolly and Wang, 2000) found that observable macroeconomic variables do not explain the bulk of estimated market return comovements. In the remainder of the paper, we intend to examine the transmission of unobservable shocks across economically unrelated markets. To that purpose, we assume that any security n in the model represents country n's all-inclusive market index. We can then interpret S_{uk} as private information on domestic risk factors (e.g., local fiscal and monetary policies, tax regimes, or political events), and $S_{\vartheta k}$ as private signals of global sources of risk, such as world (or regional) GDP growth and interest rates, commodity prices, or terms of trade.[22]

In Section 3 we defined financial contagion as the circumstance in which equilibrium asset prices covary more than what one would expect from their underlying fundamentals. To investigate the channels through which shocks propagate across countries, we need however to specify an alternative, albeit equivalent, definition that concentrates on the sources of these shocks. Consistent with Forbes and Rigobon (2002), we say that financial contagion occurs when a shock to one market affects prices of other markets fundamentally unrelated either to that shock or to that market. We find this definition appealing because it allows us to distinguish contagion from mere *interdependence*, the propagation of shocks across countries due to real cross-market linkages. The following definition makes these concepts operational in our framework by means of comparative statics analysis.

Definition 2 *In equilibrium, financial contagion from country j to country n occurs if, as a result of a real shock (to u or ϑ),*

$$\frac{\partial P_1(n)}{\partial u(j)} \neq 0 \qquad or \qquad \frac{\partial P_1(n)}{\partial \vartheta(f)} \neq 0; \tag{14}$$

if, as a result of an information noise shock (to ε_{uk} or $\varepsilon_{\vartheta k}$),

$$\frac{\partial P_1(n)}{\partial \varepsilon_{uk}(j)} \neq 0 \qquad or \qquad \frac{\partial P_1(n)}{\partial \varepsilon_{\vartheta k}(f)} \neq 0 \tag{15}$$

when $\beta(j,f) \neq 0$ but $\beta(n,f) = 0$; or if, as a result of a noise trading shock (to z or e_k),

$$\frac{\partial P_1(n)}{\partial z(j)} \neq 0 \qquad or \qquad \frac{\partial P_1(n)}{\partial e_k(j)} \neq 0. \tag{16}$$

[22] There is much anecdotal and empirical evidence of asymmetric information in the markets of developing economies, although a controversy persists on whether domestic or international investors would have the informational edge. A partial list of studies on this topic includes Chuhan (1992), Frankel and Schmukler (1996), Brennan and Cao (1997), Claessens et al. (2000), Seasholes (2000), and Froot et al. (2001).

Conversely, interdependence between country n and country j occurs if

$$\frac{\partial P_1(n)}{\partial \vartheta(f)} \neq 0 \qquad or \qquad \frac{\partial P_1(n)}{\partial \varepsilon_{\vartheta k}(f)} \neq 0 \tag{17}$$

when $\beta(j,f) \neq 0$ and $\beta(n,f) \neq 0$.

4.1 Real shocks and contagion

Real idiosyncratic $(du(n))$ and common $(d\vartheta(f))$ shocks are shocks to the terminal payoff of index n $(v(n))$ observed , with noise, only by the MFs (through S_{uk} and $S_{\vartheta k}$).[23] Proposition 4 provides an explicit characterization of financial contagion from real shocks.

Proposition 4 *The impact of shocks to u on P_1 is given by the $N \times N$ matrix*

$$\frac{\partial P_1}{\partial u'} = KH\Sigma_u \Sigma_{S_u}^{-1}, \tag{18}$$

while the impact of shocks to ϑ on P_1 is given by the $N \times F$ matrix

$$\frac{\partial P_1}{\partial \vartheta'} = KH\beta\Sigma_\vartheta \Sigma_{S_\vartheta}^{-1}. \tag{19}$$

There is financial contagion from those shocks if and only if $K > 1$ and $H \neq \frac{1}{2+\rho(K-1)}I$. Then, although $\beta(n,f) = 0$, both $\left|\frac{\partial P_1(n)}{\partial u(j)}\right| > 0$ and $\left|\frac{\partial P_1(n)}{\partial \vartheta(f)}\right| > 0$ are increasing in K and α, but independent from the intensity of noise trading.[24]

According to Definition 2, the off-diagonal terms in $H\Sigma_u \Sigma_{S_u}^{-1}$ and $H\beta\Sigma_\vartheta \Sigma_{S_\vartheta}^{-1}$ measure the magnitude of contagion by real shocks. Hence, Proposition 4 states that only when insiders' information about these shocks is heterogeneous does financial contagion arise in our model (i.e., $\frac{\partial P_1(n)}{\partial u(j)} \neq 0$ or $\frac{\partial P_1(n)}{\partial \vartheta(f)} \neq 0$), consistent with Corollary 2. In Section 3 we have in fact shown

[23] For instance, we could think of the impact of the Russian default in August 1998 on Asia and Latin-America as contagion induced by an apparently idiosyncratic shock. Alternatively, we could interpret the East Asian crisis in 1997 spilling over many emerging markets around the world as contagion induced by either a real local or a real regional (i.e., block-common) shock.

[24] Because H is not symmetric, upper and lower-triangular terms in $\frac{\partial P_1}{\partial u'}$ and $\frac{\partial P_1}{\partial \vartheta'}$ may be different from each other. Additionally, it is easy to show (using the proof of Remark 3 in Appendix A) that $\lim_{K\to\infty} \frac{\partial P_1}{\partial u'} = \Sigma_\delta \left(\Sigma_c^*\right)^{-1} \Sigma_u \Sigma_{S_u}^{-1}$ and $\lim_{K\to\infty} \frac{\partial P_1}{\partial \vartheta'} = \Sigma_\delta \left(\Sigma_c^*\right)^{-1} \beta\Sigma_\vartheta \Sigma_{S_\vartheta}^{-1}$ when $\Sigma_c^* = \alpha\Sigma_c + (1-\alpha)\rho\Sigma_\delta$ but $H \neq \frac{1}{2+\rho(K-1)}I$. When instead $H = \frac{1}{2+\rho(K-1)}I$, it ensues that $\lim_{K\to\infty} \frac{\partial P_1}{\partial u'} = \frac{1}{\rho}\Sigma_u \Sigma_{S_u}^{-1}$ and $\lim_{K\to\infty} \frac{\partial P_1}{\partial \vartheta'} = \frac{1}{\rho}\beta\Sigma_\vartheta \Sigma_{S_\vartheta}^{-1}$.

that, when MFs share their private information asymmetrically, their strategic portfolio diversification induces incorrect cross-inference about fundamentals by the MMs in equilibrium. To gain further insight on this argument, we construct a simple example along the lines of Kodres and Pritsker (2002). More specifically, we assume that there are three countries in the economy and that, as in Eq. (1), the liquidation values of the indices there traded depend on u and ϑ by way of the following expressions:

$$\begin{array}{rcccccc} v(1) & = & u(1) & + & \vartheta(1) & & \\ v(2) & = & u(2) & + & 0.5\vartheta(1) & + & 0.5\vartheta(2) \\ v(3) & = & u(3) & & & + & \vartheta(2) \end{array}. \tag{20}$$

