

**EUI Working Paper ECO No. 96/6**

Arbitrage, Hedging,  
and Financial Innovation

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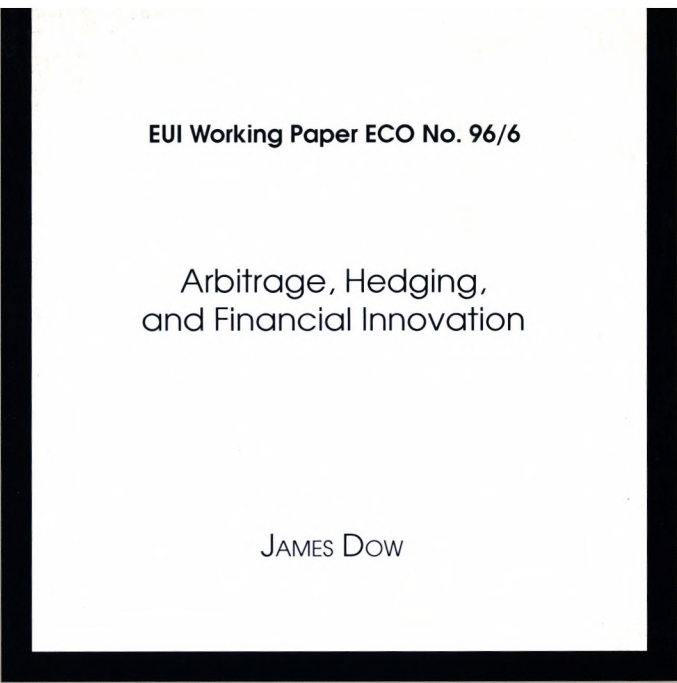
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## Arbitrage, Hedging, and Financial Innovation

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**Abstract:** I present a simple model in which it is possible that opening a new market makes everybody worse off. Unlike previous examples in the literature, the analysis does not rely on relative price changes of different consumption goods. This is shown in a standard framework in which uninformed traders with hedging needs interact with risk-averse informed traders, in security markets where prices are set by a competitive market-making system. The paper emphasises cross-market links between hedging and speculative demands: risk-averse arbitrageurs can hedge in the new market to lower the risk of speculative positions in the pre-existing market. This causes a greater incidence of speculative activity in the old market, leading some traders with pure hedging motives in that market to withdraw and reducing liquidity in the old market. The general point argued here is that a risk-averse informed trader who believes an asset to be mispriced will typically be able to reduce the risk of speculating on his belief by hedging with other assets. The availability of such hedging instruments will in turn determine which types of speculative activity are of low risk, and this will influence the strategies to which traders will devote resources. *Journal of Economic Literature* classification numbers G12, D60, D82, G18.

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## 1. Introduction

This paper has two purposes. First, it is motivated by an interest in the general question of the economic costs and benefits of financial innovation. A comprehensive treatment of this question is probably beyond the scope of current research and certainly beyond the scope of this paper, which confines itself to a narrower problem within this general area. In particular, it seeks to apply the standard methods of analysis of welfare economics (particularly Pareto ranking) to a model of a security market equilibrium in which a new security is introduced. The structure of this model is itself standard in finance research: asymmetric information about asset values, price formation by a market-maker, interaction between informed and uninformed traders. However, welfare analysis of this type of model is rare and has not previously been used to study the value of financial innovation.

The second, and subsidiary, purpose of this paper is to explore the links between arbitrage and hedging demands for securities. A trader who believes a security to be mispriced will generally not be able to predict the value with certainty: in other words, trading in the security will expose him to risk. However, by simultaneously trading in other securities he may be able to hedge these risks, at least partially and sometimes even perfectly. Hence a large volume of hedging demand for securities may actually emanate from arbitrage activity. It is this link that is explored in this paper to analyze the effects of introducing a new security.

### *Financial Innovation*

The general problem of understanding the benefits and costs of financial innovation includes many complex issues. However, some basic questions in

this area remain open for research: Does opening a market tend to increase economic welfare? If the market in a new security attracts many traders does this indicate that the market is beneficial?

The First Welfare Theorem of general equilibrium theory shows that an economy with complete markets is Pareto efficient. Hence, introducing new markets to an economy with incomplete markets will make at least one person better off - so long as sufficient new markets are introduced to make the set of markets complete. The statement that at least one agent is better off is of course very weak, but it is the strongest statement that can be hoped for in general. Hence considerable research effort has been devoted to investigating its validity.

The condition that markets be complete in the literal sense required to apply this result could presumably never be attained in reality. Yet, introducing some new markets without opening all conceivable markets can in principle make everybody worse off. It is simple to generate such examples when there are non-pecuniary externalities: if a market opens for cars that produce noxious emissions, but there is no market for regulating pollution, we might all suffer more from choking on the fumes than we benefit from motoring. However, this type of externality seems unlikely to prevail in financial markets. Examples have also been derived of how opening financial markets could make everybody worse off: Hart (1975), Newbery and Stiglitz (1984) and Kemp and Sinn (1993). Indeed, Cass and Citanna (1995) and Elul (1995) show that, with more than one consumption good, it is always possible to make everybody worse off by introducing a new security. On the other hand, they also show that these welfare effects are based on the idea that introducing a new market changes the relative prices of different consumption goods across different states of nature,

and that if there is only a single consumption good ("money"), introducing a new market must make at least one agent better off. This general result applies to the standard model of general equilibrium theory, i.e. Walrasian, price-taking market clearing and perfect information.

In contrast, much research in finance has focused on a different type of model: security prices and trading volume are determined by the interplay of traders who trade because they have superior information, and those who trade for non-informational reasons such as liquidity or hedging needs. Following Kyle (1985) and Glosten and Milgrom (1985), much of the literature has relied on a competitive market-maker to set prices and clear the market. As standard in the finance literature, these models use a single consumption good: they do not investigate, and the results do not depend on, relative price changes of different commodities.

This paper uses this framework to consider the welfare effect of adding a new security. Although, with the market for the new security open, markets are not complete in the Arrow-Debreu sense, they are complete enough to allow agents to construct a perfect hedge against their initial risk exposure.

