Financial Intégration, Comovements and Monetary policy

Julien Idier

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THESE

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FINANCIAL INTEGRATION, COMOVEMENTS AND MONETARY POLICY

Directrice de thèse : Gaëlle Le Fol, Professeure à l'Université d'Evry Val d'Essonne

JURY :

M. Sanvi Avouyi-Dovi,	Chef du service de recherche en économie financière Banque de France et Université Dauphine Paris IX
M. Christian de Boissieu,	Professeur à l'Université Paris 1 Panthéon-Sorbonne
M. Laurent Calvet,	Rapporteur, Professeur à HEC Paris
M. Thierry Chauveau,	Président du jury, Professeur à l'Université Paris 1 Panthéon-Sorbonne
Mme. Mardi Dungey,	Rapporteur, Professeure à University of Tasmania
Mme. Gaëlle Le Fol,	Professeure à l'Université d'Evry Val d'Essonne

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The current thesis reflects the opinions of the author and does not necessarily express the views of the European Central Bank, of the Banque de France nor of the University of Paris 1 Panthéon-Sorbonne.

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Contents

Introduction Générale

"An empirical measure of market integration is implicitly, though rarely explicitly, a necessary adjunct to any policy discussion", Obstfeld and Taylor (2004).

12 Juillet 1925, *Chambre des députés*, Paris.

En ce jour, est soumis au vote des députés français le projet de loi de finances de 1925. L'adage sus-cité est déjà vrai depuis longtemps, avec le rôle croissant de l'intégration globale des marchés du début du siècle. En particulier, ce projet de loi budgétaire propose au gouvernement de lever de nouveaux impôts sur le capital. Ce débat est une illustration, parmi beaucoup d'autres, de la façon dont l'intégration financière, la concurrence transfrontalière pour l'allocation des capitaux et les arbitrages peuvent interagir avec des objectifs de politique nationale.

Le pays est déficitaire et se noie sous les coûts liés à la reconstruction d'après guerre. Ces coûts sont beaucoup plus élevés que prévu et l'Allemagne n'en supportera pas la charge: le pays a donc de forts besoins de financement. Le gouvernement Poincaré sait que les taxes imputées sur le capital ne sont pas efficaces à cause de la fraude et cherche un moyen de les imposer (Hautcoeur et al. (1998)). Ce sujet débattu depuis de nombreuses années, s'est traduit en une spéculation baissière sur le franc et de nombreux investisseurs se séparent largement des titres français.

Tous les députés savent que l'intégration financière est à l'œuvre depuis plus de deux décennies. Juglar (1868) a notamment montré sur la base des documents fournis par la Banque de France et de la Banque d'Angleterre que les crises financières se produisent de façon cyclique et plus ou moins synchrone dans ces deux pays en raison de l'accumulation du capital et du cycle des affaires. L'économiste Schumpeter (1911) a également souligné l'importance du développement du secteur financier dans les pays en raison de son influence positive sur le revenu par habitant. Les députés savent aussi que l'on est en situation de concurrence internationale pour les investissements et l'allocation des capitaux : Lowensfeld (1909) a notamment souligné que le British trustee (un ensemble d'actions britanniques supposées robustes et équivalent des constituants de nos indices nationaux contemporains) est certainement le plus solide des investissements en insistant sur les avantages de l'intégration financière en termes d'allocation optimale et de partage des risques.

Le début de ce processus de mondialisation financière est apparu avant la Première Guerre mondiale, période de l'étalon-or et de l'hégémonie de Londres en tant que place financière mondiale. Cette hégémonie a créé en Europe un degré élevé de crédibilité dans le système financier et dans les banques centrales engagées dans le soutien de la parité or. Cette crédibilité associée à l'étalon-or est alors favorable à la mobilité des capitaux, et permet au système financier de fonctionner sans trop de heurts.

Toutefois, après la Première Guerre mondiale, l'intégration financière s'est arrêtée dans une certaine mesure. Nationaux (ou internes) les objectifs des gouvernements sont très élevés et poussent les pays à abandonner l'étalon-or afin de monétiser les dépenses induites par la guerre. La Banque de France decide aussi de ne pas intervenir davantage jugeant inutile de vendre son stock d'or, méthode somme toute inefficace en raison d'un manque de confiance généralisé dans la monnaie française.

Tout cela constitue les éléments pris en compte dans les débats de la Chambre des députés de cette journée de Juillet 1925. L'Assemblée n'ignore manifestement pas dans quelle mesure dans les économies sont financièrement intégrées et comment le pays interagit avec le reste du monde. L'intégration financière est évidemment d'intérêt pour les décideurs politiques sachant qu'elle peut modifier une large gamme d'interventions publiques, de leurs pertinences et que toute action doit être validée à travers le prisme de la mondialisation. C'est pourquoi, à la fin de la journée du 12

Juillet 1925, le Chambre des députés décidait d'exclure toute nouvelle augmentation des impôts sur le capital de la loi de finances. Cela contribua à arrêter la fuite des investisseurs de France et à la stabilisation de la monnaie.

De retour à aujourd'hui, de nombreux pays du monde, développés ou émergents, ont connu au cours des deux dernières décennies, une profonde et rapide mutation de l'intégration des marchés tant dans la sphère réelle de l'économie que financière. La présente thèse présente certaines implications de cette dynamique, basée sur la définition et la mesure des comouvements, et l'impact du cadre opérationnel de la politique monétaire de la BCE sur certains marchés d'actifs. La complexité de la sphère financière, le cycle entre la concurrence et la consolidation, et la grande diversité des investisseurs exigent le développement de méthodologies appropriées pour une analyse et un contrôle efficace de la stabilité du système financier. Cette préoccupation est centrale dans l'analyse de comouvements et de l'interdépendance en finance.

Ce processus d'ouverture a été examiné par les économistes qui soulignent son importance en termes de développement et de croissance économique comme dans Goldsmith (1969) qui considère le parallélisme entre les évolutions économique et financière. Néanmoins le lien de causalité entre le développement du marché financier et le développement économique n'est pas évident comme l'a souligné Robinson (1952) ou, plus récemment, Cole et Obstfeld (1992), King et Levine (1993), Devereux et Smith (1994), King et Singal (2000) ou Dumas, Harvey et Ruiz (2003).

Comme l'a souligné Bekaert et al. (2002), dater l'émergence d'un marché intégré n'est pas chose facile. Dans une perspective historique l'émergence d'un marché mondial des capitaux commence à la fin du XIXe siècle et se poursuit au cours du XXe siècle pour finalement s'accentuer depuis 1980.

Sur une perspective à long terme, de nombreuses études soulignent la progression non homogène de l'intégration des marchés dans le domaine financier. En particulier, certains auteurs ont fait valoir que l'intégration au cours du XXe suit une courbe en U, conséquence des deux guerres mondiales pendant lesquelles la mobilité des capitaux d'abord en 1914 et ensuite pendant les années

40 a largement diminué. Par exemple, Zevin (1992) ou Obstfeld et Taylor (2004) montrent que le niveau de l'intégration financière avant la Première Guerre mondiale a été autant prononcé que lors de la fin du XXe siècle. Bordo et Eichengreen (2001) avancent même que les crises financières à la fin du XIXe et au début du XXe sont aussi graves qu'aujourd'hui, même si elles se produisent à des fréquences plus faibles. Pour Goetzmann et al. (2005), la courbe en U de l'intégration financière est ainsi une incitation pour les chercheurs à regarder l'histoire de l'intégration financière pour comprendre les faits contemporains survenus dans le marché international des capitaux.

1. La naissance d'un marché global en trois étapes: ouverture, intégration, concentration

1.1. L'ouverture des marchés financiers

La courbe en U de long terme de l'intégration financière est compréhensible en raison des deux guerres mondiales qui ont mécaniquement annihilé les mouvements internationaux des capitaux. En Europe et dans le monde, de nombreuses mesures, au sortir de la première guerre mondiale, ont été prises pour satisfaire des objectifs internes de politiques économiques, aux détriments des objectifs externes de type mobilité des capitaux. La multiplication des difficultés pour les investissements internationaux était notamment due à un haut degré d'asymétrie d'information pour les investisseurs et une forte incertitude sur les différents redressements économiques. Cela explique la très courte période de temps pendant laquelle l'étalon-or a été restauré, ou la difficulté des ancrages de parités entre certaines devises.

L'augmentation des contrôles de capitaux a profondément sapé le processus d'intégration financière avec pour conséquence la non optimalité de l'allocation des ressources, qui ne permet pas ainsi une découverte des prix des actifs basée sur leur valeur fondamentale. La crise de 1929 aux États-Unis et la Grande dépression ont été des facteurs décisifs et ont largement anéanti les transactions internationales de capitaux jusqu'à la fin de la Seconde Guerre mondiale.

Néanmoins, l'après 45 ne signifie pas la fin des contrôles de capitaux, mais ceux-ci se produisent de façon plus coopérative entre les pays avec les institutions et accords de Bretton Woods. Keynes estime par exemple qu'il est nécessaire d'établir un haut contrôle de la monnaie et de la mobilité des capitaux pour assurer la stabilité macro-économique internationale. Cela a été le leitmotiv de nombreux pays jusqu'à la fin des années 50 où le débat sur le système optimal du change a commencé à pencher vers un système dit flottant.

Ce débat au sein de l'Europe a conduit à de profonds changements du marché international des capitaux. Un exemple des plus illustratifs vient d'Allemagne où les résidents furent autorisés d'acquérir et détenir des actifs étrangers alors que cela avait été proscrit dans beaucoup d'autres pays. En 1957, le traité de Rome entre la Belgique, la France, l'Allemagne, l'Italie, le Luxembourg et les Pays-Bas a créé la Communauté Economique Européenne et l'article 67 stipule que:

"signatories will undertake the progressive abolition between themselves of all restrictions on the movements of capital belonging to persons resident in Member States".

En mai 1960, le conseil économique européen et les ministres des finances des pays membres ont demandé aux signataires, dans la première directive, d'engager la libre circulation des crédits commerciaux à court et moyen terme, des investissements directs et des opérations transfrontalières de souscription d'actions. Toutefois, certaines crises successives en Europe, l'énorme afflux de capitaux en Allemagne, la réévaluation et dévaluation de certaines devises n'ont pas permis d'accomplir cet objectif de libre circulation des flux de capitaux, même si certaines améliorations se doivent d'être remarquées. Cette période est très troublée pour les devises européennes avec notamment une forte volatilité. La Communauté Européenne a alors émis une dérogation à la 1ère directive de 1960 (qui sera ensuite complètement appliquée seulement en 1985), en Mars 1973 tous les pays rentrent dans un système de change flottant par rapport au dollar et l'Europe crée le serpent monétaire pour six de ses membres.

Ce débat se rapporte au « trilemna » avancé notamment par Mundell (1960) ou plus récemment par Krugman et Obstfeld (2003) : il existe une impossibilité pour tout décideur politique d'imposer à la fois (i) la pleine liberté de circulation des capitaux entre les pays, (ii) un taux de change fixe et (iii) une politique monétaire indépendante orientée vers des objectifs nationaux.

Étant donné que les flux de capitaux internationaux ne sont pas faciles à maîtriser complètement, et de nombreux objectifs nationaux ont une haute priorité pour les décideurs politiques, le contrôle des taux de change est alors impossible à maintenir de sorte que 1973 est un tournant en faveur des taux de change flottants et de ceci découle alors une forte incitation pour l'ouverture des mouvements de capitaux. Toutefois, cette ouverture ne sera pas concrète immédiatement en raison des chocs pétroliers et crises des années 70 auxquels les pays sont confrontés, avec en Europe la volonté de limiter à l'intérieur du serpent monétaire les parités entre pays membres.

Finalement, en 1979 au Royaume-Uni, M. Thatcher libéralise complètement le compte de capital ce qui lance une vague de décisions similaires dans tous les autres pays industrialisés. Au même moment, le système monétaire Européen succède au serpent monétaire pour améliorer la stabilisation des devises. Ainsi, la déréglementation est devenue compétitive avec l'incitation de la concurrence entre investisseurs internationaux pour bénéficier d'une diversification et d'une allocation optimale des capitaux.

De plus, à la fin des années 70, de nombreuses études ont particulièrement porté sur la non optimalité de la diversification du portefeuille en raison des fortes frictions sur les marchés: Markowitz (1959); Granger et Morgenstern (1970); Levy et Sarnat (1971); Grubel et Fadner (1972); Solnik (1974); Farber, Roll et Solnik (1977)). Toutes ces pressions faites sur le marché ont donc permis de plaider en faveur d'un processus de libéralisation qui recouvre depuis trente ans de nombreux défis pour les chercheurs en économie et finance.

1.2. L'intégration des marchés

Plusieurs tendances, comme l'a souligné Frankel (1994), ont caractérisé le développement d'un marché mondialement intégré des capitaux: une généralisation de l'ouverture des marchés nationaux et un processus d'intégration financière couplé à un renforcement des incitations à la titrisation.

La première est la tendance débutée dans les années 70 avec l'ouverture dans la plupart des pays industrialisés des comptes de capital. Cela a été un processus lent au cours des vingt dernières années et concerne maintenant les économies émergentes.

Deuxièmement, l'augmentation du degré d'intégration est clairement associée à une augmentation de la titrisation. Ce processus caractérise une migration d'un système traditionnel bancaire du financement à une vision plus globale de la recherche de financement avec un accès facilité aux marchés de capitaux. Notamment en France, la part de l'intermédiation financière se situe autour de 40/45% entre 2000 et 2006 alors qu'elle s'établissait aux environs de 70% au début des années 80 (*source: Banque de France*).

Ces tendances ont diverses implications concernant la structure internationale d'un marché financier intégré, avec en particulier le rôle de la diversité des investisseurs sur les marchés, et l'impact des législations, nationales et internationales, qui ont globalement favorisé un marché mondial. Cependant, comme souligné par la crise de 2008 cette intégration peut présenter un côté obscure (Beine et al. (2008)). En effet, ce processus d'intégration a récemment été souligné comme un facteur d'anéantissement des opportunités de diversification. Les liens plus étroits entre les pays et leurs marchés financiers, si elles facilitent les investissements étrangers d'un côté, est aussi la raison pour laquelle les comouvements entre les prix des actifs sont plus forts et, enfin, que les chocs sont transmis d'un marché à l'autre. En ce sens, un grand volet de la littérature a mis l'accent sur les raisons pour lesquelles les comouvements sont observés et pourquoi l'infrastructure de marché a évolué vers ce risque potentiel, tandis que la diversification est l'une des premières incitations dans le processus de libéralisation.

La littérature sur l'intégration des marchés et les comouvements de prix d'actifs est très large, mais deux catégories principales peuvent être dressées. La première met l'accent sur le degré d'intégration du marché en tentant de définir une mesure de l'intégration des marchés (ceci fera l'objet du premier chapitre de cette thèse avec une revue des méthodologies usuelles). Le deuxième volet de la littérature examine les facteurs qui peuvent influencer le niveau de l'intégration des marchés. Dans cette classe de modèles de nombreuses raisons ont été avancées pour expliquer le degré de comouvements.

Un premier facteur est la situation géographique du pays comme il a été utilisé dans la littérature associée au commerce international: voir Portes et Rey (2005) ou Martin et Rey (2000). En conséquence, de nombreuses études sur les comouvements se concentrent sur un groupe particulier de pays, par exemple les économies émergentes d'Asie (Masih et al. (1999), Palac-McMiken (1997)) ou d'Amérique latine (Christofi et Pericli (1999), Choudhry (1997)), ou d'Europe (Fratzscher (2001), Bartram, Taylor et Wang (2004)).

Un deuxième facteur qui joue un rôle important est le niveau de développement économique, ce qui est étroitement lié au précédent critère dit géographique. Plus précisément, ce critère peut se comprendre comme le degré d'industrialisation ou de spécialisation industrielle. En effet, de nombreux auteurs ont tenté de démêler la nature des comouvements d'une part en termes d'incitations d'investissement dans une industrie particulière ou d'autre part d'incitations d'investissement dans un pays en particulier. Roll (1992) avance des éléments en faveurs de décisions principalement guidées par des facteurs industriels tandis que Serra (2000), en cohérence avec les conclusions de Rouwenhorst (1999), trouve des incitations davantage géographiques.

Un autre facteur est la taille du marché boursier et le panel d'actifs proposés à la négociation, ou de la capitalisation même des entreprises cotées. En effet, la taille de la capitalisation de l'entreprise échangée est importante (Fama and French (1993)) de sorte que ceci peut créer plus ou moins d'attrait pour les investisseurs sur la base des rendements escomptés, de la liquidité de marché ou du niveau de la volatilité.

Un quatrième facteur qui influence les comouvements est l'apparition de crises. Il peut être ambigu d'envisager cela comme un facteur, mais l'occurrence de crises entre les pays peut directement impacter le degré de comouvements, expost, à la fois sur les court et long termes. La crise est-elle un facteur ou une conséquence de l'existence de comouvements? La littérature sur la contagion est large en économie et cette question est très débattue. D'un côté, la crise est une conséquence des comouvements entre les marchés, mais les comouvements sont certainement exacerbés après la crise sur les court et long termes en ce que les investisseurs ont alors réalisé que des mouvements irrationnels peuvent être induits durant des crises communes entre deux marchés originellement utilisés pour la diversification.

Tous ces facteurs de l'intégration financière ont notamment accéléré les mutations du marché des actifs, d'abord au niveau national et ensuite international.

En effet, au cours des dix dernières années, il y a eu une accélération des accords et fusions entre les bourses d'échanges. Ce phénomène n'est pas nouveau dans la mesure où il a déjà été observé au niveau national entre les marchés financiers régionaux, mais son accélération et son nouveau caractère international, en font un facteur clé dans l'analyse des comouvements. La récente crise dite des *subprimes* a clairement mis en évidence la capacité de ces phénomènes de comouvements à déclencher un risque systémique, non seulement au niveau national, mais pour le système financier mondial.

1.3. La consolidation des marchés

Dans cette section, nous nous proposons quelques rappels concernant l'histoire de la consolidation internationale de l'industrie des bourses d'échange, pour ensuite se focaliser sur l'hétérogénéité des investisseurs sur un ensemble de marchés transfrontaliers, et enfin le rôle des législations nationales et internationales, notamment en Europe. Ces deux facteurs associés à l'accélération du processus de consolidation est d'importance capitale en termes de gestion du risque, de transparence et de liquidité des marchés.

Consolidation des marchés d'actifs

La consolidation des bourses d'échange en elle même n'est pas nouvelle mais son caractère international est néanmoins très récent. Le processus de concentration entre les différentes bourses est clairement apparu aux États-Unis à la fin du XIXe siècle. Sans aucun dispositif de communication moderne, rapide et bon marché, les lieux centralisés d'échange d'actifs financiers ont été développés principalement autour des zones industrielles où le financement était nécessaire. Par exemple, près de San Francisco où une grande industrie minière est installée, les bourses d'échange sont centrées sur un ensemble de titres liés à cette industrie. Un autre exemple est dans le Massachusetts où s'est développé au début du XXe l'industrie du téléphone et de la communication: les premières actions d'AT & T sont alors cotées à Boston. Le rôle initial des échanges a ainsi été de proposer un lieu local et unique où le financement, l'investissement et l'échange de titres peut se produire (Arnold et al. (1999)).

Entre 1920 et 1930, le développement des nouvelles technologies de communication a lancé la concurrence entre ces bourses régionales. L'attractivité de la bourse d'échange devient centrale et dépend à la fois des coûts de transaction associés et de la liquidité du marché. Ceci est lié à la transparence mais également au système d'information implémenté pour les cotations et transactions. Tandis que plus d'une centaine de bourses sont recensées au XIXe aux Etats-Unis , la concurrence a abouti aujourd'hui à la survie de seulement trois d'entre elles: Chicago Stock Exchange, Chicago board of exchange, Cincinatti (appelé National Stock Exchange depuis 2003). Récemment, le Pacific stock exchange a disparu, avalé par la bourse de New York en 2006; le Boston stock exchange et le Philadelphia stock exchange ont eux été rachetés par Nasdaq en Octobre et Novembre 2007.

En Europe, il est difficile de dater précisément l'émergence des bourses d'échange des valeurs mobilières. L'origine du terme "bourse" se situe en Flandre, où la maison de la famille *Van der beurz* concentrait et gérait les négociations entre les agents économiques autour de 1450. En France, Diderot et D'Alembert définissent dans l'Encyclopédie le terme "bourse" comme suit:

BOURSE, (Commerce.) en terme de Négocians, est un endroit public dans la plûpart des grandes villes, où les Banquiers, Négocians, Agens, Courtiers, Interpretes, & autres personnes intéressées dans le commerce, s'assemblent en certains jours, & à une heure marquée, pour traiter ensemble *d'affaires de commerce, de change, de remises, de payemens, d'assùrances, de fret, & d'autres choses de cette nature, qui regardent les intérêts de leur commerce, tant sur terre que sur mer".*

Ceci constitue les premiers éléments d'un lieu centralisé pour les négociations. Il existe très tôt en France (vers le XIIe siècle) des lieux où les échanges de titres de propriétés ont lieu. L'exemple le plus caractéristique est l'émission et l'échange des titres émis par la société "moulin de Bazacle" pour financer un barrage le long de la Garonne. Ces titres de créances, anonymes, n'ont cependant pas fait l'objet d'échanges en un endroit unique, centralisé et organisé. Leurs échanges ont cependant perduré jusqu'au XIXe siècle.

Ce n'est pas avant le XVIe siècle, et l'avènement de Lyon, en tant que lieu central de négociation que nous pouvons parler stricto sensu de Bourse. Cependant, à ce moment-là se pose un problème majeur: la non homogénéisation de la monnaie. En effet, chaque "seigneur" peut frapper sa monnaie et ainsi de nombreuses transactions en devises sont nécessaires. Pour l'anecdote, cela donne naissance à l'Union des "agents de change" et à leur installation sur un pont de Paris (entre le IXe et XIIe siècle), qui est depuis resté "Le pont au change". Au cours du XIXe et XXe siècles, le processus d'homogénéisation et l'avènement des technologies d'information a généré la fusion des bourses régionales en France (Lyon, Lille, Nancy, Marseille, Bordeaux et Nantes), finalement centralisées à Paris en 1991 (voir Le Fol (1998)).

Cette description de l'évolution des bourses d'échange met en exergue plusieurs choses. Premièrement pour consolider il faut un certain degré d'homogénéisation entre participants : langue, monnaie, législation. Deuxièmement, la définition d'une bourse locale devient parfaitement caduc à partir du moment où les participants ont accès à des moyens de communication efficaces et peu chers. Troisièmement, les coûts de transaction, liquidité, transparence, règles d'échange ont motivé la concurrence dont découle aujourd'hui la marginalisation de certaines places.

En Europe, le London Stock Exchange (LSE) a été le premier à surfer sur la vague de la concurrence. Le LSE a permis en 1980 aux banques et institutions financières d'ouvrir à la négociation les entreprises étrangères, cotées à l'étranger. En outre, le LSE lança des systèmes automatisés de cotation et de placements d'ordres : le SEAQ, Stock Exchange Automated Quotations. Ceci a permis à Londres la cotation des entreprises non-britanniques sans l'approbation de celles-ci : Paris a alors perdu 50% du volume de ses *blue chips*, et un tiers pour les entreprises allemandes (Benos et Crouhy, 1996).

Cela a bien sûr créé une incitation pour les réformes des bourses française et allemande avec une réduction des coûts de transactions, de listing, et l'introduction de nouvelles technologies pour automatiser le processus de cotation : le système CAC ("*cotation assistée en continu*"). Tous ces éléments nous ont aujourd'hui conduit à un nombre réduit de lieux d'échanges qui gèrent des capitalisations boursières très importantes, souvent supérieur en valeur pour certaine au PIB des plus gros pays industriels.

Est ensuite apparue une incitation naturelle à se concentrer grâce aux potentielles économies d'échelle et de gamme. Une fois les coûts technologiques assurés, (assimilés à des coûts fixes ou d'entrée), la recherche d'une certaine diversification des produits conduit directement à une forte concurrence entre les bourses et vers la création de monopoles pour le cas extrême. Cette diversification s'applique à la gamme des produits (actions et produits dérivés par exemple) et à la nationalité des sociétés cotées.

Ceci permet de justifier l'ensemble du processus de concentration en particulier en Europe depuis dix ans. Euronext est né de la fusion de Paris, Bruxelles et Amsterdam en Septembre 2000. En Février 2002, Euronext a fusionné avec la bourse de Lisbonne. En conséquence, cette bourse paneuropéenne a diversifié son offre aux investisseurs en termes de pays et facilite également les entreprises cotées à trouver des financements en s'adressant à un ensemble élargi d'investisseurs potentiels. En parallèle, Euronext a également fusionné en Janvier 2002 avec le LIFFE de Londres afin d'être présent dans le commerce des produits dérivés. Dans cette direction, la Deutsche Börse a lancé la création d'un marché mondial pour les options et dérivés (Eurex) avec la Bourse suisse et, récemment, avec le marché américain par le biais de la création de l'Eurex US basé à Chicago.

En 2006, le NASDAQ a augmenté sa participation dans le London Stock Exchange d'environ 15%, alors que Euronext et Deutsche Börse ont été longtemps en concurrence pour fusionner avec le LSE. Cependant, fin 2007, le Nasdaq a abandonné sa procédure de rachat du LSE en vendant ses parts aux bourses des Emirats Arabes Unies qui possèdent maintenant 1/3 du LSE. Evidemment, l'un des exemples les plus saillants est certainement l'ultime fusion entre Euronext et la Bourse de New York pour parvenir à une capitalisation boursière globale d'environ 20.000 milliards $ en 2007.

Cette vague de consolidation grâce aux technologies de l'information et des innovations a été ensuite complétée par un processus réglementaire et l'amélioration de la concurrence conduisant à une harmonisation au niveau Européen de la législation ce qui rend encore plus artificielle la notion de frontière en finance.

Le rôle de la législation

Un autre aspect de la concentration et de la concurrence est le rôle joué par la législation (voir Lombardo et Pagano (1999)). Un exemple aux Etats-Unis a été l'abrogation de la NYSE-règle 390 qui avait jusque là restreint la concurrence entre les bourses régionales (Kam et al. (2003)).

En Europe, comme nous l'avons vu précédemment, la législation a commencé à jouer un rôle avec le traité de Rome (article 67 directive 1960-01) adopté par la Belgique, la France, l'Allemagne, l'Italie, le Luxembourg et les Pays-Bas pour permettre à la circulation des capitaux entre ces pays. Pour répondre aux critères d'un marché européen unifié des capitaux, l'adoption de plusieurs législations a profondément modifié la structure des bourses Européennes. Cependant, ces législations ne présentent pas elles-mêmes suffisamment de garantie afin d'assurer la libre circulation des capitaux, telle que la libre circulation des biens et des personnes ont, elles, été mises en œuvre en parallèle.

En fait, cette libre circulation des capitaux a été seulement opérationnelle vers le milieu des années 80 en raison de la période fortement perturbée connue par les pays membres suite de l'adoption du taux de change flottant et des successives crises pétrolières.

Au début des années 80, seuls l'Allemagne, le Royaume-Uni, la Belgique et le Luxembourg s'étaint conformés à la libre circulation des capitaux. En raison de l'instauration du serpent monétaire européen sur les taux de change, certains ont clairement craint toute répercussion d'une libéralisation du compte de capital. Enfin, c'est en 1985 que la Communauté européenne a affirmé que la libéralisation totale du marché des capitaux est un élément fondamental pour la constitution d'un marché unique européen et en fait une prérogative: la directive en question a été adoptée le 24 Juin 1988. Les deux principales et dernières législations en Europe, pour l'échange des actifs financiers sont les ISD1 (directive sur les services d'investissement) de 1995 et sa révision ISD2 (ou MiFID) en application en 2007. En 1995, l'ISD1 est censée améliorer et, enfin, permettre de réunir les conditions pour renforcer l'existence d'un seul marché d'actif en Europe (Ramos (2003)). D'une part, cette directive permet aux intermédiaires d'opérer dans d'autres marchés de l'UE en limitant le fardeau réglementaire lié à l'hétérogénéité des législations nationales. Cependant, l'article 15.5 de l'ISD1 stipule également qu'un pays peut faire obstruction à l'introduction de concurrents dans les services financiers correspondants. Cette directive a donc amélioré les activités internationales des intermédiaires, mais présente des lacunes certaines pour la création d'un marché concurrentiel des bourses d'échange.

Cette directive a donc été récemment complétée par la directive MiFID (ou ISD2): Markets in Financial Instruments directives. La première partie de cette directive (appelée niveau 1) a été adoptée en avril 2004 par la Commission européenne et le Parlement. Le deuxième niveau est applicable depuis le 1er Novembre 2007. Le commissaire au Marché intérieur Frits Bolkestein a exprimé sa satisfaction à mettre en œuvre cette directive. Il a déclaré l'adoption de la directive comme:

"bad news for financial wide boys and [...] good news for ethical operators, for the market as a whole and for Europe's economy" (avril 2004, discours suivant l'adoption de la directive votée au Parlement).

Cette directive concerne directement le protectionnisme de l'article 15.5 de l'ISD1 et va profondément modifier l'ensemble des structures de l'industrie européenne d'échanges pour plusieurs raisons. D'abord et principalement, MiFID donne aux institutions financières, aux banques et aux sociétés de bourse en particulier un passeport unique pour opérer dans toute l'Union européenne. Cela devrait accélérer l'harmonisation des règles de marché grâce à la concurrence. Deuxièmement, cette directive impose des normes minimales et des exigences pour améliorer la protection des investisseurs à l'échelle européenne. En particulier, il est demandé la divulgation d'information clé permettant de garantir l'éxécution au meilleur prix pour tous les investisseurs.

De ce fait, la mise en place de la réglementation MIFiD ou ISD-2, fin 2007, abandonne la règle de concentration des ordres et permet désormais la multi-cotation des titres et donc un regain de concurrence. Cette multiplication des places de négociation, transfrontalières pour certaines, va de nouveaux favoriser une baisse des coûts de transaction, la présence d'investisseurs globaux aux portefeuilles diversifiés internationalement, favorisant et accélérant les phénomènes de comouvements

L'incitation première de cette réglementation est donc de favoriser largement la transparence de marché afin de garantir le lancement d'un marché unique des actifs et de limiter les barrières informelles aux investissements étrangers.

En effet, dans la littérature financière, Harioka et Feldstein (1980) souligne le paradoxe qui sous-tend la corrélation entre l'épargne et l'investissement. Théoriquement, ils insistent sur le fait que le marché international des capitaux permet au capital (épargne) d'être investi dans des pays où les possibilités d'investissement garantissent les rendements les plus élevés. Cependant, ceci n'est pas vérifié et la corrélation entre l'épargne et l'investissement nationale est très élevée. Dans une moindre mesure ceci est toujours vérifié aujourd'hui.

En fait, leur hypothèse est vraie si les marchés des capitaux sont parfaitement libres et sans frictions, ce qui n'est pas vérifié. Ce paradoxe identifié par Obstfeld et Rogoff (2005) est lié au biais domestique de l'investissement. Ce dernier représente le fait que les investisseurs détiennent un montant toujours limité d'avoirs étrangers. Cela a été souligné par Black (1974), Stulz (1981) ou French et Poterba (1991). Il est principalement expliqué par des asymétries d'informations et les obstacles à l'échange d'information.