The two "peripheral" countries, 1 and 3, are fundamentally unrelated ($\beta(1,2) = \beta(3,1) = 0$) but share an exposure to the "core" market 2 via the systematic factors $\vartheta(1)$ and $\vartheta(2)$, respectively ($\beta(1,1) = \beta(3,2) = 1$). Therefore, Eq. (20) violates the no-contagion condition of Proposition 3. We use a parsimonious baseline parametrization of this model (reported in Appendix B). In the resulting economy, we can think of country 2, with the lowest fundamental variance ($\Sigma_v(2,2) = 1.25$) and exposure to both $\vartheta(1)$ and $\vartheta(2)$ ($\beta(2,1) = \beta(2,2) = 0.5$) as a developed, globalized market, and of countries 1 and 3 as emerging, developing markets. We also impose that $\Sigma_z = \Sigma_e = I$, so that $\Sigma_n = \sigma_n^2 I$, to ensure that the linear equilibrium of Proposition 1 is unique (see Remark 1). Finally, we assume that $\gamma = 0$ in U_k of Eq. (4), since Proposition 4 implies that Eqs. (18) and (19) do not depend on γ. We relax this restriction later, when considering shocks to z and e_k. In Figure 1a we plot the impact of a real idiosyncratic shock to the terminal value of index 1 ($du(1)$) on the equilibrium price of index 3 as a function of the number of insiders (K) and for different values of α in Σ_c^*. The measure $\frac{\partial P_1(3)}{\partial u(1)}$, computed according to Eq. (18), is positive and increasing in K and α, even though countries 1 and 3 are ex ante independent (i.e., $cov[v(1), v(3)] = 0$).[25]

What is the intuition for this result? For example, ceteris paribus, a negative shock to $u(1)$ (hence to the K signals $S_{uk}(1)$) prompts each MF to decrease cautiously his optimal demand for that security. The MMs observe the resulting $d\omega_1(1) < 0$ and revise downward their beliefs about $v(1)$, therefore the equilibrium price $P_1(1)$ ($\Lambda(1,1) > 0$ since the matrix Λ is SPD), based on the signals' relative precision ($\Sigma_u \Sigma_{S_u}^{-1}$). To prevent this $dP_1(1) < 0$ from eroding their expected profits from the trade in country 1, the MFs

[25] The dynamics of contagion from real systematic shocks (e.g., $\frac{\partial P_1(1)}{\partial \vartheta(2)}$) are very similar to Figure 1a, so are not reported here but are available from the author on request.

buy more (sell fewer) units of index 2.[26] This trade leads in fact the MMs to the incorrect inference not only $dv(2) > 0$ may have occurred but also that it may be due to $d\vartheta(1) > 0$, given country 2's exposure to that factor ($\beta(2,1) > 0$). A higher $E[\vartheta(1)|\omega_1]$ by the MMs ensues, thereby attenuating the drop in $P_1(1)$, as $\beta(1,1) > 0$, although at the cost of an increase in $P_1(2)$, so of greater expected losses for the MFs from their trade in index 2. Moreover, the exposure of country 2 to $\vartheta(2)$ ($\beta(2,2) > 0$) ends up mitigating the impact of $dX_k(2) > 0$ on the dealers' beliefs about $\vartheta(1)$. Thus, using the fact that $\beta(3,2) > 0$ as well, the insiders demand country 3's index less aggressively to induce the MMs to adjust downward their beliefs about $\vartheta(2)$ and $v(3)$, hence to set a lower $P_1(3)$ and a smaller $dP_1(2) > 0$, and to adjust upward $E[\vartheta(1)|\omega_1]$ and $P_1(1)$.[27]

In short, the MFs, aware of the MMs' cross-inference process, trade strategically across countries (not only $dX_k(1) < 0$ but also $dX_k(2) > 0$ and $dX_k(3) < 0$) to dissipate as little as possible of their initial informational advantage. At the same time, however, the MMs, aware of the MFs' activity, account for it in clearing the market. Eventually, the perceived possibility that $d\vartheta(1) > 0$ and $d\vartheta(2) < 0$ leads the dealers to select a smaller $dP_1(1) < 0$ (thus allowing greater profits for the insiders) than if the MFs had traded exclusively in index 1. In equilibrium, contagion arises only when the MFs are heterogeneously informed, since in that case the MMs are unable to control for their less than perfectly correlated trades in the observed $d\omega_1$ with sufficient accuracy. In the above example, only if $\alpha > 0$ the buying pressure on country 2 and the selling pressure on country 3 result in fundamentally unjustified $dP_1(2) > 0$ and $dP_1(3) < 0$, although both $dv(2) = 0$ and $dv(3) = 0$.[28] These excessive movements represent financial contagion, as defined in Section 4, and explain up to 21% of the unconditional variance of $P_1(3)$ due to private information about v when $\alpha = 1$ (Figure 1d).

More asymmetric sharing of private information among speculators (higher α in Figure 1a) induces a greater impact of $du(1)$ on $P_1(3)$, since it makes MMs' cross-inference more incorrect. Indeed, Kallberg and Pasquariello (2004) found that excess comovement in the U.S. stock market over the last three decades is positively related to the dispersion of analysts' earnings forecasts, a proxy for information heterogeneity suggested by Diether et al. (2002). Furthermore, many empirical studies of institutional and foreign investors' trading behavior offer supporting evidence of intense portfolio rebalancing, rather than generalized sales of assets, during recent financial

[26] E.g., $\frac{\partial X_k(2)}{\partial u(1)} = \left[C\Sigma_u\Sigma_{S_u}^{-1}\right](2,1) = -0.061$ for $K = 15$ and $\alpha = 1$.

[27] E.g., $\frac{\partial X_k(3)}{\partial u(1)} = \left[C\Sigma_u\Sigma_{S_u}^{-1}\right](3,1) = 0.027$ for $K = 15$ and $\alpha = 1$.

[28] E.g., $dP_1(2) = 0.055$ and $dP_1(3) = -0.149$ for $K = 15$ and $\alpha = 1$.

crises in developing economies (e.g., Borensztein and Gelos, 2000; Kaminsky et al., 2000, 2001; Kallberg et al., 2002). Accordingly, Disyatat and Gelos (2001) showed that those investors' holdings contain reliable information about future returns in emerging markets.

However, why are emerging markets especially vulnerable (and increasingly so) to episodes of financial contagion? Our model may help us address this question. Assume, for instance, that only for country 1 and only for $u(1)$ do insiders share private information asymmetrically: $S_{uk}(1) \neq S_{ui}(1)$ but $S_{uk}(n) = S_{ui}(n)$ and $S_{\vartheta k}(f) = S_{\vartheta i}(f)$ for $n = \{2,3\}$ and $f = \{1,2\}$. Eq. (3) then implies that $\Sigma_c = \Sigma_\delta$ with the exception of $[\Sigma_c](1,1) = \left[\Sigma_u \Sigma_{S_u}^{-1} \Sigma_u \Sigma_{S_u}^{-1} \Sigma_u\right](1,1) + \left[\beta \Sigma_\vartheta \Sigma_{S_\vartheta}^{-1} \Sigma_\vartheta \beta'\right](1,1)$. In the resulting equilibrium, shocks from country 1 do not affect countries 2 and 3, but shocks to $u(3)$ and $\vartheta(2)$ do affect the equilibrium price $P_1(1)$, although both $u(3)$ and $\vartheta(2)$ are uncorrelated to $v(1)$.[29] Intuitively, this occurs because the MMs learn from ω_1 about MFs' strategic trading in securities 2 and 3 with sufficient precision to avoid incorrect cross-inference about countries 2 and 3, but not enough to prevent incorrect cross-inference about country 1.