### *Arbitrage and Hedging*

The basic idea explored in this paper is of cross-market links between hedging and speculative demands. Agents may be speculators in one market and hedgers in another, and these roles may be linked: they may use the first market to lay off part of the risk of their speculative position in the second market. Indeed, although the term "arbitrage" strictly speaking refers to an entirely riskless profitable trading strategy, even the least risky speculative trades involve an element of risk. Hence, in this paper I use the term in the broader

sense common among practitioners, to describe an informed trade that is highly profitable in relation to its risk. The general point argued here is that a risk-averse informed trader who believes an asset to be mispriced will typically be able to reduce the risk of speculating on his belief by hedging with other assets. The availability of such hedging instruments will in turn determine which types of speculative activity are of low risk, and this will influence the types of speculative strategies to which traders will devote resources.

The following examples include both cases of virtually risk-free arbitrages, and of risky speculative positions where the risk may be reduced but not eliminated.

(1) In stock index arbitrage, an investment bank buys individual stocks and sells short an index futures contract. To reduce transaction costs and execution problems, the stock portfolio consists of a much smaller number of stocks than the whole index, leaving a residual tracking risk. (2) An investment bank may hold a speculative position in Latin American external debt (denominated in US\$) because it believes the probability of default to be implicitly overestimated by the current market prices. This speculative position exposes it to movements in US interest rates, and it can hedge the exposure using interest rate futures. (3) Stock-pickers buy individual stocks they believe to be underpriced relative to the market in general, and hedge exposure to overall market movements by selling short index futures. (4) A bank taking a short position in the interest rate swap spread (the spread between the swap rate and the Treasury bond rate) would hold a swap portfolio that is short the fixed side of the swap and long the floating side, and hedge it with a long position in bond futures, generating a hedging demand for bond futures that arises as a by-product of the development of the swap market. (5) A typical "arbitrage" position in the government bond market will consist of a combination of long and short positions in different bonds designed to isolate the risk factor which the trader believes to be

mispriced while minimizing exposure to other risks. (6) Finally, one of the main trading strategies that the management of Barings apparently believed their trader Nick Leeson to be engaged in was a nearly risk-free arbitrage combining a long position in one contract, Nikkei 225 stock index futures traded on the Osaka Securities Exchange, with an offsetting short position in a closely related contract traded on SIMEX.

### *The paper*

This paper shows that opening a financial market in a new security can in principle make everybody worse off. The intuition for the result is straightforward: risk-averse arbitrageurs can use hedging in the new market to eliminate the risk of speculative positions in the pre-existing market. This causes a greater incidence of arbitrage activity in the old market, leading some traders with pure hedging motives in that market to withdraw. Liquidity in the old market is reduced, as manifested by a greater bid-ask spread for trades. This illiquidity can harm both arbitrageurs and hedgers. These cross-market liquidity effects are similar to the "destructive interference" between different securities in Bhattacharya, Reny and Spiegel (1995), but they are weaker because in the case studied in this paper, the market does not close completely. In the context of a single security market, Glosten (1989), Bhattacharya and Spiegel (1991) and Spiegel and Subramanyan (1992) have studied market breakdown due to an excessive incidence of informed trading.

The model presented in this paper is a simple one. The question of whether *all* agents may be made worse off is of course a very narrow one (albeit a central one in welfare economics). The model also abstracts from many potentially important effects of financial innovation, for example the possible improvement in production and investment decisions caused by more efficient prices (this

paper studies an exchange economy with no production). However, the welfare economics of financial market innovation is at present at an early stage of development (see Allen and Gale (1994) and Duffie and Rahi (1995) for surveys of research on related questions). The importance of understanding the economic welfare implications of speculative trading and securities market innovation, particularly for markets in derivative securities, seems self-evident. The analysis in this paper is intended as a preliminary step towards achieving a better understanding of this question.

The rest of the paper shows the result in the context of a formal model: section 2 describes the model; section 3 describes equilibrium in the pre-existing market; section 4 describes equilibrium when the new market opens. The possibility of Pareto inferior innovation is demonstrated in section 5. Section 6 presents brief concluding remarks.

## **2. The Model**

I consider a model with two periods. In the first period, agents trade securities. In the second period, securities' payoffs are realized and agents consume. The securities may be thought of as derivative contracts, or alternatively as stocks that pay a liquidating dividend, or as zero-coupon bonds. The interpretation as derivative contracts will perhaps seem most natural to the reader. In order to provide an example that displays the desired properties in an intuitive way, random variables and utility functions will be assumed to have the simplest functional forms, and the number of securities (two) and of agents (two types of hedgers and two types of arbitrageur) are also chosen for simplicity of exposition.

### *Securities*

The first security has an uncertain payoff  $\bar{x}$ . This may be decomposed into two independent components,  $\bar{x} = \bar{y} + \bar{z}$ . The second security has an uncertain payoff  $\bar{y}$ . The random variables  $\bar{y}$  and  $\bar{z}$  are each equally likely to take the values  $+1$  and  $-1$  (hence  $\bar{x}$  takes the value  $0$  with probability  $\frac{1}{2}$ , and the values  $-2$  and  $+2$  each with probability  $\frac{1}{4}$ ). The assumption that the expected values of the securities are of mean zero is WLOG: one can interpret the variables treated here as deviations from the mean, and add on the mean as a constant in all expressions for valuations and prices.

### *Agents*

There are two main types of agents. The first type (hedgers) are risk-averse and have risky endowments which they can hedge by trading suitable quantities of the securities. The second type of agent (an arbitrageur) may also be risk-averse but is not endowed with risk initially. He has private information about the value of the first security,  $\bar{x}$ , although he cannot predict its value perfectly (he learns  $\bar{z}$ ). Taking a position in this security therefore exposes him to risk (which he may choose to hedge using the other security,  $\bar{y}$ , if it is traded). The relative frequencies in the market of the arbitrageur and the hedgers affect the liquidity of the market. The probability of the arbitrageur arriving is denoted  $\pi$ , the probability of hedgers arriving is  $(1 - \pi)$ .