En ce sens, la législation veut garantir les meilleures procédures de divulgation de l'information, la meilleure exécution et la meilleure transparence sur les transactions. C'est clairement l'objectif de la directive MiFID. Néanmoins, l'impact global de la fragmentation des flux d'ordres est difficilement prévisible. En effet celle-ci va largement influencer l'état de la liquidité sur le marché, et donc sur le processus de découverte des prix. D'un coté, les coûts de transaction vont certainement diminuer sur les marchés, mais en contrepartie, le processus de découverte des prix va pâtir de la dispersion de la liquidité entre les différents systèmes de négociation.

La mise en place de ces systèmes nécessite alors une surveillance accrue des dynamiques de prix des actifs financiers. Les phénomènes de transmission entre les dynamiques de prix d'un système à l'autre, d'un pays à l'autre, d'un type d'actif à un autre se trouvent largement complexifiés. En outre, les asymétries d'information sont d'autant plus aigües avec la réunification sur les principales places d'échange d'agents venant de pays différents, avec des techniques d'investissement diverses mais avec l'exigence d'un fonctionnement juste, équitable et efficient des marchés financiers.

Hétérogénéité des participants de marché

Ce processus de concentration, associée notamment au développement de nouvelles technologies de communication a motivé l'internationalisation des investisseurs.

Au cours des crises, il est assez commun de souligner le rôle de ces investisseurs internationaux dans les phénomènes de contagion, en raison d'une propension accrue d'arbitrages internationaux. Cette hétérogénéité des investisseurs est particulièrement adressée en ce qui concerne les économies émergentes. Comme l'a souligné Wolf (1998), un important afflux d'investissements en actifs sur les marchés des économies émergentes provient de fonds communs de placement, ou d'hedge funds avec de fortes positions de levier.

Kim et Wei (1999) soulignent par exemple le rôle de ces investisseurs internationaux au cours de la crise coréenne. Ils confirment partiellement que ces investisseurs jouent un rôle important dans l'amplification de la crise en raison de leurs comportements: c'est-à-dire à acheter lorsque le marché est en plein essor et de vendre lorsque le marché s'effondre, accélérant et amplifiant ainsi les processus d'ajustement (voir aussi Choe, Kho et Stulz (1998) par exemple).

Les auteurs ont avancé plusieurs raisons pour lesquelles ces investisseurs accentuent les co-mouvements en période de crise et de contagion entre les pays. L'une de ces raisons est que le coût d'obtention des informations spécifiques concernant la crise dans un pays est si élevé, en raison des asymétries d'information, que les comportements moutonniers constituent la stratégie la plus efficace lorsque les choses vont mal, si bien que les décisions d'investissement ne sont plus pilotées par des facteurs fondamentaux. Cela est la clé de la littérature concernant les modèles en asymétrie d'information des crises financières comme dans Jeanne et Masson (2000) par exemple.

Si l'on examine l'évolution récente de la structure des investisseurs dans le monde, un développement prédominant est l'avènement de l'industrie des hedge funds. Le terme hedge fund est appliqué à tout organismes privés de placement collectif avec un véhicule financier "sophistiqué", investisseurs peu réglementés et utilisant largement l'effet de levier (Crockett (2007)). Si les hedge funds ne sont pas un nouveau type dans le secteur des entités financières, leur forte et récente progression attire fortement l'attention sur leur rôle international. Le nombre de hedge funds, et le volume de leurs actifs sous gestion ont clairement augmenté depuis le début des années 1990 avec des stratégies d'investissement internationales (appelées styles). En 2000, autour de 4000 hedge funds géraient 500 Milliards de dollars d'actifs alors qu'en 2006, presque 9500 hedge funds géraient 1600 Milliards de dollars d'actifs (*source: Hedge Fund research*).

Un autre fait dans cette perspective internationale des marchés des capitaux est l'impact global d'une institution majeure comme la BCE. En effet, la mise en oeuvre de la BCE a profondément modifié certains marchés via la réunification à l'échelle européenne des marchés nationaux. Cela implique une grande hétérogénéité dans le marché interbancaire, avec des agents ayant différents niveau d'information et de compétences. Ceci est clairement vérifié, par exemple, sur les différents segments du marché interbancaire pour le refinancement, où les agents sont les banques, et sur les marchés utilisés comme collatéral durant les opérations institutionnelles de refinancement. Cela motive les décideurs politiques à examiner et à surveiller l'impact de cette hétérogénéité transfrontalière des agents dans la dynamique de découverte des prix.

2. Objet de la thèse

La présente thèse contribue à la compréhension et à la mesure des comouvements dans un marché international des capitaux intégré et concentré. Notre approche empirique est double.

Dans la première partie nous introduisons de nouvelles méthodes pour comprendre et mesurer le degré de comouvements entre actifs financiers (des chapitres 1 à 4). En particulier, les mutations exposées précédemment et les perturbations induites par les crises financières, nous pousse à raffiner la nature des comouvements à la fois sur le long terme, mais aussi sur le court terme voire même dans leur dimension intra-journalière. En effet, il est essentiel de prendre en compte l'accélération des comouvements provoquée par des progrès technologiques, une transparence améliorée, imposée par le législateur, et une haute réactivité d'un ensemble hétérogènes d'investisseurs sur les marchés financiers. Nous commençons par une revue de la littérature concernant les méthodologies usuelles associées à l'analyse des comouvements pour montrer comment l'évolution des techniques économétriques a permis de prendre en compte cette accélération. Ces méthodologies sont présentées pour être ensuite utilisées voire améliorées pour prendre en compte les derniers développements concernant les comouvements. Pour des raisons d'homogénéité et faciliter la comparaison des résultats, la base de données est identique entre les chapitres 2, 3 et 4 avec les rendements d'indices boursiers pour les trois places européennes (Paris, Londres et Francfort) et un supplémentaire pour les États-Unis (New-York).

La deuxième partie de la thèse (chapitres 5 et 6) se focalise davantage sur l'impact du cadre opérationnel de la BCE sur certains marchés et l'usage empirique de données haute fréquence pour l'évaluer. La BCE peut favoriser les comouvements en raison du cadre opérationnel de la politique monétaire de la zone euro. Ces questions ont été soulevées en particulier suite à la crise de 2008 et à l'importante intervention de la BCE dans le processus de refinancement des banques. Nous nous concentrons particulièrement sur les comouvements dans le marché de la dette souveraine française qui résultent de l'utilisation des titres associés comme collatéral dans les opérations d'*Open Market* étant donné l'augmentation des durations et des fréquences de ces opérations en 2007 et 2008. De plus, ce marché étant implémenté à l'échelle de la zone euro, les banques qui participent au marché interbancaire sont très hétérogènes avec un risque fort d'asymétrie d'information. Ceci fera l'objet du dernier chapitre.

Le premier chapitre, est une revue de la littérature sur les techniques économétriques largement utilisées dans la présente thèse permettant l'analyse de l'intégration des marchés et plus précisément des comouvements. Comme nous avons pu le voir plus tôt dans l'introduction, la littérature analyse les comouvements sur différentes échelles. Concernant les comouvements de long terme, de nombreux auteurs se réfèrent à l'intégration ou interdépendance entre les marchés financiers. Il s'agit d'une analyse des changements structurels sur le long terme. Ces analyses ont été réalisées principalement à l'aide de techniques de cointégration, et la détermination de relations d'équilibre. Toutefois, il est difficile, compte tenu de l'accélération des comouvements, de reposer entièrement sur ces techniques vu que les comouvements de court terme sont également forts et d'intérêt. C'est la raison pour laquelle de nombreux auteurs ont utilisé des données quotidiennes couplées à des modèles GARCH multivariés pour analyser sur le court terme, la dynamique entre les prix des actifs, en analysant les comouvements via la volatilité et les corrélations. La mise en œuvre de ces modèles pour des portefeuilles de grande taille est cependant difficile en raison du nombre de paramètres à estimer. Cette limite a motivé l'implémentation de modèles plus parcimonieux avec indépendance entre le nombre de paramètres et le nombre d'actifs dans le portefeuille (par exemple, le modèle de corrélation dynamique conditionnelle (DCC) d'Engle et Sheppard (2002)).

La succession des crises internationales depuis 1997 connues dans le domaine financier a également motivé deux autres approches dans la mise en œuvre de ces modèles. La première est la mise en œuvre de dépendance-état dans les modèles pour tenir compte de la transmission ponctuelle et exacerbée (généralement dénotée contagion) des mouvements de prix des actifs. Une autre approche est de considérer la dynamique du prix de l'actif à fréquence plus élevée que la journée pour comprendre l'accélération de la transmission des chocs de prix.

Le recours à des données haute fréquence est une des dernières branches de la littérature et présente certaines promesses afin de mieux comprendre le rôle de l'intégration financière et les phénomènes de comouvements. L'économétrie financière pour le moment, a mis l'accent sur la volatilité réalisée, en lien avec les précédents modèles MGARCH. Au lieu d'avoir une mesure paramétrique de la matrice de variance covariance, on obtient une mesure indépendante de tout modèle, avec aucun paramètre à estimer. Ceci ouvre de grandes possibilités pour mettre en œuvre expost une certaine variété de dynamiques de la transmission.

En outre, par la disponibilité des données de transactions, de nombreuses autres informations d'intérêt peuvent permettre de mieux comprendre les canaux de transmission entre les dynamiques de prix. Ces études peuvent désormais s'appuyer sur la volatilité et la corrélation de la dynamique des prix, mais aussi sur les données liées aux volumes, à la liquidité, la profondeur du marché ou la résilience du marché. Dans cette direction, nous appliquons les approches empiriques mentionnées ci-dessus et proposons une analyse empirique des comouvements dans les chapitres suivants.

Dans le deuxième chapitre, nous considérons deux approches traditionnelles des comouvements d'actifs financiers à savoir des techniques de cointégration et des modèles GARCH multivariés. En particulier, nous couplons dans un cadre unifié ces deux cadres économétriques pour évaluer les comouvements. Dans le premier moment de la série de prix nous considérons un modèle à correction d'erreur i.e. une transmission moyenne via une relation d'équilibre. Ce modèle est ensuite complété par un modèle multivarié hétéroscédastique, précisément un modèle DCC, où nous analysons la dynamique dans les seconds moments qui ne sont pas expliqués par la relation de cointégration. Beaucoup d'auteurs ont évoqué l'interdépendance entre les marchés par le recours à des techniques de cointégration et à court terme via des effets hétéroscédastiques sur le deuxième moment. La question est de savoir si nous on peut considérer le deuxième moment comme un effet "contagion". D'une part, la réponse est oui: en effet, le deuxième moment est la transmission effective entre les résidus de prix de la série des rendements, c'est-à-dire la partie de la dynamique qui n'est pas expliquée par l'équilibre. Cependant, la contagion est définie comme la part inexpliquée de la transmission en période de crise. Or il existe quelle que soit la période un résidu non nul sans être constamment en période de crise. Ainsi, ce que nous capturerons dans les résultats de ce chapitre est une sorte de contagion au sens large, mais pas à proprement parler des phénomènes de contagion pendant les périodes uniquement de crise.

Ce chapitre adresse plusieurs problématiques auxquelles nous essayons de répondre dans les deux prochains chapitres. Tout d'abord, il existe plusieurs types de transmissions qui sont interdépendants et que nous devrions essayer d'affiner. Est-il possible de bien mesurer les comouvements sur différentes échelles ? Comment est-il possible de moins dépendre de la fréquence des données utilisées pour mesurer les comouvements? Il est clair que la dépendance à long terme sur les données journalières est toujours difficilement établie tandis que sur des fréquences plus hautes l'hétérogénéité des chocs peut être forte. Cela montre bien que les comouvements ont plusieurs dimensions, compte tenu de l'hétérogénéité des chocs et l'hétérogénéité des résiliences de marché. Le troisième chapitre précise donc la notion de comovements en s'attaquant à ces questions.

Dans le troisième chapitre, nous examinons les comouvements grâce à un modèle de dépendance-état : le modèle multifractal des rendements d'actifs de Calvet et al. (2006). Ce modèle considère une agrégation des cycles dans le processus de volatilité si bien que la volatilité apparaît comme une cascade d'information.

L'hétérogénéité des chocs sur les prix des actifs, l'hétérogénéité des participants de marché, et l'hétérogénéité des résiliences de marché rend l'analyse de comouvements plus complexe.

Les propriétés fractales des rendements d'actifs sont liées aux cascades d'information i.e. l'incapacité des agents à prendre une première décision de façon rationnelle. En d'autres termes, une première stratégie adoptée de façon aléatoire (par exemple acheter un actif) devient rationnelle expost, les autres agents ne disposant pas d'information l'adoptant à leur tour. En conséquence, acheter l'actif fut rationnel car le marché est *in fine* orienté à la hausse.

Les changements dans les prix des actifs ensuite s'accélèrent, car le réseau d'agents observant les stratégies des autres s'étend de plus en plus : les chocs sont donc analysés grâce à leur étendue (transmission, mouvements transfrontaliers des chocs, phénomènes de contagion) et par la résilience du marché suivant ce choc (impact des chocs, accélération, résilience, cycles).

De ce modèle bivarié Markov switching Multifractal (MSM), nous construisons et exploitons la structure probabiliste associée à la chaine de Markov pour fournir un ensemble d'indicateurs : les cycles de la volatilité, une probabilité de crise, une probabilité de comouvements extrêmes, les cycles de long terme de forte ou faible volatilité.

Nos résultats montrent que les deux principales crises qui ont eu un impact sur le marché au niveau mondial sont la crise asiatique en 1997 et celle qui en 2008 a suivi la faillite Lehman Brother aux Etats-Unis. Avec la crise asiatique, une longue période de forte volatilité, jusqu'en 2003, a été lancée. Ensuite, le marché a été assez stable jusqu'en 2008 avec une situation de crise extrême à l'échelle mondiale, avec de forts comouvements entre les marchés.

Nous insistons dans ce chapitre sur la nécessité de conditionner les mesures de comouvement à l'instabilité du marché. Ceci est capital afin de considérer d'une part les comouvements de long terme et d'autre part les comouvements extrêmes et courts qui se manifestent durant les périodes de crises. Toutefois, cette définition conditionnelle à la volatilité des comouvements elle-même ne suffit pas. Pour être clair l'un des principaux inconvénients du modèle MSM est que la dimension temporelle n'apparaît que dans les différentes probabilités expost qui peuvent s'avérer assez rigides pour définir en particulier la corrélation, indicateur traditionnellement utilisé pour les comouvements. Il est connu que des facteurs autres que la volatilité interfèrent avec le processus de corrélation. Par exemple, l'Union économique et monétaire européenne a favorisé l'intégration financière avec la disparition du risque de change et ainsi un lien plus étroit entre les dynamiques des prix. De ce fait une définition uniquement basée sur le modèle MSM n'est pas satisfaisante en raison de l'absence de toute dimension temporelle : tel est l'objet du chapitre suivant.

Dans le quatrième chapitre, nous allons plus loin dans la dynamique des comouvements en associant à la fois le modèle multifractal des rendements des actifs et un modèle à corrélation dynamique conditionnelle afin d'introduire la dépendance temporelle. Comme exposé précédemment le MSM modèle donne une interprétation économique très satisfaisante en termes de volatilité grâce aux indicateurs d'intérêt développés dans le chapitre précédent. Tous ces indicateurs sont essentiels pour préciser la notion de comouvements et d'intégration des marchés. Toutefois la corrélation, indicateur largement utilisé dans la littérature, n'est pas satisfaisante dans sa modélisation, en raison de sa définition uniquement conditionnelle à l'état de la volatilité. Un exemple parfaitement illustratif est la situation en Europe avec depuis 1999 une progressive augmentation des corrélations entre prix d'actifs que ne prend pas en compte le modèle MSM.

Pour ce faire, nous considérons les deux modèles sus-cités dans un modèle baptisé le MSMDCC. Ce modèle prend en compte deux types de dépendances: les dépendances temporelles du modèle DCC et la dépendance état de la volatilité du modèle MSM. Ainsi la corrélation couple d'une part des dynamiques progressives et d'autre part l'apparition de chocs plus ou moins résilients et un asynchronisme potentiel des réponses entre différents marchés.

En particulier, ce modèle se concentre sur un phénomène en plein cœur de la crise de 2007-2008 qui est le risque de Re-corrélation. Pendant des cycles de faible volatilité les portefeuilles peuvent apparaître relativement bien diversifiés alors que ceci n'est pas vérifié pendant les périodes de crise, avec une forte corrélation et des pertes en chaîne. Si ce risque de recorrélation est ignoré par les praticiens, ils ne conditionnent pas la corrélation à l'état de la volatilité et s'exposent à un tel risque. Le MSMDCC propose un modèle de caractérisation de ce risque en découplant la corrélation temporelle d'une part et l'excédent de corrélation induit par l'état de la volatilité d'autre part. En particulier, nous montrons que la re-corrélation des rendements a eu lieu entre les indices boursiers (même si ceux-ci sont structurellement étroitement liés) : 37 fois entre le CAC et le DAX entre 1996 et 2008 par exemple et seulement 5 fois entre le DAX et le NYSE.

De ces premiers quatre chapitres de thèse, nous avons vu comment l'intégration dans le marché des actions, en particulier, est très forte à l'intérieur de la zone euro. Qu'en est-il sur les autres marchés de la zone euro ? En effet, il apparaît un classement des interdépendances de marchés. Paris et Francfort sont étroitement liés en raison de l'union monétaire. Ces deux places sont également très liées, mais d'une façon plus faible avec Londres et ensuite vient New-York. Cependant, entre des marchés de la zone euro (comme le marché du refinancement ou ceux dont les actifs peuvent servir de collatéral), l'hétérogénéité des opérateurs (principalement des banques de tailles différentes provenant de pays différents) est un danger pour une transmission claire du signal de politique monétaire et peut créer des déséquilibres entre les marchés.

L'impact du cadre institutionnel en union monétaire où les marchés sont largement ouverts est une question clé et notre originalité est de l'examiner à l'aide de donnée de haute fréquence.

En particulier, la zone euro, si elle se caractérise par des liens étroits dans le marché des actions, présente le défi d'unifier sur un marché économique intégré une grande hétérogénéité de participants dans certains autres marchés. En règle générale, les marchés obligataires de la zone euro sont relativement hétérogènes (fondamentaux économiques, ouvertures, diversités d'actifs) et la même chose s'applique au marché interbancaire du refinancement.

Notamment, qu'en est-il également de l'hétérogénéité des banques (en termes de tailles et d'implantations) sur le marché interbancaire unifié? Clairement les marchés des actions ne peuvent être l'objet de ces questions car leur large ouverture les rend moins sensibles, et que la BCE, institution majeure a un impact direct sur d'autres marchés très particuliers que sont le marché du refinancement et le marché du collatéral. Ces deux marchés étaient notamment au coeur de la crise débutée en 2007-2008.

Dans le chapitre cinq, nous nous concentrons sur les comouvements entre les instruments de la dette négociable de court et long termes du marché obligataire français. Ces deux segments de marché sont utilisés comme collatéral sur le marché du refinancement si bien que nous étudions si l'ensemble des règles de la BCE relatives à l'immobilisation de collatéral au cours des opérations de refinancement peut modifier les comouvements entre échéances de court et à long termes.

La BCE en 2007, a notamment approuvé une liste unique de garanties. Elle concerne un ensemble de titres négociables sur les marchés pour qu'ils puissent être immobilisés pendant les opérations de refinancement. Bien que ceci vise à limiter le risque de crédit induit par ces opérations, ces garanties répondent à une valorisation marquée au marché ce qui transforme dans les faits le risque de crédit en un risque de marché où la volatilité et la liquidité sont des facteurs clés. Pour prendre ceci en compte certaines mesures et restrictions sur l'usage du collatéral ont été imposées en termes de liquidité.

Toutefois, cet ensemble de règles est particulièrement faible et peut conduire à, ce que nous appelons, le cercle vicieux des opérations de refinancement. Ce mécanisme envisage que l'augmentation des opérations de refinancement (en termes de montants alloués et de durées) impliquent une immobilisation importante de collatéral, et donc un assèchement de la liquidité sur le marché associé et une augmentation de la volatilité créant ainsi des pertes.

Ces pertes sont ensuite supposées être compensées par un appel de marge de la BCE, i.e. un transfert de liquidités des banques à la BCE et donc de nouveaux besoins de refinancement et des pressions pour de nouvelles opérations, aggravant ainsi la situation. Cette hypothèse est testée par l'intermédiaire d'un modèle multivarié à changement de régimes markoviens sur la volatilité (bipower variations de Barndorff-Nielsen et Shephard (2003)) et la liquidité (fourchettes de cotation), des indicateurs calculés via des données à haute fréquence.

Il est vérifié empiriquement que la multiplication des opérations spéciales de refinancement ont un impact sur le marché du collatéral et modifie la nature des comouvements entre actifs aux différentes échéances. Elle conduit à une diminution de la liquidité pour les bonds à long terme avec une disparition du premium de liquidité suggérant une demande forcée pour ces titres. Ceci est motivé par la participation au marché de refinancement pour les banques. En outre, certains comouvements sont modifiés entre les primes de liquidité et de volatilité sur le marché.

La fixation de règles par la BCE a ainsi des répercussions sur certains marchés financiers via des opérations de refinancement même si à l'origine ces règles visent à assurer la stabilité du système financier de la zone euro. Pour aller plus loin dans l'impact de ces règles, le chapitre six est centré sur le marché interbancaire du refinancement et l'asymétrie d'information qu'il peut résulter des règles de collatéral.

Dans le chapitre six, nous mettons l'accent sur l'hétérogénéité des participants sur le marché interbancaire et le rôle des asymétries d'information via le cadre opérationnel de la BCE.

Le système bancaire dans la zone euro accède à la liquidité de refinancement via deux canaux. Le premier est le refinancement direct via les opérations de refinancement menées par la banque centrale. Le deuxième est le marché interbancaire où les banques échangent la liquidité sur la base de transactions bilatérales. Ces opérations bilatérales sont très touchées par l'hétérogénéité en termes de taille des banques, de leur pays, leur participation aux opérations de refinancement, leur possession de collatéral, et de leurs besoins de liquidités. Tout cela rend les asymétries d'information clé et elles doivent être limitées pour le bon fonctionnement du marché et la solidité du système bancaire européen.

Le marché interbancaire et sa liquidité a été au cœur de la crise de 2007-2008 en raison de son dysfonctionnement lié à une crise de confiance dans la robustesse des potentielles contreparties dans les transactions. Ceci a débouché sur un assèchement profond et durable de la liquidité de marché. Dans ce cadre, la BCE a été obligée de mener plusieurs opérations, comme on l'a vu dans le chapitre précédent.

La BCE, dans le passé, avait examiné ce problème potentiel des asymétries dans le marché interbancaire et le risque potentiel de marginaliser certaines petites banques dans le processus de refinancement. Cela a motivé en 2004 une réforme de la cadre opérationnel de la politique monétaire examinée dans le présent chapitre.

En particulier, nous explorons les conséquences de ces changements de cadre opérationnel de la politique monétaire, et la dynamique du marché au jour le jour du refinancement interbancaire non sécurisé lors de la crise financière en 2008 via l'usage de la probabilité d'échange informé issu du modèle de Easley et O'Hara (1992) en utilisant des données à haute fréquence.

Nos résultats montrent que la réforme de 2004 a diminué les asymétries d'information dans le marché interbancaire, notamment en raison d'un niveau élevé de liquidité allouée pendant les opérations de refinancement de la BCE, une politique expansionniste, à partir de 2005. En 2007, ce processus s'est ralenti. Cependant, les interventions de la banque centrale pour faciliter le refinancement a permis une augmentation de la liquidité sur le marché interbancaire et baissé la possibilité d'échanges stratégiques entre les banques (diminution de PIN). Toutefois, en 2008, cette augmentation de la liquidité de marché s'est arrêtée et la PIN est clairement revenue à un niveau élevé en raison de la diminution du nombre de transactions sur ce marché.

Tous ces chapitres essaient donc en premier lieu de mesurer le degré d'intégration des marchés financiers et ouvrent quelques réflexions sur le rôle et l'impact sur certains marchés de la zone euro de la BCE, notamment à la lumière des récents événements qui se sont déroulés en 2008. L'ultime partie de cette thèse tire des conclusions générales sur ces questions et propose des extensions futures des différentes recherches ci présentées dans la thèse.

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General introduction

"An empirical measure of market integration is implicitly, though rarely explicitly, a necessary adjunct to any policy discussion", Obstfeld and Taylor (2004).

July 12^{th} 1925, *Chambre des députés*, Paris.

On this day, the deputies had to vote the 1925 French budget bill. This adage above cited has been true for a long time now since market integration is globally at play. In particular, this 1925 budget bill asked if the government should raise new taxes or not on capital. This debate is an illustration, among many others, on how financial integration, cross-border competition for capital allocation and arbitrages can interact with national policy objectives.

In 1925, the country was in deficit and drew in costs related to post war rebuilding. The costs were much higher than expected and Germany would not bear this burden, implying strong needs for funding. The government already knew that Poincaré taxes charged on capital were not effective because of evasion and seek a way to impose these taxes (Hautcoeur et al. (1998)). These discussions resulted in bear speculation on the franc and many investors were largely abandoning French securities.

All deputies knew that financial integration was at play since more than two decades. Juglar (1862) already showed on the basis of documents provided by the *Banque de France* and the Bank of England that financial crises may occur cyclically in both countries due to the *cycle* *des affaires* linked to capital investment and accumulation. The economist Schumpeter (1911)[1] also emphasized the importance of the financial sector development in any country because of its positive influence on per capita income. Members also knew that there was an international competition for investment and capital allocation: Lowenfeld (1909) notably stressed that the British trustee (a set of securities expected to be sound, equivalent of the components of our national indices) was probably the most robust investment by insisting on the benefits of financial integration in terms of optimal allocation and risk sharing.

The beginning of this process of financial globalization appeared before the First World War period, with the gold standard and the hegemony of London as a world financial center. This hegemony in Europe created a high degree of credibility in the financial system and in the central banks engaged in supporting the parities. This credibility associated with the gold standard favoured the mobility of capital, and allowed the financial system to function smoothly.

However, after the First World War, financial integration stopped in some extent. National (or internal) objectives of governments were preponderant and had pushed countries to abandon the gold standard in order to monetize the costs induced by the war. The *Banque de France* also decided not to intervene anymore judging pointless trying to sell its gold, since it would be an ineffective method because of a widespread lack of confidence in the currency.

All these elements must be taken into account in the deliberations of the *Chambre des députés* on this day. The Assembly did not ignore to what extent the country was already financially integrated and how it interacted with the rest of the world. Financial integration was (and still is) obviously of interest to policy makers since it can modify a wide range of policy interventions, their relevance and that any action must be validated through the prism of globalization. At the end of this day, the *Chambre des députés* finally decided to exclude of the budget bill any new tax

[1] See "Schumpeter 1911: Farsighted Visions on Economic Development" by Becker & Knudsen (2003) and Rajan and Zingales (1998).

increase on capital. This helped to stop the flight of investments out of France and to stabilize the currency.

Back to nowadays, many countries around the world, developed or emerging markets, have experienced over the past two decades, a profound and rapid change of market integration both in the real economy and in the financial sphere. The current thesis presents some implications of these dynamics, based on the definition and measure of asset comovements, and on the impact of some supra-national institutions (the ECB for instance). The complexity of the financial sphere, the cyclicity between competition and consolidation between exchanges, and the great diversity of investors requires the development of appropriate methodologies for analyzing and monitoring the stability of the financial system effectively. This concern is central in the analysis of financial comovements and interdependence.

The opening process has largely been scrutinized by economists who emphasize its importance in terms of development and economic growth. For instance, Goldsmith (1969) considers the parallelism between economic and financial developments. However, the causal link between financial market development and economic development is not clear as early stressed by Robinson (1952) or, more recently by King and Levine (1993), Devereux and Smith (1994), Kim and Singal (2000) or Dumas, Harvey and Ruiz (2003).

As stressed by Bekaert et al. (2002), dating the emergence of an integrated market is not an easy task. However, it is widely admitted that the emergence of a global capital market began in the late nineteenth century, had continued during the twentieth century and finally became stronger since 1980.

On this long-term perspective, many studies highlight the non-homogeneous progress of market integration in the financial sector. In particular, some authors have argued that integration during the twentieth follows a U-shaped curve, a result of the two world wars during which capital mobility first in 1914 and then during the 40s had greatly diminished. For example, Zevin (1992) or Obstfeld and Taylor (2004) show that the level of financial integration before the First World War was as high as at the end of the twentieth century. Continuing on this comparison, Bordo et al. (2001) stress that financial crises in the late nineteenth and early twentieth were as serious as now, even if they occurred at lower frequencies. For Goetzmann (2004) or Goetzmann et al. (2005), this U-shaped curve of financial integration is an incentive for researchers to look back the history of financial integration to understand the contemporary developments in the international capital market.

1. The birth of a global market in three steps: open, integrate and concentrate

1.1. The financial market opening

The long-term U-shaped curve of financial integration is understandable because of the two world wars that have destroyed mechanically international movements of capital. In Europe and in the world, many measures at the end of the First World War were taken to meet objectives of internal economic policies, to the detriment of external objectives of capital mobility. The increasing difficulties for international investments were primarily attributable to a high degree of information asymmetry for investors as well as the high uncertainty about the economic adjustments. This explains the very short period of time during which the gold standard was restored, or the difficulty to ensure some currency pegs.

The increase in capital controls has profoundly undermined the process of financial integration with the consequence to mitigate optimal allocation of resources without allowing a valuation of assets based on their fundamental determinants. The 1929 crisis in the United States and the following Great Depression have been crucial and largely destroyed the international capital transactions until the end of the Second World War.

However, the post WWII period does not mean the end of capital controls, but they were established more cooperatively among countries within the Bretton Woods institutions and agreements. Keynes believed that it was necessary to impose a high control of money and capital mobility to ensure international macroeconomic stability. This was the leitmotif of many countries until the late 50s when the debate on the optimal exchange rate system began to favour the floating system.

This debate within Europe has led to profound changes in the international capital market. One of the most illustrative examples comes from Germany, where residents were allowed to acquire and hold foreign assets when it was outlawed in many other countries. In 1957, the Treaty of Rome between Belgium, France, Germany, Italy, Luxembourg and the Netherlands established the European Economic Community in which Article 67 stipulated that:

"signatories will undertake the progressive abolition between themselves of all restrictions on the movements of capital belonging to persons resident in Member States".

In May 1960, the European Economic Commission and Finance Ministers of the member-countries asked the signatories, in the first directive to initiate free trade for short and medium term trade credits, direct investments and cross border trades of listed shares. However, some successive crises in Europe, the huge influx of capital in Germany, the revaluation and devaluation of some currencies, have failed to meet the objective of free movement of capital flows, though some improvements must be noticed. This is a very troubled period for European currencies with high volatility forcing the European Community to issue a derogation to the 1st Directive of 1960 (which will be fully implemented only in 1985), and in March 1973 all countries fell into a system of floating exchange rates against the dollar and Europe then created the monetary snake for six of its members.

This situation relates to the "trilemna" notably advanced by Mundell (1960) or recently by Krugman and Obstfeld (2003): there is an impossibility for any policymaker to impose both (i) full freedom of capital mobility between countries, (ii) a fixed exchange rate and (iii) an independent monetary policy oriented towards national targets.

Given that international capital flows are not easy to control, and that, in parallel, national objectives have high priority for policy makers, it incurs that the control of exchange rate parities appears impossible to maintain: 1973 is thus a turning point in favour of floating exchange rates and to this, follows a strong incentive for the complete opening of capital markets. However, this opening is not immediately concrete in Europe due to the oil shocks and crises in the 70s with the will to limit, inside the monetary European snake, the parity variations between member states.