Thus, heterogeneity of private information about domestic sources of risk in a country makes that country more sensitive to fundamentally unrelated shocks from other countries, i.e., increases the likelihood and magnitude of financial contagion. And significant and persistent differences in private information among traders are more likely to be observed in less mature, less heavily supervised financial markets, like the ones of less developed economies, where the process of generation and acquisition of information is still not sufficiently standardized. Homogeneous private information about developed economies can only attenuate, but not eliminate excess comovement among developing markets.[30] Proposition 4 therefore suggests that policy-makers and international organizations may be able to reduce their vulnerability to contagion by reducing the degree of asymmetric sharing of private information about them among professional money managers. This could be accomplished, for example, by encouraging the adoption of uniform and stringent regulations across emerging financial markets for the generation and disclosure of corporate and macroeconomic information.

In their study of strategic hedging due to risk aversion, Kodres and Pritsker (2002) attributed the recurrence of episodes of financial contagion in emerging markets to their greater degree of information asymmetry. It is arguably the case that reliable information is generally accessible to fewer

[29] E.g., for $K = 15$ and $\alpha = 1$, the effect of $du(3) < 0$ on $P_1(1)$ is given by $dP_1(1) = -0.085$; yet $dP_1(2) = dP_1(3) = 0$ in response to any $du(1) \neq 0$ or $d\vartheta(1) \neq 0$.

[30] E.g., if $S_{uk}(2) = S_u(2)$, $K = 15$, and $\alpha = 1$, then in equilibrium $dP_1(2) = 0.003$ and $dP_1(3) = -0.113$ in response to $du(1) < 0$.

players in those markets. Nonetheless, the increased interest of professional money managers in them, spurred by the process of financial integration and liberalization of the past two decades (e.g., Bekaert et al., 2002), should have led to lower (and not higher) information asymmetry, so decreasing (and not increasing) their vulnerability to contagion. Proposition 4 also implies that such process may have instead raised its magnitude, since a greater number of MFs makes it more difficult for the MMs, motivated to cross-inference by greater economic integration (a non-diagonal Σ_v), to learn their individual trades. In the example of Figure 1a, $\frac{\partial P_1(3)}{\partial u(1)}$ is in fact increasing in K.[31]

4.2 Information noise shocks and contagion

In our model the insiders receive noisy signals of the idiosyncratic and systematic risks in the economy. Shocks to the errors in these signals (ε_{uk} and $\varepsilon_{\vartheta k}$) may also induce contagion, as shown in the following proposition.

Proposition 5 *The impact of shocks to any ε_{uk} on P_1 is given by the $N \times N$ matrix*

$$\frac{\partial P_1}{\partial \varepsilon'_{uk}} = H \Sigma_u \Sigma_{S_u}^{-1}, \tag{21}$$

while the impact of shocks to any $\varepsilon_{\vartheta k}$ on P_1 is given by the $N \times F$ matrix

$$\frac{\partial P_1}{\partial \varepsilon'_{\vartheta k}} = H \beta \Sigma_\vartheta \Sigma_{S_\vartheta}^{-1}. \tag{22}$$

There is financial contagion from those shocks if and only if $K > 1$ and $H \neq \frac{1}{2+\rho(K-1)} I$. Then, although $\beta(n,f) = 0$, both $\left|\frac{\partial P_1(n)}{\partial \varepsilon_{uk}(j)}\right| > 0$ and $\left|\frac{\partial P_1(n)}{\partial \varepsilon_{\vartheta k}(f)}\right| > 0$ are independent from the intensity of noise trading.

A shock to S_{uk} or $S_{\vartheta k}$ has the same effect on a MF's informational advantage δ_k whether it is induced by shocks to u and ϑ or by shocks to ε_{uk} and $\varepsilon_{\vartheta k}$. However, any du or $d\vartheta$ modifies the signals observed by all MFs, hence has a bigger impact on P_1. Shocks to ε_{uk} or $\varepsilon_{\vartheta k}$ lead only the k-th insider to the incorrect inference that a fundamental event took place, and induce him alone to revise his portfolio strategically. Information asymmetry prevents the MMs from learning whether the resulting $d\omega_1$ is due to news or noise. Information heterogeneity prevents the MMs from learning whether that shock is due to idiosyncratic or systematic news. Incorrect cross-inference by the MMs and contagion may then occur, as in the stylized economy of Eq. (20)

[31] But at a decreasing rate, for ω_1 is now more informative about v as well.

(e.g., $\frac{\partial P_1(3)}{\partial \varepsilon_{uk}(1)} > 0$ in Figure 1b). Thus, Proposition 5 suggests that financially integrated markets in which private information is shared asymmetrically may experience excess price comovements as a result not only of real shocks but also of false and misleading information about the fundamentals of a single country in the hands of one or few speculators.

As in Proposition 4, both $\left|\frac{\partial P_1(n)}{\partial \varepsilon_{uk}(j)}\right|$ and $\left|\frac{\partial P_1(n)}{\partial \varepsilon_{\vartheta k}(f)}\right|$ are unambiguously unrelated to the intensity of noise trading, since so is the information content of the order flow. The impact of K on their magnitude is instead the result of two contrasting effects. An increasing number of heterogeneously informed MFs makes it more difficult for the MMs to learn about their less than perfectly correlated trading strategies. However, a bigger K also makes ω_1 more informative about v, and P_1 less sensitive to shocks to ω_1 coming from a single insider (i.e., $|\Lambda|$ smaller). For a small K, the former might dominate the latter, so inducing greater contagion, as in the example of Figure 1b. Yet, for a big K, as competition among MFs and the information content of ω_1 increase, the incorrect cross-inference from a shock to ε_{uk} or $\varepsilon_{\vartheta k}$ eventually has a negligible effect on P_1. Indeed, $\lim_{K\to\infty} H = O$ regardless of α. Hence, according to our model, rising participation of insiders to multi-market trading (e.g., due to the integration of world capital markets) may reduce the vulnerability of all countries to contagion from information noise, although it increases the magnitude of contagion from real shocks.

4.3 Noise trading shocks and contagion

Liquidity and short-term trading play an important role in our model. Their presence in fact makes the order flow only partially revealing about v, hence MMs' incorrect cross-inference from shocks to MF's signals possible in equilibrium. Noise trading also provides more direct channels for financial contagion, as the following proposition illustrates.

Proposition 6 *The impact of shocks to z on P_1 is given by the $N \times N$ matrix*

$$\frac{\partial P_1}{\partial z'} = \frac{\sqrt{K}}{2}\Lambda, \tag{23}$$

while the impact of shocks to any e_k on P_1 is given by the $N \times N$ matrix

$$\frac{\partial P_1}{\partial e_k'} = \frac{\sqrt{K}}{4}\left(\frac{\gamma}{1-\gamma}\right)\Lambda. \tag{24}$$

The existence of contagion from those shocks does not depend on the number of insiders (K) or on whether they share information asymmetrically (H).

Because of the information asymmetry between MMs and MFs, any noise trading shock to asset n affects $P_1(n)$ via $\omega_1(n)$. This shock, however, does not induce the insiders to revise their cross-hedging strategies in equilibrium, since any MF is either unaware it occurred ($dz(n)$ or $de_i(n)$) or aware it is uninformative ($de_k(n)$).[32] Nonetheless, if fundamental risks are correlated across countries ($\beta \neq O$), the MMs deem the observed $d\omega_1(n)$ potentially revealing about other terminal payoffs $v(j)$ and MFs' portfolio rebalancing activity. This incorrect cross-inference eventually induces excess comovement in P_1 (e.g., $\frac{\partial P_1(3)}{\partial z(1)} \neq 0$ in Figure 1c) for any possible H or K.