The assumptions on the random variables, the information structure and the hedging needs may be summarized as follows:

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Random variables:	$\tilde{\kappa} = \tilde{\gamma} + \tilde{z}.$
	$\tilde{\gamma}, \tilde{z}$ iid.
Markets:	First security has payoff $\tilde{\kappa}$ .
	Second security has payoff $\tilde{\gamma}$ .
Private information:	on $\tilde{z}$
Hedging needs:	for $\tilde{z}$

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### *Trading and Price Formation*

Prices are set by a risk-neutral market-maker. He observes one order at a time, infers (in equilibrium) the relative likelihood that the order emanates from an informed trader or a hedger, sets price equal to conditional expected value, and meets the order from inventory (as in Glosten and Milgrom (1985)). In case both markets are open, the market-makers for each security are able to communicate.

### *Hedgers*

Hedgers have a concave utility function  $U$ , and a risky endowment of  $W \pm \tilde{z}$ ;  $W$  is normalized to zero WLOG. They first find out whether their endowment is  $\tilde{z}$  or  $-\tilde{z}$ , then they are able to trade, and then  $\tilde{z}$  is realized. In case the endowment is  $\tilde{z}$ , they have a negative hedging need for the first security: they will hedge their endowment risk by selling short one unit of the security. Conversely if the endowment is  $-\tilde{z}$ , they have a positive hedging need and can hedge with a long position; positive and negative hedging needs are equiprobable.

Hedgers are of two types: they may either be very risk-averse, or less risk-averse. With probability  $\delta$ , the hedgers' (if present) are very risk-averse and with probability  $(1 - \delta)$ , they are less risk-averse. For the very risk-averse type, the hedgers' utility function is  $U(w) = w$  for  $w \leq 0$ , and  $U(w) = \alpha w$  for  $w > 0$ , where  $\alpha \in (0, 1)$ . Note that this may also be written  $U(w) = \min\{w, \alpha w\}$ , a more compact notation that will be used below. The less risk-averse type has a similar utility function, but with a different parameter:  $U(w) = \min\{w, \beta w\}$  where  $\beta \in (\alpha, 1)$ .

### *The Arbitrageur*

An arbitrageur knows the realization of  $\tilde{z}$  in advance of the trading round. The arbitrageur should be interpreted as an investment bank whose risk-aversion in a given market at any time depends on the positions it has taken in other markets, in relation to its capital. Thus, the arbitrageur acts as if his risk aversion is variable. This may be represented by  $U(w) = w$  for  $w \leq 0$ ,  $U(w) = \gamma w$  for  $w > 0$ , where the initial endowment is 0 with probability  $1 - \epsilon$  and 100 with probability  $\epsilon$  (100 was chosen simply because it is a large number in relation to the amounts of money that can be made or lost by speculating in the assets considered here).

Effectively, therefore, the arbitrageur acts as if his risk aversion is variable, i.e. as if with probability  $\epsilon$  he were risk neutral, and with probability  $(1 - \epsilon)$  he were risk-averse with utility function  $U(w) = w$  for  $w \leq 0$ ,  $U(w) = \gamma w$  for  $w > 0$  where  $\gamma \in (0, 1)$ . For convenience, I shall refer to "the risk-neutral arbitrageur," or the "risk-averse arbitrageur," rather than "the arbitrageur whose initial wealth realization is 100" or "the arbitrageur whose initial wealth realization is 0." As a technical digression, note that in this formulation the investment bank is risk-averse at the lower wealth level (0), and risk-neutral at

the higher wealth level (100). This is consistent with the standard property of decreasing absolute risk aversion (DARA), although the piecewise linear utility function used here does not display DARA at all other wealth levels.

### *Remarks on the Assumptions*

*Functional Forms:* The functional forms of the utility functions and the random variables have been chosen to be the simplest possible (the additive structure of the values of the two securities is similar to that in Oh (1994)). The results are not dependent on these functional forms. For example, many papers on price formation have used exponential utility functions and normally distributed asset returns (following Kyle (1985)). As an illustration, in Appendix 4 I give a version of the model in that framework and show the same results, effectively embedding a single-asset framework similar to that of Spiegel and Subramanyan (1992), generalized to allow a risk-averse informed trader, into a two-security model. The solutions, since they can only be derived numerically, are somewhat less transparent than those of the main model of the paper.

*Price Formation Process:* For the purposes of this paper, the details of the trading process are not particularly important. What is needed here is a trading mechanism that allows only partial revelation of private information (this implies that privately informed traders will profit to some extent from their information). The mechanism used here, proposed by Glosten and Milgrom (1985), is often used in the literature: recent examples include Biais and Hillion (1994) and Madhavan (1995). An earlier version of this paper used the price formation mechanism of Kyle (1985) with the same functional forms for utilities and distributions to derive the same results. Also, in Appendix 4 I present a version of the model with Kyle (1985) price formation, but with different functional forms for preferences and distributions. In the model of Kyle

(1985), the market maker observes the (net) sum of the individual orders, whereas in Glosten and Milgrom (1985) he observes one of the orders selected at random. The advantage of the Glosten-Milgrom process is that agents do not face execution risk in their orders, i.e. when they place an order they know exactly at what price it will clear. This also makes the computation and exposition of the equilibrium simpler.

Although this is not a paper on market microstructure, the following brief comments on the realism of the Glosten-Milgrom price formation process seem appropriate: the mechanism is based on the actual institution of an NYSE market-maker, but seems equally suitable for modelling the trading process on the floor of a futures exchange. This is because the condition that price equal expected value, trade-by-trade, relies on Bertrand competition. On the NYSE the market-maker is a monopolist but faces potential competition from the "crowd" of traders on the floor. On the floor of a futures exchange there is no single designated market-maker, but there is indeed a crowd of traders (including "locals") who are ready to take the opposite side of incoming orders at a competitively determined price. The model also seems reasonable as a description of the foreign exchange trading process, since normally the person initiating the trade will simultaneously ask for quotes from two or three dealers.

*Information Flow between the Two Markets* The assumption that the market makers for different securities can communicate is not important for the results. In fact, it is easy to verify that in this model there is no information gained (in equilibrium) from observing the orders in the other market, so that it makes no difference whether communication is possible. However, *a priori* one might imagine that allowing communication would make it harder to demonstrate the possibility of welfare reducing innovation (by making it easier for the market

maker to distinguish informed from uninformed trades). The model in the paper (including the version in Appendix 4) has therefore been chosen so that the results hold when orders from one market are fully visible in the other market.

### 3. Equilibrium with One Market

I start by considering the case where only the first market is open: I assume that the second market is exogenously closed, perhaps by regulatory fiat. Since similar models have been studied in the literature following Glosten and Milgrom (1985) and Kyle (1985), this is a standard problem.