Finally in 1979, in the United Kingdom, M. Thatcher fully liberalizes the capital account which launched a wave of similar decisions in all other industrialized countries. At the same date, the European monetary system followed the Euopean monetary snake to improve currency stabilization between European members. Deregulation has then become competitive with the encouragement of competition among international investors to benefit from diversification and optimal allocation of capital.

Moreover, in the late 70s many studies have focused on the non optimality of portfolio diversification due to the high degree of market frictions: Markowitz (1959); Granger and Morgenstern (1970); Levy and Sarnat (1971); Grubel and Fadner (1972); Solnik (1974); Farber, Roll and Solnik (1977)). All these pressures made on markets have advocated for a liberalization process that covers, until now, three decades of challenges for researchers in economics and finance.

1.2. Market integration

Several trends, as stressed by Frankel (1994), have characterized the development of a capital market globally integrated: a generalization of the opening of national markets, a process of financial integration and a strengthening of incentives for securitization.

This process first began in the 70s with the opening in most industrialized countries of the capital accounts. This has been a gradual process over the past twenty years and now concerns emerging economies. Then, the increasing degree of integration is clearly associated with an increase in securitization. This process characterized the migration from a traditional bank based system for funding to a more holistic view of funding with easier access to capital markets. Notably in France, the share of financial intermediation settled around 40/45% between 2000-2006 while it was higher than 70% in the early 80s. These evolutions have various implications on the international structure of an integrated financial market. In particular, the diversity of investors in the financial markets and the impact of national and international laws have generally favoured a global market. However, as outlined by the crisis in 2008, financial integration may also present a dark side (Beine et al. (2008)).

Indeed, this integration process has recently been highlighted as a factor in the destruction of diversification opportunities. The closer links between countries and their financial markets facilitate foreign investments. However, it is also responsible for the intensification of asset price comovements and shock transmissions from one market to another. In this sense, a large part of the literature has focused on the reasons why comovements are observed and why the market infrastructure has evolved into this potential risk, even if diversification is one of the first incentives for the liberalization process.

The literature on market integration and comovements of asset price is very broad, but two main categories can be established. The first one focuses on the degree of market integration by trying to define a measure of market integration and dependence (this will be the cornerstone of the first chapter of this thesis with a survey of methodologies).

The second strand seeks to examine the factors that can influence the level of market integration. In this direction many potential explanatory factors have been proposed.

A first factor is the country's geographical location as it has been used in the literature associated with international trade: see Portes and Rey (2005) and Martin and Rey (2006). Consequently, many studies on comovements focus on a particular group of countries, such as the emerging economies in Asia (Masih et al. (1999), Palac-McMiken (1997)); in Latin America (Christofi and Pericli (1999) and Choudhry (1997)); or in Europe (Fratzscher (2001), Bartram, Taylor and Wang (2004)).

A second important factor is the level of economic development which is closely related to the geographical above criterion. Specifically, this criterion can be understood as the degree of industrialization and industrial specialization. Indeed, many authors have tried to unravel the nature of comovements, on the one hand, in terms of incentives for investment in specific industries or incentives related to a particular country. On the other hand, Roll (1992) argues that decisions are mainly driven by industrial factors while Serra (2000), consistently with the findings of Rouwenhorst (1999), finds that incentives are more geographical.

Another factor is the size of the stock market, the panel of securities available for trading, or the market capitalization of listed companies. Indeed, the size of traded market capitalizations is an important factor (Fama and French (1993)) as it can create more or less attractiveness: expected returns, market liquidity or the level of volatility.

A fourth factor influencing the comovements is the emergence of crises. It may be ambiguous to consider this as a factor, but the occurrence of crises between countries may have a direct impact on comovements, ex-post, both in the short and long terms. Is the crisis a factor or a consequence of comovements? The literature on contagion is wide and this issue is highly debated. On the one hand, the crisis is a consequence of comovements between markets. On the other hand, comovements are exacerbated, after the crisis, in the short and long terms as investors have realized that irrational comovements can take place between two markets originally used for diversification.

All these factors of financial integration have accelerated the mutations in asset markets, first nationally and then internationally.

Indeed, during the last ten years, there has been an acceleration of the mergers and agreements between exchanges. This phenomenon is not new as it has already been at the national level between the regional financial markets, but its acceleration and its new international character, becomes a key factor in the analysis of comovements. The recent so-called subprime crisis has clearly demonstrated the ability of these comovement phenomena to trigger a systemic risk, not only nationally but for the global financial system.

1.3. The stock exchange industry: from local emergence to global consolidation

In this section, we propose a short history of the international consolidation of exchanges to subsequently focus on emerging issues as the heterogeneity of investors on cross border markets and the role of national and international legislations, notably in Europe. These two factors associated with an acceleration of the consolidation process is of great importance for risk management, transparency and market liquidity.

Equity market consolidation

The consolidation of exchanges, in itself, is not new but the international character of this process is recent. The process of concentration among the various exchanges started in the United States in the late XIXth century. Without any communication device, modern, fast and cheap, local centralized exchanges for financial assets have been developed mainly around industrial areas where funding was needed. For example, near San Francisco where a large mining industry is installed, the exchanges are concentrated on a pool of securities linked to this industry.

Another example is in Massachusetts at the beginning of the XXth where the phone and communication industry grew and where the first shares of AT & T were listed (Boston). Thus, the initial role of exchanges was to offer a local and unique place where financing, investment and exchange of securities may occur (Arnold et al. (1999)). In this way, we see a high proportion of local exchanges specialized in trading activity surrounding industrial areas.

Between 1920 and 1930, development of new communication technologies has launched competition between these regional exchanges. Attractiveness of the stock market is key and obviously depends on transaction costs but also on liquidity. These are linked to the market transparency as well as the settlement and information systems.

While over a hundred exchanges are identified during the XIXth in United States, competition has resulted today in the survival of only three of them: Chicago stock exchange, Chicago Board Options Exchange, Cincinnati (called National Stock Exchange since 2003). Recently, the Pacific Stock Exchange disappeared, acquired in 2006 by the New York Stock Exchange; in addition, the Boston Stock exchange and the Philadelphia stock exchange were bought in October and November 2007 by Nasdaq.

In Europe, it is difficult to date precisely the emergence of exchanges for securities. The origin of the term "bourse" (exchange in English) is located in Flanders, where the house of the family *Van Der Beurz* concentrated and managed negotiations between economic agents around 1450. In France, Diderot and D'Alembert in the Encyclopedia defines the terms of exchange as follows:

EXCHANGE, (Commerce.) in terms of negocian, is a public place in most major cities, where bankers, negocians, agents, brokers, interpretes, & others interested in trade, gathered together in some days at marked hours, to handle all business trade, currency, discounts, payments, insurance, freight and other things of that nature, watching the interests of their trade, both on land and sea".

These are the first elements of a centralized location for the negotiations. In France, from the XIIth century, there was some trading of anonymous securities. The most characteristic is the issuing and trading of securities issued by the company "moulin de Bazacle" to finance a dam along the Garonne. However, the trading of these anonymous debt securities, were not traded at a single, centralized and organized place. These securities, however, lasted until the XIXth century.

It was not until the XVIth century and the advent of Lyon, as a central bargaining place that we can define stricto sensu an Exchange. However, at this time remains a major problem: the non homogenization of the currencies. Indeed, each "lord" can strike its currency so that many currency transactions were needed. For the anecdote, this gave the society of "*agents de change*" and their installation on a bridge in Paris (between the IX^{th} and XII^{th} century), which has since remained "Le Pont au Change". Throughout the XIX^{th} and XX^{th} the homogenization process and the advent of information technologies led to the merger of all French regional stock exchanges (Lyon, Lille, Nancy, Marseille, Bordeaux and Nantes), finally centralized in Paris in 1991 (see Le Fol (1998)).

This description of the evolution of exchanges highlights several things. First we need a certain degree of homogeneity among participants to consolidate: language, currency, laws. Second, the definition of a local stock exchange becomes perfectly useless from the time that participants have access to efficient and inexpensive communication devices. Third, competition can be understood in terms of transaction costs, liquidity, transparency or rules of exchange. All these factors motivate competition and lead to the marginalization of some places.

In Europe, the London Stock Exchange (LSE) was the first to slide on the wave of competition. The LSE allowed in 1980 banks and financial institutions to trade foreign companies listed abroad. In addition, the LSE launched automated trading: the SEAQ, Stock Exchange Automated Quotations. This enabled the listing in London of non-UK companies without the approval of them: Paris lost 50% of its blue chips, and one third for German firms (Benos and Crouhy (1996)).

This obviously created some incentives for reforms of exchanges in France and Germany with a reduction in transaction costs, listing costs and introduction of new technologies to automate the process of quotation: the CAC system ("*cotation assistée en continu*" implemented in 1986). From this, it results nowadays a small number of exchanges managing very large capitalizations, higher than the value of the GDP of some of the largest industrial countries.

Consolidation is thus motivated by the potential economies of scale and scope. Once the technology costs engaged, (treated as fixed costs or entry costs), the search for product diversification leads to strong competition between exchanges and to the creation of monopolies in the extreme case. This diversification applies to the range of products (equities and derivatives for example) and to the "nationalities" of the listed companies.

This justifies the whole process of concentration in particular in Europe for the last ten years. Euronext is born from the merger of Paris, Brussels and Amsterdam in September 2000. In February 2002, Euronext merged with the Lisbon Stock Exchange. Accordingly, this pan-European stock exchange diversified its offering to investors in terms of countries and also facilitated listed companies to raise money by addressing to a wider set of potential investors. In parallel, Euronext merged in January 2002 with the LIFFE in London to be present in the trade of derivatives.

In the same move, Deutsche Börse launched the creation of a global market for options and derivatives (Eurex) with the Swiss Exchange and, recently, with the U.S. market through the creation of Eurex U.S., based in Chicago.

In 2006, the Nasdaq increased its share in the London Stock Exchange, while Euronext and Deutsche Börse have long been competing to merge with the LSE. However, in the late 2007, Nasdaq gave up to take over the LSE and sales its share to the United Emirates based exchanges that possess now around one third of the LSE.

Obviously, one of the most striking examples is certainly the ultimate merger between Euronext and the NYSE to achieve a market capitalization of approximately $ 20,000 billion in 2007.

This wave of consolidation through information technologies and innovations was then supplemented by a regulatory process to improve competition leading to a harmonization in the European legislations which makes even more artificial the concept of border in finance.

The role of the legislation

Another aspect of concentration and competition is the role played by legislation (see Lombardo and Pagano (1999)). One example in the United States was the rescission of the 390 NYSE-rule which had previously restricted competition between exchanges (Kam et al. (2003)).

In Europe, as we have seen previously, the legislation begun to play a role with the Treaty of Rome (Article 67 Directive 1960-01) adopted by Belgium, France, Germany, Italy, Luxembourg and the Netherlands to allow free capital moves between countries. To meet the criteria of a unified European capital market, the adoption of several laws has profoundly changed the structure of European bourses. In addition, these laws were not themselves sufficient guarantees to ensure the free movement of capital, such as the free movement of goods and people have themselves been implemented in parallel.

Actually, the free movement of capital was only operational in mid-eighties due to some periods of high disruptions experienced by member countries following the adoption of floating exchange rates and the successive oil crises.

In the early 80s, only Germany, the United Kingdom, Belgium and Luxembourg had complied with the free movement of capital. Finally, a European Community Directive ensuring the total liberalization of capital market was adopted on June 24^{th}, 1988 to strongly support the advent of a single European market.

The two most recent laws concerning exchanges in Europe of financial assets are ISD1 (directive on investment services) of 1995 and its revision ISD2 (or MiFID) with application in 2007. In 1995, ISD1 was supposed to improve and, finally, to create conditions to strengthen the existence of a single asset market in Europe (Ramos (2003)). On the one hand, this directive enabled financial institutions to operate in other EU markets by reducing the regulatory burden related to the heterogeneity of national legislation. On the other hand, the Article 15.5 of the ISD1 also stipulated that a country can prevent its domestic market, to be introduced by a competitor. Although this directive has improved international intermediaries, it also presented some shortcomings to create a competitive market of exchanges.

This directive was thus recently completed by the MiFID (or ISD2): Markets in Financial Instruments Directive. The first part of this directive (called Level 1) was adopted in April 2004 by the European Commission and Parliament with application in 2007. The Unified Market

Commissioner Frits Bolkestein expressed his appreciation to implement this directive. He said the adoption of the directive was:

"bad news for financial wide boys and [...] good news for ethical operators, for the market as a whole and for Europe's economy" (April 2004, speech following the adoption of the directive passed in Parliament).

This directive tackles with the protectionism of Article 15.5 of the ISD1 and will profoundly change the whole structure of European exchange industry for several reasons.

First and foremost, MiFID gives financial institutions, banks and stockbroking firms in particular, a single passport to operate throughout the EU. This should speed up the harmonization of market rules through competition.

Second, this directive imposes minimum standards and requirements to improve investor protection at the European level. It notably requires to disclose a certain amount of information on market transactions and to ensure the best execution price for all investors.

Therefore, the implementation of MiFID (or ISD-2) in late 2007, abandons the rule of concentration of orders and now allows multi-listing of securities that launches a new wave of competition. This increasing number of exchanges will further encourage a reduction in transaction costs and the presence of global investors with internationally diversified portfolios, promoting and accelerating the phenomena of comovements. MiFID aims at promoting market transparency to ensure the launch of a single European asset market and limit informal barriers for foreign investments.

Indeed, in the finance literature, Feldstein and Harioka (1980) highlight the paradox that underlies the relationship between savings and investments. Theoretically, they insist on the fact that the international capital market allows capital (savings) to be invested in countries where investment opportunities guarantee the highest returns. However, this is not verified and the correlation between savings and domestic investments is very high.

In fact, their assumption is true if capital markets are perfectly free and without friction which is not verified in practice. This paradox identified by Obstfeld and Rogoff (2000) is related to the home bias. The home bias represents the fact that investors still hold a limited amount of foreign assets (as stressed by Black (1974), Stulz (1981) or French and Poterba (1991)) and this is mainly explained by information asymmetries and obstacles to exchange information.

In this sense, the legislation has to ensure the best procedures for the disclosure of information, a fair market design and greater transparency on transactions. This is clearly the objective of the MiFID.

Nevertheless, the overall impact of order flow fragmentation is hardly predictable. Indeed, it will greatly influence the market liquidity, and thus the process of price discovery. On the one hand, transaction costs will certainly be reduced for market participants, but on the other hand, the process of price discovery will suffer from the dispersion of liquidity among different trading systems.

The establishment of these systems then requires an increased surveillance of the dynamics of financial asset prices. The phenomena of shock transmission from one exchange to another, from one country to another, from one type of asset to another are largely complexified. In addition, information asymmetries become more paradoxically heavy with the reunification on major centres of agents from different countries or investment techniques but with the requirement of a fair and robust functioning of financial markets.

Market participants heterogeneity

This process of concentration, associated with the development of new communication technologies has led to the internationalization of investors.

During crises, it is quite common to stress the role of international investors in the phenomena of contagion, due to an increased propensity of international arbitrages. This heterogeneity of investors is addressed especially in the literature as regards the emerging economies since they are the most impacted by this tendency. As stressed by Wolf (1998), there is a major flow of investments in emerging markets from mutual funds or hedge funds with highly leveraged positions. Kim and Wei (2002) for example emphasize the role of international investors during the Korean crisis distinguishing between foreign institutional investors and individual investors. They partially confirm that these investors play an important role in the development of the crisis because of their behaviours, i.e. to buy when the market is booming and sell when the market is collapsing, accelerating and thereby heightening the adjustment process (see also Choe, Kho and Stulz (1998) for example).

Authors have advanced several reasons why these investors accentuate the comovements in times of crisis and contagion across countries. One key factor is that the cost of obtaining specific information regarding the ongoing crisis in a country is very high due to asymmetric information. In this sense, herding behaviours constitute the most effective strategy, so that investment decisions are not driven anymore by fundamental factors. This is the key of the literature on the information asymmetry models of financial crises as in Jeanne and Masson (2000) for example.

Looking at recent developments in the structure of investors in the world, a predominant development is the advent of the hedge fund industry. The term hedge fund is applied to any private investment funds with a financial "sophisticated" vehicle, little regulated and widely using the leverage effect (Crockett (2007)). If hedge funds are not a new kind of institution in the financial sector entities, their recent strong growth draws the attention on their international role. The number of hedge funds, and the volume of assets under management have clearly increased since the early 1990s with international investment strategies. In 2000, around 4000 hedge funds managed 500 billions of USD of assets while in 2006, almost 9500 hedge funds managed 1600 billions of USD of assets (*source: hedge fund research*).

Another fact in this international perspective of capital market is the global impact of some major institutions as the ECB. Effectively, the ECB implementation has deeply modified some specific markets with the reunification at the European level of national markets. This implies high heterogeneity as in the interbank market, with agents with different level of information. This is clearly verified, for example, on the several segments of the interbank market for refinancing, where agents are banks, and on markets used as collateral in the refinancing institutional process. This motivates policy makers to consider and monitor the impact of this cross border heterogeneity of agents in the price discovery dynamics.

2. Purpose of the thesis

This thesis contributes to a better understanding and measuring of comovements in the international integrated and concentrated capital market. Our empirical approach is twofold.

In the first part of the thesis, we introduce new ways to understand and measure comovements (from chapter 1 to 4). In particular, the previously discussed mutations and disruptions caused by financial crises, lead us to precise the nature of comovements on both the long and short terms or even in their intra-day dimension. It is indeed essential to take into account the acceleration of comovements because of technological advances, improved transparency imposed by the legislation, and high reactivity of a heterogeneous set of investors in financial markets. The first chapter is a survey of methodologies that shows how financial econometrics have improved to take into account this acceleration of comovements. These methodologies are presented and discussed for being then used in chapter 2, 3 and 4. For reasons of consistency and in order to facilitate result comparisons, these chapters share the same database of stock index returns for three European markets (CAC, FTSE and DAX) and one for the United States (NYSE).

The second part of the thesis (chapters 5 and 6) focuses on the impact of the ECB operational framework in some markets and the empirical use of high frequency data to evaluate it. The ECB may encourage comovements due to the operational framework for monetary policy in the Euro zone. These questions have been raised especially during the 2008 crisis and the numerous interventions by the ECB in the process of banks refinancing. We particularly focus on comovements on the French sovereign bond markets resulting from the use of these assets as collateral in open market operations [OMO], since operation durations and frequencies were raised in 2007 and 2008. Moreover, as this market is settled at the European scale, banks participating in the interbank market are very heterogeneous with the potential risk of asymmetric information. This will be the object of the last chapter.

The first chapter, is a review of the literature on econometric techniques widely used in this thesis for the analysis of market integration and more specifically comovements. As earlier mentioned in the introduction, the literature analyses comovements at different scales. Considering long term comovements, authors usually refer to the integration, convergence and interdependence between financial markets. It is an analysis of structural changes in the long term. These tests have been conducted mainly through cointegration techniques and equilibrium relationship. However, it is difficult, given the acceleration of comovements, to rely entirely on these techniques since short term comovements are also very strong and of interest. That is why many authors have used daily data coupled with multivariate GARCH models to analyze the short-term dynamics between asset prices, analyzing comovements via volatilities and correlations. The implementation of these models for large portfolios is nonetheless difficult due to the number of parameters to estimate. This has prompted the implementation of more parsimonious models with independence between the number of parameters and the number of assets in the portfolio (for example, the model of dynamic conditional correlation [DCC] of Engle and Sheppard (2002)).

The succession of international crises since 1997 experienced in financial markets has also impelled two other approaches. The first one concerns the introduction of state-dependency in the models to take into account the transmission of asset price movements in normal and crisis periods (usually denoted as contagion). Another approach is to consider the dynamics of asset prices at a higher frequency than the day to understand the acceleration of the transmission of price shocks.

The use of high frequency data is a recent new branch of literature and presents some promises to better understand the role of financial integration as well as the phenomena of comovements. Financial econometrics literature focuses on the realized volatility, in connection with previous MGARCH models. Instead of having a parametric model, the variance covariance matrix obtained is an independent measure of any underlying model, with no parameters to estimate. This opens up great opportunities for considering then a variety of transmission dynamics.

In addition, the availability of transaction data gives many other informations of interest to better understand the transmission channels between the price dynamics. Studies can now rely on the volatility and return correlations, but also on the related data volumes, liquidity, market depth, order book data or the resiliency of the market.

In this line, we then implement the empirical approaches mentioned above and propose an empirical analysis of comovements in the next chapters.

In the second chapter, we consider two traditional approaches of comovements in the equity market through the use of cointegration and multivariate GARCH model. In particular, we couple in a unified framework both models for assessing comovements. In the first moment we set an error correction model i.e. a long term equilibrium relation that is then supplemented by a multivariate heteroskedastic model to analyze the dynamics in the second moment via the residuals of the model.

Many authors have discussed the interdependence of markets through the use of cointegration techniques, and in the short-term via heteroskedastic models. The question is whether we can consider the second moment as a "contagion" phenomenon. On the one hand, the answer is yes: indeed, the second moment is obtained from the residuals, i.e. the part of the returns not explained by the equilibrium relationship. However, the contagion is defined as the unexplained transmission in times of crisis. There is whatever the period a non-zero residual without assuming that we are continuously in times of crisis. As a consequence, what we catch in the results of this chapter is a kind of contagion in the broad sense, but not strictly speaking phenomena of contagion only during periods of crisis.

This chapter addresses several issues which we respond within the next two chapters. First, there are numerous interdependent types of transmission that we must refine. Is it possible to measure comovements on different scales? How is it possible to reduce our dependency on the frequency of data used to measure comovements? It is clear that the long-term dependency on daily data is still hardly established while at higher frequencies, shock heterogeneity can really be strong. This shows that comovements have many dimensions, given the heterogeneity of shocks and resiliencies of the different markets. The third chapter therefore specifies the concept of comovements in addressing these issues.

In the third chapter, we examine the comovements through a model of state-dependency: the multifractal model of asset returns in the line of Calvet et al. (2006). This model assumes an aggregation of heterogenous cycles in the process of volatility.

The heterogeneity of shocks on asset prices, the heterogeneity of market participants, and the heterogeneity of the resiliencies in the markets make the analysis of comovements more complex.

The fractal properties of asset returns are related to information cascades. A cascade of information is the inability of agents to take an initial decision in a rational way. In other words, once an initial strategy is randomly taken, this decision (for example to buy an asset) then becomes rational, the other agents taking into account this action to adopt a similar strategy. Thus, players do not have other information and therefore adopt strategies similar to the first agent. Accordingly, the asset purchase was ex-post a good decision because the market is now upward.

Changes in asset prices are then accelerating as the network of agents observing the strategies of other spreads more and more. As a consequence, shocks are analyzed through the extent of their transmission and the resiliencies of the markets following the shock (shock impact, acceleration, resiliency, and cycles).

Using this bivariate Markov switching Multifractal model (MSM), we build from the structure associated with the probabilistic Markov chain a set of comovement indicators: volatility cycles, probability of crisis, probability of extreme comovements and the long-term cycles of high and low volatility.

Our results show that the two major crises that have had an impact on the global market are the Asian crisis in 1997 and the one that started in 2008 following the bankruptcy of Lehman Brother in the USA. With the Asian crisis, a long period of high volatility, until 2003, was launched. Then, the market has been fairly stable until we reach in 2008, a situation of crisis on a global scale with extreme comovements between markets.

We stress in this chapter on the need to condition the comovement measures to market instability. This is important to consider comovements on the long term and those extreme comovements that fast occur during periods of crisis, i.e. of high volatility. However, the construction of correlation only conditional on the volatility itself is not enough.

To be clear one of the main drawbacks of the MSM model is that the time-dimension is only obtained from the filtered probabilities that can be too much rigid to define the correlation, the traditionally used indicator for comovements. It is known that factors other than volatility interfere with the process of correlation. For example, the European Economic and Monetary Union has progressively promoted financial integration with the disappearance of currency risk and a closer link between the dynamics of prices. Therefore the MSM-correlation is not satisfactory due to the absence of any temporal dimension: this is the subject of the next chapter.

In the fourth chapter, we improve the dynamics of comovement by completing the multifractal model of assets returns with a model of dynamic conditional correlation to introduce temporal dependence. As stated above the MSM model gives a very satisfactory economic interpretation in terms of volatility due to indicators of interest developed in the previous chapter. All these indicators are essential to perfect the concept of comovements and market integration. However, the correlation indicator widely used in the literature is not satisfactory in its modelling only conditional on the state of the volatility on the markets. An illustrative example is the situation in Europe since 1999 with a progressive increase in correlations between asset prices that is not taken into account by the MSM model alone.

We tackle with this issue by associating the two aforementioned models in a model called the MSMDCC (for Markov switching multifractal model with dynamic conditional correlation). The MSMDCC model takes into account two dependencies: the dependence on the volatility from the MSM model and the temporal dependencies from the DCC model. Thus, the correlations present some progressive dynamics with the appearance of shocks more or less resilient and potential asynchronous shock responses between different markets.

In particular, this model focuses on a phenomenon in the height of the crisis in 2007-2008 which is the risk of re-correlation. During cycles of low volatility portfolios may appear relatively well diversified while this is not verified during periods of crisis, with strong correlations and chain losses. If this risk of re-correlation is ignored by practitioners, they do not condition correlation to the state of volatility and face such a risk. The MSMDCC characterizes this risk by separating the temporal correlation on the one hand and the surplus correlation induced by the state of volatility on the other hand. In particular, we show that the re-correlation of returns took place between the stock indices (even if they are structurally closely related) 37 times between the CAC and the DAX between 1996 and 2008 for example, and only 5 times between DAX and the NYSE.

From these first four chapters, we saw how integration in the stock market, in particular, are very strong within the euro zone. What about some other types of markets in the Euro area?

Indeed, there is a clear ranking in the market interdependencies. Paris and Frankfurt are closely linked because of the monetary union. Both places are also closely related, but in a weak form with London and then comes New York. However, in some markets within the Euro area itself (as the refinancing market or asset markets used as collateral), the heterogeneity of operators (mainly banks from different countries and different sizes) is a danger for a clear transmission signal of monetary policy and may create imbalances between markets.

The impact of the institutional framework in a monetary union where markets are largely open is a key question and our originality is to examine this question with high frequency.

In particular, the Euro zone if it is characterized by close links in the stock market presents the challenge of unifying markets that include a large heterogeneity of participants. In general, bond markets in the Euro zone are relatively heterogeneous (economic fundamentals, openness, asset diversity, etc.) and the same applies to the interbank market for refinancing.

Notably, what about the heterogeneity of banks (in terms of sizes and locations) on the unified interbank market? Clearly the stock market cannot be the subject of such issues as their openness makes them less sensitive. Moreover, the ECB as a cross border institution, has a much more direct impact on other markets that are very specific as the market for collateral and the refinancing market. In particular these two markets, considered in the two following chapters, were at the height of the crisis started in 2008.

In chapter five, we focus on comovements in the bond market between negotiable short-term French debt instruments and the long term ones. These two segments are used as collateral on the market for refinancing so that we study the ECB rules regarding the detention of collateral in refinancing operations and how this may change comovements between short and long term rates. The ECB in 2007, approved a single list of collateral that concerns a set of marketable securities that are eligible during the refinancing process. Even if this reduces the credit risk induced by Open Market Operations [OMOs], these guarantees are marked to the market. This is thus transforming the credit risk in a market risk where volatility and liquidity are key factors. To take this into account some measures and restrictions on the use of collateral was imposed in terms of liquidity.

For example, any loss in the value of the collateral must be compensated by cash (the so-called variable margins). However, this set of rules is particularly low and may lead to what we call the vicious circle of refinancing operations.

This mechanism envisages that the increase in refinancing operations (in terms of amounts and durations) involves an important search for assets used as collateral, and thus a drying up of the liquidity in the associated market incurring losses. These losses are supposed to be offset by a margin call of the ECB, i.e. a transfer of cash from banks to the ECB and hence new refinancing needs and pressures for new operations which may worsen the situation even more.

This hypothesis is tested through a multivariate Markov switching model on the volatility and liquidity indicators based on high frequency data. To analyze liquidity, we use bid-ask spreads and to analyze volatility, we use bipower variations of Barndorff-Nielsen and Shephard (2003).

It is empirically verified that the multiplication of special refinancing operations has an impact on the market of collateral and changes the dynamics of comovements between assets with different maturities. It leads to a decline in liquidity for long-term bonds coupled with a disappearance of liquidity premia suggesting a forced demand for these assets. This is related to the will to participate to refinancing operations for banks. In addition, some comovements are modified between liquidity and volatility premia in the market.

The setting of rules by the ECB has an impact on some financial markets via refinancing operations even if the rules are originally implemented to ensure the financial system soundness in the Euro zone. To further analyze the impact of these rules, chapter six focuses on the interbank market for refinancing and information asymmetries that may also impact this market as a result of the eligibility rules for collateral.

In chapter six, we focus on the heterogeneity of participants on the interbank market, the role of asymmetric information and on the operational framework of the ECB.

The banking system in the euro area accesses to funding liquidity via two channels. The first one is the direct refinancing channel via OMOs conducted by the central bank. The second is the interbank market where banks exchange liquidity on the basis of bilateral transactions. These bilateral operations are severely affected by the heterogeneities in bank sizes, their countries, their participation in the OMOs, their possession of collateral and their liquidity needs. All these information asymmetries ought to be limited to ensure the smooth functioning of the market and the strength of the European banking system.

The interbank market liquidity was at the height of the crisis of 2007-2008 because of the failure of this market linked to a crisis of confidence in the robustness of potential counterparties during transactions. This has resulted in a profound and lasting drying up of the market liquidity forcing the ECB to conduct several operations, as we saw in the previous chapter.

The ECB, in the past, had already considered the potential problem of information in the interbank market and the potential risk of marginalizing some small banks in the process of refinancing. This has motivated in 2004 a reform of the operational framework of monetary policy discussed in this chapter.

In particular, we explore the consequences of these changes in the operational framework for monetary policy, and market dynamics on the overnight interbank unsecured market until the financial crisis in 2008. The probability of informed trading [PIN] from the model of Easley and O'Hara (1992) combined with high frequency data is used for this purpose.

Our results show that the reform of 2004 mitigated information asymmetries in the interbank market, partly because of a high level of liquidity allocated during the refinancing operations. This has slowed down in 2007 due to some tensions. However, the interventions of the central bank to ease refinancing have helped to increase liquidity in the interbank market and to lower the possibility of strategic trade in this market (the PIN decreases). However, in 2008, this increase in market liquidity has stalled and the PIN has clearly recovered at a high level due to the large decrease in the number of transactions in this market.

All these chapters will therefore first attempt to measure the degree of integration of financial markets and open up some thoughts on the role and impact in the euro area of the ECB in some markets, particularly in light of recent events that took place in 2008. The final part draws conclusions on these issues and proposes future research extensions.

Chapter 1

Financial asset comovements: a survey of methodologies

Non technical summary

This chapter presents a review of methodologies to measure the degree of comovements between markets. In particular, this thesis is then constructed in line with this review of econometric frameworks, by using or improving them. Along with profound changes that financial markets experience, economists have to often reconsider methodologies in econometrics to reflect the new nature of relationships that might exist between markets. Notably, the previous exposed changes generate a strong acceleration of comovements between financial markets.