That contagion from noise trading shocks may occur despite H does not contradict Corollary 2. In equilibrium, both the MFs and the MMs account for the expected impact of z and e_k on ω_1. Therefore, $EC = O$ when $H = \frac{1}{2+\rho(K-1)}I$. Yet, any dz or $d\delta_{ek}$ may still entail contagion, along the lines of Definition 2, because the resulting $d\omega_1$ is insensitive to the equilibrium market depth $\frac{2}{\sqrt{K}}\Lambda^{-1}$. Accordingly (and contrary to Propositions 4 and 5), the magnitude of these effects (but not EC) depends on the MMs' perceived intensity of adverse selection in trading, since it affects the magnitude of Λ (see Section 2.4) but not $d\omega_1$ (nor its informativeness). For instance, when K increases, more informed trading in ω_1 and more aggressive competition among MFs induce the MMs to make each market more liquid, thus ultimately reducing the impact of $dz(n)$ or $de_k(n)$ on P_1: $\lim_{K\to\infty} \frac{\partial P_1}{\partial z'} = \lim_{K\to\infty} \frac{\partial P_1}{\partial e'_k} = O$ because $\lim_{K\to\infty} \sqrt{K}\Lambda = O$. However, as in Section 4.2, a greater number of heterogeneously informed MFs not only makes it easier for the MMs to learn the shared portion of the MFs' private signals from ω_1, but also makes it more difficult for them to learn the individual portions of those signals. Indeed, $\frac{\partial P_1(3)}{\partial z(1)}$ and $\frac{\partial P_1(3)}{\partial e_k(1)}$ in Figures 2a and 2b (for $\gamma = 0.5$) initially increase (in absolute terms) for greater K when $H \neq \frac{1}{2+\rho(K-1)}I$, since then it induces more incorrect cross-inference by the MMs, before eventually declining toward zero. Conversely, when the insiders are homogeneously informed, only the first effect arises and both measures converge monotonically to zero.[33]

In our model, realizations of z are unobservable, thus can be interpreted as caused by supply shocks, shifts to life-cycle motivations, or shocks to liquidity trading. The vector e_k represents instead a MF's private information: In equilibrium, he uses it to deviate from his optimal long-term demand of risky assets to increase the short-term value of his portfolio. This behavior is

[32] In particular, the optimal X_k does not depend on Λ and $\frac{\partial X_k(j)}{\partial e_k(n)} = 0$, so $d\omega_1(j) = 0$.

[33] In Figure 1c, there is no such trade-off for $\frac{\partial P_1(3)}{\partial z(1)}$ when $\alpha = \{0.25, 0.50\}$ because the resulting information heterogeneity is too low for higher K to induce further incorrect cross-inference by the MMs.

consistent with reputation considerations, size-based compensation schemes, or the principals' attempt to induce truthful revelation of managerial skills.[34] Final investors may also choose to redeem their claims in a fund early in face of unexpected liquidity shocks or when disappointed by its past performance. Therefore, we can think of $e_k' \left[E_1^k (P_1) - P_0\right]$ in $E_1^k (U_k)$ as cash inflows or outflows a money manager anticipates depending on the expected performance of the N markets in which he invests, and e_k as the sensitivity of his customer base to future market conditions. In particular, the path-dependence in Eq. (5) implies that final investors display preference for winners. Then, according to Proposition 6, a shock to that sensitivity (e.g., due to shifts in their tastes or risk-aversion or to changes in the load fees) may eventually induce financial contagion, as in Figure 2b. The greater is MFs' focus on their short-term NAVs (higher γ), the greater is the amount of uninformative trading in ω_1, the lower is MMs' perceived risk of adverse selection, hence the more liquid is each market (i.e., the smaller are $|\Lambda|$ and $\left|\frac{\partial P_1}{\partial z'}\right|$) and the greater is $\left|\frac{\partial P_1}{\partial e_k'}\right|$ (e.g., in Figures 2c and 2d).[35]

There is some empirical support for this channel of contagion. For example, Connolly and Wang (2000) showed that noise trading from foreign markets may spill over domestic markets through the imprecise signal extraction process of uninformed traders; Kaminsky et al. (2000, 2001) found that underlying investors in mutual funds systematically engaged in contemporaneous and lagged momentum trading during recent emerging markets crises, forcing many professional money managers to trade regardless of their beliefs about fundamentals. Calvo (1999) and Yuan (2000) also explored the possibility that noise transactions by insiders (albeit only when financially constrained) cause financial contagion. The effect of Eq. (24) moves in a similar direction. Nevertheless, our analysis of the relation between positive feedback flows and the vulnerability of the global financial system to contagion is novel to the financial literature on excess comovement.

5 Conclusions

There is growing empirical evidence that comovement of asset prices within and across domestic and international financial markets is excessive, i.e., cannot be justified by economic fundamentals. The main motivation of this

[34] See Chevalier and Ellison (1997) for a discussion of this topic.

[35] In fact, only the square root of the intertemporal MRS enters Λ. Intuitively, for greater γ, a shock to e_k induces a bigger shift in X_k and ω_1, hence further incorrect cross-inference by the MMs. However, if $\gamma = 1$, $\frac{\partial P_1}{\partial z'} = \frac{\partial P_1}{\partial e_k'} = O$ since then $E\left[v|\omega_1\right] = \overline{v}$ and $\Lambda = O$.

study was to investigate why financial contagion has been occurring with increasing frequency and magnitude, especially for emerging markets.

It is often argued that greater price and return comovements (e.g., Bekaert and Harvey, 2000) and the recurrence of crises and contagion events (e.g., Bordo et al., 2000) should be attributed to the intensification of capital mobility and financial integration across world capital markets, in particular (as in Kodres and Pritsker, 2002) when this process is accompanied by persistent information asymmetries among market participants. It is nonetheless difficult to believe that the increased interest of institutional investors in emerging markets, spurred by recent liberalization measures, would have led to higher (not lower) information asymmetry, hence increasing (not decreasing) their vulnerability to contagion.

We claimed instead that economic and financial integration, by making the world economy more interconnected and increasing investors' interest in emerging markets, may have raised their vulnerability to financial contagion from real shocks, if those investors share private information about these markets asymmetrically. Significant differences in private information among imperfectly competitive traders are indeed more likely in the smaller, less mature and regulated financial markets of developing economies, where the process of generation, acquisition, and dissemination of information is still insufficiently standardized and large speculators can still affect market prices. Our analysis further indicated that disparities in the degree of information heterogeneity across countries could explain why contagion occurs more often and with greater extent in some markets than in others. Short-term trading by speculators is also frequently accused of exacerbating the propagation of shocks across markets. Our analysis suggested that this behavior does not play any role in explaining the magnitude of excess comovement by real shocks. However, we also showed that shocks to the sensitivity of mutual funds' customer base to past performance (due, for instance, to shifts in tastes or risk aversion) could indeed result in financial contagion, consistent with recent findings by Kaminsky et al. (2000, 2001).

Is globalization at least partially responsible for the contagion events sweeping several developing economies in the recent past? The process of economic and financial integration has taken place only in the last two decades, and is still at an early stage in many countries. Professional money managers investing in emerging capital markets are still relatively less numerous, and the information they produce (or receive) and use for trading is still more heterogeneous than in the more mature markets of developed economies. According to our model, these facts currently justify a high, even rising vulnerability of the global financial system to contagion among emerging markets. Yet, the trend for greater participation of institutional investors to those markets and the adoption of uniform, more stringent rules for the production and disclosure of corporate and macroeconomic information may lead to greater competition and less information asymmetry and heterogeneity among traders, hence potentially reducing such vulnerability.