In equilibrium the hedgers will trade an amount  $\pm t$ , to be determined below. It follows that the arbitrageur will also trade  $\pm t$  to avoid detection (if he does choose to trade). Any other quantity would reveal his information about the asset value to the market. There is a possibility that the arbitrageur, when risk-averse, will choose not to trade at all, because speculation forces him to bear the  $\tilde{y}$ -risk. Alternatively, both risk-averse and risk-neutral arbitrageurs may trade; which type of equilibrium occurs will depend on the values of the exogenous parameters. The focus of this paper is on the case where the exogenous parameters (particularly the cautiousness of the risk-averse arbitrageur) are such that in equilibrium the arbitrageur trades only if he is risk-neutral, while both types of hedger trade.

Since the risk-averse arbitrageur is inactive, with probability  $\pi\epsilon$  there is a trade from a (risk-neutral) informed trader, with probability  $\pi(1-\epsilon)$  there is no trade, and with probability  $(1-\pi)$  there is a trade from a hedger. So the conditional probability of an order coming from an informed trader is  $\pi\epsilon/[1-\pi(1-\epsilon)]$ . Let

$p$  be the price on a buy order. Since the expected value of the asset is 1 if an informed agent buys and 0 if an uninformed hedger buys, we have

$$p = \pi\epsilon/[1 - \pi(1 - \epsilon)].$$

Similarly, the price on a sell order is  $-\pi\epsilon/[1 - \pi(1 - \epsilon)]$ .

Next, I verify the condition for the arbitrageur to choose not to trade when he is risk-averse. Suppose that he learns that the realization of  $\tilde{z}$  will be 1. If he buys the asset, his wealth will be

$$t(\tilde{x} - p),$$

i.e. it is equally likely to be  $t(2-p)$  or  $-tp$  (in case  $\tilde{y} = 1$  or  $-1$ , respectively). Similarly if he learns that  $\tilde{z} = -1$  and sells the asset, his wealth is  $-t(p - \tilde{x})$ . In either case therefore his expected utility (conditional on being in the risk-averse region of his utility function) is:

$$\frac{1}{2}t[\gamma(2-p) - p].$$

He will choose not to trade whenever this is negative, i.e. when  $\gamma < p/(2-p)$ .

When he is risk-neutral, the arbitrageur's expected profits are  $t(1-p)$  (i.e. his expected utility, conditional on being in the risk-neutral area of the utility function is  $\gamma t(1-p)$ ).

Next, consider the hedgers' behaviour. Recall that the hedgers' initial endowment is  $\pm \tilde{z}$ , so by trading  $\tilde{x}$  they will not be perfectly hedged; they

will still be exposed to  $\tilde{y}$ . For the hedgers with a positive hedging need who buy  $t$  units of the security at price  $p$ , their wealth is:

$$\begin{aligned} t(\tilde{x} - p) - \tilde{z} \\ = t(\tilde{y} + \tilde{z} - p) - \tilde{z}. \end{aligned}$$

As shown in Appendix 1, the expected utility of the (more risk-averse) hedgers when they buy a quantity  $t$  is:

$$\begin{aligned} \frac{1}{4}[\min\{t(2-\pi)-1, \beta[t(2-\pi)-1]\} + \beta(1-t\pi) + (-1-t\pi) \\ + \min\{1-t(2+\pi), \beta[1-t(2+\pi)]\}]. \end{aligned}$$

Their optimal hedging policy is to buy a quantity

$$t = 1/(2+p)$$

if  $\alpha < (1-p)/(1+p)$ , and not to trade at all otherwise. Symmetrically, hedgers with a negative hedging need will sell  $t = 1/(2+p)$  as long as  $\alpha < (1-p)/(1+p)$ . Their resulting expected utility is:

$$\frac{1}{2}(\alpha - 1 - 2p)/(2+p).$$

Again, Appendix 1 gives details of the computations for the above expressions. For the less risk-averse hedgers, similar expressions hold with  $\alpha$  replaced by  $\beta$ , i.e. they trade a quantity  $t = 1/(2+p)$  as long as  $\beta < (1-p)/(1+p)$ , obtaining an expected utility of  $\frac{1}{2}(\beta - 1 - 2p)/(2+p)$ .

To summarize the above derivation, the paper will consider situations where (with only the first market open) both types of hedgers trade, but the arbitrageur trades only when risk neutral. This imposes the following restrictions on the exogenous parameters:  $\beta < (1-p)/(1+p)$  and  $\gamma < p/(2-p)$ , where  $p = \pi\epsilon/(1 - \pi(1-\epsilon))$ .

#### 4. Equilibrium with Both Markets Open

Now consider the case where both markets are open. An arbitrageur who takes a position in  $\bar{x}$  will be able to hedge his risk entirely in the new market, the market for  $\bar{y}$ , and perform a riskless arbitrage. Hence the arbitrageur will always trade, even if risk-averse. As before, the amount he trades is the same as the hedgers, denoted  $t'$ . This increased arbitrage activity makes the equilibrium price less favourable to the hedgers, and the more risk-averse hedgers may drop out of the market. The paper focuses on the case where the exogenous parameters are such that this is indeed what happens.

Since the more risk-averse hedger is inactive, with probability  $\pi$  there is a trade from an informed trader, with probability  $(1-\pi)\delta$  there is a trade from a hedger, and with probability  $(1-\pi)(1-\delta)$  there is no trade. So the price on a buy order, which is equal to the conditional probability of an order coming from an informed trader, is

$$p' = \pi/[1-(1-\pi)(1-\delta)].$$

Similarly the price on a sell order is  $-p'$ .