To analyze comovements, the literature presents three main streams. One considers the dynamics of the first and second moments of price series; another one considers factor models such as APT or CAPM (Arbitrage pricing theory model and Capital asset pricing model); finally, the last one concerns extreme dependencies. To account for the acceleration of the dynamics between financial assets, we focus here on the first strand of the literature based on three approaches: the cointegration approach linked to a long-term analysis, the multivariate heteroskedastic approach for a short to medium term analysis, and finally methodologies based on transaction data (high frequency).

In first place, we are interested in the cointegration approach. This approach seeks to determine an equilibrium relationship between long-term asset prices. This approach began with the work on the Granger causality (Granger (1969)) and continued in the 80s and 90s with the work of Engle and Granger (1987) or Johansen (1992). These works offer testing and estimation methods of the equilibrium relationship towards which prices tend to converge.

This is consistent for applications made on empirical data whom frequencies are not too high. Indeed, using daily data, the strength of a long term relationship may not be robust, given the heterogeneity of potential shocks. Similarly, large samples of available financial data may require the inclusion of structural breaks, or regimes, in the long-term relationship.

To address these weaknesses and that comovements take place elsewhere than in the long term relationship, economists have also studied the dynamics associated with the second moment of asset prices.

These methodologies concern the implementation of heteroskedastic models. Since the work of Bollerslev (1990) there is a plethora of multivariate models of volatility and correlations (Engle and Kroner (1995); Engle and Sheppard (2002), Tse and Tsui (2002); Billio et al. (2005)). It also allows the introduction of regime switching to produce studies on the nature of comovements during and outside periods of crisis.

The disadvantage of this second approach is the parametric specification of variance covariance matrices. These approaches require the estimation of models with a number of parameters that grows rapidly with the size of the portfolio. There exist some methods to limit the number of parameters to be estimated, but they are also at the expense of measurement accuracy.

To tackle this problem and to open up new avenues of research, we are also interested in methodologies that use intraday data.

This last approach is first used to define nonparametric variation and co-variation measures. These nonparametric specifications (i.e. that do not depend on the estimation of a set of parameters related to a model) allow a degree of freedom in the analysis of dynamics between these indicators (realized volatility and co-volatility).

In addition, the use of high frequency allows the development of analysis based on the dynamics of prices but also on indicators of liquidity. For example, the bid-ask spreads, the trading volumes, or the frequency of transactions, may be of interest to understand the transmission channels of financial instability between markets.

1.1 Introduction

As seen in the introduction, several changes of financial markets imply an acceleration of comovements, their transmission and amplification. Actually, some factors (information technologies, international investors, etc.) allow the opening of new channels for comovements on the very short term. The processing of trades, the trading platforms and the wide range of market participants induce a very strong persistence of some shocks while some others are resilient with intraday impacts. The result is an aggregation of very short cycles with the more traditional longer ones.

The factors that play a role in this acceleration have been exposed before and we now propose a review of methods used to assess the degree of comovements between assets. In the literature on price comovements there are essentially three main approaches in terms of methodology. One is based on the first and second moments of the series. The second uses factor models where the CAPM and APT models are paramount. Finally, the last one concerns the theory of extreme values on the basis of specific distributions that enable the inclusion of extreme dependencies. In this chapter, we focus on the analysis of the dynamics of the first and second moments of price series. This choice is guided by the need to consider accelerating comovements with an analysis from the long term up to the use of high-frequency data.

The first part of this review considers the comovements with a long-term perspective. This has mainly been studied in the 70s by authors willing to demonstrate the benefits of market liberalization and cross border diversification (for example, Granger and Morgenstern (1970); Levy and Sarnat (1971); Grubel and Fadner (1972); Solnik (1974); Farber, Roll and Solnik (1977)). Some of these papers notably use Granger causality (Granger (1969)) which is a premise technique of cointegration. Then, from Engle and Granger (1987), cointegration is widely used in financial econometrics. These cointegrated relations are called interdependencies because of the long term horizon on which comovements are assessed. However, the application of these techniques to higher frequencies (as daily data in finance), and longer samples, has motivated some adaptations. Indeed, resiliencies and persistencies of some shocks in financial asset prices vary so much that a long-term perspective is not always easy to implement. Moreover on long samples, especially after 1997 with the succession of financial crises, some shifts and breaks may be needed.

The second part focuses on short-term comovements and the class of multivariate heteroskedastic models. This class of models allows for instantaneous analysis of comovements between assets via the calculations of the variance-covariance matrices. Some analyses in the 70s are already based on the correlation of asset prices. For example, Panton et al. (1976) examine the benefits of the end of capital control on international diversification. The analysis of correlation patterns has notably surged with the work of Bollerslev (1990) and the conditional constant correlation model. As a result, there is now a myriad of multivariate heteroskedastic models: dynamic correlation, BEKK GARCH (Baba Engle Kraft and Kroner Generalized Auto Regressive Conditional Heteroskedastic model), vec-GARCH (vector GARCH), Markov switching multivariate GARCH, Markov switching correlation models among others. These models allow for the analysis of common shocks that affect the price dynamics, usually at daily frequency. The analysis of the correlation and comovements concerns mainly stock markets as in Longin and Solnik (1995 & 2001), Karolyi and Stulz (1996), Engle and Sheppard (2002). In addition, this class of models includes many studies focused on contagion during crises based on dynamic correlations (for a review of the literature on contagion see Karolyi (2003) and Dungey et al. (2005) for example). One main drawback of this type of models is the parametric specification that usually involves a very large number of parameters to estimate.

The third part finally concerns the nonparametric measures of comovements and the extensive use of high frequency data. This literature revolves around the specifications of realized volatility and covolatility indicators independent of any parametric specification. It gives a high degree of freedom to introduce more economic significance to comovements compared to the previous class of models. In this non parametric category, the analysis is based on the very short term and comovements can be completed by the analysis of other transaction data such as order flows, volumes or liquidity indicators that opens up some research avenues. However, some drawbacks have to be mentioned. For example, the construction of the volatility and covolatility indicators is obscured by microstructure noises in the data. Many studies have thus focused on the definition of the most robust indicator to this noise. Furthermore, to define the covariance matrices, it is necessary to consider assets traded in parallel with comparable market liquidity conditions. Another issue is the consideration of the overnight period in the indicators and the ways to take it into account. All these elements complicate the implementation of empirical studies.

The chapter is organized as follows. The following section 1-2 considers the cointegration techniques used for long term comovements. Section 1-3 considers the short-term comovements through the class of multivariate heteroskedastic models. The fourth section focuses on the use of high frequency data. We first remind the reader the genesis of the realized volatility and its interest and then present some models that use these measures. In addition, it opens some thoughts regarding the analysis of comovements with data such as volumes, order flows and liquidity. Finally, section five concludes and outlines the main differences between these three approaches.

1.2 Long term comovements: cointegration based analysis

Cointegration is widely used in the literature to analyze market linkages. The aim is to define an equilibrium relationship between financial prices where prices are converging even if there are some transient perturbations. This has been widely used in the 90s following some improvements in econometric concepts: it relies on Vector Error Correction Mechanism (VECM) introduced by Engle and Granger (1987), Granger causality, and cointegration tests of Johansen and Juselius (1992). In finance, there are many applications to asset prices as in Kasa (1992), Kanas (1998), Bhattacharyya and Banerjee (2004), Davies (2006), Idier (2006), Favero et al. (2008) for example. The analysis of long term comovements refers to interdependence and is based on some structural relationships between prices. Cointegration is also used in some models as in Harris et al. (1995

& 2002) and Hasbrouck (1995) for example. The Hasbrouck (1995) model of leader and follower market is especially taken as an illustration along the chapter.

1.2.1 The use of cointegration in finance

In finance, cointegration is used to determine equilibria between asset prices. Let consider two price series X_t and Y_t of the same dimension, integrated of order 1 (random walks). If there exist a value β such that $Y_t + \beta X_t$ is stationary, the two prices are said cointegrated. Although X_t and Y_t are both integrated of order one, there exists a linear relationship between the two random walks which is stationary. The vector (1, β) is called the cointegrating vector.

Cointegration is linked to long run equilibrium between prices: the "long run commonality" between Y_t and βX_t cancels out in a stationary process when subtracting each others. In Hasbrouck (1995) cointegration appears directly in the structure of the model. Let consider an economy with a leader market (subscript L), and a follower one (subscript F). The respective log prices of a common traded asset is given by:

$$p_{L,t} = p_{L,t-1} + \varepsilon_{L,t}, \tag{1.1}$$

$$p_{F,t} = p_{L,t} + \varepsilon_{F,t}. \tag{1.2}$$

The log price on the leading place is a random walk while the other one follows the contemporaneous leader price. The two log prices are integrated of order 1 [$I(1)$], the returns are stationary:

$$r_{L,t} = \varepsilon_{L,t} \tag{1.3}$$

$$r_{F,t} = \varepsilon_{L,t} + \varepsilon_{F,t} - \varepsilon_{F,t-1} \tag{1.4}$$

and the log prices are cointegrated with a the cointegrating vector $\beta = \left[\begin{smallmatrix}1\\-1\end{smallmatrix}\right]$. The techniques presented below aim at detecting this equilibrium relationship.

1.2.2 Cointegration tests and long run relationship estimation

1.2.2.1 The Granger Causality

Granger (1969) introduces the concept of Granger causality which is defined as follows : a variable X is said to Granger cause a variable Y if the past values of X have any predictable power of variable Y. It is one of the first formal way to analyze dependencies between markets (Granger and Morgenstern (1970)).

Formally, let consider two prices $p_{i,t}$ and $p_{j,t}$ and an information set $\digamma_t = (p_{i,t}, z_t, p_{i,t-1}, z_{t-1}, \ldots\ p_{i,t-n}, z_{t-n})$, where $p_{i,t}$ and z_t are vectors of explanatory variables for $p_{j,t}$. It is said that $p_{i,t}$ Granger causes $p_{j,t}$ if the variance of the optimal linear prediction of $p_{j,t}$ (i.e. $p_{j,t+h}$), conditional on the information set $\digamma_t$, is smaller than a linear prediction based on $\digamma_t^{'} = (z_{t,} z_{t-1}, \ldots z_{t-n})$.

As an illustration, we consider a general Vector Auto-Regressive model with S lag [VAR(S)]:

$$p_t = \sum_{s=1}^{S} \Phi_s p_{t-s} + \mu + \varepsilon_t, \tag{1.5}$$

which becomes for two prices i and j:

$$\begin{aligned} \begin{pmatrix} p_{i,t} \\ p_{j,t} \end{pmatrix} &= \begin{pmatrix} \mu_i \\ \mu_j \end{pmatrix} + \begin{pmatrix} \phi_{1,ii} & \phi_{1,ij} \\ \phi_{1,ji} & \phi_{1,jj} \end{pmatrix} \begin{pmatrix} p_{i,t-1} \\ p_{j,t-1} \end{pmatrix} + \ldots \\ &+ \begin{pmatrix} \phi_{S,ii} & \phi_{S,ij} \\ \phi_{S,ji} & \phi_{S,jj} \end{pmatrix} \begin{pmatrix} p_{i,t-S} \\ p_{j,t-S} \end{pmatrix} + \begin{pmatrix} \varepsilon_{i,t} \\ \varepsilon_{j,t} \end{pmatrix}. \end{aligned} \tag{1.6}$$

The Granger causality test of $p_{i,t}$ on $p_{j,t}$ is a F-test such that $\phi_{1,ji} = \phi_{2,ji} ... = \phi_{S,ji} = 0$. Similarly, the Granger causality test of $p_{j,t}$ on $p_{i,t}$ is a F-test such that $\phi_{1,ij} = \phi_{2,ij} ... = \phi_{S,ij} = 0$.

As an illustration, the Hasbrouck model is written as:

$$\begin{pmatrix} p_{L,t} \\ p_{F,t} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 1 & 0 \end{pmatrix} \begin{pmatrix} p_{L,t-1} \\ p_{F,t-1} \end{pmatrix} + \begin{pmatrix} \varepsilon_{L,t} \\ \varepsilon_{F,t} \end{pmatrix},$$

so that the leader price Granger causes the follower price and this relation is univocal.

Granger causality is included in a more general framework using VAR models as in King et al. (1990), Koch et al. (1991) or more recently Bekaert et al. (2003), Bonfiglioli and Favero (2005), Baele et al. (2008) for example. The VAR methodology is presented by Bekaert et al. (2003) as an alternative of an asset price model that uses partial information and restricts interactions between the considered returns. The Granger causality test is usually applied to prices or returns (see Smith et al. (1993) or Meric et al. (2008) for recent use) but some papers use it also on volatilities (Chow and Lawler (2003)). Some authors have notably considered Granger causality with regime dependencies as in Bialkowski et al. (2005).

This definition of causality relies on the ability of one variable to help predicting another variable. Nevertheless, it is possible that there is no causality but just that one of the two variables reacts to an unmodelled factor before the other one so that the definition of the information set $\mathcal{F}_t$ is crucial. In this case, it is not causality, since the real transmission channel between prices is ignored. This is typically what may occur between stock index data: the US market may have a predictable power over European stock indexes only because the US index is more reactive to new information or events.

Granger causality also depends on the frequency of the data used. It is possible to find Granger causality at weekly frequency but no Granger causality at daily frequency. Moreover, it ignores instantaneous correlation between prices whereas prices tend, nowadays, to respond very quickly to similar factors.

Finally, a last issue is the stationarity properties of the variables. Some papers have shown how the use of integrated variables in this test may lead to spurious results (Hsiao (1981), Park and Phillips (1989) or Stock and Watson (1989)). These critics has finally achieved to a more rigorous framework for cointegration analysis, first for the univariate case and then in a multivariate setup.

1.2.2.2 Residual-based cointegration

To capture long run relationships between integrated data, Engle and Granger (1987) proposed cointegration tests based on unit root tests on the residuals of the long run relationship. Cointegration tests are thus directly linked to the power of unit root tests: this approach is called residual-based cointegration tests. This is here applied to market prices.

The first test is the one of Dickey and Fuller (1979) [DF]. Testing for unit roots is testing whether the variances and covariances are finite and independent of time. For example testing for cointegration in equation (1.2) is equivalent to test the stationarity of $\varepsilon_{F,t}$. The DF test considers the following equation:

$$\varepsilon_{F,t} = \theta\varepsilon_{F,t-1} + \epsilon_t. \tag{1.7}$$

The null hypothesis is that $\theta = 1$. OLS are used to estimate this parameter and the associated standard error. Beside, Dickey and Fuller shows that under H_0 the standard t-ratio does not have a t-distribution. This comes from the non stationarity of the process and the fact that the variance of $\varepsilon_{F,t}$ is not defined under H_0: critical values are thus given by Dickey and Fuller for the statistic $\hat{\tau} = \frac{\hat{\theta}-1}{\sigma_{\hat{\theta}}}$ with $\sigma_{\hat{\theta}}$ the usual OLS standard error. $\varepsilon_{F,t}$ is stationary if the statistic $\hat{\tau}$ is higher than the critical value so that H_0 is rejected and that $p_{F,t}$ and $p_{L,t}$ are cointegrated. However, one main issue is that unit roots tests usually over-reject the H_0 hypothesis even if there is no cointegration between the prices (Davidson and MacKinnon (1993)).

Nevertheless, if $p_{L,t}$ and $p_{F,t}$ are effectively cointegrated, OLS then applied to equation (1.2) produces super consistent estimators of the long run relationship since the non stationarity dominates asymptotically all mispecifications in the stationary part: incomplete short run dynamics[1], seasonalities or endogeneity problems (Banerjee et al. (1993)). This long run relationship is often defined in the literature as interdependence. This term of interdependence reflects that cointegration does not provide any information on the temporality of transmission: it just addresses the fact that at date t the two prices are closely linearly linked. Clearly, the super consistency of the OLS estimator implies that an equivalent relationship of equation (1.2) is asymptotically verified:

$$p_{L,t} = p_{F,t} + \varepsilon_t^*$$

with $\varepsilon_t^* = -\varepsilon_{F,t}$ being stationary, so that the leader price is asymptotically influenced by the follower one, which is contradictory.

All these elements imply very cautiousness when interpreting the results. In addition, even if it is accepted, it can only conclude to interdependence without providing any clue of transmission, timing nor of market leadership.

On the long run, one main difficulty is the stability of the cointegration relationship. Many factors may change and invalidate temporarily or definitively the linkages between prices. To circumvent this, a first step is to include some trends, drifts, seasonalities or more lags, directly in the equation of the Dickey-Fuller test. A second step consists in improving the power of stationary tests by proposing some alternatives: KPSS test, PP tests among other. A third step is to introduce some refined specifications with, for example, structural breaks. However, these tests are still not

[1] This allows a two step procedure by first estimating the long run relationship ignoring the short run one and then using the residuals of this OLS regression in the short run dynamic equation.

direct tests for cointegration and have the main drawback to consider one single relationship while cointegration may effectively occur between more than two prices with more than one relationship.

1.2.2.3 Multivariate cointegration

The Johansen test is a multivariate specification of the previous Engle and Granger methodology for N series. One difficulty is that the cointegrating vector expands to a cointegrating space which dimension has to be determined. For N series, up to $N-1$ linear independent stationary relationships may be found while any linear combinations of these relationships are also stationary. This makes the individual cointegrating vectors no longer statistically identified.

To circumvent the problem, the Johansen test is based on the rank of the cointegration matrix. Formally, let consider the VAR in equation (1.6) rewritten as the following Vector Error Correction Mechanism [VECM]:

$$\begin{aligned}\Delta p_t &= \left(\sum_{s=1}^{S}\Phi_s - I\right)p_{t-1} + \left(\sum_{s=2}^{S}\Phi_s\right)\Delta p_{t-1} + \left(\sum_{s=3}^{S}\Phi_s\right)\Delta p_{t-2} + \\ &\quad ... + \Phi_S \Delta p_{t-S+1} + \mu + \varepsilon_t,\end{aligned} \tag{1.8}$$

or

$$\Delta p_t = \left(\sum_{s=1}^{S}\Phi_s - I\right)p_{t-1} + \sum_{l=1}^{S-1}\Gamma_l \Delta p_{t-l} + \mu + \varepsilon_t, \tag{1.9}$$

where $\Gamma_l = \sum\limits_{s=l+1}^{S}\Phi_s$, Δ is the first difference operator and p_t is a vector of N prices. The matrix $\Pi = \left(\sum\limits_{s=1}^{S}\Phi_s - I\right)$ represents the cointegration space. It is decomposed as the product of two $(N \times k)$ matrices where k is the number of cointegrated relationships between the N prices. The first matrix, β, represents the long run relationship(s) between the prices. The second one, α, represents the adjustments coefficients to these relationships. The Johansen and Juselius (1992) cointegration test estimates the rank of the matrix $\Pi = \left(\sum_{s=1}^{S} \Phi_s - I \right) = \alpha\beta'$ to determine the number k, (for $0 \leq k \leq N-1$) of cointegrating vectors. This test takes two possible forms and are based on likelihood ratio tests. The first one is called the trace test and considers the following hypotheses:

$$H_0(k): \ rank(\Pi) = k \text{ vs. } H_1(k): \ rank(\Pi) > k.$$

The second one is called the maximum Eigenvalue test and considers that

$$H_0(k): \ rank(\Pi) = k \text{ vs. } H_1(k): \ rank(\Pi) = k+1.$$

For a discussion of these two tests and refinements see Lütkepohl *et al.* (2001) or Hubrich *et al.* (2001). As an illustration, the Hasbrouck model is written as

$$\binom{p_L}{p_F} = \begin{pmatrix} 1 & 0 \\ 1 & 0 \end{pmatrix} \binom{p_{L,t-1}}{p_{F,t-1}} + \begin{pmatrix} \varepsilon_{L,t} \\ \varepsilon_{F,t} \end{pmatrix},$$

with a VECM representation as

$$\Delta \binom{p_L}{p_F} = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \begin{pmatrix} 1 & -1 \end{pmatrix} \binom{p_{L,t-1}}{p_{F,t-1}} + \begin{pmatrix} \varepsilon_{L,t} \\ \varepsilon_{F,t} \end{pmatrix},$$

so that $\alpha = \begin{pmatrix} 0 & 1 \end{pmatrix}'$ and $\beta = \begin{pmatrix} 1 & -1 \end{pmatrix}'$. This representation shows there is no adjustment to the long run relationship for the leader market. In contrast, the follower completely adjusts to the leader market. Formally, $\Pi = \begin{pmatrix} 0 & 0 \\ 1 & -1 \end{pmatrix}$ so that $rank(\Pi) = 1$ i.e. there is only one cointegrated relationship.

Multivariate cointegration is notably used for price comovements between more than two markets. For example, Kasa (1992) finds only one cointegration relationships between the major stock exchanges concluding a low level of interdependence between markets. Richard (1995) criticized these results arguing that the sample size used by Kasa is too small[2]. Chou et al. (1994) also find poor evidence of cointegration between G7 countries stock markets indicating weak convergences. This has been confirmed by many other authors for several countries (see Hung and Cheung (1995), Bachman et al. (1996), Kanas (1998), Manning (2002), Cotter (2004)).

In a more dynamic way, recursive or dynamic cointegration as initiated by Hansen and Johansen (1992) or Gregory and Hansen (1996) has also been applied : see Rangvid (2001) for European asset markets, Rangvid et al. (2002) or Aggarwal et al. (2005), testing the convergence of currencies in the European exchange rate mechanism (ERM). These last approaches are more general since they include breaks and potential regime shifts in the cointegration test[3].

However, we should keep in mind that using cointegration consists in an analysis of commonality that is different from causality. To pursue in this framework, the analysis of leader and follower behaviors between markets has been done via the analysis of the adjustment coefficients in the matrix α. This is notably the cornerstone of the price discovery statistics.

1.2.2.4 Price discovery measures based on cointegration

A direct approach to gauge price discovery is to compare adjustment coefficients in the estimated VECM. The price series with the smallest adjustment coefficient is supposed to be the one where there is almost no adjustment to equilibrium, and thus where price discovery occurs. We focus here on two related statistics: the Gonzalo and Granger statistics [GG] or Hasbrouck (1995) information share [IS]. Coming back to the VECM in equation (1.9) for the two returns $\binom{\Delta p_{i,t}}{\Delta p_{j,t}}$ the GG measures

[2] Kasa (1992) uses end of month stock index data for US, Japan, Canada, Germany and UK between 1974 and 1990.

[3] For a survey of these technics based on non linear multivariate cointegration see Dufrénot and Mignon (2002).

are defined as:

$$GG_i = \frac{\alpha_j}{\alpha_j - \alpha_i},$$

and

$$GG_j = \frac{\alpha_i}{\alpha_i - \alpha_j},$$

where $\alpha = (\alpha_i \ \alpha_j)$. As an illustration, going back to the situation where there is one leader and one follower market, it is clear that $GG_L = 1$ and $GG_F = 0$. However, some links may transit via the residuals and appear in the volatility. Hasbrouck (1995) proposes to also considering the volatility of the residuals in the VECM.

Let consider $H = (\sigma_{ij})_{i,j=1\ldots N}$ the variance covariance matrix of the residuals of the VECM. The information share of price i (or market i) is defined as

$$IS_i = \frac{([\alpha_\perp F]_i)^2}{\alpha_\perp H \alpha_\perp},$$

where $FF' = H$, and $\alpha\alpha_\perp = 0$. F is obtained via the Cholesky factorization of H. In the case of the VECM in equation (1.9) for the two returns $\binom{\Delta p_{i,t}}{\Delta p_{j,t}}$, it is obtained that

$$IS_i = \frac{\left(\alpha_j \sigma_i - \alpha_i \frac{\sigma_{ij}}{\sigma_i}\right)^2}{\alpha_j^2 \sigma_i^2 - 2\alpha_i \alpha_j \sigma_{ij} + \alpha_i^2 \sigma_j^2},$$

and

$$IS_j = \frac{\alpha_i^2 \left(\sigma_j^2 - \left(\frac{\sigma_{ij}}{\sigma_i}\right)^2\right)}{\alpha_j^2 \sigma_i^2 - 2\alpha_i \alpha_j \sigma_{ij} + \alpha_i^2 \sigma_j^2}.$$

Considering the Hasbrouck (1995) model of a leader and a follower so that $\binom{\Delta p_{i,t}}{\Delta p_{j,t}} = \binom{\Delta p_{L,t}}{\Delta p_{F,t}}$ and $\alpha = (0 \ \alpha_j)'$, it is clear that $IS_F = 0$, and $IS_L = 1$. An alternative example is that each market i

and j contributes for example equally so that $\alpha = (0.5\ -0.5)'$ and the error are uncorrelated. In this case, the respective IS measure are $IS_i = \frac{\sigma_i^2}{\sigma_i^2+\sigma_j^2}$ and $IS_j = \frac{\sigma_j^2}{\sigma_i^2+\sigma_j^2}$, the respective contribution of each price to the global variance.

However, the main drawback of this measure is to rely on a Cholesky decomposition of the variance that depends on the ordering of the variables in the VECM. Moreover, as we know, the variances on market are not constant especially when considering weekly or daily data.

To summarize, the results obtained from cointegration analyses are heterogeneous for several reasons. First, the relationships are mainly not stable. Indeed, the sample period is not neutral since many structural changes occurred since the 80s in the financial sphere followed by a succession of crises since 1997. Second, these changes occur on various horizons: on the short term, many shocks may be some simple arbitrages or spillovers while on the long term, the market structure of exchanges, the regulation, the investing entities, and the nature of market participants evolve. Finally, volatilities are ignored while they are key in financial markets and their modelization is important to understand market dynamics.

The following section focuses on the methodology of comovements belonging to the class of models that focus on the variance-covariance matrices. These approaches are particularly designed for shorter horizons.

1.3 The short term perspective : the multivariate heteroskedastic based approach

One key factor that is considered on the short-term is heteroskedasticity so that comovements analyses, in this strand, rely on variance, covariance and correlation dynamics. Indeed, cointegration analysis controls for relationships between prices and their own lags but ignore the second moment of prices. However, the model may additionally exert correlation between the residuals with some kind of "instantaneous" comovements between prices. As an illustration, back to Hasbrouck model the returns are defined as:

$$r_{L,t} = \varepsilon_{L,t} \quad (1.10)$$

$$r_{F,t} = \varepsilon_{L,t} + \nu_{F,t}, \quad (1.11)$$

so that returns share a common shock $\varepsilon_{L,t}$, the shock affecting the price on the leader market and transmitted to the follower market. Moreover, returns on the follower market do exhibit serial negative autocorrelation since $\nu_{F,t} = \varepsilon_{F,t} - \varepsilon_{F,t-1}$. This instantaneous commonality often occurs on shorter horizons with some unmodelled factors that appear in the residuals and create this commonality.

Multivariate heteroskedastic models raise several challenges compared to some univariate counterparts. First their specifications are critical since the positiveness conditions of variance covariance matrices may be sometimes difficult to obtain. Second, their estimations may imply very large portfolio and induce some improvements in estimation algorithms and methods due to the size of the obtained variance covariance matrices. Behind these challenges, the resulting outputs as dynamic correlations, covariances and variances incorporate a very large number of potential factors on the short-term.

A first generation of empirical papers is provided by Hamao et al. (1990), Harvey (1991) or Bae and Karolyi (1995) that use combinations of univariate GARCH models to assess transmission. Then, Koutmos and Booth (1995) used the multivariate specification of GARCH models with asymmetries to gauge comovements as in Karolyi (1995) and Booth et al. (1997). These techniques linked to the time varying variances, covariances and correlations have many extensions and applications as in Bekaert and Harvey (1995), Kim et al. (1999), or Fratzscher (2001). Correlation analyses have also been used in the related literature focused on contagion (see Karolyi (2003) or Dungey et al. (2005) for surveys). These techniques have also been crossed with the previous cointegration approach as in Aggarwal et al. (2002) or in the second chapter of the present thesis. We propose in this section a survey of the most used parametric multivariate heteroskedastic models for comovement analysis.

1.3.1 Multivariate GARCH models

In the class of multivariate heteroskedastic models, it is assumed that stochastic processes r_t of elements $r_{i,t}$ for $i = 1$ to N is defined as:

$$r_t \mid \Im_{t-1} \backsim \mathcal{L}(0, H_t),$$

with $\mathcal{L}$ a probability distribution function with zero mean, variance covariance-matrix H_t and $\Im_{t-1}$ the information set at date $t-1$. In the univariate case the popular GARCH(1,1) on returns of market i is defined as

$$r_{i,t} = \sqrt{h_{i,t}} u_t, \tag{1.12}$$

where u_t follows a standard Gaussian distribution and

$$h_{i,t} = \omega_i + a_i r_{i,t-1}^2 + b_i h_{i,t-1}.$$

The generalization to the multivariate case is straightforward. Let consider H_t the variance covariance matrix of returns $r_{i,t}$ for $i = 1$ to N. Equation (1.12) becomes:

$$r_t = \sqrt{H_t} u_t \ . \tag{1.13}$$

Several specifications of H_t have been proposed.

1.3.1.1 The VEC model

The vector multivariate GARCH model is a first specification that stacks the columns of the variance-covariance matrix into a vector. Let consider

$$h_t = vec(H_t),$$

so that for two assets we have

$$\begin{pmatrix} h_{11,t} \\ h_{12,t} \\ h_{22,t} \end{pmatrix} = \begin{pmatrix} \omega_{11} \\ \omega_{12} \\ \omega_{22} \end{pmatrix} + \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} \varepsilon^2_{1,t-1} \\ \varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ \varepsilon^2_{2,t-1} \end{pmatrix} + \begin{pmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{pmatrix} \begin{pmatrix} h_{11,t-1} \\ h_{12,t-1} \\ h_{22,t-1} \end{pmatrix}. \tag{1.14}$$

This specification is the most general specification of the variance-covariance matrix with $\frac{N(N+1)}{2} + 2\left[\frac{N(N+1)}{2}\right]^2$ parameters. To circumvent this problem a diagonal vec-GARCH model specification has been proposed with diagonal matrix parameters so that the number of parameters decreases to $\frac{3N(N+1)}{2}$. It is however very difficult to estimate since there is no control for the positiveness of the resulting variance covariance matrix.

1.3.1.2 BEKK-GARCH specification

To overcome partially this problem, Engle and Kroner (1995) propose the BEKK specification. It comes directly from the extension of GARCH process introduced by Engle (1982) and Bollerslev

(1986) with H_t specified as

$$H_t = W'W + A^{'} r_{t-1} r_{t-1}^{\prime} A + B^{'} H_{t-1} B. \tag{1.15}$$

where $W = (w_{ij})_{i=1...N,j=1...N}$ is a triangular matrix of constant terms, $A = (a_{i,j})_{i=1...N,j=1...N}$ and $B = (b_{i,j})_{i=1...N,j=1...N}$ are $(N \times N)$ positive definite parameter matrices .