6 Appendix A

Definition A1. (Greene, 1997 p. 32) *A matrix A is **block-diagonal** if it can be represented as a partitioned matrix where all the off-diagonal submatrices are null matrices.* ■

Definition A2. (Greene, 1997 p. 46)) *If A is a real matrix and the quadratic form $q = x'Ax > 0$ for all real nonzero vectors x, the matrix A is **positive definite**. If the matrix A is also symmetric, then A is **symmetric positive definite** (SPD).* ■

Theorem A1. (Bellman, 1970 p. 54 and p. 91) *A necessary and sufficient condition that the matrix A be **positive definite** is that all the characteristic roots of A be positive. Therefore, a positive definite matrix A is always **nonsingular**. If the matrix A is SPD, so is A^{-1}.* ■

Proof of Proposition 1. The proof is by construction, as in Caballé and Krishnan (1994). We first specify general linear functionals for the pricing rule and insiders' demands, and then show that those functionals indeed represent a rational expectations equilibrium when their parameters are the ones in Eqs. (8) and (10). We start by guessing that the equilibrium price vector (P_1) and market orders submitted by each MF (X_k) are given by

$$P_1 = A_0 + A_1 \omega_1 \tag{A-1}$$

and, for $k = 1, \ldots, K$, by

$$X_k \left(\delta_k, \delta_{ek}\right) = B_0 + B_1 \delta_k + B_2 \delta_{ek}, \tag{A-2}$$

respectively, where the matrix A_1 is SPD and the matrix B_1 is nonsingular. The definition of ω_1 and Eqs. (A-1) and (A-2) imply that each MF's expected equilibrium prices before trading occurs, $E_1^k \left(P_1\right)$, are equal to

$$\begin{aligned} E_1^k \left(P_1\right) &= A_0 + A_1 \Big[X_k + \left(K-1\right) B_0 + B_1 \sum\nolimits_{i \neq k} E_1^k \left(\delta_i\right) \\ &\quad + B_2 \sum\nolimits_{i \neq k} E_1^k \left(\delta_{ei}\right) + \overline{z}\Big], \end{aligned} \tag{A-3}$$

where $E_1^k(\delta_i) = \Sigma_c \Sigma_\delta^{-1} \delta_k$ and $E_1^k(\delta_{ei}) = \underline{0}$ because of the distributional assumptions made in Sections 2.1 and 2.2 and the properties of multivariate normal random variables (e.g., Greene, 1997 pp. 89-90). From Eq. (A-3), the symmetry of A_1 ($A_1' e_k = A_1 e_k$), and the fact that $E_1^k(v) = \delta_k + \overline{v}$ (by definition of δ_k), we derive the first order condition of the maximization of the objective function $E_1^k(U_k)$ defined in Eq. (5) as

$$\begin{aligned} \underline{0} &= \gamma A_1 e_k + (1-\gamma)\left[\delta_k + \overline{v} - A_0 - (K-1) A_1 B_0 + \right. \\ &\quad \left. - A_1 \overline{z} - (K-1) A_1 B_1 \Sigma_c \Sigma_\delta^{-1} \delta_k - 2 A_1 X_k \right]. \end{aligned} \tag{A-4}$$

The second order condition is satisfied, for the matrix $2(1-\gamma) A_1$ is positive definite. Dividing both sides of Eq. (A-4) by $(1-\gamma)$, replacing X_k with the conjecture of Eq. (A-2), and equating the resulting coefficients, we obtain

$$(K+1) A_1 B_0 = \overline{v} - A_0 - A_1 \left(\overline{z} - \frac{\gamma}{1-\gamma} \overline{e} \right), \tag{A-5}$$

$$2 A_1 B_1 = I - (K-1) A_1 B_1 \Sigma_c \Sigma_\delta^{-1}, \tag{A-6}$$

and

$$2 A_1 B_2 = \frac{\gamma}{1-\gamma} A_1. \tag{A-7}$$

Since A_1 is invertible (Theorem A1), Eq. (A-7) implies that $B_2 = \frac{1}{2}\left(\frac{\gamma}{1-\gamma}\right)$. Moreover, because ω_1 is MND with mean $E(\omega_1) = K B_0 + \overline{z}$ and variance

$$var(\omega_1) = K B_1 \Sigma_\delta B_1' + \Sigma_n + K(K-1) B_1 \Sigma_c B_1' \tag{A-8}$$

(as $cov(\delta_k, \delta_i) = \Sigma_c$ and $cov(e_k, e_i) = O$), and $cov(v, \omega_1) = K \Sigma_\delta B_1'$, then

$$\begin{aligned} E(v|\omega_1) &= \overline{v} + K \Sigma_\delta B_1' \left[K B_1 \Sigma_\delta B_1' + \Sigma_n + \right. \\ &\quad \left. + K(K-1) B_1 \Sigma_c B_1' \right]^{-1} \left[\omega_1 - K B_0 - \overline{z} \right]. \end{aligned} \tag{A-9}$$

According to Definition 1 (Eq. (7)), $P_1 = E(v|\omega_1)$ in equilibrium. Therefore, the conjecture of Eq. (A-1) implies that, given the invertibility of B_1,

$$A_1 = \left[B_1 + (K-1) B_1 \Sigma_c \Sigma_\delta^{-1} + \frac{1}{K} \Sigma_n (B_1')^{-1} \Sigma_\delta^{-1} \right]^{-1} \tag{A-10}$$

and that

$$A_0 = \overline{v} - A_1 \overline{z} - K A_1 B_0. \tag{A-11}$$

The expressions for A_0, A_1, B_0, and B_1 implied by Eq. (8) for P_1 and by Eq. (10) for X_k must solve the system made of Eqs. (A-5), (A-6), (A-10), and (A-11) to represent a linear equilibrium of our economy. Defining $A_1 B_0$ from Eq. (A-5) and substituting it into Eq. (A-11) leads us to

$$A_0 = \overline{v} - A_1 \left(\overline{z} + \frac{\gamma}{1-\gamma} K \overline{e} \right). \tag{A-12}$$

Plugging Eq. (A-12) into Eq. (A-5), we obtain $B_0 = \frac{\gamma}{1-\gamma}\overline{e}$. We are left with the task of finding A_1 and B_1. Solving Eq. (A-6) for A_1, we get

$$A_1 = \left[2B_1 + (K-1) B_1 \Sigma_c \Sigma_\delta^{-1} \right]^{-1}. \tag{A-13}$$

Equating Eq. (A-13) to Eq. (A-10), it follows that $B_1 = \frac{1}{K}\Sigma_n \left(B_1'\right)^{-1} \Sigma_\delta^{-1}$. Substituting this expression for B_1 back into Eq. (A-10) gives us

$$A_1 = \left[\frac{2}{K} \Sigma_n \left(B_1'\right)^{-1} \Sigma_\delta^{-1} + (K-1) B_1 \Sigma_c \Sigma_\delta^{-1} \right]^{-1}. \tag{A-14}$$

Using the invertibility of A_1 and Eq. (A-13), it is easy to derive

$$B_1 = A_1^{-1} \left[2I + (K-1) \Sigma_c \Sigma_\delta^{-1} \right]^{-1} \tag{A-15}$$

and

$$\left(B_1'\right)^{-1} = A_1 \left[2I + (K-1) \Sigma_\delta^{-1} \Sigma_c \right]. \tag{A-16}$$