If the arbitrageur buys  $t'$  of asset  $\bar{x}$  and sells an equal amount of asset  $\bar{y}$ , his

wealth will be:

$$\begin{aligned} & t'(\bar{x} - p') - t'\bar{y} \\ &= t'(\bar{z} - p'). \end{aligned}$$

So when he learns  $\bar{z} = 1$ , he buys  $\bar{x}$ , sells  $\bar{y}$ , and makes a profit of  $t'(1 - p')$ . Similarly when he learns  $\bar{z} = -1$ , he sells  $\bar{x}$ , buys  $\bar{y}$ , and also makes profit  $t'(1 - p')$ . His expected utility (whether risk-neutral or risk-averse) is therefore:

$$\gamma t'(1 - p').$$

Next, consider the hedgers' behaviour. They can hedge their endowment risk perfectly by taking appropriate positions in  $\bar{x}$  and  $\bar{y}$ , but they may choose not to do so because of the cost of hedging (reflected in a high  $p'$ ). For the hedgers with a positive hedging need who buy  $t'$  units of  $\bar{x}$  and sell  $t'$  units of  $\bar{y}$ , their wealth is:

$$\begin{aligned} & t'(\bar{x} - p') - t'\bar{y} - \bar{z} \\ &= t'(\bar{z} - p') - \bar{z}. \end{aligned}$$

As shown in Appendix 2, this results in expected utility (for the more risk-averse hedger) of

$$\frac{1}{2}[\max\{1 - t'(1 + p'), \alpha(1 - t'(1 + p'))\}] + \frac{1}{2}[t'(1 - p') - 1]$$

which is maximized at  $t' = 1/(1 + p')$  so long as  $\alpha < (1 - p')/(1 + p')$ . The case

of a negative hedging need is symmetric. The discussion here has not derived the result that hedgers take equal and opposite positions of the same size in  $\tilde{\gamma}$  and  $\tilde{z}$ , but that is straightforward to show. Similarly, the more risk averse-hedgers do not trade if  $\beta > (1-p')/(1+p')$ . The hedgers' maximal expected utility is  $-p'/(1+p')$ . Details are in Appendix 2.

To summarize the above derivation, the paper will consider situations where (with both markets open) the arbitrageur always trades, but only the more risk averse-hedgers trade. This imposes the following restrictions on the exogenous parameters:  $\alpha < (1-p')/(1+p') < \beta$  where  $p' = \pi/[1-(1-\pi)(1-\delta)]$ .

## 5. Opening a New Market

The implications of the above analysis can now be drawn together into the following statement:

**Theorem:** *It is possible that opening a new market may make everybody worse off.*

*Proof:* I will show that there are values of the exogenous parameters where all agents are made worse off. The exogenous parameters are  $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $\delta$ ,  $\epsilon$ , and  $\pi$ . To start with, consider the restrictions derived in sections 3 and 4, i.e.  $\beta < (1-p)/(1+p)$  and  $\gamma < p/(2-p)$ , where  $p = \pi\epsilon/(1 - \pi(1-\epsilon))$ , and  $\alpha < (1-p')/(1+p') < \beta$ , where  $p' = \pi/[1-(1-\pi)(1-\delta)]$ . They imply that when the new market opens, the less risk-averse hedgers will cease to trade. On the other hand, the risk-averse arbitrageurs, previously inactive, will now be willing to take speculative positions. This was shown in sections 3 and 4 above. Clearly, the conditions on  $\alpha$ ,  $\beta$  and  $\gamma$  can always be satisfied for given values

of  $\delta$ ,  $\epsilon$ , and  $\pi$  by choosing  $\alpha$  and  $\gamma$  sufficiently small, and  $\beta$  in the interval  $[(1-p')/(1+p'), (1-p)/(1+p)]$ .

It is clear that the less risk-averse hedgers are worse off (by revealed preference). For the more risk-averse hedgers, this is less clear since although they now face a wider bid-ask spread in the market for  $\bar{x}$ , they are now able to trade in  $\bar{y}$  also, which gives them a better hedge for their exposure to  $\bar{z}$ . For them to be worse off, we require:

$$-p'/(1+p') < \frac{1}{2}(\alpha - 1 - 2p)/(2+p).$$

As shown in Appendix 3, substituting for  $p$  and  $p'$  in terms of the exogenous parameters, this is implied by:

$$2\pi[2(1-\pi)+3\pi\epsilon] > (1-\pi+3\pi\epsilon)[2\pi+\delta(1-\pi)]. \quad (1)$$

The arbitrageur now faces a wider spread in the market for  $\bar{x}$ , but is able to construct a riskless arbitrage by trading in  $\bar{y}$  also. For him to be worse off we need:

$$\epsilon\gamma(1-p)/(2+p) > \gamma(1-p')/(1+p')$$

Substituting for  $p$  and  $p'$ , this becomes:

$$\delta/[2\pi+\delta(1-\pi)] < \epsilon/[2-2\pi+3\pi\epsilon], \quad (2)$$

as shown in Appendix 3. I will show that (1) and (2) may be satisfied simultaneously by setting  $\epsilon = k\delta$  for fixed  $k$  and considering the limit for small

$\delta$  (hence small  $\epsilon$  also). In the limit, (1) becomes simply:

$$4\pi(1-\pi) > (1-\pi)2\pi,$$

which clearly holds. Setting  $\epsilon = k\delta$  in (2) gives  $\delta/[2\pi + \delta(1-\pi)] < k\delta/[2-2\pi+3\pi k\delta]$ , i.e.:

$$k(2\pi + \delta(1-\pi)) > 2(1-\pi) + 3k\delta.$$

In the limit, this becomes  $2k\pi > 2(1-\pi)$ , i.e. it will hold if we set  $\pi > 1/(k+1)$ . For example  $k=1/2$  and  $\pi=3/4$ . Q.E.D.

A complete exploration of the different combinations of parameter values for which all agents are worse off, and of combinations for which various groups of agents are better off while others are worse off, would be of limited value (in relation to its complexity) given the special nature of the model. However, the intuition behind the parameter values chosen to derive the example is straightforward. For small  $\gamma$ , the arbitrageur is very risk-averse at the lower initial wealth level (0) so is unwilling to trade except when arbitrage is riskless. Also, small  $\alpha$  means that the very risk-averse hedger will be willing to hedge with both markets open, even if the market (for  $\tilde{x}$ ) is highly illiquid because of the high incidence of informed trading.  $\beta$  has to be chosen so that the less risk-averse hedgers are risk-averse enough that they want to trade when the first market is quite liquid (and the second market is closed), but not so risk-averse that they continue wanting to hedge when the first market becomes less liquid (as a result of the second market opening).  $\pi$  large enough ensures there is enough arbitrage activity to make the effects studied here quite strong. When  $\epsilon$  becomes small, the arbitrageur is more likely to be risk-averse: hence opening

the new market causes a big increase in arbitrage activity in the market for  $\bar{x}$ . When  $\delta$  becomes small, most hedgers are less risk-averse and will cease trading when the new market is open. Both the last two effects (small  $\delta$  and  $\epsilon$ ) cause an increased bid-ask spread in the market for  $\bar{x}$  as a result of the new market opening, and this tends to damage both arbitrageurs and the more risk-averse hedgers who continue to trade.