In this formulation the number of parameters is large $(\frac{N(N+1)}{2} + 2N^2)$ so that we are rapidly constraint on the number of prices to be considered. In this direction, it has been introduced the diagonal BEKK specification where W is still a triangular matrix, but $A = (a_{ij})_{i=1...N,j=1...N}$ and $B = (b_{ij})_{i=1...N,j=1...N}$ are now diagonal. Moreover, to ensure the positiveness of the matrix and reduce, once more, the number of parameters, it is common to use the following specification

$$H_t = (1 - A'A - B'B)\bar{H} + A' r_{t-1} r_{t-1}^{\prime} A + B' H_{t-1} B. \tag{1.16}$$

with $\bar{H}$ the unconditional variance-covariance matrix. In this case the number of parameters is only $2N$. Variances and covariances are:

$$h_{ij,t} = (1 - a_{ii} a_{jj} - b_{ii} b_{jj})\bar{h}_{ij} + a_{ii} a_{jj} r_{i,t-1} r_{j,t-1} + b_{ii} b_{jj} h_{ij,t-1}, \tag{1.17}$$

and correlations is:

$$\rho_{DBEKK_t}(ij) = \frac{h_{ij,t}}{\sqrt{h_{ii,t} h_{jj,t}}}.$$

This model is estimated by maximum likelihood derived from the distribution of the returns. It is generally used a multivariate Gaussian distribution for simplicity even if this assumption may be discussed. In this case, the likelihood for the set of parameters Ω conditional on the information set $\Im_t$ (the history of past returns) is given by

$$L(\Omega; \Im_T) = \prod_{t=1}^{T} \frac{1}{(2\pi)^{N/2} \det(H_t)^{1/2}} \exp\left[-\frac{1}{2} r_t' H_t^{-1} r_t\right] \tag{1.18}$$

To summarize there is a clear trade off between the precision of the estimation (by increasing the number of parameters) and its feasibility.

1.3.2 Correlation models

To manipulate portfolio of high dimension without being constraint on the number of parameters as it is previously, some models propose to consider directly the correlations instead of the covariances. The first version is a constant correlation model as in Bollerslev (1990) [CCC-GARCH].

This model considers H_t so that:

$$H_t = D_t R D_t, \tag{1.19}$$

where $R = \left(\rho_{ij}\right)_{i=1...N, j=1...N}$ is the constant correlation matrix, and $D_t = diag\left\{\sqrt{h_{11,t}}...\sqrt{h_{NN,t}}\right\}$ with $h_{ii,t}$ the volatility following a GARCH process:

$$h_{ii,t} = \omega_{ii} + a_{ii} r_{i,t-1}^2 + b_{ii} h_{ii,t-1}.$$

This model is not really interesting because the correlation is constant by definition in the model. However, this model is the basis of the two following dynamic correlation models.

1.3.2.1 Dynamic conditional correlations of Engle and Sheppard (2002)

Engle and Sheppard (2002) propose the correlation to be dynamic instead of constant as in the Bollerslev (1990) specification:

$$R_t = \left(\rho_{ij,t}\right)_{i=1...N,j=1...N}.$$

so that

$$R_t = D_t^{-1} H_t D_t^{-1}$$

with $u_t = D_t^{-1} r_t$ is assumed to be Gaussian and $E_t(u'_{t-1}u_{t-1}) = R_t$. Similar to the CCC-GARCH model of Bollerslev (1990), the variances $h_{ii,t}$ are specified as GARCH. The specification is achieved by considering that

$$R_t = Q_t^{*^{-1}} Q_t Q_t^{*^{-1}} \tag{1.20}$$

with

$$Q_t = (1 - a - b)\bar{Q} + a u_{t-1} u_{t-1}{}' + b Q_{t-1} \tag{1.21}$$

where

(i) u_t are the standardized returns $\frac{r_{i,t}}{\sqrt{h_{i,t}}}$;

(ii) the unconditional correlation $\bar{Q}$ is defined as $\bar{Q} = \frac{1}{T}\sum_{t=1}^{T} u_t u'_t$;

(iii) $Q_t^* = diag\{\sqrt{q_{ii,t}}, ...\sqrt{q_{NN,t}}\}$ where $q_{cc,t}$ are the diagonal elements of Q_t for $c = 1$ to N;

(iv) the stationary condition is that $a + b < 1$ and $a, b > 0$.

The introduction of Q_t^* is a necessary normalization to guarantee that R_t is a correlation matrix with ones on the diagonal.

This model is popular in addressing correlation issues due to its flexibility and its simple estimation process. The main drawback of the model is to consider as scalar parameters a and b since the dynamic of the entire matrix is only determined by these two parameters. This limitation, however, allows for considering very high portfolio dimension with a fixed number of parameters.

On the one hand, this flexibility of the model allows for the integration of jumps, breaks, Markov switching specification and others. On the other hand, the explanatory power of the model is decreasing with the number of prices to be considered.

To estimate this model a two step estimation procedure is applied. The log likelihood l is written similarly to equation (1.18) as:

$$l(\Omega; \Im_t) = -\frac{N}{2}\ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T}(\ln(|H_t|) + r_t' H_t^{-1} r_t). \tag{1.22}$$

In a first step the likelihood is maximized by replacing the correlation matrix by the Identity matrix, which is equivalent to estimating GARCH specifications on the variances. Then, the full likelihood is estimated by using the variances estimated from the first step.

The dynamic of the correlation in the DCC model is quite rigid since the number of parameters is independent of the number of assets, so that all the correlations present the same dynamics:

$$\rho_{DCC_t}(ij) = \frac{1}{\sqrt{q_{ii,t}q_{jj,t}}}\left[(1-a-b)\bar{q}_{ij} + a u_{i,t-1}u_{j,t-1} + b q_{ij,t-1}\right]$$

This is one of the main difference with the general BEKK or the diagonal BEKK. One advantage is that these two parameters a and b are independent of the volatility process which is not the case in the previous models.

1.3.2.2 Alternative dynamic conditional correlation models

In parallel, Tse and Tsui (2002) has introduced a DCC specification which presents the dynamics directly on the correlation matrix R_t without any normalization as it is done in the previous version. The correlation is still

$$R_t = D_t^{-1} H_t D_t^{-1} \tag{1.23}$$

with

$$R_t = (1 - a - b)\bar{R} + a\Psi_{t-1} + bR_{t-1},$$

where $\Psi_t = \left(\psi_{ij,t}\right)_{i=1...N,j=1...N}$ so that

$$\psi_{ij,t} = \psi_{ji,t} = \frac{\sum_{s=1}^{S}\left(u_{i,t-s}u_{j,t-s}\right)}{\sqrt{\sum_{s=1}^{S}\left(u_{i,t-s}^2\right)\sum_{s=1}^{S}\left(u_{j,t-s}^2\right)}},$$

where $u_{i,t}$ and $u_{j,t}$ are the standardized returns so that $\psi_{ij,t}$ is a correlation over a window of S days. In this case there is no normalization since it is the correlation between the residuals that appears in the dynamic, and not the residual itself. This specification is very close to the DCC of Engle and Sheppard (2002). In this case, the positiveness condition is that $S > N$ and the stationary condition that $a + b < 1$ with $a, b > 0$.

Some other specifications of dynamic conditional correlations are of interest in this strand of literature. Hafner and Franses (2003) introduce vector parameters γ_1 and γ_2 instead of scalars a and b such as:

$$H_t = (1 - \bar{\gamma}_1 - \bar{\gamma}_2)\bar{H} + \gamma_1\gamma_1' * r_{t-1}r_{t-1}' + \gamma_2\gamma_2' H_{t-1}, \tag{1.24}$$

with $*$ is the Hadamar product and $\bar{\gamma}_1$ and $\bar{\gamma}_2$ are the means of vector elements γ_1 and γ_2. This adds flexibility to the model, but with a number of parameter to be estimated of $2N$. This model is actually similar to a diagonal BEKK model with some restrictions.

To capture asymmetries in the correlation process, Engle Capiello and Sheppard (2006) propose an asymmetric DCC by adding an indicator function for negative returns in the dynamics similar to Glosten et al. (1993) for GARCH models. Billio et al. (2004) have also proposed to modelize the correlation using block diagonal matrices (Block Diagonal DCC model) or with partitioned vectors (Flexible-DCC) or partitioned diagonal matrices (Quadratic Flexible DCC).

1.3.2.3 State dependencies in DCC models

It is essential to consider state dependencies in comovement models. Indeed, the alternation of crises (or high volatility periods) with calm periods imply non linearity in the volatility process. This may directly impact the correlation process. Some approaches consider pre-determined periods to estimate a model during crisis, and non crisis period. However, since it is necessary to ex ante determine the crisis period, the results may depend on this ad-hoc segmentation of the sample. Another approach is to consider some hidden Markov switching processes so that the alternation of crises and calm periods is directly determined in the estimation of the model without any a priori on the dates.

This state dependency originates from the model of Tong and Lim (1980) which considers a threshold on one variable of interest so that the model jumps from one dynamic to another one (Threshold Autoregressive model or TAR). Some refinements to this model are, for example, the self-exciting TAR model [SETAR] or smooth transition AR model of Teräsvirta (1994).

In this strand, Silvennoinen and Teräsvirta (2005 & 2007) introduce the Smooth Transition Dynamic Conditional Correlation model [STDCC]. In this model, the correlation is supposed to move from one constant correlation state to another constant correlation state via a transition function driven by some variables. This is halfway between a CCC-GARCH and a DCC-GARCH since there are two levels of constant correlation linked by a transition function.

A more flexible approach is to consider a Markov switching approach for the correlation, so that the state of the correlation is an hidden process which results in a mixture of densities. This state dependency is, for example, considered in the Markov switching DCC model of Billio and Caporin (2005) or in Pelletier (2006). Coming back to the previous DCC of Engle and Sheppard (2002), it is assumed that the coefficients of the dynamic are state dependant so that the correlation may have different patterns between the crisis and non crisis periods. Following Billio et al. (2005) the MS-DCC is expressed as:

$$Q_t(s_t = n \mid s_{t-1} = m) = (1 - a_{s_t} - b_{s_t})\bar{Q}_{s_t} + a_{s_t} u_{t-1} u_{t-1}{}' + b_{s_t} Q_{t-1}(s_{t-1} = m). \quad (1.25)$$

This specification allows to switch from one correlation model to another one, and indeed, the model considers the alternation of high and low correlation periods. The estimation of this process follows Kim (1994) using maximum likelihood. Markov switching in an autoregressive model may be difficult since it implies an infinite number of states due to the recursive equation (the presence of Q_{t-1} in the equation). This is encompassed in the model by considering an expectation of Q_{t-1} over the possible states.

These models of Markov switching correlations are at the frontier with the literature on contagion. The jumps from one state to another and the persistency of the several states may help understanding the nature of comovements during crises. In contrast, the STCC model is related to the analysis of a structural change in the level of correlation (since the model moves, more or less smoothly from one CCC-GARCH at the beginning of the sample to another one at the end of the sample). The Markov switching DCC is different in spirit since the alternation of regimes are numerous and that all the regimes (unobserved) finally coexist all together at any date.

Another model of regime dependent correlation is the one by Calvet et al. (2006). This model is based on the assumptions that many shocks occurs at many unpredetermined frequencies. Moreover, these frequencies define cycles with different lengths that correspond to market volatility states. These aggregation of cycles, short and long lasting, refines the idea of comovements on several horizons since their lengths are not imposed directly by the frequency of the data that are used in empirical applications. Results in this strand are yet relatively scarce and will be developed in chapters 3 and 4 of the present thesis.

The coexistence of cycles shows the importance of considering several horizons in models. The extreme case of analysis is to consider intraday transaction data. It opens a wide range of empirical approaches to analyze comovements with the use of realized volatility models. Moreover, this opens a new research dimension with the analysis of liquidity comovements.

1.4 The intraday horizon: realized volatility based models

Transaction data represent the extreme dimension on which we can consider comovements. One main direction consists in implementing volatility and covolatility indicators to analyze comovements: use of realized volatility and covolatility. Indeed, the previous approaches concern parametric volatility, i.e. that depends on a model and a set of previous information such as past volatilities, past returns, etc. This class of model is strongly linked to their benchmark model and their sensitivity to the model may have an impact on the robustness of the results. The class of realized volatility measures[4] is based on the traditional sample standard deviation. Indeed, the availability and quality of high-frequency data encourage practitioners and researchers to return to some nonparametric indicators (i.e. without dependence on the underlying model). These measures were used in financial econometrics for some time, but considered on a methodological point of view in early 2000. Merton (1980) is the first one to propose realized volatility by calculating monthly volatility based on the monthly sum of daily square returns. This approach is similar to that used to construct the daily volatility and correlation from high frequency data. We first return to the definition of realized volatility before exposing their use in the literature on comovements.

[4] This part is a revised and adapted version of Avouyi-Dovi and Idier (2008), Realized Volatility and High frequency data: what contribution to financial market analysis?, mimeo.

Finally, transaction data can be considered to derive daily liquidity indicators. Indeed, the availability of bid-ask spreads, volumes, order flows may help specifying liquidity comovements. This opens the analysis of comovements and should refine the notion of commonality between markets.

1.4.1 Realized volatility definition

Several parametric estimation approaches to assess the volatility process can be found in the literature (conditional heteroskedastic models, stochastic volatility models, factor models). The main drawback of these methods is that volatility measurements depend on the underlying model. Furthermore, market analysts and decision-makers usually set up volatility measures in a non parametric manner. The most common "model-free" measure is the historical volatility spanning a given number of days. This measure clearly lacks in accuracy. This section builds a bridge between a standard stochastic volatility model and the realized variance. Especially, in this extreme dimension of comovements, indicators rely on a continuous definition of the returns.

Let p_t be the log price as a continuous time diffusion process on a frictionless market such that the return is:

$$r(t) = dp_t = \mu(t)dt + \sigma(t)dW(t), \tag{1.26}$$

where $W(t)$ is a Brownian motion process, $\mu(t)$ is a drift component and $\sigma(t)$ the instantaneous volatility: positive and square integrable. In this setting, the returns are defined as:

$$r(t) = \int_{t-1}^{t} \mu(\nu)d\nu + \int_{t-1}^{t} \sigma(\nu)dW(\nu) \tag{1.27}$$

so that returns are conditionally Gaussian on $\Theta(t)$ the historical price process:

$$r(t) \mid_{\Theta(t)} \sim N\left(\int_{t-1}^{t} \mu(\nu)d\nu, QV(t)\right) \tag{1.28}$$

where $QV(t) = \int_{t-1}^{t} \sigma^2(\nu)d\nu$ is the quadratic variation in the class of continuous stochastic volatility semi martingales (see Barndorff-Nielsen and Shephard (2002)). The quadratic variation, which corresponds, under certain conditions, with the integrated variance, is in fact the limit sum of Riemann of the squared returns over infinitesimal intervals.

Let us consider the partition into M sub-intervals indexed by m of a trading day t such that $\Psi = \{t_0 = 0,\ t_1, t_2, ...t_M = 1\}$. p_{t_0} represents the opening price on day t and p_{t_M} the closing price at t_M. For example, for an 8-hour trading day, with sub-intervals of 15 minutes, we have $M = 32$. In this setting, the quadratic variation for day t is:

$$QV(t) = p\lim_{M\to\infty} \sum_{m=1}^{M} \left[p_{t_m} - p_{t_{m-1}}\right]^2, \tag{1.29}$$

and its estimator, the realized volatility is defined as:

$$RV(t, M) = \sum_{m=1}^{M} r_{t_m}^2, \tag{1.30}$$

where r_{t_m} is the return associated with the subinterval m. This is a convergent estimator of the quadratic variation (equation (1.29)) for the class of semimartingales when M tends to infinity (see Andersen et al. (1999) and Barndorff-Nielsen and Shephard (2002), Andersen and Benzoni (2008)).

$$RV(t, M) \to QV(t) \text{ as } M \to \infty. \tag{1.31}$$

Schwert (1990) also uses this definition to measure daily volatility using 15-minutes interval returns aiming at analyzing the 1987 crash. However, problems with this estimator (equation (1.30)) stem from the presence of microstructure noises or jumps in the price process.

The microstructure noise stems from the frictions observed on the market when high frequency data are considered. For example, transactions are not continuous on the market; there exists a bid-ask spread so that at least two prices are available; the size of this spread depends on the size of the tick; market liquidity influences the price discovery process. All these noises make the true price process unobservable and estimators of volatility have to deal with this set of noises to get unbiased estimates of the integrated variance. A log-price subject to microstructure noise is defined as:

$$p_{t_m} = p^*_{t_m} + u_{t_m} \tag{1.32}$$

where p_{t_m} is the observed price, $p^*_{t_m}$ the latent price process and u_{t_m} the microstructure noise. In this case, $RV(t, M)$ (as in equation (1.30)) is not a converging estimator of the integrated variance. The return corresponding to p_{t_m} for any $m = 1$ to M is defined as:

$$r_{t_m} = r^*_{t_m} + \varepsilon_{t_m}$$

with

$$\varepsilon_{t_m} = u_{t_m} - u_{t_{m-1}}$$

so that returns exhibit negative autocorrelation (see Roll (1984), Hasbrouck (1995), Zhou (1996), Bandi and Russel (2005)). Note that this autocorrelation mainly comes from the microstructure noise, the latent process being a martingale. The estimator of the integrated variance, $RV(t, M)$, becomes:

$$\begin{aligned} RV(t,M) &= \sum_{m=1}^{M} r_{t_m}^2 \\ &= \sum_{m=1}^{M} r_{t_m}^{*2} + \sum_{m=1}^{M} \varepsilon_{t_m}^2 + 2\sum_{m=1}^{M} \varepsilon_{t_m}.r_{t_m}^{*} \end{aligned}$$

Due to the non-observance of the latent price process, the quantity of interest $\sum_{m=1}^{M} r_{t_m}^{*2}$ cannot be computed directly. Moreover, the term $\sum_{m=1}^{M} \varepsilon_{t_m}^2$ tends to infinity when the number of sub-intervals increases, since squared errors are cumulated over the number of intra-period returns. Then, the realized volatility as defined in equation (1.30) diverges when M tends to infinity.

Two avenues are possible to disentangle the price from the microstructure noise: first, using the raw data frequency available is not optimal and leads to diverging estimators. As a result, one can consider ways of determining the optimal frequency that limits the impact of the microstructure noise; a second option is to modify the estimator by improving its convergence properties. Taking into account these two methodologies, it is possible to improve the convergence capability of the realized volatility estimator.

Avouyi-Dovi and Idier (2008) propose a comparison of some of the most popular realized volatility estimators, in terms of forecast accuracy. This papers shows that the bipower variation of Barndorff-Nielsen and Shephard (2003) is the easiest and most stable estimator of the volatility.

1.4.2 Realized volatility based models

To gauge comovements, many papers have proposed the use of volatility model transmission or the multivariate extension of realized volatility estimators. As documented in Andersen et al. (2003) and Ait-Sahalia and Mancini (2007), the log realized volatility is assumed to be Gaussian and stationary so that it can be derived from an $AR(p)$ process as:

$$\log(h_{i,t}) = \mu + \sum_{p=1}^{P} \phi_p \log(h_{i,t-p}) + \epsilon_t, \tag{1.33}$$

where $h_{i,t} = \sqrt{(RV_i(t, M) \times 252)} \times 100$ is the daily annualized volatility; ϵ_t is white noise and μ is an intercept. This expression assumes that the $\log(h_{i,t})$ stationary hypothesis is not rejected.

On the basis of this model, it is possible to include in equation (1.33) a set of explanatory variables. A direct extension used as in Dimpfl and Jung (2007) among other is to consider a $VAR(S)$ model of different market volatilities. In the case of two markets we have:

$$\begin{aligned} \begin{pmatrix} \log(h_i) \\ \log(h_j) \end{pmatrix}_t &= \begin{pmatrix} \mu_i \\ \mu_j \end{pmatrix} + \begin{pmatrix} \phi_{1,ii} & \phi_{1,ij} \\ \phi_{1,ji} & \phi_{1,jj} \end{pmatrix} \begin{pmatrix} \log(h_i) \\ \log(h_j) \end{pmatrix}_{t-1} + \ldots \\ &+ \begin{pmatrix} \phi_{S,ii} & \phi_{S,ij} \\ \phi_{S,ji} & \phi_{S,jj} \end{pmatrix} \begin{pmatrix} \log(h_i) \\ \log(h_j) \end{pmatrix}_{t-S} + \begin{pmatrix} \varepsilon_i \\ \varepsilon_j \end{pmatrix}_t . \end{aligned} \tag{1.34}$$

This is a direct extension of the log volatility model of Andersen et al. (2003). On this basis, Granger causality may be applied to study the impulse response functions to gauge the timing of volatility transmission between markets. However, this approach neglects the covariances of the processes, so that it is more accurate to directly consider a realized variance covariance matrix and create a dynamic on this global matrix. This last approach is close to the multivariate GARCH approach, but in this case for observable datasets of variance covariance matrices.

1.4.3 Realized co-volatility based models

Realized variance covariance matrices are a direct extension of the realized variance. Following Barndorff-Nielsen and Shephard (2004), the realized covariance matrix is given by:

$$RC(t, M) = \sum_{m=1}^{M} r_{t_m} r'_{t_m}. \tag{1.35}$$

where r_{t_m} is a vector of N returns. As in the univariate case, for the class of continuous semi martingales, Barndorff-Nielsen and Shephard (2004) has derived the asymptotic distribution of the realized covariance matrix. All the above problems encountered in the univariate framework are expended to the multivariate case: the presence of the microstructure noise (see Lunde and Voev (2007)) or the positive definiteness of the estimated matrix. Moreover, some additional problems occur in this framework. One main problem is the non synchronicity in trades, and this occurs at two levels. The first level is the fact that at date t_m it is not obvious that the two returns exist. Second, for example in the case of assets from the United States on one side, and from Europe on the other side, market data daily overlap only during two or three hours. In this case it is not possible to calculate a complete variance covariance matrix for the day. This is the reason why, variance covariance matrices are usually used for asset traded on the same market, or at least on two synchronous markets.

In the univariate case, Avouyi-Dovi and Idier (2008) show that the bipower variations from Barndorff-Nielsen and Shephard (2003) appears to be the most efficient estimator on the basis of forecasts. For this reason we focus here on the extension of this work for multiple assets.

In particular, the bipower co-variation matrix $\{\mathrm{BP}_t; q\}$for N asset prices is defined as:

$$\{BP_t;q\} = \begin{pmatrix} \{BP_t^1;BP_t^1;q\} & \{BP_t^1;BP_t^2;q\} & ... & \{BP_t^1;BP_t^N;q\} \\ \{BP_t^2;BP_t^1;q\} & \{BP_t^2;BP_t^2;q\} & ... & \{BP_t^2;BP_t^N;q\} \\ ... & & & \\ \{BP_t^N;BP_t^1;q\} & & & \{BP_t^N;BP_t^N;q\} \end{pmatrix}$$

with

$$\{BP_t^i;BP_t^j;q\} = \frac{M}{4(M-q)} \sum_{m=q+1}^{M} [\left|r_{t_m}^i + r_{t_m}^j\right| \left|r_{t_{m-q}}^i + r_{t_{m-q}}^j\right| - \left|r_{t_m}^i - r_{t_m}^j\right| \left|r_{t_{m-q}}^i - r_{t_{m-q}}^j\right|]. \quad (1.36)$$

This measure was introduced by Barndorff-Nielsen and Shephard (2004) and Barndorff-Nielsen and Shephard (2005) demonstrated that it is resistant to jumps similarly to the univariate case. Note that the condition $i = j$ induces that the above equation (1.36) is similar to the univariate bipower variations.

These measures have the main drawback to not being positive definite. This is one of the main difficulty for constructing some dynamics of these matrices. Some methods have been proposed to encompass this problem. Bauer and Vorkink (2007) consider dynamics on the exponential transformation of this matrix to ensure its positiveness instead of directly working on the matrix. Another approach is introduced by Chiriac and Voev (2008) and modelizes the elements of the Cholesky factorization of the realized covariance matrix.

From this modelization, it is then easy to extract the realized correlation and analyze comovements on the same basis than the multivariate GARCH models for example.

Beyond this use of high frequency data, many other research directions are of interest. Indeed, high frequency data for some of the databases may include other transaction variables so that comovements may be gauged not only on the price dynamics, but also in terms of liquidity.

1.4.4 High frequency data and comovements: one step further

To investigate comovements, high frequency data open a range of some new indicators other than prices and returns. This is directly linked to the literature on microstructure that analyzes the dynamics of indicators such as spreads, order flows, volumes, market depth etc. Notably, the analysis of market liquidity comovements should complete analyses focused on price dynamics. The last period of market turbulences in 2007 and 2008 has shown the major implications of market liquidity in the crisis transmission mechanisms. Some markets where no transactions occurred where only monitored through some market liquidity indicators. Moreover, in the process of asset pricing, market liquidity is now taken into account and directly impacts asset comovements via the "liquidity premium" incorporated in prices. This is analyzed in chapter 5 for the French bond market.

Some studies support the “commonality” in the market liquidity of assets in the U.S. (Chordia, Roll, and Subrahmanyam (2000), Hasbrouck and Seppi (2001), Huberman and Halka (2001), Coughenour and Saad (2004)). One important issue, after the 2007-2008 crisis is clearly the cross border linkages in liquidity for several markets (Karolyi et al. (2008) and Huang and Wang (2008)). The debate that wonders if international diversification is possible or not following the market integration process of the last 30 years may be transposed to market liquidity risk. Is there any possibility to ensure to investors good market liquidity conditions? The benefits of market integration in these terms are not clear for liquidity. Some investment flights on markets, the dynamics in different countries of liquidity premia and the transmission of liquidity risk needs some investigations. In this strand, a first step will be to define liquidity on a market and then to robustly transpose or create models for the transmission mechanisms (Domowitz et al. (2001)). This will be further analyzed in this thesis.

1.5 Conclusion

The literature on comovements is very large and the same applies to the techniques associated with a large scope of applications. It is interesting to note that the three current methods of analysis, even if they capture the so-called comovements are significantly different for several reasons.

First, the cointegration approach is based on the first moment of the prices while multivariate heteroskedastic models and realized volatility are based on the second moment of the price. In addition, methods associated with the cointegration focus on return and price comovements, while heteroskedastic models consider volatility comovements. This dichotomy is present in financial econometrics.

Then cointegration approaches try to capture what is called a long-term relationship between prices, while the discrimination between short and long term is not included in the multivariate heteroskedastic models or realized co-volatility. There is no question about a long-term trend since in the heteroskedastic models, the martingale is generally assumed to be verified so that practitioners focus on the second moment of prices.

Finally, a problem can be raised for the three classes of methods: the frequency of the data used. Due to the acceleration of information in the process of price discovery, comovements are usually evaluated on daily frequency or even intra daily frequencies. But, as pointed out in the case of cointegration for empirical results, a comovement relationship may differ because of the frequency of data used (daily, weekly or monthly). In general, the persistence of shock in multivariate GARCH models depends (as for cointegration) on the frequency of the database.

All these remarks opened a field for future research in two directions. First, research must try to combine the different approaches above to discuss comovements both on the first and second moments. Second, the models may try to limit the impact of the frequency of data considered given the frequency, nature and duration of shocks on comovement measures. Finally, some other indicators related to market liquidity should be considered. In the current turmoil with the widespread shortage of liquidity, prices analyses should be completed by some other indicators. That should motivate research on comovements beyond price comovements.

Chapter 2

Fundamental comovements and excess comovements *via* cointegration and dynamic correlation models

Non-technical summary[1]:

This chapter presents a study of short and long term asset linkages from 1996 to 2008 at daily frequency. We examine four stock exchanges: Euronext, New York Stock Exchange (NYSE), London Stock Exchange (LSE) and Deutsche Börse and their respective indexes (CAC, NYSE, FTSE, DAX). Several dimensions for comovements are essential to consider. For example, the consolidation of exchanges leads to progressive changes and structural comovements while successive crises in the financial sphere since 1997 involve a shorter-term dimension of comovements. We therefore have structural factors associated with progressive modifications of financial integration on the one hand and comovements on the short term, on the other hand.

To address this issue, we consider cointegration techniques coupled with a multivariate autoregressive conditional heteroskedastic model (MGARCH) to take into account the long-term interdependence between indices, the correction of any gap to this long term equilibrium and the unexplained linkages between the residuals.

From a theoretical microstructure point of view, the model of Hasbrouck (1995) is generalized into a vector error correction mechanism (VECM) that we complete with a BEKK-GARCH model on the residuals (Baba-Engle-Kraft-Kroner in Engle and Kroner (1995)). This approach is convenient to analyze the dynamics of correlations obtained from the estimated variance-covariance matrix.

In the long term, a cointegration relationship is validated. We obtain that the NYSE, FTSE and CAC are oriented in the same direction and this is not the case for the DAX. We explain this discrepancy by a potential composition effect in the index since the weight of financial sector is lower for the DAX than for other indexes.

Major events took place between 1996 and 2008: the Asian crisis, the Russian crisis, the implementation of the euro,the Y2K, the Internet bubble in 2000, the terrorist attacks of 09.11, the

[1] This is a revised and adapted version of Idier, 2006, "Stock exchanges industry consolidation and shock transmission", WP Banque de France 159. I would like to thank Gaëlle Le Fol, Sanvi Avouyi-Dovi, Olivier Darné and Jean-Michel Zakoian for helpful comments.

accounting scandals in the U.S., Iraq war II, and the subprime crisis. The following analysis of these events is based on volatilities and correlations.

Indeed, correlations may respond in a heterogeneous way to these shocks. If the relationship has a positive impact, there is an excess of comovements on the market. When the shock on the correlations is negative, the shocks are considered more local. This occurrence of local shocks may come, however, from two things: it is local because the shock only affects one place, or the impact is negative because the response of the markets to a common shock is not synchronous.

The results show that one of the main examples of excess comovements is the Asian crisis on a global scale while the effects, for example, of the Internet bubble is not synchronous between markets and more spread over time. The terrorist attack is another example of non-synchronous absorption since the U.S. market was closed during these days while the European market remained open, so that correlations fell around these dates.

However, when a negative shock is observed on the correlation, it is usually very resilient and overall correlations are upward oriented. This advocates in favour of transitional shocks, even more inside the Euro zone.

2.1 Introduction

Financial market liberalization has been one of the main mechanisms at work in the economic world for the last twenty years. Financial markets (stocks, bonds, currencies) are all the more linked that investors (institutional or not) are used to trade-off between financial products from different countries. The wide range of financial products allows for diversification and substitution, in other words, international portfolio management. This practice leads to faster and more significant expected transmission phenomena between exchanges. Moreover, financial globalization has many consequences in exchanges rules homogenization (through competition between exchanges), and the way portfolio management finally (in the extreme case) leads to a global market where diversification is meaningless, since all shocks are instantaneously and commonly transmitted to every place.

Transmission has to be considered on several levels. Transmission may be considered through fundamental links between countries (or products). However, transmission may also be understood as excess transmission with contagion or excess comovements (see Dungey et al. (2005)) and this is observed during financial crisis episode. These periods of uncertainty generate additional transmission phenomena compared to the prevailing fundamental links.

These interactions between exchanges are all the more interesting when it concerns a country or a monetary union. The recent consolidation of the European stock exchanges through NYSE-Euronext, Deutsche Börse and the London Stock Exchange leads to the idea that only one stock exchange may survive in Europe in a close future. These concentration dynamics raise the issue of capital allocation through stock markets in a monetary union and the necessity of tools for the regulator to gauge transmission between markets. Stock markets integration is a major issue since it leads to trade-offs between stock markets and is obviously of interest for the euro area policy makers in a sense that attractiveness of stock markets can create asymmetric effects in economic cycles and may weaken countries where stock markets are less attractive. Several quantitative methods have been developed, in parallel or conjointly for analyzing these phenomena.

Kasa (1992) uses cointegration to analyze this process and finds only one common stochastic trend between US, Japanese, Canadian, British and German markets. This suggests weak market integration and justify market portfolio diversification. Kanas (1998) considers the European equity markets one-by-one coupled with the US market and find no evidence of integration. To analyze the regional consolidation process in the United States, Harris et al. (1995 & 2002) use the standard cointegration approach. They first show interactions between American regional stock exchanges and the NYSE, AMEX or NASDAQ. They shed light on the influence of these three main exchanges on IBM prices in the regional places. However, they also tackle with information feedback between regional stock exchanges first, and from the regional ones to the biggest places then. Via cointegration, Hasbrouck (1995) uses the information sharing approach to analyze interactions between stock exchanges and detect leadership behaviors of the US national exchanges on the US regional ones.