We insert Eqs. (A-15) and (A-16) into Eq. (A-14) and rearrange terms to obtain

$$\frac{K}{4} A_1^{-1} \Gamma = \frac{2}{K} \Sigma_n A_1, \tag{A-17}$$

where the matrix Γ, defined as

$$\begin{aligned} \Gamma &= \left[\Sigma_\delta^{-1} + \frac{K-1}{2} \Sigma_\delta^{-1} \Sigma_c \Sigma_\delta^{-1} \right]^{-1} + \\ &\quad - \left[2\Sigma_\delta^{-1} + \frac{K-1}{2} \Sigma_\delta^{-1} \Sigma_c \Sigma_\delta^{-1} + \frac{2}{K-1} \Sigma_c^{-1} \right]^{-1}, \end{aligned} \tag{A-18}$$

is SPD by the *Rayleigh's principle* (e.g., Bodewig, 1959 p. 283) and Theorem A1, since so is Σ_c. Because we can write Eq. (A-17) as

$$\frac{K}{4} \left(\Sigma_n^{1/2} \Gamma \Sigma_n^{1/2} \right) = \left(\Sigma_n^{1/2} A_1 \Sigma_n^{1/2} \right) \left(\Sigma_n^{1/2} A_1 \Sigma_n^{1/2} \right) \tag{A-19}$$

(where $\Sigma_n^{1/2}$ is the unique SPD square root of Σ_n), and because the left-hand-side of Eq. (A-19) is itself SPD, the matrix $\Sigma_n^{1/2} A_1 \Sigma_n^{1/2}$ represents its unique SPD square root (e.g., Bellman, 1970 pp. 93-94). It then ensues that

$$A_1 = \frac{\sqrt{K}}{2}\left(\Sigma_n^{-1/2}\Psi^{1/2}\Sigma_n^{-1/2}\right) = \frac{\sqrt{K}}{2}\Lambda, \tag{A-20}$$

where $\Psi = \Sigma_n^{1/2}\Gamma\Sigma_n^{1/2}$, is clearly the unique SPD matrix that solves Eq. (A-19). The matrix B_1 is derived by plugging the above expression for A_1 into Eq. (A-15), and is equal to $\frac{2}{\sqrt{K}}\Lambda^{-1}H$ (i.e., C in Eq. (10)). Because the matrix Λ in Eq. (A-20) is SPD, it is simple to verify that B_1 is invertible, consistently with our initial assumptions, using Theorem A1 and the definition of H in Proposition 1. Finally, it remains to prove that, given any linear pricing rule, the symmetric linear strategies X_k in Eq. (10), for $k = 1, \ldots, K$, represent the unique Bayesian Nash equilibrium of the Bayesian game among insiders. This is shown by extending to our setting the "backward reaction mapping" introduced by Novshek (1984) to find n-firm Cournot equilibria. Proposition 1 is in fact equivalent to a symmetric Cournot equilibrium with K MFs. The key to Novshek's argument is to look for the actions of each fund manager that are consistent with utility maximization and the aggregate demand ω_1, instead of specifying the actions for each MF which are consistent with the choices of the other MFs. Uniqueness then follows from observing that, because the optimal demands X_k depend only on individual attributes δ_k and δ_{ek}, there is only one ω_1 that can be decomposed into the sum of those vectors X_k and liquidity trading, but also that such aggregate order flow ω_1 can be decomposed only in one way into those vectors X_k, given z. ■

Proof of Remark 1. The equilibrium of Proposition 1 is the unique linear equilibrium for which $\Lambda = \frac{2}{\sqrt{K}}A_1$ is symmetric because, as previously mentioned, the matrix A_1 is the only SPD matrix solving Eq. (A-19). That such linear equilibrium is also unique when $K = 1$ has been shown by Caballé and Krishnan (1990). When instead $\Sigma_n = \sigma_n^2 I$, uniqueness ensues from a straightforward extension of Proposition 3.2 of Caballé and Krishnan (1994) to our setting with $\gamma \in [0, 1]$. ■

Proof of Corollary 1. $\Lambda_{K=1}$ and $\Lambda_{K>1}$ are easily derived using the definitions of Ψ and Λ in Proposition 1, the definition of Γ in Eq. (A-18), and the observation that, when all MFs receive the same or similar set of signals, the matrix Σ_c is equal to Σ_δ or $\rho\Sigma_\delta$, respectively. Inspection then shows that $\Lambda(n,n)_{K=1} \geq \Lambda(n,n) \geq \Lambda(n,n)_{K>1}$ for each $n = 1, \ldots, N$, with a strict inequality holding for at least some n. ■

Proof of Proposition 2. The definition of H in Proposition 1 implies immediately that $H_{K=1} = \frac{1}{2}I$ and $var\left(P_1\right)_{K=1} = \frac{1}{2}\Sigma_\delta$, and that $H_{K>1} = \frac{1}{2+\rho(K-1)}I$ and $var\left(P_1\right)_{K>1} = \frac{K}{2+\rho(K-1)}\Sigma_\delta$, as Σ_c is equal to Σ_δ or $\rho\Sigma_\delta$ when there is only one insider or the MFs' private information is homogeneous, respectively. Finally, using the fact that $\left|\Sigma_u\Sigma_{S_u}^{-1}\left(n,j\right)\right| \leq \rho I\left(n,j\right)$ and $\left|\Sigma_\vartheta\Sigma_{S_\vartheta}^{-1}\left(n,j\right)\right| \leq \rho I\left(n,j\right)$ for any $\rho \in (0,1]$ and for each $n, j = 1,\ldots,N$ (with a strict inequality holding for at least each $n = j$), it can easily be shown that, given the definitions of Σ_δ and Σ_c in Section 2.2, $\left|\Sigma_c\Sigma_\delta^{-1}\left(n,j\right)\right| \leq \rho I\left(n,j\right)$, hence that $\left|KH\left(n,j\right)\right| \geq \frac{K}{2+\rho(K-1)}I\left(n,j\right) \geq \frac{1}{2}I\left(n,j\right)$ for each $n, j = 1,\ldots,N$, with a strict inequality holding for at least one $n = j$ and one $n \neq j$. The inequality in Eq. (13) then follows from Eq. (11). ■

Proof of Corollary 2. That information heterogeneity is a necessary and sufficient condition for financial contagion ensues from Proposition 2 and the definition of excess covariance provided in the text. Indeed, $EC = O$ when $\Sigma_c = \rho\Sigma_\delta$, but $EC\left(n,j\right) > 0$ for at least one $n = j$ when $\Sigma_c \neq \rho\Sigma_\delta$. Further, the matrices H and Σ_δ in EC clearly do not depend on the variance of noise trading Σ_n nor on any of its components (γ, Σ_e, and Σ_z). ■