## 6. Concluding remarks

The model studied here is a special one. The model focuses on cross-market liquidity effects, and ignores many other effects such as the implications of more efficient security prices for allocative efficiency, individual incentives for futures exchanges or other financial innovators that may differ from social incentives, etc. Subject to these provisos, however, one can venture the following observations: introducing a new security in this type of model will increase the incidence of arbitrage activity, by making informed trading less risky. For hedgers, there is a trade-off between the increased illiquidity that may result and the greater flexibility to design appropriate hedges with a wider range of securities. Only if the former effect is very strong will they reduce their trades to the extent that even arbitrageurs are worse off - a possibility that is demonstrated in this paper.

To some extent, the intended contribution of this paper is methodological: analyzing the costs and benefits of financial innovation is an important area for research and policy. An obvious starting point for such research is to explore conditions under which introducing a new security may make all agents worse off, and there is an existing literature that has done so. The examples in this literature share a common framework of perfect information, walrasian market

clearing, and multiple commodities and rely on the effects of relative price movements of different commodities, compared across different states of the world. In contrast, this paper explores the question using an alternative framework: a single consumption good ("money"), heterogeneously informed traders, and price formation by a competitive market-maker, a framework that is widely used for finance research.

There are many interesting questions for further research on financial innovation. One of them concerns the order of opening of securities markets. In the model presented here, the order of opening of markets makes a difference in that the market for  $y$  is of no value, and would generate no trading, without the market for  $x$ . If the market for  $y$  were open first, opening the market for  $x$  would benefit everybody - though not as much, of course, as simultaneously closing the market for  $y$ . In that sense, the model in this paper exhibits the property that the order of opening of markets makes a difference. However, a more satisfactory, more dynamic treatment of this question would capture the fact that a market may become established, and liquidity develop over time, as a result of people trading the security.

Finally, a more general implication of the model in this paper is that a large part of trading volume may be due to speculators' hedging needs. This is of interest because of the general inability of finance theory to explain high trading volume (see Dow and Gorton (1994)). It seems clear that similar effects to the ones studied in this paper will arise under a wider variety of conditions, and that in liquid markets a speculator may take large hedging positions in several different markets.

## Appendix 1

*Hedger's optimization problem when only one market is open:* as derived in the main text, the wealth of the (more risk-averse) hedgers with a positive hedging need who buy  $t$  units of the security at price  $p$  is  $t(\bar{x} - p) - \bar{z} = t(\bar{y} + \bar{z} - p) - \bar{z}$ . Depending on the realized values of  $\bar{y}$  and  $\bar{z}$ , there are four possible values of wealth:

1.  $\bar{y} = 1, \bar{z} = 1$  (which implies  $\bar{x} = 2$ ).

Wealth:  $t(2-p) - 1$

Utility:  $\min\{t(2-p) - 1, \beta[t(2-p) - 1]\}$ .

2.  $\bar{y} = 1, \bar{z} = -1$  (which implies  $\bar{x} = 0$ ).

Wealth:  $t(0-p) + 1$

Utility:  $\beta[1 - tp]$

3.  $\bar{y} = -1, \bar{z} = 1$  (which implies  $\bar{x} = 0$ ).

Wealth:  $t(0-p) + 1$

Utility:  $-1 - tp$

4.  $\bar{y} = -1, \bar{z} = -1$  (which implies  $\bar{x} = -2$ ).

Wealth:  $t(-2-p) + 1$

Utility:  $\min\{1 - t(2+p), \beta[1 - t(2+p)]\}$ .

The expected utility of the hedger is therefore:

$$\frac{1}{4}[\min\{t(2-p) - 1, \beta[t(2-p) - 1]\} + \beta(1 - tp) + (-1 - tp) + \min\{1 - t(2+p), \beta[1 - t(2+p)]\}].$$

Note that of the four equiprobable possible values for wealth:  $t(2-p)-1$ ,  $1 - tp$ ,  $-1 - tp$ ,  $1 - t(2+p)$ , the first is positive for  $t > 1/(2-p)$ , while the last is positive for  $t < 1/(2+p)$  (the second is always positive and the third always negative). Expected utility is therefore linear (or affine to be precise) in  $t$  on each of the three intervals  $[0, 1/(2+p)]$ ,  $[1/(2+p), 1/(2-p)]$  and  $[1/(2-p), 1]$ . It follows that one of the four values  $0$ ,  $1/(2+p)$ ,  $1/(2-p)$ ,  $1$  must be optimal for  $t$ .

On the interval  $[0, 1/(2+p)]$ , expected utility is

$$\frac{1}{4}[t(2-p)-1 + \beta(1-tp) - (1+tp) + \beta(1 - t(2+p))],$$

whose derivative with respect to  $t$  is  $\frac{1}{2}(1 - p - \beta(1+p))$ . This is positive iff  $\beta < (1-p)/(1+p)$ . Similarly, on the interval  $[1/(2+p), 1/(2-p)]$ , expected utility is

$$\frac{1}{4}[t(2-p)-1 + \beta(1-tp) - (1+tp) + (1 - t(2+p))],$$

whose derivative with respect to  $t$  is  $\frac{1}{4}(-3p - \beta p) < 0$ . Finally, on the interval  $[1/(2-p), 1]$ , expected utility is

$$\frac{1}{4}[\beta(t(2-p)-1) + \beta(1-tp) - (1+tp) + (1 - t(2+p))],$$

whose derivative with respect to  $t$  is  $\frac{1}{2}[\beta(1-p) - (1+p)] < 0$ . This shows the hedgers will never trade more than  $1/(2+p)$ .