Stock index comovements suppose that exchanges do not have the same "leader or benchmark power" in a monetary union. For example, Biais and Martinez (2004) focus their analysis on interactions between Euronext and Frankfurt stock exchange. They show how Frankfurt is a leading place in Europe, and in what extend the CAC40 follows the DAX. Nonetheless, the DAX leadership is still puzzling since Frankfurt and Euronext are of comparable size and traded asset performances. Kearney and Potì (2005) analyze the dynamics of correlations between European equity indexes and find evidence for a structural break at the beginning of the monetary integration process. Earlier paper by Danthine, Giavazzi and von Thadden (2000) review the first possible consequences of the monetary union on financial market integration: a single currency in Europe is expected to improve liquidity and depth on the market since foreign investors are not exposed to currency risk anymore. Hardouvelis et al. (2004) show how equity markets in the euro area, during the second half of the nineteens, tend to converge to a full degree of integration. Longin and

Solnik (1995) assert the higher the degree of international integration, the higher the correlation. Disentangling fundamental links and excess comovements, Forbes and Rigobon (2002) define contagion as transitory while interdependence as a durable state. They show how correlation results are biased due to heteroskedasticity in the data as higher volatility induces higher correlations during periods of trouble.

We contribute understanding the concentration process in the stock exchange industry in Europe. The aim of the chapter is to gauge the level of the different kinds of transmission (fundamental links and excess comovements). Moreover, since the implementation of the euro, we can suppose some resistance of European markets, with less currency risk inside Europe and less heterogeneity in economic cycles. European places may loose their tendency to be systematically impacted by the "American shocks".

Cointegration techniques focuses on conditional means and ignore correlations between places. In order to analyze in a dichotomous way interdependence and shock transmission, we consider a standard Vector Error Correction Mechanism (VECM), extended by a multivariate General AutoRegressive Conditional Heteroskedastic model (GARCH) on the residuals (Engle (1982), Bollerslev (1986), Bollerslev (1990), Engle and Kroner (1995)). We consider, on the one hand, a long term dynamic on the conditional mean as interdependence. On the other hand, we consider shock transmission through the unexplained part of the model (the residuals) and analyze it through MVGARCH dynamic correlations.

The cointegration approach follows the standard empirical microstructure model of Harris et al. (1995) or Hasbrouck (1995). The MGARCH extensions of the model are derived from the Baba-Engle-Kraft-Kroner model (as BEKK) derived in Engle and Kroner (1995). This model is applied for the French (CAC40), German (DAX30), UK (FTSE100), and US (NYSE) indexes between 1996 and 2008.

Section 2-2 provides preliminary analysis and the theoretical econometric background to empirically analyze interdependence and shock transmission between stock exchanges. Section 2-3 presents the data and preliminary analyses. Section 2-4 provides empirical results and interpretations. Finally, section 2-5 concludes.

2.2 The Model

2.2.1 A VECM approach

Cointegration tests have been widely used to analyze comovements and long term relationship between price dynamics. Cointegration and Error Correction models (ECM) have been introduced by Engle and Granger (1987) and cointegration tests by Johansen and Juselius (1992). Cointegration is used, notably by Chou et al. (1994) and Kasa (1992) or Kanas (1998). Bhattacharyya and Banerjee (2004) estimate a standard VECM on the main European, American and Asian indexes, showing how the American index is never influenced by other indexes. Davies (2006) exploits the idea that the level of integration between markets is evolving and considers a regime switching cointegration approach. From a microstructure point of view, Harris et al. (1995 & 2002) and Hasbrouck (1995) consider stock market integration through cointegration as well, as shown in chapter 1 (page 70).

We consider the following VECM for S lag as

$$\Delta p_t = \Pi p_{t-1} + \sum_{l=1}^{S} \Gamma_l \Delta p_{t-l} + \mu + \varepsilon_t, \tag{2.1}$$

where Δ is the first difference operator, p_t the logarithm of the price at date t. The Johansen and Juselius (1992) cointegration test estimates the rank of the matrix Π decomposed in $\alpha\beta'$ to determine the number k of cointegrated vectors. α is a $(N \times k)$ adjustment coefficient matrix and β a $(N \times k)$ long run coefficients matrix. Long run coefficients indicate the long run behaviors of indexes while the adjustment coefficients indicate how strong is the adjustment to this long run behavior. Each stock index (price) is more or less influenced by the others, and this is understood as interdependence between places.

In contrast with these long run relationships between prices, many shocks more or less common between prices occur and are not captured by the VECM. To analyze the commonality of these shocks between prices the previous VECM model is extended by a multivariate GARCH process on the residuals.

2.2.2 Multivariate volatility models

We couple the two frameworks together (VECM and MGARCH) to take into account short and long term comovements between prices. Precisely, some commonality, usually referred as integration or interdependence has to be disentangle from the excess short run comovements that practitioners usually observe on the market during periods of trouble. This dichotomy is capital since literature often refers to an increase of comovements during crises. However, this must be gauged conditionally on the usual links (fundamental or long run links) between prices.

It is considered that the residuals of the VECM follow an heteroskedastic process through a multivariate GARCH process :

$$\varepsilon_t = \sqrt{H_t} u_t \ , \tag{2.2}$$

with H_t the $(N \times N)$ variance-covariance matrix and u_t a vector of standard Gaussian residuals.

The multivariate GARCH model may take several forms as exposed in chapter 1. The further empirical application is on a reasonable number of prices, so that it is considered a less constraint form of multivariate GARCH model which is the diagonal Baba- Engle- Kraft- Kroner (BEKK) representation of multivariate GARCH from Engle and Kroner (1995). The variance covariance matrix of the VECM residuals is defined as:

$$H_t = D_t R_t D_t \ , \tag{2.3}$$

such that

$$D_t = diag\left\{\sqrt{h_{ii,t}}\right\} \ , \tag{2.4}$$

where $h_{ii,t}$ represents elements of the diagonal of H_t and R_t is a $(N \times N)$ correlation matrix with ones on the diagonal so that:

$$H_t = (\bar{H} - B'\bar{H}B - A'\bar{H}A) + B'\varepsilon_{t-1}\varepsilon'_{t-1}B + A'D'_{t-1}R_{t-1}D_{t-1}A. \tag{2.5}$$

with coefficient matrices A and B are $(N \times N)$ diagonal and $\bar{H}$ is the $(N \times N)$ unconditional covariance matrix. The variance covariance matrix is positive definite since $(\bar{H} - B'\bar{H}B - A'\bar{H}A) > 0$. The dynamics of the correlations from the BEKK model are obtained from:

$$R_t = D_t^{-1}H_tD_t^{-1} \ . \tag{2.6}$$

The set of parameter θ to be estimated in this framework is twice the number of considered prices. This model is estimated by maximizing the log likelihood l written as:

$$l(\theta; \Delta p_1 ... \Delta p_T) = -\frac{N}{2}\ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T}(\ln(|H_t|) + r'_tH_t^{-1}r_t). \tag{2.7}$$

The MGARCH extension on the VECM residuals permits to analyzing the unexpected shock transmission in a dichotomous way from the analysis of interdependence in the conditional mean. We make the hypothesis that correlations may have a particular pattern (negative for example) even if interdependence is greater for the last years. In fact, stronger market integration should not mean that all shocks are transmitted or have the same effects between places.

2.3 Empirical analysis

2.3.1 Market data

We use daily market data for the NYSE, the CAC, the DAX and the FTSE indexes between January the 2^{nd} 1996 and July the 1^{st} 2008, from Thomson-Reuters. Because of non synchronous openings, we take indexes at 3 p.m. Due to national celebrations, Christmas days, eastern holidays or special events, some markets are closed while others are opened. Thus, we consider on these days, index returns are null for the closed markets.

The FTSE index assesses if belonging to the euro area is a necessary condition to be a leading place in Europe, or have a high degree of dependency with other indexes. We also expect, inside the euro area (i.e. between CAC and DAX) a high degree of comovements. Finally, the NYSE index may be a highly influencing index for the European ones. The question is whether several exchanges can really survive the integration process of the stock exchange due to the increasing competition of the last years.

Table 2-1 provides some summary statistics of these indexes:

	CAC	**DAX**	**FTSE**	**NYSE**
Mean	0.028	0.034	0.013	0.032
Median	0.072	0.118	0.060	0.080
Min	-10.5	-10.06	-9.10	-8.3
Max	9.27	7.65	7.62	6.58
Standard deviation	1.396	1.536	1.125	1.045
Skewness	-0.277	-0.446	-0.248	-0.191
Kurtosis	7.351	7.398	7.485	7.828
Jarque-Berra	2373.64	2485.79	2513.14	2894.17

Table 2-1: *Descriptive statistics for index returns in percentage, January the 2^{nd} 1996 - July the 1^{st} 2008*

We can see from Table 2-1 that daily index returns are positive in mean but vary in a wide range, approximately from -10bp to 10bp. The medians reveal that more than 50% of the daily returns for all indexes are positive. The skewness associated with each of the returns are negative, which means that returns have long left tails. In other words, negative shocks are predominant. Finally, the daily returns distribution is leptokurtotic (kurtosis greater than 3) which can be attributed to some infrequent extreme events. This is confirmed by the Jarque Bera test which indicates that returns do not follow a Gaussian distribution. This is a common feature of financial data due to the presence of heavy tails for example. Table 2-2 provides sample correlations:

	CAC	**DAX**	**FTSE**	**NYSE**
CAC	1			
DAX	0.906	1		
FTSE	0.846	0.821	1	
NYSE	0.786	0.773	0.785	1

Table 2-2: Sample correlations between returns, January the 2^{nd} 1996 - July the 1^{st} 2008

First, correlations are all positive. Correlations between European places are stronger than correlations of European markets with the NYSE. The highest is obtained between the DAX and the CAC. Then, the correlations FTSE-CAC and FTSE-DAX are quite similar around 0.80. Finally, sample correlations with the NYSE are slightly greater than 0.75 and similar for each European place.

Table 2-3 presents a Principal Component Analysis (PCA). We obtain that 86% of the variance in returns is explained by the first component. Together, the two first main components explain more than 90% of the index returns variance confirming narrow linkages between markets.

	1^{st} Comp	**2^{nd} Comp**	**3^{rd} Comp**	**4^{th}Comp**
Eigenvalue	3.46	0.26	0.18	0.09
Variance Prop.	0.865	0.065	0.046	0.022
Cum Variance Prop	0.865	0.930	0.977	1

Table 2-3: Principal Component Analysis on the covariance matrix of returns, 02/01/96 - 01/07/08

Stock exchange industry consolidation and market integration have accelerated these last years, and encourage markets to move closely. Figure 2-1 compares correlations in 1996 and correlations in 2007. The largest increase is obtained for the CAC-NYSE and CAC-FTSE correlations which rose by 40% to reach 0.9. It is followed by the DAX-NYSE correlation which rose by 35% to reach 0.84. DAX-FTSE correlation jumps by 24%. Finally, CAC-DAX increased by 20% to attain 0.90.

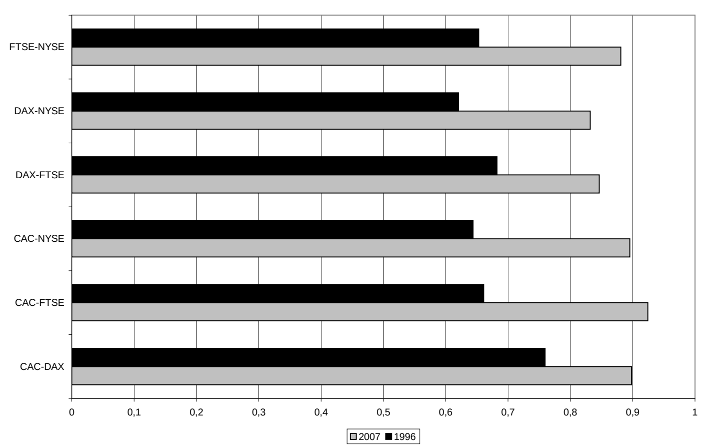


Figure 2-1: Correlation comparisons, 1996 vs. 2007

An interesting feature is that the sample CAC-FTSE correlation in 2007 is higher than the CAC-DAX correlation even if France and Germany share the same currency. This may be due to the end of the sample when the subprime crisis has occurred and an index composition effect.

As a matter of fact, stock exchange integration does not only take place between European places. The euro area creation has had an effect on European places. However, some other forces play a role in the integration of stock exchanges as seen before and have globally accelerated in the world.

2.3.2 Stationary hypothesis tests

Stationarity tests are performed on log index prices and geometric returns. Non-stationarity in financial data is well documented in the literature (Granger and Starica (2004) for example). We use the Augmented Dickey-Fuller (ADF) test and the Kwiatkowsky- Phillips- Schmidt- Shin Test (KPSS). The ADF test accepts or rejects the null hypothesis of "unit root" while the KPSS considers that stationarity is the null hypothesis. Note that the rejection of the null hypothesis by the ADF test does not mean the variable does not have a unit root, but that the information contained in the variables is not enough to conclude in favour of a unit root. Thus we decide to associate to this test the KPSS test.

ADF Test	**CAC**	**DAX**	**FTSE**	**NYSE**
log(p)	-2.41	-2.11	-2.24	-2.04
Δlog(p)	-52.98*	-53.77*	-54.54*	-54.38*
critical value	-2.86	-2.86	-2.86	-2.86

Table 2-4: ADF test statistics for log prices and returns, January the 2^{nd} 1996 - July the 1^{st} 2008

The logarithms of index prices are all I(1). The returns are thus stationary with a test statistic smaller than the critical value. Table 2-5 displays the KPSS test statistics.

KPSS Test	**CAC**	**DAX**	**FTSE**	**NYSE**
log(p)	2.19	1.61	0.98	4.94
Δlog(p)	0.36*	0.22*	0.17*	0.16*
critical value	0.463	0.463	0.463	0.463

Table 2-5: KPSS test statistics for log prices and returns, January the 2^{nd} 1996 - July the 1^{st} 2008

KPSS test confirms that series are all I(1)[2].

2.3.3 Cointegration and long-run relation

Johansen-Juselius procedure (as JJ) tests the rank of the matrix $\Pi = \left(\sum_{s=1}^{S} \Phi_s - I\right)$ in equation (2.1). The JJ test indicates that we cannot reject one cointegrated vector at the 5% level (see appendix 2-A). The estimated coefficients of the long run relation are reported in table 2-6. The global results of the VECM are presented in appendix 2-B.

Variables	**Coefficient**	**std. error**
NYSE	0.12	0.066
FTSE	1	-
DAX	-0.645	0.096
CAC	0.011	0.0056
R^2	0.91	-

Table 2-6: Long run coefficients β from January the 2^{nd} 1996 - July the 1^{st} 2008

[2] Additionnal not reported tests with alternative specifications (trend, constant) are available upon request.

The parameters indicate some heterogeneity in price evolutions with the NYSE, FTSE and CAC on one side and the DAX on the other side. This would indicate some arbitrages on the long run. However, one counter-argument to this relationship is that there exist an index composition effect for which we do not control. The industry specializations at the national level are heterogeneous so that during particular events some indexes may be more impacted in some countries than others.

In the literature, Gill et al. (2005) estimate from 1990 to 2004 a non-cointegrated VAR model on daily index returns and find significant price spillovers between Paris and New-York, with a much more significant effects for the transmission from Paris to New-York. Moreover, they find that inside Europe, Paris is the most influencing place that is contradictory with Biais and Martinez (2004) who find a preponderance of Frankfurt in Europe between 1998 and 2001. However, Antoniou et al.(2003) suggests that leader-follower relationships change over the time.

The VECM in our framework has to be understood as a long run mean effect. It supposed that there is some "commonalities" through a long run relationship that catch the fundamental interactions between prices. Nevertheless, the transitory unexpected links between the markets are caught through the dynamic of the residuals. More than a dichotomy between long and short run transmissions, we prefer the distinction between the fundamental (or mean) transmission and the unexpected movements (the residuals of the model).

2.3.4 Dynamic correlations between places

To sketch the temporary excess links between equity markets, we analyze the dynamic conditional correlations estimated on the residuals of the VECM. The variance and covariance equations can be written as follows:

$$h_{ij,t} = (1 - b_i b_j - a_i a_j)\overline{h_{ij}} + b_i b_j \varepsilon_{i,t-1}\varepsilon_{j,t-1} + a_i a_j h_{ij,t-1}, \tag{2.8}$$

with a_i , b_i elements of the diagonal matrices A and B. ε_t are the residuals from the VECM. Dynamic correlations are then obtained by:

$$\rho_{ij,t} = \frac{h_{ij,t}}{\sqrt{h_{ii,t}h_{jj,t}}} \tag{2.9}$$

Table 2-7 gives the estimated diagonal matrices A and B [3].

variable(i)	$\mathbf{b}_i$	$\mathbf{a}_i$
CAC	0.1863 (0.000)	0.9815 (0.0005)
DAX	0.1987 (0.000)	0.9786 (0.0006)
FTSE	0.1988 (0.000)	0.9787 (0.0005)
NYSE	0.2085 (0.000)	0.9750 (0.0006)

Table 2-7: Estimated coefficients a and b from the diagonal BEKK model, January the 2^{nd} 1996 - July the 1^{st} 2008

Tables 2-8 provides the persistence of the variance-covariance process which equals $b_i b_j + a_i a_j$.

Persistence	**NYSE**	**DAX**	**CAC**	**FTSE**
NYSE	0.9980	0.9975	0.997	0.9958
DAX	0.9975	0.9972	0.9972	0.9955
CAC	0.9976	0.9972	0.9973	0.9956
FTSE	0.9958	0.9956	0.9956	0.9941

Table 2-8: Persistence for common positive shocks and diverging shocks ,January the 2^{nd} 1996 - July the 1^{st} 2008

[3] Explicit estimated equations for variances and covariances are reported in Appendix 2-C.

We find a high persistence of daily conditional variances and covariances. The persistence of daily volatility is a well known feature in the empirical literature. Kearney and Poti (2005) estimate as well a persistence close to one on European indexes. Similar estimations can be found in Engle and Sheppard (2002) or Avouyi-Dovi and Neto (2003). This set of estimated parameters permits to calculate the conditional volatility and dynamic correlations and are presented in figure 2-2[4].

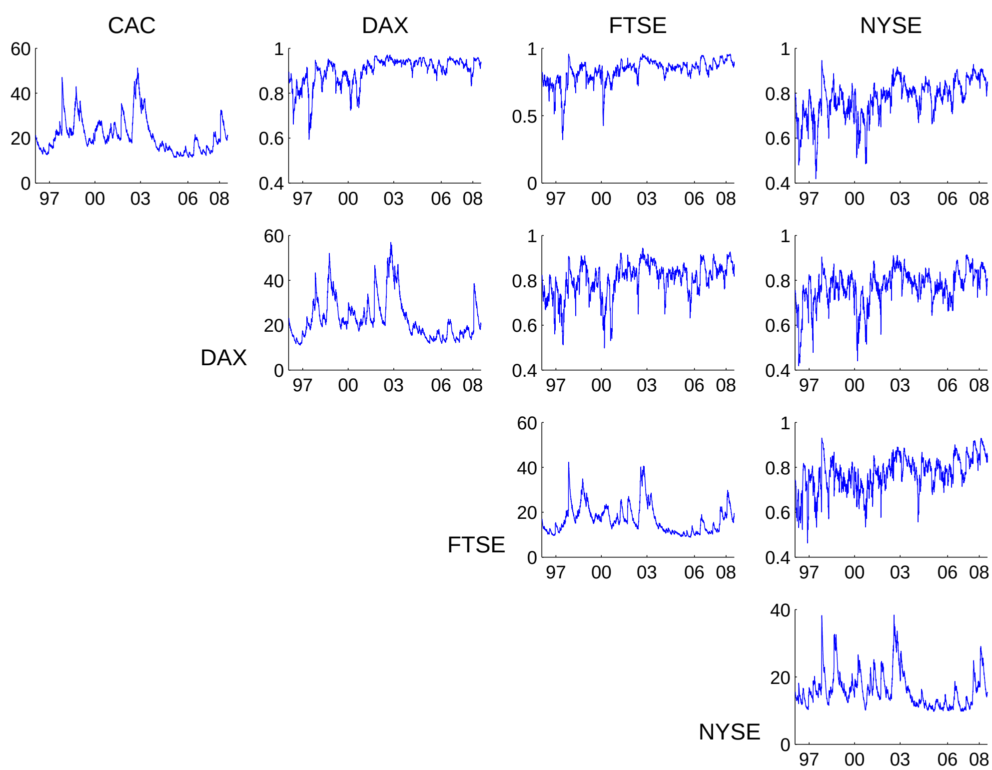


Figure 2-2: Correlations and volatilities from the BEKK model, 1996-2008

[4]They are additionnally reported in Appendix 2-D and 2-E.

These graphs are interesting to interpret since we obtain a day to day analysis of the events that induce higher market volatility, and some shocks on the correlations. A large part of the index movements are not captured by simply considering a VECM model on the conditional mean. These graphs confirmed the hypothesis that market interdependence is one thing but the unexpected risk transmission is another. The two following sections discuss the identifiable shocks observed in the volatility and correlation processes.

2.4 Turbulences analysis

During periods of trouble, or crisis (high volatility), the effects on correlation is potentially quite heterogeneous. The different nature of events, in a context of consolidation process, may induce higher correlations due to stronger interdependence. However, correlations may eventually be negatively impacted if the shocks have diverging effects or not perfectly synchronous. All these effects are linked to potential spillovers or arbitrages during high volatility episodes.

2.4.1 High volatility episodes

According to the diagonal in Figure 2-2, the DAX and CAC are the most volatile indexes followed by the FTSE and the NYSE. We observe four or five common peaks in volatility.

The first peak starts at the end of October 1997 on all indices and lasts until January 1998. This period corresponds to the Asian crisis, with a peak of volatility around the 29/10/97 and 30/10/97.

The second period of turbulences is identified in late 1998 and early 1999. In fact, there are tensions on all markets from the end of September 1998. This period of disorder is more resilient for the U.S. It continues until February 1999 for non-US indexes. Several events played a role during this period: the implementation of the euro zone, the Russian crisis, the volatility of the United States and the uncertainty about the risks associated with some emerging markets.

A third period of turmoil in 2000 comes in two stages. First, we see a spike in volatility during the first days of 2000, potentially linked to the possibility of the Y2K bug, mainly in France and Germany between 04/01/00 and 10/01/00. In a second step, the turbulence is reactivated from the end of February until March. On February the 20^{th}, the CAC has a sharp increase in volatility, and then in other markets around March the 15^{th}. This seems to be a consequence of the bursting of the IT bubble.

A new volatile period is observed in September 2001, specifically on the 18. This is directly related to the re-opening of U.S. markets after the attacks of 09/11 and the monetary policy decisions following this event.

Another period of turmoil, actually the longest, occurs between the end of July 2002 and April 2003. This last period began around 25 July 2002, which is adjacent to two events. First, there is a sharp increase in suspicions about the invasion of Iraq (Tony Blair saying that possibility in front of the British Parliament). Secondly, there was a period of sharp decline in stock indexes that have very low levels because of accounting scandals in the United States. A new peak in volatility occurred on October the 16^{th}. This follows a speech by President Bush about his intentions against Iraq on October 11, and the adoption of the resolution by the Senate on October the 15^{th}. A final peak in this period occurred in March 2003 with the actual start of the Iraq war, and finally, peak volatility on March 18, 19 and 20 with the entry of U.S. troops in Iraq.

The last period of high volatility in the sample is observed in early 2008. Volatility in all places has gradually raised during 2007 due to the subprime crisis. It reached a peak in late January 2008 with a significant reduction of indices following downgrading decisions of rating agencies, the Société Générale case, the rate cuts following it, rising uncertainty and incipient lack of confidence which will then be confirmed.

To summarize, all these shocks involve different impacts between markets. Some events are clearly global (Asian crisis), while others are more local. To examine this question of comovements, the following section discusses the dynamics of correlations between stock market indices.

2.4.2 Impact on dynamic correlations

When the dynamic correlation is impacted, it may take the form of an increase in the case of a common shock or a fall, if the shock is divergent or non-simultaneous. Accordingly, the impacts on the correlations are not so obvious and depend on the nature of shocks.

The consequences of the Asian crisis are clearly seen in the dynamic correlation between European markets and the U.S. market that has surged between October 28 and November 4 in 1997 to exceed 0.9. This event was global, and has initiated stronger comovements among the markets.

The second event, which may be associated with the implementation of the European currency, the Russian crisis and uncertainty in emerging markets, produced a period of high volatility, longer for the French and German places. However, there is no effect on the correlations in early 1999 and therefore no excessive comovements.

In the case of the Y2K bug, if the volatility has increased during the first days of 2000, it produces only a slight decrease in correlations. However, the bubble burst in March 2000 was observed with the first effects on the CAC-FTSE correlation from the end of February. Then, during the first days of March, the DAX-NYSE and CAC- NYSE correlations have been hit (the correlation dropped to 0.45). However, this drop was temporary and only underlines a transitional resistance.

The terrorist attacks of 09/11 are also observed in the process of correlation with the New York Stock Exchange. Indeed, on September 19, the week after the closure of U.S. markets, the correlations are reduced mainly with the DAX and FTSE. We do not get such an impact on the relationship between the European places. The period of closure of the U.S. market resulted in a non-synchronous absorption of the shock between the equity markets since the European markets have remained open (e.g. Charles and Darné (2006)). Accordingly, 09-11 appears to be a "spurious" shock caused by local institutional intervention.

Finally, the period 2007-2008 is characterized by gradual increasing trend in correlations (except those with the DAX until the end of 2007). However, the already high level of correlation between places, limits the analysis of positive shocks that took place during this period.

From a global point of view, since the end of 1998, the correlations between the CAC and the DAX have converged to 1, and in a weaker form, the same thing is remarkable for the FTSE-DAX and CAC-FTSE. Monetary union would result in an increase in the transmission of shocks between the French and German indexes due to the destruction of currency risk and the convergence of economies. In the United States, we are also witnessing a growing trend, but weaker, in correlations.

It is clear that the Asian crisis is a starting point for increasing comovements between stock markets. But the transmission is not perfect, there are still heterogeneities in the transmission process. However, when there is a negative impact on correlation, it should be noted that the duration of the shock is very short lasting.

2.5 Conclusion

The consolidation of Stock Exchange is at work and drive a significant part of the literature to analyze the dynamics of the links between exchanges in the world. Indeed, integration is not only between the European markets following the currency union, but concerns the global exchanges. The recent alliance between the Nasdaq and the LSE, or between the NYSE and Euronext makes interesting to note the linkages between these places of negotiations. This chapter looks at two levels of transmission.

First, the actual transmission on the long-term as a first moment effect: said a fundamental link. The use of multivariate cointegration techniques allow to analyze transmission patterns in line with the work of Harris et al. (1995) or Hasbrouck (1995).

Second, we analyze the transmission of residual shocks more or less common, in a more short-term perspective. The correlations are derived from the dynamic model of Engle and Kroner (1995) and highlight the events that affect markets: the Asian crisis, the birth of the Euro area in 2000, the attacks of 09/11, the war in Iraq and the subprime crisis.

It is clear that all shocks do not have the same effects on the correlations in periods of high volatility. In addition, some shocks involve a negative impact on the relationship, although they are very short lasting.

The latest events associated with the subprime crisis, occur especially when the correlation is already close to the unit so it is difficult to analyze the excess comovements. This highlights a limitation of the analysis of correlations (in this context) to assess the excess comovements and should initiate research to improve our vision of comovements. An example lies in the use of the realized estimators of variance-covariance, or in models using the fractal properties of assets return as follows in this thesis.

2.6 Appendix

Appendix 2-A Johansen and Juselius: maximum eigenvalue cointegration test

The null hypothesis of no cointegration relationship is rejected at the 5% confidence interval.

Hypothesis #cointegration relationships	Eigen value	max Eigen stat	0.05 crit. value	Prob
0	0.0096	28.55	27.58	0.0375**
1	0.0026	7.89	21.13	0.9100
2	0.0014	4.21	14.26	0.8362
3	0.0004	1.24	3.841	0.2636

Appendix 2-B VECM Estimations[5]:

$$\Delta \ln \begin{pmatrix} NYSE \\ DAX \\ CAC \\ FTSE \end{pmatrix}_t = \alpha\beta'. \ln \begin{pmatrix} NYSE \\ DAX \\ CAC \\ FTSE \end{pmatrix}_{t-1} + \sum_{s=2}^{S} \Phi_s \Delta. \ln \begin{pmatrix} NYSE \\ DAX \\ CAC \\ FTSE \end{pmatrix}_{t-s+1} + \mu + \epsilon_t$$

[5]VECM is performed on index returns (%) for the sample 02/01/1996 - 01/07/2008. Lag lenght is selected using the Akaike and Schwartz information criteria. The t-student are reported below the coefficients.

	$\Delta\ln$(**NYSE**)	$\Delta\ln$(**DAX**)	$\Delta\ln$(**CAC**)	$\Delta\ln$(**FTSE**)
$\Delta\ln$(**NYSE(-1)**)	−0.011 (−0.35)	0.029 (0.62)	−0.008 (−0.183)	0.012 (0.361)
$\Delta\ln$(**NYSE(-2)**)	−0.004 (−0.14)	0.041 (0.85)	0.031 (0.71)	0.054 (1.54)
$\Delta\ln$(**NYSE(-3)**)	0.007 (0.21)	0.049 (1.03)	0.016 (0.37)	0.031 (0.89)
$\Delta\ln$(**NYSE(-4)**)	**−0.082** (−2.54)	**−0.15** (−3.14)	**−0.11** (−2.66)	**−0.104** (−2.98)
$\Delta\ln$(**DAX(-1)**)	−0.015 (−0.49)	0.015 (0.32)	−0.009 (−0.23)	**−0.055** (−1.65)
$\Delta\ln$(**DAX(-2)**)	0.001 (−0.024)	−0.052 (−1.15)	−0.044 (−1.058)	**−0.055** (−1.64)
$\Delta\ln$(**DAX(-3)**)	−0.047 (−1.53)	−0.06 (−1.41)	−0.044 (−1.06)	−0.044 (−1.34)
$\Delta\ln$(**DAX(-4)**)	−0.003 (−0.12)	0.0035 (0.076)	−0.017 (−0.43)	0.013 (−0.405)
$\Delta\ln$(**CAC(-1)**)	0.048 (1.32)	0.063 (1.16)	**0.122** (2.48)	**0.066** (1.66)
$\Delta\ln$(**CAC(-2)**)	0.054 (1.47)	0.077 (1.44)	0.047 (0.95)	**0.077** (1.96)
$\Delta\ln$(**CAC(-3)**)	0.038 (1.04)	0.011 (0.208)	−0.012 (−0.236)	0.051 (1.28)
$\Delta\ln$(**CAC(-4)**)	0.024 (0.66)	0.047 (0.885)	0.019 (0.399)	0.058 (1.49)
$\Delta\ln$(**FTSE(-1)**)	−0.044 (−1.24)	**−0.119** (−2.30)	**−0.131** (−2.79)	**−0.029** (−0.77)
$\Delta\ln$(**FTSE(-2)**)	**−0.092** (−2.60)	**−0.087** (−1.67)	**−0.083** (−1.75)	**−0.106** (−2.79)
$\Delta\ln$(**FTSE(-3)**)	0.014 (−0.39)	−0.004 (−0.087)	−0.016 (−0.34)	**−0.075** (−1.96)
$\Delta\ln$(**FTSE(-4)**)	0.055 (1.57)	**0.096** (1.86)	0.076 (1.61)	0.016 (0.416)
Intercept	**0.034** (1.78)	0.033 (1.18)	0.031 (1.19)	0.014 (0.689)
$\boldsymbol{\alpha}$	**−0.010** (−3.74)	**−0.015** (−3.72)	**−0.013** (−3.51)	**−0.0043** (1.48)
R^2	0.013	0.014	0.015	0.014

Appendix 2-C MGARCH Explicit estimate cross products[6]

variable(i)	$\mathbf{a}_i\mathbf{a}_{NYSE}$	$\mathbf{a}_i\mathbf{a}_{DAX}$	$\mathbf{a}_i\mathbf{a}_{CAC}$	$\mathbf{a}_i\mathbf{a}_{FTSE}$
CAC	0.0346	0.0370	0.0370	0.0388
DAX	0.0370	0.0394	0.0394	0.0414
FSTE	0.0370	0.0394	0.0394	0.0414
NYSE	0.0388	0.0414	0.0414	0.0435

variable(i)	$\mathbf{b}_i\mathbf{b}_{NYSE}$	$\mathbf{b}_i\mathbf{b}_{DAX}$	$\mathbf{b}_i\mathbf{b}_{CAC}$	$\mathbf{b}_i\mathbf{b}_{FTSE}$
CAC	0.9384	0.9406	0.9470	0.9377
DAX	0.9406	0.9429	0.9493	0.9400
FTSE	0.9470	0.9493	0.9557	0.9463
NYSE	0.9377	0.9400	0.9463	0.9369

[6] Estimated parameter matrices are obtained from the diagonal BEKK implemented on the VECM residuals estimated between January the 2^{nd} 1996 and July the 1^{st} 2008 (see table 2-7).