Proof of Remark 3. That each positive element of the matrix $EC = \left|K\left[H - \frac{1}{2+\rho(K-1)}I\right]\Sigma_\delta\right|$ increases for higher K under the conditions of the remark ($\Sigma_c^*\Sigma_\delta^{-1} \neq \rho I$) is evident from rewriting $K\left[H - \frac{1}{2+\rho(K-1)}I\right]$ as $\left(\frac{2}{K}I + \frac{K-1}{K}\Sigma_c^*\Sigma_\delta^{-1}\right)^{-1} - \left(\frac{2}{K}I + \frac{K-1}{K}\rho I\right)^{-1}$, using the definition of H in Proposition 1, and the fact that $\left|\Sigma_c\Sigma_\delta^{-1}\left(n,j\right)\right| \leq \rho I\left(n,j\right)$ for any $\rho \in (0,1]$, as shown in the proof of Proposition 2. Moreover, $\lim_{K\to\infty}\left(\frac{2}{K}I + \frac{K-1}{K}\Sigma_c^*\Sigma_\delta^{-1}\right) = \Sigma_c^*\Sigma_\delta^{-1}$ for any $\alpha \in [0,1]$, as $\lim_{K\to\infty}\frac{1}{K} = 0$ and $\lim_{K\to\infty}\frac{K-1}{K}I = I$ by *L'Hôpital's rule*. It then follows that $\lim_{K\to\infty}KH\Sigma_\delta = \left(\Sigma_c^*\Sigma_\delta^{-1}\right)^{-1}\Sigma_\delta = \Sigma_\delta\left(\Sigma_c^*\right)^{-1}\Sigma_\delta$, $\lim_{K\to\infty}\frac{K}{2+\rho(K-1)}\Sigma_\delta = \frac{1}{\rho}\Sigma_\delta$ (again by *L'Hôpital's rule*), and consequently $\lim_{K\to\infty}EC = \left|\left[\Sigma_\delta\left(\Sigma_c^*\right)^{-1} - \frac{1}{\rho}I\right]\Sigma_\delta\right|$. Finally, each positive element of the matrix EC also decreases for lower α, as $\lim_{\alpha\to 0}\Sigma_c^* = \Sigma_\delta$, $\lim_{\alpha\to 0}H = \frac{1}{2+\rho(K-1)}I$, and $\lim_{\alpha\to 0}K\left[H - \frac{1}{2+\rho(K-1)}I\right]\Sigma_\delta = O$. ■

Proof of Proposition 3. In Sections 2.1 and 2.2 we assumed that all liquidity, information noise, and endowment shocks are independent across assets, i.e., that the matrices Σ_z, Σ_{ε_u}, $\Sigma_{\varepsilon_\vartheta}$, and Σ_e are diagonal. Hence, if the matrix Σ_v is either diagonal or block-diagonal, it is easy to see that the matrices Σ_δ and Σ_c are either diagonal or block-diagonal as well. All their sums, products, and inverses are therefore either diagonal or block-diagonal, and so are the matrices Λ, C, and H. The no-contagion result then ensues from inspection of the expression for $var\left(P_1\right)$ in Eq. (11). Note however that, when $H \neq \frac{1}{2+\rho(K-1)}I$, $EC\left(n,n\right) > 0$ even if $\beta = O$, because a multiplicity of diverse signals for u and ϑ increases the information content of the order flow, thus driving $KH\Sigma_\delta$ toward Σ_v. ■

Proof of Proposition 4. Eqs. (18) and (19) ensue straightforwardly from Proposition 1, given the definitions of S_{uk} and $S_{\vartheta k}$ and the fact that δ_k is equal to $\Sigma_u\Sigma_{S_u}^{-1}\left(S_{uk} - \overline{u}\right) + \beta\Sigma_\vartheta\Sigma_{S_\vartheta}^{-1}\left(S_{\vartheta k} - \overline{\vartheta}\right)$ for all $k = 1, \ldots, K$. When $H = \frac{1}{2+\rho(K-1)}I$, inspection of $KH\Sigma_u\Sigma_{S_u}^{-1}$ and $KH\beta\Sigma_\vartheta\Sigma_{S_\vartheta}^{-1}$ immediately reveals that $\frac{\partial P_1(n)}{\partial u(j)} = 0$ and $\frac{\partial P_1(n)}{\partial \vartheta(f)} = 0$ (for $\beta\left(n,f\right) = 0$) for any $n, j = 1, \ldots, N$, $n \neq j$, and for any $f = 1, \ldots, F$. When instead $K > 1$ but $\Sigma_c \neq \rho\Sigma_\delta$ (i.e., when $H \neq \frac{1}{2+\rho(K-1)}I$), the matrix H is nondiagonal, hence so are $KH\Sigma_u\Sigma_{S_u}^{-1}$ and $KH\beta\Sigma_\vartheta\Sigma_{S_\vartheta}^{-1}$. In this case, the absolute magnitude of contagion, as measured by $\left|\frac{\partial P_1(n)}{\partial u(j)}\right|$ and $\left|\frac{\partial P_1(n)}{\partial \vartheta(f)}\right|$, is increasing in K and α because so is each positive element of the matrix $|KH| = \left|\left(\frac{2}{K}I + \frac{K-1}{K}\Sigma_c^*\Sigma_\delta^{-1}\right)^{-1}\right|$, as $\left|\Sigma_c\Sigma_\delta^{-1}\left(n,j\right)\right| \leq \rho I\left(n,j\right)$ for any $\rho \in (0,1]$ (see the proof of Proposition 2), $\frac{\partial \frac{1}{K}}{\partial K} = -\frac{1}{K^2} < 0$, and $\frac{\partial \frac{K-1}{K}}{\partial K} = \frac{1}{K^2} > 0$. Finally, both Eqs. (18) and (19) clearly do not depend on the intensity of liquidity or short-term trading, for the matrices H, Σ_u, Σ_{s_u}, Σ_ϑ, Σ_{s_ϑ}, and β do not depend on Σ_z, Σ_e, or γ. ■

Proof of Proposition 5. The statement of the proposition follows straightforwardly from Proposition 1, the proof of Proposition 4 in Appendix A, and the definitions of S_{uk}, $S_{\vartheta k}$, δ_k, and H, which also imply that both $\frac{\partial P_1}{\partial u'} = \frac{\partial P_1}{\partial \varepsilon'_{uk}}$ and $\frac{\partial P_1}{\partial \vartheta'} = \frac{\partial P_1}{\partial \varepsilon'_{\vartheta k}}$ when $K = 1$. ■

Proof of Proposition 6. Eqs. (23) and (24) follow straightforwardly from Eq. (9) in Proposition 1. Corollary 1 and the fact that Λ is nondiagonal (unless $\beta = O$) then ensure that the existence of contagion induced by shocks to z and e_k does not depend on K or H. ■

7 Appendix B

$$\Sigma_u = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0.25 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \qquad \Sigma_{\varepsilon_u} = \begin{bmatrix} 2 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 2 \end{bmatrix}, \tag{B-1}$$

$$\Sigma_\vartheta = \begin{bmatrix} 3 & 0 \\ 0 & 1 \end{bmatrix}, \qquad \Sigma_{\varepsilon_\vartheta} = \begin{bmatrix} 0.25 & 0 \\ 0 & 0.25 \end{bmatrix}. \tag{B-2}$$

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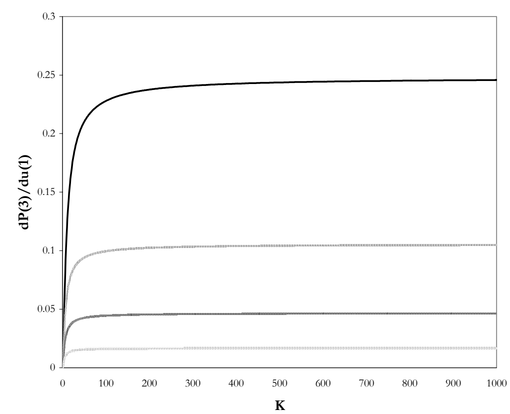
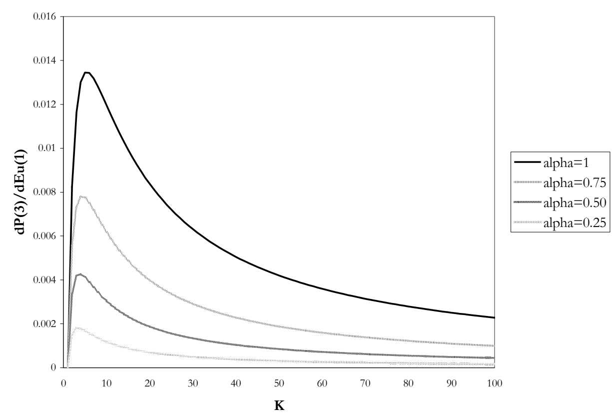
Figure 1. Measures of contagion when $\gamma = 0$