## Appendix 2

*Hedger's optimization problem when both markets are open:* as derived in the main text, the wealth of the (more risk-averse) hedgers with a positive hedging need who trade  $t$  units of the securities is  $t'(\tilde{z} - p') - \tilde{z}$ . Depending on the realization of  $\tilde{z}$ , wealth is equally likely to be either  $[t(1-p') + 1]$  or  $[t(1-p') - 1]$ . Note that the latter is always negative, while the former is positive if  $t' < 1/(1+p)$ . Hence expected utility is

$$\frac{1}{2}[\max\{1 - t'(1+p'), \alpha(1 - t'(1+p'))\}] + \frac{1}{2}[t'(1-p') - 1].$$

On the interval  $[0, 1/(1+p')]$  this is

$$\frac{1}{2}\alpha[1 - t'(1+p')] + \frac{1}{2}[t'(1-p') - 1],$$

which is increasing in  $t'$  if the derivative,  $\frac{1}{2}\alpha(1+p') + \frac{1}{2}(1-p')$ , is positive, i.e.  $\alpha < (1-p')/(1+p')$ . On the interval  $[1/(1+p'), 1]$  expected utility is

$$\frac{1}{2}[1 - t'(1+p')] + \frac{1}{2}[t'(1-p') - 1] = -t'p',$$

so the hedgers will never trade more than  $1/(1+p')$ . Finally note that expected utility at  $t' = 1/(1+p')$  is  $-p'/(1+p')$ .

### Appendix 3

*Details for proof of theorem:* Consider the inequality in the text:

$$-p'/(1+p') < \frac{1}{2}(\alpha - 1 - 2p)/(2+p).$$

Since the right-hand side exceeds  $-\frac{1}{2}(1+2p)/(2+p)$ , a sufficient condition for the inequality is given by  $-p'/(1+p') < -\frac{1}{2}(1+2p)/(2+p)$ , or, substituting  $p = \pi\epsilon/(1 - \pi(1-\epsilon))$  and  $p' = \pi/[1-(1-\pi)(1-\delta)]$ :

$$-\pi/[1-(1-\pi)(1-\delta)+\pi] < -\frac{1}{2}(1-\pi(1-\epsilon)+2\pi\epsilon)/[2-2\pi(1-\epsilon)+\pi\epsilon]$$

or  $2\pi[2(1-\pi)+3\pi\epsilon] > (1-\pi+3\pi\epsilon)[2\pi+\delta(1-\pi)]$ , which is inequality (1).

Next, consider

$$\gamma(1-p')/(1+p') < \epsilon\gamma(1-p)/(2+p).$$

Substituting for  $p$  and  $p'$ , we obtain:

$$\frac{[1 - (1 - \pi)(1 - \delta) - \pi]}{[1 - (1 - \pi)(1 - \delta) + \pi]} < \frac{\epsilon(1 - \pi(1 - \epsilon) - \pi\epsilon)}{[2 - 2\pi(1 - \epsilon) + \pi\epsilon]}$$

or

$$\delta(1-\pi)/[2\pi+\delta(1-\pi)] < \epsilon(1-\pi)/[2-2\pi+3\pi\epsilon].$$

Cancelling  $(1-\pi)$ , we obtain inequality (2).

## Appendix 4

*Variant of the model with CARA and normal distributions:* as before, I assume  $\bar{x} = \bar{y} + \bar{z}$ , where  $\bar{x}$  is the first security and  $\bar{y}$  is the new security. The hedger has an initial endowment (risk exposure)  $-\bar{\pi} \bar{z}$  (he observes  $\bar{\pi}$  before trading) and constant risk aversion  $R_h$ . The arbitrageur has constant risk aversion  $R_a$  and observes  $\bar{z}$ .  $\bar{y}$ ,  $\bar{z}$  and  $\bar{\pi}$  are independently normally distributed with mean zero and with variances  $\sigma_y^2$ ,  $\sigma_z^2$  and  $\sigma_\pi^2$ . Recall that an agent with normally distributed wealth  $\bar{w}$  and exponential utility (CARA) with risk aversion  $R$  will maximize  $E\bar{w} - \frac{1}{2}R\text{Var}(\bar{w})$  (this can be seen from the moment-generating function of a normal random variable  $\bar{w}$  with mean  $\mu$  and variance  $\sigma^2$ , i.e.  $\Psi(t) \equiv E(\exp(t\bar{w})) = \exp(t\mu + \frac{1}{2}t^2\sigma^2)$ ). (I shall refer to  $E\bar{w} - \frac{1}{2}R\text{Var}(\bar{w})$  as the agent's objective, since it is not actually the agent's expected utility, but is a strictly increasing function of expected utility.) Prices are set by a risk-neutral market maker who observes the total order flow in both markets and sets price equal to the conditional expected value of the asset (as in Kyle (1985)).

Because the functional forms used here imply continuous responses to changes, rather than the all-or-nothing responses of piecewise linear utilities, the analysis can be carried out with only one type of hedger and does not need the arbitrageur's risk-aversion to be variable. Note that the exponential/normal functional forms used here could not be combined with the Glosten and Milgrom (1985) price formation process used in the main text since their market-maker samples a mixture of the individual orders, and a mixture of normals is not normal; hence the linearity of pricing and trading strategies would be lost.

Although the trading strategies and pricing function are linear functions which

can be computed easily in terms of the other agents' trading/pricing functions, the computations in terms of all the exogenous parameters have no closed-form solutions and can only be performed numerically, as shown in Appendix B of Spiegel and Subramanyan (1992) in a similar model with risk-averse informed trader. They also show that the linear equilibrium studied here will fail to exist for certain values of the exogenous parameters, in particular when the hedgers are not risk-averse enough. The question of existence of non-linear equilibrium remains open. Subject to these provisos, the model has a unique linear equilibrium which can be computed as follows.