Appendix 2-D Volatilities[7]

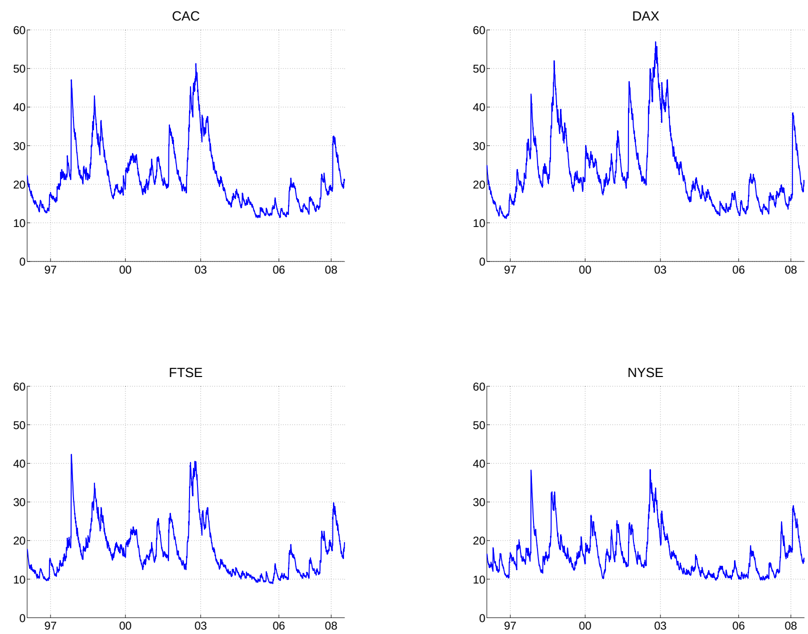


Figure 2-3: Annualized Volatilities from GARCH-BEKK model for the CAC, DAX, FTSE and NYSE indexes

[7]Volatilities are obtained from the diagonal BEKK model between January the 2^{nd} 1996 to July the 1^{st} 2008.

Appendix 2-E Dynamic correlations[8]

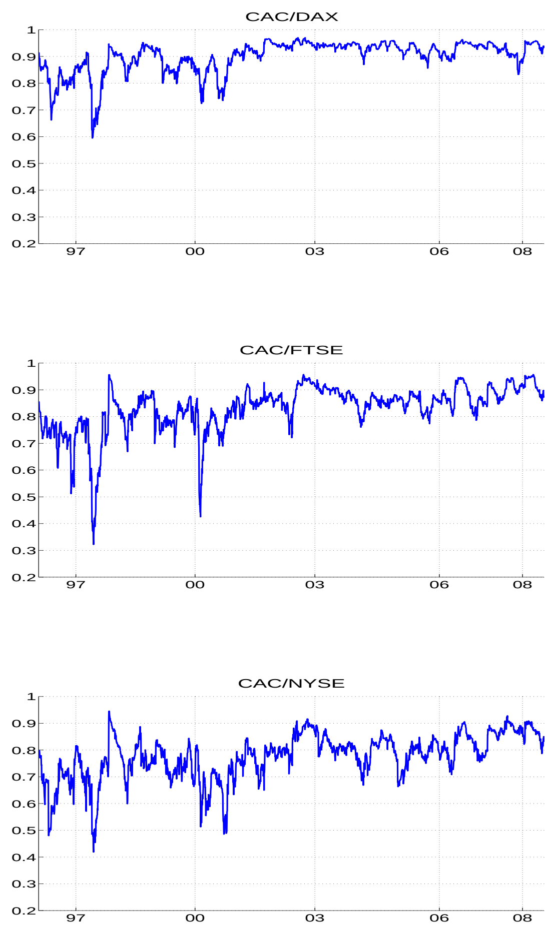


Figure 2-4: Dynamic correlations from GARCH-BEKK model for the CAC, DAX, FTSE and NYSE indexes

[8]Dynamic correlations are obtained from the diagonal BEKK model estimated on a daily basis between January the 2^{nd} 1996 and July the 1^{st} 2008.

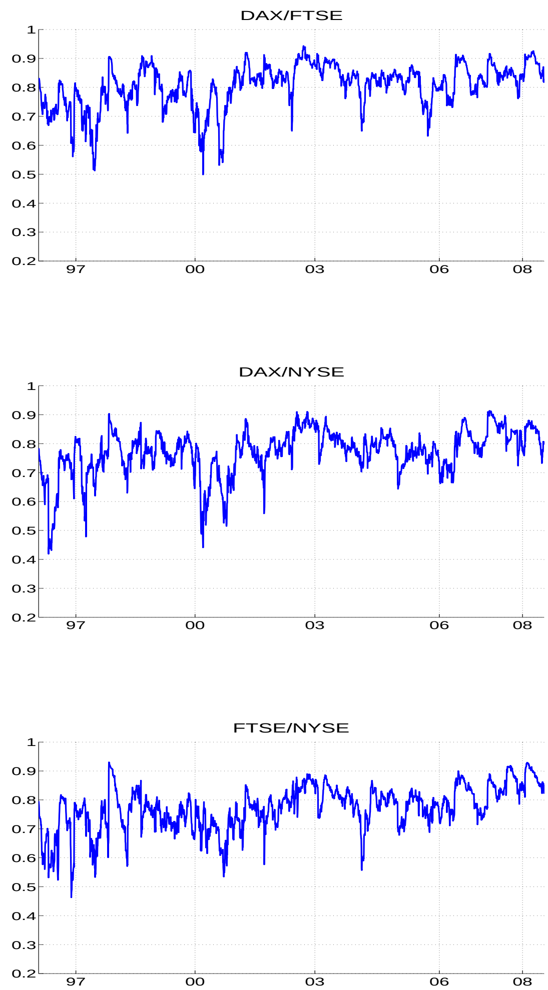


Figure 2-5: Dynamic correlations from GARCH-BEKK model for the CAC, DAX, FTSE and NYSE indexes

Chapter 3

Long term vs. short term comovements in stock markets : the use of Markov-switching multifractal models

Non Technical Summary[1]

The recent developments in financial markets have shown the need for market participants to have measures of risk. The strength of time-varying comovements between financial assets is one potential risk that should be addressed. The contribution of this chapter is to develop several new indicators for assessing the volatility and comovements between stock markets in both, the long and short terms. Several econometric techniques have already been developed such as cointegration, multivariate conditional volatility models or dynamic correlations as used in the previous chapter. Here, a new set of indicators is derived from the multifractal model of asset returns in a bivariate form initiated by Mandelbrot et al. (1997) and Calvet et al. (2006).

The use of fractal mathematics consider that dependencies can be assessed at different horizons. This idea stems from the diversity of investors and the diversity of information to which they react. For example, some investors react to the disclosure of accounting information or publication of national statistics, while some others react to a fall in a particular market or to some purchasing dynamics observed on a specific asset.

The MSM model (Markov switching multifractal model) clearly improves from this point of view the characterization of a superimposed structure of investment decisions and allows to disentangle the linkages between markets over several horizons with unpredetermined lengths.

This chapter presents empirical evidences for four indices between January 1996 and November 2008: the CAC, the FTSE, the DAX and the NYSE indexes. A structure of three superimposed cycles is estimated by the model. The NYSE appears to be the most resilient with a short-term cycle of 20 days, while the length of the cycle is around 40 days for European markets. The medium

[1] This is a revised version of the corresponding Banque de France working paper 218 (2008). This paper received the best paper award for a macro finance paper at the research in international economics and finance conference in 2008. I would like to thank Gaëlle Le Fol, Jean-Michel Zakoian, Nour Meddahi, Laurent Calvet, Mardi Dungey, Fulvio Pegoraro, Thierry Michel and Patrick Fève. I also thank participants of : the Royal Economic society conference 2008; the French Finance Association conference 2008; the North American summer meeting of the Econometric Society 2008.

term is around 120 days whatever the market and then, the long-term varies between 250 and 500 days. From these estimates, we draw a set of indicators of interest to quantify comovements.

The first indicator is the probability of crisis. It corresponds to the probability of being in the highest volatility states in the market for all volatility components. The second indicator is the probability of extreme comovements, defined as the probability of being in crisis for a market knowing that the other market is in crisis. Finally, the long-term cycles of volatility are derived and correspond to the most persistent component of volatility.

Major financial crises are detected by the model: the Asian crisis, the Russian crisis, March 2000, September 11, the accounting scandals in the U.S., the Second Iraq War and the crisis of 2008. Note that in 2007 the so-called subprime crisis is not considered as a crisis since the component of long-term volatility has remained low. However, in the short and medium term, components of volatility have migrated to a high state which has weakened the market and increased the threat of a crisis. This crisis is finally clear in September 2008.

The phenomena of extreme comovements have changed over the sample period and differ between markets. They are strong in the Euro zone between France and Germany and less pronounced, but still strong in Europe (i.e. between the UK and France or the UK and Germany). These extreme comovements with the United States appear stronger for the UK than for France or Germany. However, overall, extreme comovements with the United States appear more irregular and sudden when they occur.

Finally, we derive the probability for long term components of volatility to be in a high state. The Asian crisis is a key event in the sample which has generated, until the end of 2003, a long-term cycle of high volatility in all markets. However, the period from 2004 until the end of 2006 is remarkably characterized by a very low volatility in the long term. As mentioned previously, 2007 is a transition period with an increase in the short and medium term volatility components and 2008 finally opened a new round of high long term volatility across markets.

3.1 Introduction

This article proposes a new set of indicators to determine the degree of comovements and volatility spillovers between asset prices. From the bivariate Markov-Switching multifractal model of asset returns initiated by Calvet et al. (2006) are derived :

- the volatility cycles or periods;
- a crisis probability;
- a probability of extreme comovements;
- and probabilities of long term high (or low) volatility cycles.

In the literature, many authors conclude that globalization allows for diversification in non crisis period but this advantage disappears during crisis when it is the most needed (see Beine et al. (2008), for example). This assertion is certainly true for very short periods of time, however the heterogeneity in the resiliencies of markets can rapidly guarantee some portfolio diversification. The above mentioned indicators take into account this commonality or heterogeneity in cycle lengths that may guarantee diversification during crisis.

Several quantitative methods aim at measuring risk transmission and comovements. For example, many papers use cointegration analysis using Johansen (1992) tests to assess the degree of market integration (e.g. Kasa (1994), Chou et al. (1994), Kanas (1998), Manning (2002)). More recently, with the idea there exists several types of comovements between markets (as Forbes and Rigobon (2002) dichotomy between integration and contagion), Billio, Lo Duca and Pellizon (2005) in a Vector Error Correction Mechanism (VECM) framework introduce regimes to address switches in the integration or contagion process. In chapter 2, we use as well a VECM framework, and separate transmission between the first and second moments by expanding the model with a multivariate General Auto Regressive Conditional Heteroskedastic model [GARCH], building a bridge between cointegration analysis and the wide class of multivariate GARCH models.

The use of multivariate GARCH model has also been widely explored by researchers in assessing risk and volatility transmission (survey by Bauwens et al. (2006) or Engle and Sheppard (2007)). From the Baba-Engle-Kraft and Kroner (as BEKK) model to the Dynamic Conditional Correlation of Engle et Sheppard (2002) several improvements have been introduced in these models as asymmetries or structural breaks. Recently, Billio and Caporin (2005) have introduced a two state Markov switching DCC model. Some recent approaches use high frequency data, realized volatilities or realized variance-covariance matrices. The analysis of these non parametric estimates of volatilities are integrated in models such as the Heterogenous Autoregressive model of Corsi (2006) or the paper by Bauer and Vorkink (2007) modelling the realized Bipower variance matrices issued from the work of Barndnorff-Nielson and Shephard (2004). In the strand of multivariate volatility models, a last class of specifications, recently developed by Calvet, Fisher and Mandelbrot (1997), Calvet and Fisher (2001,2002,2004) or Calvet, Fisher and Thompson (2006) uses the fractal properties of asset returns.

Fractal properties of asset returns are related to information cascade and network effects in the arrival of information on markets. Information arrive very often and market participants may be very heterogeneous for some classes of assets. As underlined by Zumbach and Lynch (2001), from hedge funds with substantive positions to small individual traders, market moves are motivated by different types of information that launch relatively long or short periods of volatility clustering: information and statistics disclosure, arbitrages between markets, market moves etc. Generally, it may be assumed that different types of traders, use different types of information, at different frequencies, and so the market moves in terms of frequencies. One can thus expect from an empirical model to consider this heterogeneity in news, and this superimposed structure of information revelation in price processes. In this direction, fractal properties of asset returns may be useful.

Calvet, Fisher and Mandelbrot (1997) have shown on exchange rate data that returns satisfy scale properties of fractal objects. From these observations, they develop a Multifractal Model of Asset returns, and latter a Markov switching Multifractal in a bivariate form, derived in Calvet et al. (2006). These models always applied to exchange rate data refine the notion of comovements since it estimates a strata structure of cycles with different lengths. The model also exerts a probabilistic structure on a wide range of volatility states that refines the nature and the degree of comovements between returns. Concerning stock market prices, Fillol (2003) analyses the fractal properties of asset returns for the French CAC40 index that also satisfy fractal scale properties. Lux and Kaizoji (2007) study the behavior of prices in the Japan stock market using this model.

Following the distinction of Forbes and Rigobon (2002) concerning integration and contagion, the model estimates a probabilistic structure for the several cycles in prices. These different estimated cycle lengths help distinguishing long term versus short term linkages between index returns. The model thus allows for non discrimination between short term comovements and long term comovements, but for a discrete scale of potential shifts affecting volatilities at different frequencies. Advantages are twofold. First, this graduation in the different horizons is endogenous and not imposed by the model. Second, the structure of the model results in a wide set of volatility and comovement states from a relatively reasonable number of parameters.

An empirical application is done for stock indices (CAC FTSE DAX and NYSE) at daily frequency from 01/01/1996 to 15/11/2008. The four indices are coupled to each other in Bivariate Markov switching models. The maximum likelihood estimations give the different cycle durations, the state dependent correlations and a probabilistic structure to assess comovements. A new way to detect crises is proposed and opposed to the long term cycles identified in index returns. Finally, it gives a complete new set of indicators concerning links on several horizons between markets.

Notably, it appears that the 2008 crisis is the most important crisis since 1997 with a global effect both on any considered market, and also on any volatility horizon (from the short to the long term). It is the first example since 1997 of diversification annihilation. Before that, diversification has always been possible due to some heterogeneity in market resiliencies.

The following section presents the MSM model first in a univariate framework. Section 3-3 presents the bivariate form and the derivations of the comovement indicators. Section 3-4 presents the empirical application of the MSM models for stock indexes. Finally section 3-5 concludes.

3.2 The Univariate multifractal model of asset returns

3.2.1 The model

This modelization combines persistent changes in the value of the asset and very short lasting shifts. For example, major events are considered to have long lasting effects while the impacts of minor news are considered short lasting. From Calvet and Fisher (2002), the returns are formalized as:

$$x_t = \left(\prod_{k=1}^{\bar{k}} M_{k,t}\right)^{1/2} \sigma\varepsilon_t \tag{3.1}$$

with σ being the unconditional standard error and ε a residual following a standard Gaussian distribution. Returns are specified as the product of $\bar{k}$ components M_k. These components are drawn at each date from a binomial distribution taking values $m_0 \in [1; 2]$ and $2 - m_0$ with equal probability so that $E(M_k) = 1$, to guarantee a conservative mass measure. The binomial distribution is considered to be state and time invariant : if an information arrival occurs, the new multiplier M_k is drawn from the time invariant M binomial distribution but the M_k differ in the occurrence of information arrivals, in other words in their jump frequency γ_k. The index k, corresponds to the several horizons so that for $k = 1$, a short lasting shift is obtained while for $k = \bar{k}$ the shift is long lasting. Horizons of each component are defined in the line of Calvet and

Fisher (2004). The frequencies at which components M_k jump, indexed by k, are defined as:

$$\gamma_k = 1 - (1 - \gamma_1)^{b^{(k-1)}}, \tag{3.2}$$

where $\gamma_1 \in [0; 1]$ is the highest frequency of information arrivals (and so the shortest horizon) and $b \in]0; 1]$ so that $\gamma_k \in [0; 1]$ for all k[2].

Some components M_k often jump between values m_0 and $m_1 = 2 - m_0$ while other components stay constant for longer periods of time. The heterogeneity in traders and news give a more complex dependency on the market than a simple time dependency. Publications of GDP bring some traders on the market with a certain behavior. Some arbitrage opportunities bring some other traders on the market with different behaviors or launch some algorithm trading. Therefore, a superimposition of different trading cycles results from different shocks and different persistencies. Low frequency components can be attributed to biggest events in the market while highest frequency components would be algorithm trading for example.

3.2.2 Univariate estimation procedure

Calvet and Fisher (2004) use a maximum likelihood optimization procedure to estimate the set of parameters $\Omega = (m_0, \sigma, b, \gamma_1) \in \mathbb{R}^4$. Since M_k follows a binomial distribution, we get $2^{\bar{k}}$ volatility states. A volatility state is defined as a vector $m^i = (M_1,\ M_2, ...M_{\bar{k}})$ of dimension $\bar{k}$. Updating the probability state vector Π_t of elements $\Pi_t^j = \Pr(M_t = m^j \mid x_1, x_2, ...x_t)$ consists in recursively calculating the probabilities of the $2^{\bar{k}}$ possible states in volatilities. The transition matrix A of the

[2] This differs from the original model since here $b \in]0; 1]$ for computational interest in bounding the b parameter.

Markov chain has elements a_{ij} defined as:

$$\begin{aligned} a_{i,j} &= \Pr(M_{t+1} = m^j \mid M_t = m^i) \\ &= \prod_{k=1}^{\bar{k}} \left[(1-\gamma_k)\mathbb{1}_{\{m_k^i = m_k^j\}} + \gamma_k \times \Pr(M = m_k^j) \right], \end{aligned} \tag{3.3}$$

with $\mathbb{1}$ a variable taking value one if $m_k^i = m_k^j$ and zero otherwise. The conditional density of returns in period t is

$$f_{x_t}(x \mid M_t = m^i) = \left[\left(\prod_{k=1}^{\bar{k}} M_{k,t} \right)^{1/2} \sigma \right]^{-1} \times \varphi \left(x \times \left[\left(\prod_{k=1}^{\bar{k}} M_{k,t} \right)^{1/2} \sigma \right]^{-1} \right), \tag{3.4}$$

with φ the density of a standard Gaussian distribution. Considering the vector ω_t of dimension $2^{\bar{k}}$ of element $f_{x_t}(x \mid M_t = m^i)$ with $i = 1$ to $2^{\bar{k}}$, Calvet and Fisher (2004) show that the updated probability Π_{t+1} is:

$$\Pi_{t+1} = \frac{\omega(x_{t+1}) * \Pi_t A}{[\omega(x_{t+1}) * \Pi_t A\ ]\ \iota'}, \tag{3.5}$$

and the log likelihood is:

$$l(x_1, ...x_t \mid m_0, \sigma, b, \gamma_1) = \sum_{t=1}^{T} \ln(\omega(x_t).\Pi_{t-1}A). \tag{3.6}$$

Note that Π_t is initialized in Π_0 in the estimation procedure such that $\Pi_0^i = \prod_{k=1}^{\bar{k}} \Pr(M_t = m^i)$ for all i.

3.3 Market comovements and the bivariate MSM model

Since volatility is decomposed on several horizons, each type of shock can be characterized by the correlation in the components of the same frequency k between the several assets. It may help understanding if very high level of comovements is observed in transient components, or in the most persistent ones. This is related to the usual distinction between integration and contagion, as in Forbes and Rigobon (2002), with the major improvement that a gradual scale from the short common changes up to persistent shifts is defined. The MSM is thus expressed as a bivariate model to analyze the links between two markets (Calvet et al.(2006)).

Let re-define by $x_t = \binom{x_t^\alpha}{x_t^\beta}$ the vector of returns for markets α and β. The vector of the components at the k^{th} frequency is $M_{k,t} = \binom{M_{k,t}^\alpha}{M_{k,t}^\beta}$. The period t volatility is characterized by the (2,$\bar{k}$) matrix $M_t = \left(M_{1,t}; M_{2,t}; ...; M_{\bar{k},t}\right)$ where $\bar{k}$ is the index for the lowest frequency. Each row stands for a market indexed by c=$\{\alpha, \beta\}$, while each column for a frequency k=$\{$1,2,...$\bar{k}\}$. Consistently with the previous section, the vector of returns may be written as:

$$x_t = \begin{pmatrix} M_t^{\alpha^{1/2}} \\ M_t^{\beta^{1/2}} \end{pmatrix} * \varepsilon_t, \tag{3.7}$$

with * referring to the Hadamard product, $M_t^c = \prod_{k=1}^{\bar{k}} M_{k,t}^c$ and $\varepsilon \in \mathbb{R}^2$ the vector of residuals which are IID Gaussian (0,$\sum$) with:

$$\sum = \begin{pmatrix} \sigma_\alpha^2 & \rho_\varepsilon \sigma_\alpha \sigma_\beta \\ \rho_\varepsilon \sigma_\alpha \sigma_\beta & \sigma_\beta^2 \end{pmatrix}. \tag{3.8}$$

$\rho_\varepsilon \in [0;1]$ represents the unconditional correlation between the residuals. A second source of correlation is the one between jumps: in period t, each returns α or β is potentially hit by an information arrival at frequency γ_k on each corresponding k component. The correlation between information arrivals is represented by a new $\lambda \in [0;1]$ coefficient as follows.

Let consider the dummy variables I_k^α and I_k^β which take values 1 if an information arrival (jump) occurs on component k of series α or β and 0 otherwise.

The vector $I_k = \binom{I_k^\alpha}{I_k^\beta}$ is specified as IID and, as in Calvet et al. (2006), it satisfies few conditions. The arrival vector needs to be symmetric meaning that $\binom{I_k^\alpha}{I_k^\beta} \overset{d}{=} \binom{I_k^\beta}{I_k^\alpha}$.

Then, to be consistent with the univariate case we set

$$\Pr(I_k^\alpha = 1) = \gamma_k = 1 - (1 - \gamma_1)^{b^{(k-1)}}, \tag{3.9}$$

where $\gamma_1 \in [0;1]$ is the highest frequency of jump and $b \in]0;1]$ so that $\gamma_k \in [0;1]$ for all k; and

$$\Pr(I_k^\beta = 1 \mid I_k^\alpha = 1) = (1 - \lambda)\gamma_k + \lambda. \tag{3.10}$$

Then, in line with the previous univariate case, the component $M_{k,t}^c$ is drawn from a binomial distribution taking the values m^c and $2 - m^c$ with the same probability if an information arrival occurs and stays constant otherwise, therefore:

$$M_{k,t}^c \overset{d}{=} M_{k,t-1}^c + I_{k,t}^c * (M - M_{k,t-1}^c) \tag{3.11}$$

where M is the vector-component distribution. Finally, a last parameter of the dependency structure is the correlation between M^α and M^β under the bivariate binomial distribution M.

The matrix $(p_{i,j})_k$=Pr$(M_k = (m_i^\alpha, m_j^\beta))$ with $i, j = \{H, L\}$, for High and Low values, is defined as

$$\begin{bmatrix} p_{LL} & p_{LH} \\ p_{HL} & p_{HH} \end{bmatrix}_k = \begin{bmatrix} \frac{1+\rho_m^*}{4} & \frac{1-\rho_m^*}{4} \\ \frac{1-\rho_m^*}{4} & \frac{1+\rho_m^*}{4} \end{bmatrix}_k \tag{3.12}$$

where $\rho_m^* \in [0;1]$ is the correlation between components of frequency k of series α and β. Since it is set that the binomial distribution is the same for every component $M_{k,t}^c$ whatever k, or stage invariant as in the univariate case, index k may be omitted in expression (3.12).

3.3.1 Comovements structure and typology

Some new indicators are drawn from the dependency structure of the model given by the parameters λ, ρ_ε and ρ_m^*. The parameter λ gives the unconditional correlation between jumps on the markets. ρ_ε gives the unconditional correlation between the residuals of the models. Finally, ρ_m^* gives the unconditional correlation of the multipliers M_k^α and M_k^β under the bivariate binomial distribution M. We start from the definition of state probabilities to then calculate the conditional volatilities, correlations, and probabilities of extreme comovements, crisis and cycles.

3.3.1.1 States Probabilities

Given the transition probability matrix A (see appendix 3-A), a probability Π_t^j is assigned to each state, for $j = 1$ to $d = 4^{\bar{k}}$:

$$\Pi_t^j = \Pr\left(M_t = m^j \mid X_t\right), \tag{3.13}$$

with $X_t \equiv \{x_s\}_{s=1}^t$ the history of past returns. Π_t is calculated recursively by Bayesian updating as follows.

Let consider $\Pi_t = \left(\Pi_t^1, \Pi_t^2 ... \Pi_t^d\right)$, the probability state determined for time t. The returns in $t+1$ are observed and assumed to follow a bivariate Gaussian density conditional on the volatility state $f_{x_{t+1}}(x_{t+1} \mid M_{t+1} = m^j)$, with variance covariance matrix H_j of this distribution:

$$H_j = \begin{bmatrix} \sigma_\alpha^2 M_{t+1}^\alpha & \rho_\varepsilon \sigma_\alpha \sigma_\beta \left(M_{t+1}^\alpha M_{t+1}^\beta \right)^{1/2} \\ \rho_\varepsilon \sigma_\alpha \sigma_\beta \left(M_{t+1}^\alpha M_{t+1}^\beta \right)^{1/2} & \sigma_\beta^2 M_{t+1}^\beta \end{bmatrix}. \tag{3.14}$$

The updated probability is a function of actual returns and the history of past probabilities as

$$\Pi_{t+1}^j = \frac{f(x_{t+1}) * \Pi_t A}{[(f(x_{t+1}) * \Pi_t A)\, \iota']}, \tag{3.15}$$

where ι is a $(1 \times 4^{\bar{k}})$ vector of ones, A the transition matrix and $f(x_{t+1})$ a $(1, 4^{\bar{k}})$ vector of elements $f_{x_{t+1}}(x_{t+1} \mid M_{t+1} = m^j)$. The derivation of the comovement indicators exploits this probabilistic structure.

3.3.1.2 Variances and conditional correlations

Contrary to the wide class of multivariate GARCH models where the Σ matrix is characterized by time varying elements, the MSM accounts for a fixed elements matrix. Time varying correlations in this framework are obtained from the dynamics of the state probabilities. The conditional covariance between returns is as follows:

$$Cov_t \left(x_t^\alpha, x_t^\beta \right) = \rho_\varepsilon \sigma_\alpha \sigma_\beta \prod_{k=1}^{\bar{k}} E_t \left[(M_{k,t}^\alpha M_{k,t}^\beta)^{\frac{1}{2}} \right], \tag{3.16}$$

and the conditional variance for series c, $c = \{\alpha, \beta\}$ as:

$$Var_t(x_t^c) = \sigma_c^2 E_t(M_t^c), \tag{3.17}$$

so that the correlations are written as

$$Corr_t\left(x_t^{\alpha}, x_t^{\beta}\right) = \rho_{\varepsilon}\prod_{k=1}^{\bar{k}}\frac{E_t\left[(M_{k,t}^{\alpha}M_{k,t}^{\beta})^{\frac{1}{2}}\right]}{\left(E_t(M_t^{\alpha})E_t(M_t^{\beta})\right)^{\frac{1}{2}}}. \tag{3.18}$$

Notably, the limited number of states coupled with the absence of time dependency makes these correlations less flexible than standard correlation models.

3.3.1.3 Periods

An indicator of interest is the more general notion of periods or cycles. The multifrequency setting of the model allows for the identification of the different superimposed cycles in the asset returns. This is defined as the inverse of the frequency of change γ_k in the different lasting components $M_{k,t}^c$. While in the univariate case this is only the cycles of a single asset, in the bivariate cases it is the co-cycles since it applies to the variance-covariance matrix as a whole, and not only on variances. It is defined as follows:

$$\tau_k = \frac{1}{\gamma_k} = \frac{1}{\left(1-(1-\gamma_1)^{b^{(k-1)}}\right)} \tag{3.19}$$

The number of cycles depends on the number of $\bar{k}$ frequencies considered in the model. To determine the optimal number of frequencies, the Vuong Test from Calvet and Fisher (2004) is further applied as a selection model test.

3.3.1.4 Probability of extreme comovements

Crises are define in this chapter as a joint peak in volatility components of all horizons. Therefore the crisis probability at date t is defined as:

$$\begin{aligned} \Pr(crisis)_t &= \Pr(M^{\alpha}_{1,t} =_{...} M^{\alpha}_{\bar{k},t} = m^{\alpha}_0 \text{ and } M^{\beta}_{1,t} =_{...} M^{\beta}_{\bar{k},t} = m^{\beta}_0) && (3.20) \\ &= \Pi_t.\delta_1, && (3.21) \end{aligned}$$

with δ_1 a vector of dimension $4^{\bar{k}}$ with dirac elements $\delta_{1,i} = \mathbb{1}_{\left\{M^{\alpha}_{1,t}=_{...}M^{\alpha}_{\bar{k},t}=m^{\alpha}_0\right\}} \times \mathbb{1}_{\left\{M^{\beta}_{1,t}=_{...}M^{\beta}_{\bar{k},t}=m^{\beta}_0\right\}}$ for $i = 1$ to $4^{\bar{k}}$, given that each component for a given series follows the same binomial distribution taking high value m^c_0 for $c = \{\alpha, \beta\}$ or low value $2 - m^c_0$. The dummy variable $\mathbb{1}_{\{condition\}}$ takes the value 1 if the condition is verified and 0 otherwise. In this setting, a crisis is detected when all components are at their highest values for every horizon.