Figures 1a to 1c plot measures of contagion from real shocks ($\frac{\partial P_1(3)}{\partial u(1)}$ in Proposition 4), from individual information noise shocks ($\frac{\partial P_1(3)}{\partial \varepsilon_{uk}(1)}$ in Proposition 5), and from liquidity shocks ($\frac{\partial P_1(3)}{\partial z(1)}$ in Proposition 6) with respect to the number of better-informed MFs (K) in the three-country economy of Eq. (20), given its parametrization in Appendix B. We compute these effects for different values of α in $\Sigma_c^* = \alpha\Sigma_c + (1-\alpha)\,\rho\Sigma_\delta$ with $\rho = 1$, i.e., for different degrees of information heterogeneity. Finally, in Figure 1d we plot the percentage of the unconditional variance of $P_1\,(3)$ due to fundamental information δ_k that is explained by shocks to the liquidation value of index j, for $j = \{1, 2, 3\}$, $var\left[\frac{\sqrt{K}}{2}\sum_{i=1}^{K}(\Lambda C)\,(3,j)\,\delta_i\,(j)\right]$, as a function of K and for $\alpha = 1$.

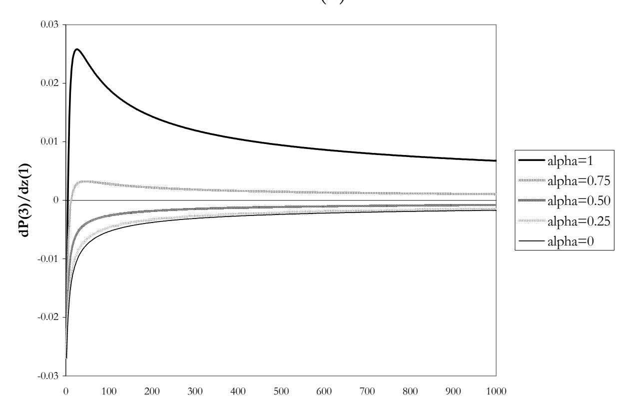
a) $\frac{\partial P_1(3)}{\partial u(1)}$



b) $\frac{\partial P_1(3)}{\partial \varepsilon_{uk}(1)}$



c) $\frac{\partial P_1(3)}{\partial z(1)}$



d) Variance decomposition

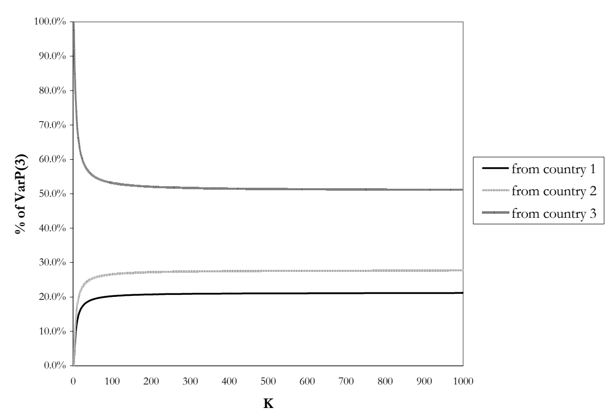
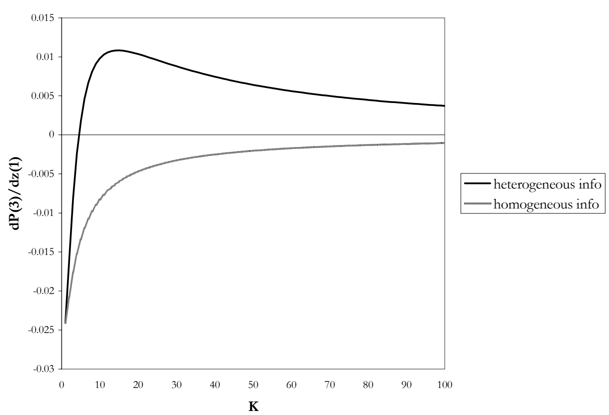


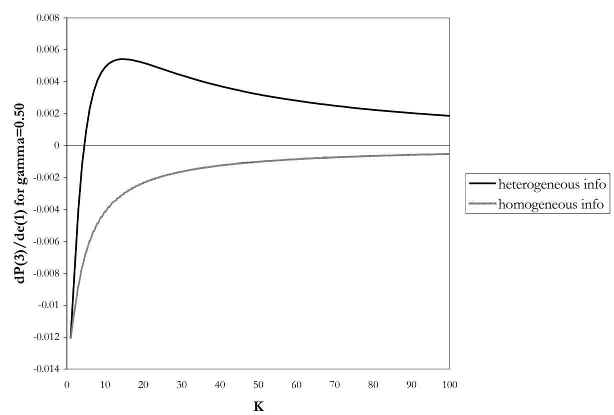
Figure 2. Contagion from uninformative trading when $\gamma > 0$

Figures 2a and 2b plot measures of contagion from shocks to liquidity trading ($\frac{\partial P_1(3)}{\partial z(1)}$) and from shocks to the insiders' short-term trading activity ($\frac{\partial P_1(3)}{\partial e_k(1)}$), defined in Proposition 6, as a function of the number of MFs (K) when $\gamma = 0.5$ and the informational advantage enjoyed by the insiders is either heterogeneous ($\Sigma_c \neq \rho\Sigma_\delta$ and $\alpha = 1$) or homogeneous ($\Sigma_c = \Sigma_\delta$ and $\alpha = 0$), given the parameters in Eqs. (B-1) and (B-2). Figures 2c and 2d instead display $\frac{\partial P_1(3)}{\partial e_k(1)}$ and $\frac{\partial P_1(3)}{\partial z(1)}$ as a function of γ, for different values of K, when the MFs are heterogeneously informed.

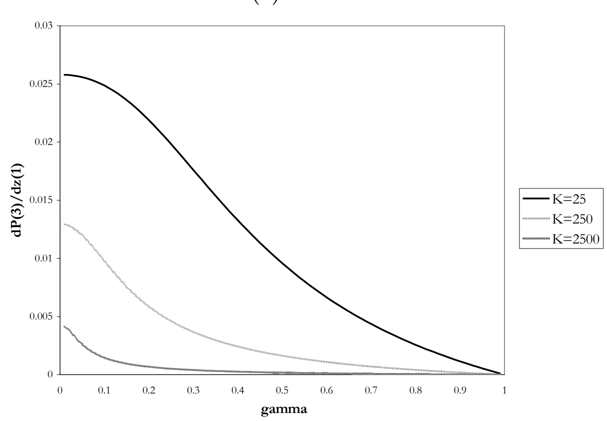
a) $\frac{\partial P_1(3)}{\partial z(1)}$



b) $\frac{\partial P_1(3)}{\partial e_k(1)}$



c) $\frac{\partial P_1(3)}{\partial z(1)}$ versus γ



d) $\frac{\partial P_1(3)}{\partial e_k(1)}$ versus γ