With only the market for  $\tilde{x}$  open, the hedger trades  $\beta_h n$ , the arbitrageur trades  $\beta_a z$ , and the price is a multiple  $\beta_p$  of trading volume (for expositional clarity, the following derivation does not derive the fact that the intercept terms are zero). To derive  $\beta_p$ , note that  $E(\tilde{y} + \tilde{z} \mid \beta_h n + \beta_a z)$  is given by the regression with slope

$$\beta_p = \text{Cov}(\tilde{z}, \beta_h \tilde{n} + \beta_a \tilde{z}) / \text{Var}(\beta_h \tilde{n} + \beta_a \tilde{z}) = \beta_a \sigma_z^2 / (\beta_h^2 \sigma_n^2 + \beta_a^2 \sigma_z^2).$$

The wealth of the hedger with an initial endowment  $-n\tilde{z}$  who trades an amount  $t$  is:

$$\begin{aligned} t(\tilde{x} - \tilde{p}) - n\tilde{z} &= t(\tilde{y} + \tilde{z} - \beta_p(t + \beta_a \tilde{z})) - n\tilde{z} \\ &= t\tilde{y} + [t(1 - \beta_p \beta_a) - n]\tilde{z} - t^2 \beta_p, \end{aligned}$$

which has expectation  $-\beta_p t^2$  and variance  $t^2 \sigma_y^2 + [t(1 - \beta_p \beta_a) - n]^2 \sigma_z^2$ . His objective is therefore to maximize  $-\beta_p t^2 - \frac{1}{2} R_h (t^2 \sigma_y^2 + [t(1 - \beta_p \beta_a) - n]^2 \sigma_z^2)$ . The first-order condition is:

$$-2t\beta_p - \frac{1}{2}R_h(2t\sigma_y^2 + 2[t(1-\beta_p\beta_a) - n](1-\beta_p\beta_a)\sigma_z^2) = 0,$$

hence

$$\beta_h = R_h(1-\beta_p\beta_a)\sigma_z^2/[2\beta_p + R_h(\sigma_y^2 + (1-\beta_p\beta_a)^2\sigma_z^2)].$$

Substituting this into the hedger's objective, it can be shown that the maximum value of the objective is  $\frac{1}{2}n^2R_h\sigma_z^2[\beta_h(1-\beta_a\beta_p)-1]$ .

The wealth of an arbitrageur who observes  $z$  and trades  $t$  is:

$$t(\bar{x} - \bar{p}) = t(\bar{y} + z - \beta_p(\beta_h\bar{\pi} + t)),$$

which has expectation  $tz - \beta_p t^2$  and variance  $t^2[\sigma_y^2 + (\beta_p\beta_h)^2\sigma_n^2]$ . His objective is to maximize  $tz - \beta_p t^2 - \frac{1}{2}R_a t^2[\sigma_y^2 + (\beta_p\beta_h)^2\sigma_n^2]$ , which has first-order condition

$$z - 2t\beta_p - tR_a[\sigma_y^2 + (\beta_p\beta_h)^2\sigma_n^2] = 0,$$

hence

$$\beta_a = 1/(2\beta_p + R_a[\sigma_y^2 + (\beta_p\beta_h)^2\sigma_n^2]).$$

Substituting into the arbitrageur's objective gives the maximum value of the objective as  $\frac{1}{2}\beta_a z^2$ .

When both markets are open, the price is given by the same regression:

$$\beta_p' = \beta_a'\sigma_z^2/[(\beta_h')^2\sigma_n^2 + (\beta_a')^2\sigma_z^2].$$

The wealth of the hedger with an initial endowment  $-n\bar{z}$  who trades an amount  $t$  of asset  $\bar{x}$  and  $-t$  of asset  $\bar{y}$  is:

$$\begin{aligned} t(\bar{z} - \bar{p}) - n\bar{z} &= t(\bar{z} - \beta_p'(t + \beta_a'\bar{z})) - n\bar{z} \\ &= [t(1 - \beta_p'\beta_a') - n]\bar{z} - t^2\beta_p', \end{aligned}$$

which has expectation  $-\beta_p't^2$  and variance  $[t(1 - \beta_p'\beta_a') - n]^2\sigma_z^2$ . His objective is to maximize  $-\beta_p't^2 - \frac{1}{2}R_h[t(1 - \beta_p'\beta_a') - n]^2\sigma_z^2$ . The first-order condition is:

$$-2t\beta_p' - R_h[t(1 - \beta_p'\beta_a') - n](1 - \beta_p'\beta_a')\sigma_z^2 = 0,$$

hence

$$\beta_h' = R_h(1 - \beta_p'\beta_a')\sigma_z^2 / [2\beta_p' + R_h(1 - \beta_p'\beta_a')\sigma_z^2].$$

The wealth of an arbitrageur who observes  $z$  and trades  $t$  of  $\bar{x}$  and  $-t$  of  $\bar{y}$  is:

$$t(z - \bar{p}) = t(z - \beta_p'(\beta_h'\bar{\pi} + t)),$$

which has expectation  $tz - \beta_p't^2$  and variance  $t^2(\beta_p'\beta_h')^2\sigma_n^2$ . His objective is to maximize  $tz - \beta_p't^2 - \frac{1}{2}R_a t^2(\beta_p'\beta_h')^2\sigma_n^2$ , which has first-order condition

$$z - 2t\beta_p' - tR_a(\beta_p'\beta_h')^2\sigma_n^2 = 0,$$

hence

$$\beta_a' = 1 / (2\beta_p' + R_a(\beta_p'\beta_h')^2\sigma_n^2).$$

As before, substituting the optimal values of  $\beta_h$  and  $\beta_a$  into the objectives gives maximum values for the hedger's objective of  $\frac{1}{2}n^2R_h\sigma_z^2[\beta_h'(1-\beta_a'\beta_p')-1]$  and of  $\frac{1}{2}\beta_a'z^2$  for the arbitrageur's objective. Therefore, the hedger will be made better off by the new market iff  $\beta_h'(1-\beta_a'\beta_p') > \beta_h(1-\beta_a\beta_p)$ , while the arbitrageur will be better off iff  $\beta_a' > \beta_a$ . Using this, the following numerical calculations show values of the exogenous parameters for which both the hedger and the arbitrageur are worse off:

Exogenous parameters:  $R_a=2.3$ ,  $R_h=1.1$ ,  $\sigma_y^2=0.1$ ,  $\sigma_z^2=0.8$  and  $\sigma_n^2=3.8$

Endogenous parameters:  $\beta_h=0.2584$ ,  $\beta_a=0.4237$ ,  $\beta_p=0.8529$ ,  $\beta_h'=0.2142$ ,  $\beta_a'=0.3914$ ,  $\beta_p'=1.0545$ .

Note that  $\beta_a = 0.4237 > \beta_a' = 0.3914$ , while  $\beta_h(1-\beta_a\beta_p) = 0.1651 > 0.1258 = \beta_h'(1-\beta_a'\beta_p')$ .

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