Then, the conditional probability to be in a crisis in market α given that market β is in crisis represents the conditional probability of extreme comovements between two markets and is defined as:

$$\begin{aligned} \Pr(extreme\ comov)_t &= \Pr(M^{\alpha}_{1,t} =_{...} M^{\alpha}_{\bar{k},t} = m^{\alpha}_0 \ \mid \ M^{\beta}_{1,t} =_{...} M^{\beta}_{\bar{k},t} = m^{\beta}_0) && (3.22) \\ &= \frac{\Pr(M^{\alpha}_{1,t} =_{...} M^{\alpha}_{\bar{k},t} = m^{\alpha}_0 \text{ and } M^{\beta}_{1,t} =_{...} M^{\beta}_{\bar{k},t} = m^{\beta}_0)}{\Pr(M^{\beta}_{1,t} =_{...} M^{\beta}_{\bar{k},t} = m^{\beta}_0)} \\ &= \frac{\Pi_t.\delta_1}{\Pi_t.\delta_2}, && (3.23) \end{aligned}$$

with δ_2 a vector of dimension $4^{\bar{k}}$ with dirac elements $\delta_{2,i} = \mathbb{1}_{\left\{M^{\beta}_{1,t}=_{...}M^{\beta}_{\bar{k},t}=m^{\beta}_0\right\}}$ for $i = 1$ to $4^{\bar{k}}$. This gives an indicator to measure the degree with which a market is influenced by the others during crisis episodes.

3.3.1.5 Long term cycles

Other indicators of interest are the long run cycles in volatility (high or low) that are shared between returns. To identify the low common long run cycles in volatility, the states for which the components with the lowest frequency of jump ($k = \bar{k}$) for the two series have both a low value $2 - m_0^c$ are considered. It means that the series may be hit on shorter cycles by shocks though the longest cycle stays low. This probability to be in a low long run cycle is thus written as:

$$\begin{aligned} \Pr(LLRC)_t &= \Pr(M^{\alpha}_{\bar{k},t} = M^{\beta}_{\bar{k},t} = 2 - m_0^{\alpha}) \quad (3.24) \\ &= \Pi_t.\delta_3, \quad (3.25) \end{aligned}$$

with δ_3 a vector of dimension $4^{\bar{k}}$ with dirac elements $\delta_{3,i} = \mathbb{1}_{\left\{M^{\alpha}_{\bar{k},t}=2-m_0^{\beta}\right\}} \times \mathbb{1}_{\left\{M^{\alpha}_{\bar{k},t}=2-m_0^{\beta}\right\}}$ for $i = 1$ to $4^{\bar{k}}$ and conversely, the probability to be in high long run volatility cycle is:

$$\begin{aligned} \Pr(HLRC)_t &= \Pr(M^{\alpha}_{\bar{k},t} = M^{\beta}_{\bar{k},t} = m_0^{\alpha}) \quad (3.26) \\ &= \Pi_t.\delta_4, \quad (3.27) \end{aligned}$$

with δ_4 a vector of dimension $4^{\bar{k}}$ with dirac elements $\delta_{4,i} = \mathbb{1}_{\left\{M^{\alpha}_{\bar{k},t}=m_0^{\beta}\right\}} \times \mathbb{1}_{\left\{M^{\alpha}_{\bar{k},t}=m_0^{\beta}\right\}}$ for $i = 1$ to $4^{\bar{k}}$. This completely new set of indicators helps to understand the nature of comovement, transmission, and the effects of several events on different markets.

3.3.2 The Maximum likelihood estimation

Calvet et al. (2006) develop a maximum likelihood optimization procedure to estimate the set of parameters $\Omega' = (\sigma_\alpha, \sigma_\beta, m_0^{\alpha}, m_0^{\beta}, b, \gamma_1, \rho_\varepsilon, \lambda, \rho^*) \in \mathbb{R}^9$. With $\bar{k}$ components, $4^{\bar{k}}$ volatility states are obtained. This geometrical growth in volatility states makes the computation quite heavy but take a very wide view of the different possible states in volatility. A GMM alternative method may also be applied as developed by Lux (2006).

The econometrician only observes the history of past returns $X_t \equiv \{x_s\}_{s=1}^t$ and does not observe the states of volatilities. The Π_t vector in empirical application, as in Calvet et al. (2006) is initialized at its ergodic distribution and updated as presented previously. The logarithm of the likelihood function is

$$l(x_{1...}x_T;\Omega') = \sum_{t=1}^{T} \ln(f(x_t \mid x_{t-1,}x_{t-2},...x_1)), \tag{3.28}$$

with

$$f(x_t \mid x_{t-1,}x_{t-2},...x_1) = \sum_{j=1}^{4^{\bar{k}}} f(x_t \mid M_{t-1} = m^j)\Pr(M_{t-1} = m^j \mid x_{t-1,}x_{t-2},...x_1),$$

so that the log likelihood is finally

$$l(x_{1...}x_T;\Omega') = \sum_{t=1}^{T} \ln(f(x_t).(\Pi_{t-1}A)). \tag{3.29}$$

3.4 Empirical applications

The dataset comprises four market indices : CAC, DAX, FTSE and NYSE. Daily prices are prices at 3pm GMT when all considered markets are opened simultaneously. The sample spans 12 years of daily market data from 01/01/1996 to 15/11/2008. Univariate estimations of the MSM model are first provided to give volatility cycles τ_k, frequencies γ_k, and sample correlations between the components $M_{k,t}$. Then the bivariate model estimations are provided and discussed for each pair of indices. All the programs and routines are written using the MatLab software and data comes from the Reuters datascope tick history database.

3.4.1 Univariate MSM

We take the geometric index returns and the MSM($\bar{k}$) model is estimated for $\bar{k} = 1$ to 8 by maximizing the likelihood derived in equation 3.6. This corresponds for each estimation to a set of $2^{\bar{k}}$ states in the volatility process. Tables 1-4 in appendix 3-B present estimations for each of the four series.

In accordance with Calvet et al. (2006), the component m_0 decreases with the number of frequencies. This is consistent with the idea that heterogeneity in volatility states is less required with an increase in the number of states (i.e. frequencies). The frequencies γ_k are, in particular, lower than frequencies obtained in the exchange rate market by Calvet et al. (2006) so that longer cycles are predominant.

The likelihood stabilizes from $\bar{k} = 4$ for all series. The selection model procedure is formalized by testing systematically a model with $\bar{k}$ components against a model with $\bar{k} + 1$ components on the basis of model likelihoods. This tests developed in Calvet and Fisher (2004) is adjusted for correlations in the addends (Vuong-HAC test) and the results are presented in appendix 3-C. This procedure gives the MSM(3) model as an optimal choice. However, it is also tested MSM(3) for each index against models with $\bar{k} = 5, 6, 7$ and 8. The trade-off between increasing the number of states in volatility by increasing $\bar{k}$ against selecting MSM(3) advocates for staying with $\bar{k} = 3$, with insignificant gains in likelihoods.

Figure 3-1 present the estimated volatilities. Peaks are obtained for well-known dates identified as major events on financial markets. Some events have much more impact on European places than for the US. In fact, the peaks in volatility for the CAC, the DAX and the FTSE observed between 1998 and 2003 that are around 10 percentage points higher in mean. Two crises are clearly predominant in the sample: Asian crisis 1997 and the 2007-2008 crisis mainly following the Lehman brother case. Details will be latter given to the light of the new comovements indicators.

The three volatility cycles are (equation 3.2) are reported in table 3-1.

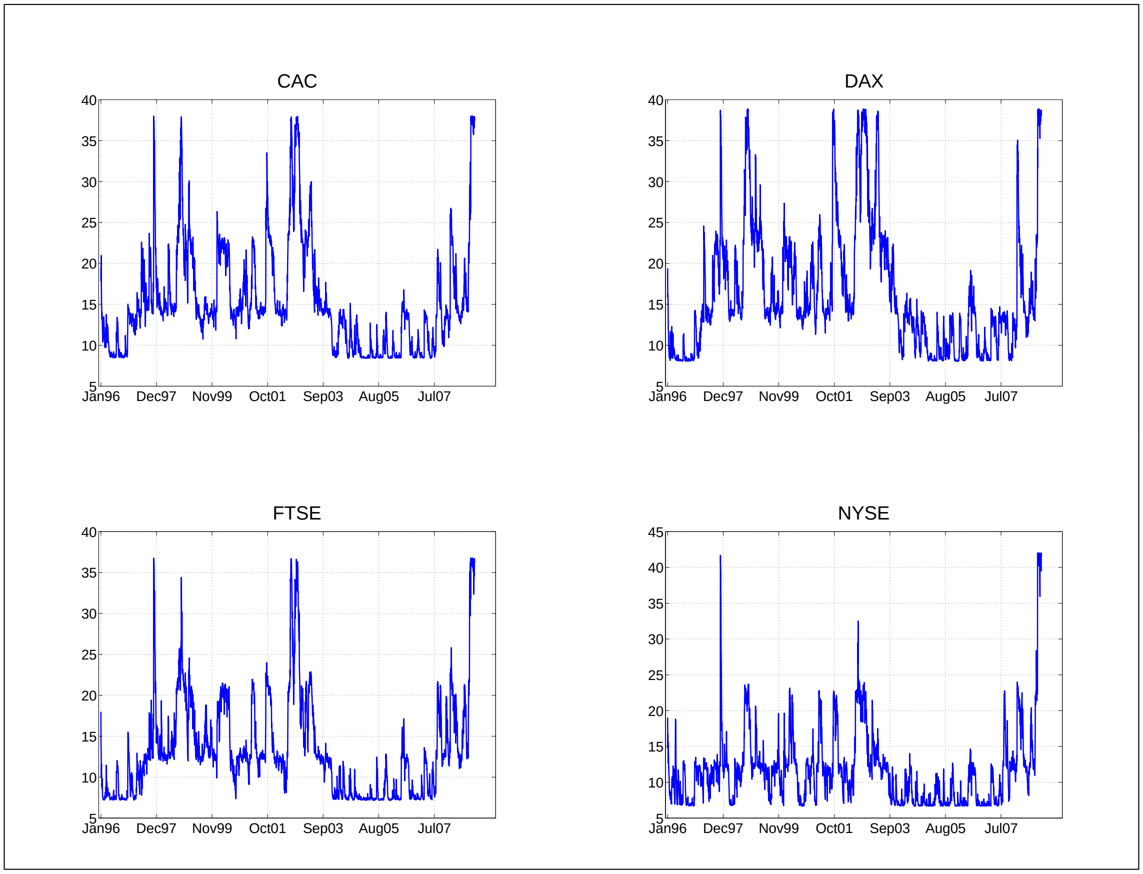


Figure 3-1: volatility MSM(3)

	CAC	DAX	FTSE	NYSE
τ_1	41.0	28.6	38.4	24.9
τ_2	124.5	110.8	117.8	112.9
τ_3	379.8	433.7	363.6	517.2

Table 3-1: Volatility cycles from MSM(3) in days

The shortest cycles are ranging from 24 days (NYSE) up to 41 days (CAC). The short run resiliency of the NYSE index is thus the most efficient. Short term represents somehow between one and 2 months and a half. Medium term is around 6 months. Finally, long term is between 18 and 24 months.

These results address two questions. First of all, from a transmission perspective, are comovements effectively higher in period of high volatility or not? If the answer is positive diversification becomes useless when it is the most needed with higher shock transmissions. This is verified if the resiliency of the shocks are the same everywhere. However, in other cases there still exist some arbitrage opportunities in favor of the most resilient markets. Shocks are obtained on volatility at the same date, but cycles in volatility are different. Therefore, if a volatility shock increase correlations at one point in time it should also perturb comovements in the following days in an heterogenous way since the shock may be on a short lasting component, or on a long lasting one.

Second, if a shock hits different lasting components of volatility in two indexes, the resilience to the shock becomes very different between places and a decrease in comovements should even be observed after a sudden rise. Typically, we expect correlations between the NYSE and the other indexes being weakened by this difference in the lengths of the cycles.

To first gauge where transmission occurs, we presented the correlations between the $\bar{k}$ components for the MSM(3) in table 3-2.

	M_1^{cac}	M_2^{cac}	M_3^{cac}	M_1^{dax}	M_2^{dax}	M_3^{dax}	M_1^{ftse}	M_2^{ftse}	M_3^{ftse}	M_1^{nyse}	M_2^{nyse}	M_3^{nyse}
M_1^{cac}	1	0.75	0.42	0.81	0.64	0.35	0.83	0.67	0.41	0.76	0.63	0.50
M_2^{cac}	0.75	1	0.77	0.61	0.89	0.70	0.78	0.89	0.72	0.58	0.84	0.69
M_3^{cac}	0.42	0.77	1	0.35	0.77	0.96	0.51	0.68	0.94	0.36	0.71	0.62
M_1^{dax}	0.81	0.61	0.35	1	0.61	0.30	0.72	0.55	0.35	0.64	0.50	0.42
M_2^{dax}	0.64	0.89	0.77	0.61	1	0.75	0.68	0.75	0.72	0.49	0.79	0.65
M_3^{dax}	0.35	0.70	0.96	0.30	0.75	1	0.45	0.64	0.88	0.33	0.66	0.53
M_1^{ftse}	0.83	0.78	0.51	0.72	0.68	0.45	1	0.78	0.50	0.75	0.69	0.52
M_2^{ftse}	0.67	0.89	0.68	0.55	0.75	0.64	0.78	1	0.71	0.58	0.86	0.70
M_3^{ftse}	0.41	0.72	0.94	0.35	0.72	0.88	0.50	0.71	1	0.36	0.73	0.66
M_1^{nyse}	0.76	0.58	0.36	0.64	0.49	0.33	0.75	0.58	0.36	1	0.54	0.41
M_2^{nyse}	0.63	0.84	0.71	0.50	0.79	0.66	0.69	0.86	0.73	0.54	1	0.76
M_3^{nyse}	0.50	0.69	0.62	0.42	0.65	0.53	0.52	0.70	0.66	0.41	0.76	1

Table 3-2: Correlations between components MSM(3)

Correlations are not surprisingly stronger between components of the same returns series and also stronger at the same frequency between two different series. However some diversification opportunities appears by considering the horizons: short on the CAC and long on the DAX for example since correlation between M_1^{cac} and M_3^{dax} is only 0.35. An interesting feature is also that correlations are higher for long term components ($k = 3$) for some series like CAC-DAX or CAC-FTSE while this is less observed between European and American markets. Indeed in Europe, even if there are some arbitrages on the shorter run (smaller correlations), there is convergence in the long run for market risk while this is not completely true with the US market.

3.4.2 Bivariate MSM estimations and comovements structure

Estimations and results are also provided in this section for the MSM(3) model. However, complete estimations of bivariate models for $\bar{k} = 2$ to 5 are presented in appendix 3-D. The following table gives estimations of bivariate MSM(3) models by pair of indexes.

	CAC-DAX	CAC-FTSE	CAC-NYSE	DAX-FTSE	DAX-NYSE	FTSE-NYSE
m_0^α	1.471 (0.0175)	1.469 (0.0186)	1.471 (0.0182)	1.488 (0.0145)	1.488 (0.0143)	1.504 (0.0177)
σ^α	1.782 (0.084)	1.801 (0.082)	1.774 (0.091)	1.827 (0.0702)	1.815 (0.075)	1.579 (0.0827)
m_0^β	1.488 (0.0152)	1.501 (0.0177)	1.551 (0.0151)	1.503 (0.018)	1.552 (0.0152)	1.551 (0.0158)
σ^β	1.828 (0.0759)	1.583 (0.07821)	1.861 (0.084)	1.581 (0.0801)	1.865 (0.0857)	1.861 (0.0939)
b	0.272 (0.0628)	0.323 (0.102)	0.251 (0.061)	0.281 (0.0689)	0.236 (0.074)	0.259 (0.0802)
γ_1	0.031 (0.0062)	0.025 (0.0065)	0.033 (0.007)	0.031 (0.0063)	0.037 (0.007)	0.033 (0.006)
λ	0.981 (0.483)	0.984 (0.488)	0.845 (0.332)	0.851 (0.227)	0.777 (0.436)	0.894 (0.429)
ρ_ε	0.888 (0.0036)	0.824 (0.0056)	0.771 (0.0092)	0.797 (0.0079)	0.762 (0.0088)	0.761 (0.0083)
lnL	-8158.3	-7893.9	-8200.4	-8324.5	-8440.6	-7503.6

Table 3-3: Models estimations for bivariate $MSM(3)$

First, estimations of the component m_0 and σ for each of the series are close to the estimations in the univariate cases and stable across models. The estimations are constrained with $\rho_m^* = 1$ as in Calvet et al. (2006) for exchange rate data. Ex ante, both types of estimations (constraint and unconstraint) have been performed. It is confirmed that ρ_m^* is not different from unity even for stock prices. Coming back to the model, the ρ_m^* parameter gives the unconditional correlation of the components $M_k^\alpha = \{m_0^\alpha; 2 - m_0^\alpha\}$ and $M_k^\beta = \{m_0^\beta; 2 - m_0^\beta\}$ under the bivariate binomial distribution M (equation (3.12)). Therefore, it means that the probability to be at date t in two opposite states in these two places (for example very high volatility state in α and very low volatility state in β) is null.

Turning to the comovement structure, estimated parameter λ gives the unconditional correlation between the component jumps (equation (3.10)). Estimates are very high ranging from 0.78 for DAX-NYSE to 0.984 between the CAC and the FTSE.

The unconditional correlations between the residuals, ρ_ε, also appears quite high (equation (3.8)). This correlation is the lowest for the NYSE whatever is the other index (around 0.76). We get a ranking in market correlations. The highest ones are between two places sharing the same currency (CAC-DAX). The second one in level is between European countries (FTSE-CAC and FTSE-DAX). The last and lowest ones are between European places and the NYSE index.

3.4.2.1 Shared cycles and correlations between indices

From equation (3.19) we calculate the co-cycles for each pair of indexes and they are reported in table 3-4.

	CAC-DAX	CAC-FTSE	CAC-NYSE	DAX-FTSE	DAX-NYSE	FTSE-NYSE
τ_1	32.3	39.5	30.1	32.4	26.9	30.5
τ_2	117.1	121.0	118.3	114.1	111.8	115.6
τ_3	428.3	372.9	469.5	405.4	470.4	444.6

Table 3-4: Volatility shared cycles length between indices (days)

The co-cycles are the shortest ones for the NYSE, whatever is the other index, CAC, DAX or FTSE and their lengths are close to univariate ones. We also report from equation (3.18), the conditional correlations in figure 3-2.

These correlations are not strictly speaking "time varying" correlations as in the class of multivariate GARCH models, but daily state dependent correlations. Persistent changes in correlations

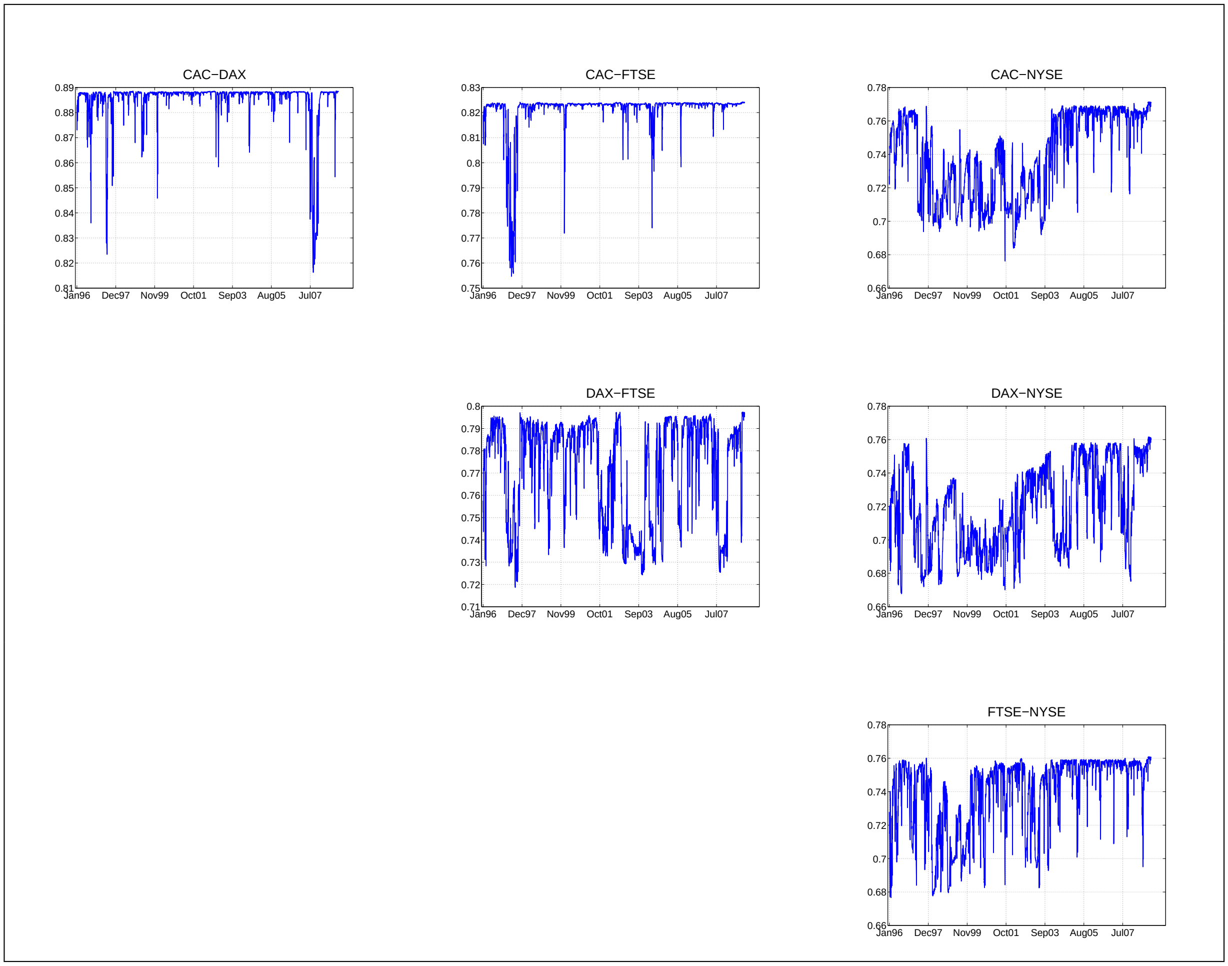


Figure 3-2: Bivariate MSM(3) Correlations

are more frequent for the NYSE index than for correlations between the CAC and the DAX ; correlations with the FTSE being an intermediate case. These correlations are quite rigid but exert some negative or positive sudden shocks driven by jumps in the heterogeneous lasting volatility components. One important feature is that conditioning correlation on the volatility state gives some negative shocks in the correlations during some crises (1997 and 2007-2008 for CAC-DAX for example). Indeed, the reactions of the several markets to similar events may not be exactly at the same time and the expost crisis period is characterized by different resiliencies. This gives imperfectly correlated volatility processes and thus weakens correlations.

3.4.2.2 Crises, extreme comovements and long term volatility cycles

Crises are detected by an increase in the probability to be for both markets in the highest volatility state defined by equation (3.20).

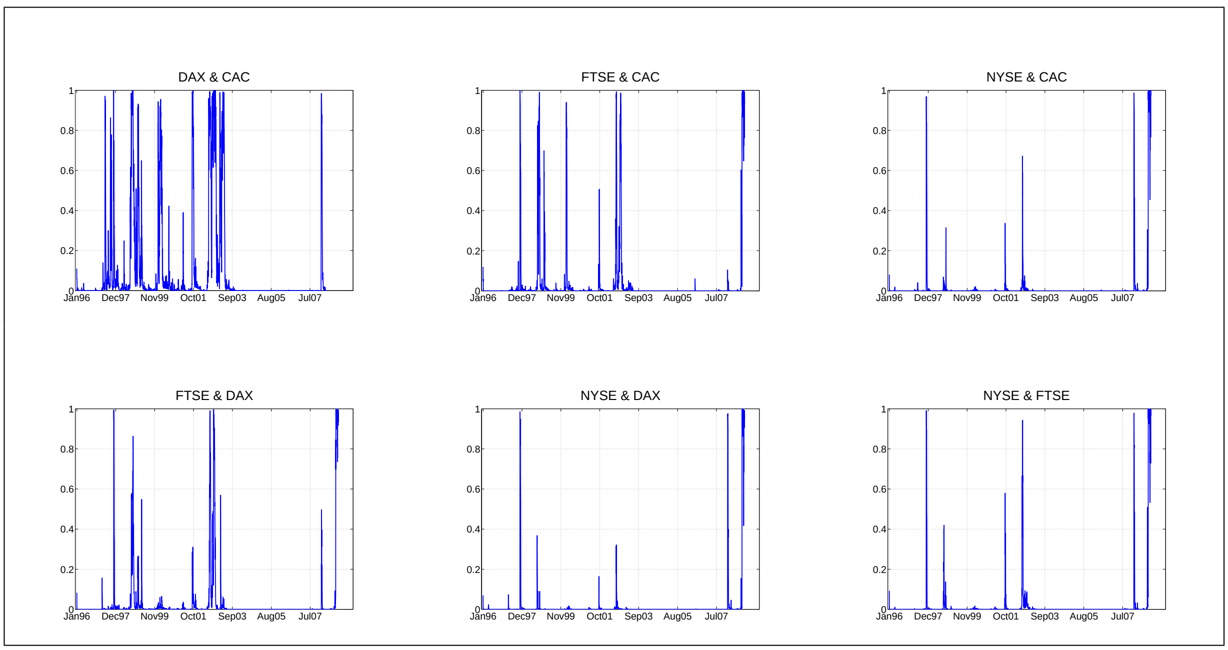


Figure 3-3: Bivariate MSM(3) joint crisis probability

Several periods of disorders are detected (fig. 3-3). The Asian crisis mainly lasts two days and all indexes are concerned: 27/10/97 and 28/10/97. The Russian crisis in August 1998 bring a period of low confidence for market participants. In addition, this period is the period of the LTCM crisis (Long Term Capital Management) combined with three successive cuts in the federal funds rate to avoid the fears of the market (29/09, 15/10, 29/11).

However, there is much more pronounced effects in Europe than in the United States so that the main disturbances would mainly come from the crisis in Russia. March 2000 emerges with a slight peak mainly for CAC and DAX. Then, 09.11 is marked by an increasing volatility. The period between 15 July 2002 and 10 August 2002, is characterized by peaks in the joint crisis probability mainly with the FTSE. This period is a period of doubts on the participation of different countries (especially England) in the Iraq war. This period is also marked by high volatility in the U.S. market due to the bankruptcy of large companies as Wordcom and ANRO and the beginning of accounting scandals in the United States. Finally, the agreement of the United States Senate in October 2002 for the Iraq war and the entry of troops in Iraq in March 2003 create a sharp rise in volatility. Then we get a long period of low probability of crisis until 2007. The end of 2007 and 2008 is marked by a peak of the joint probability of a crisis, because of the subprime episode. The climax takes place in early 2008, with strong effects of transmission between markets. Since the Asian crisis of 1997, 2008 is the most global crisis detected on indexes with a first peak in the summer of 2007 mainly observed for the U.S. market and then a spike in all markets in September 2008.

A complementary key indicator of the model is the probability of extreme volatility comovements between markets as in equation (3.22). Figure 3-4 concerns extreme comovement phenomena involving the CAC index. All the remaining graphs are reported in the appendix 3-E.

Structurally, it appears that the probability of extreme comovements is higher among the European places (fig. 3-4). They are also higher from the U.S. to Europe than vice versa, which is not surprising. However, we note in particular a negative shock in 1999, the year of the creation of the Euro area, but it was fleeting.

Regarding the extreme comovements of the CAC subject to the New York Stock Exchange, the peaks are observed during periods of turbulences, notably by the end of the sample, which is linked to the 2008 crisis. In addition, during the periods of high volatility, there is a risk of non-diversification. However, this risk is very transient due to the variation in the lengths of the cycles and market resiliencies.

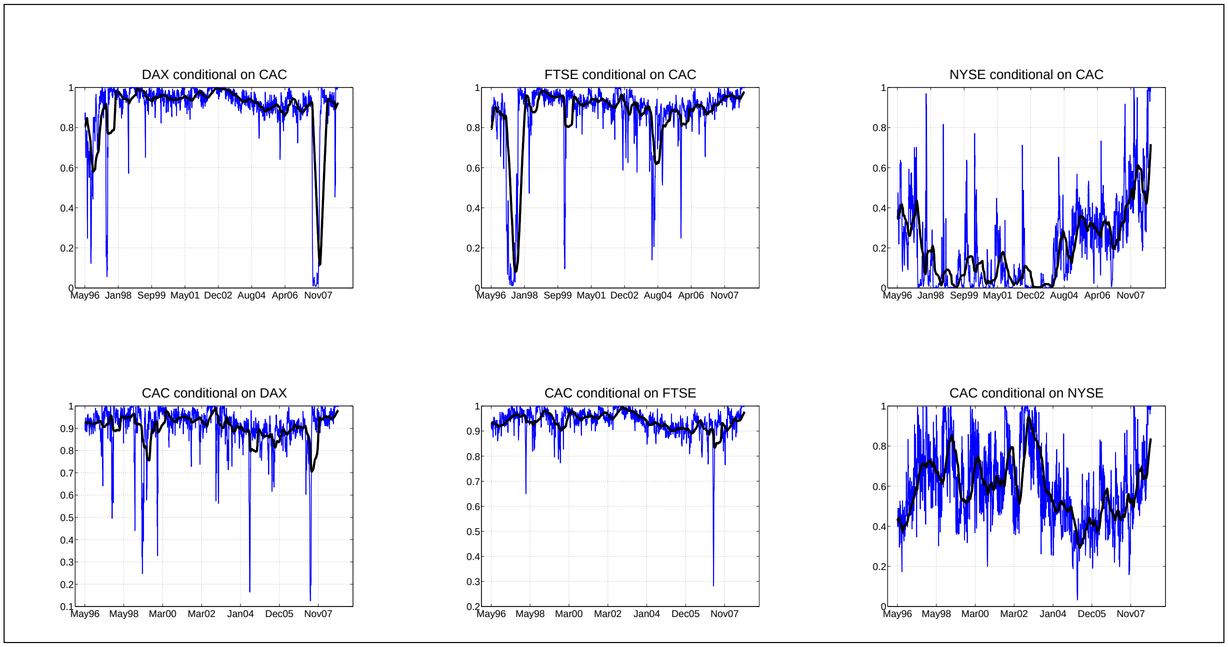


Figure 3-4: Bivariate MSM(3) : Conditional probability of extreme comovements

For the DAX conditional on CAC, comovements are also strong, except after the month of August 2007 where a large rupture is obtained for the DAX with all other indices. One reason is especially because the financial industry is not as weighted in the DAX as other countries like France or the United-Kingdom, and also in 2007 the performances of the German economy have been better. However, it is very transient and 2008 is characterized by the global spread of the crisis.

For the FTSE, the extreme comovements are stronger conditionally to the CAC and to the DAX, and present an intermediate case with the NYSE. Regarding the latter, the risk of extreme comovements induced by European markets, has always been very low, although this risk has increased since 2005 and surged in 2008.

The probability of long term high common cycle from equation (3.26) is very high in all European places from end-1997 to end-2003 (see fig. 3-5 and appendix 3-F). The probability to be in a

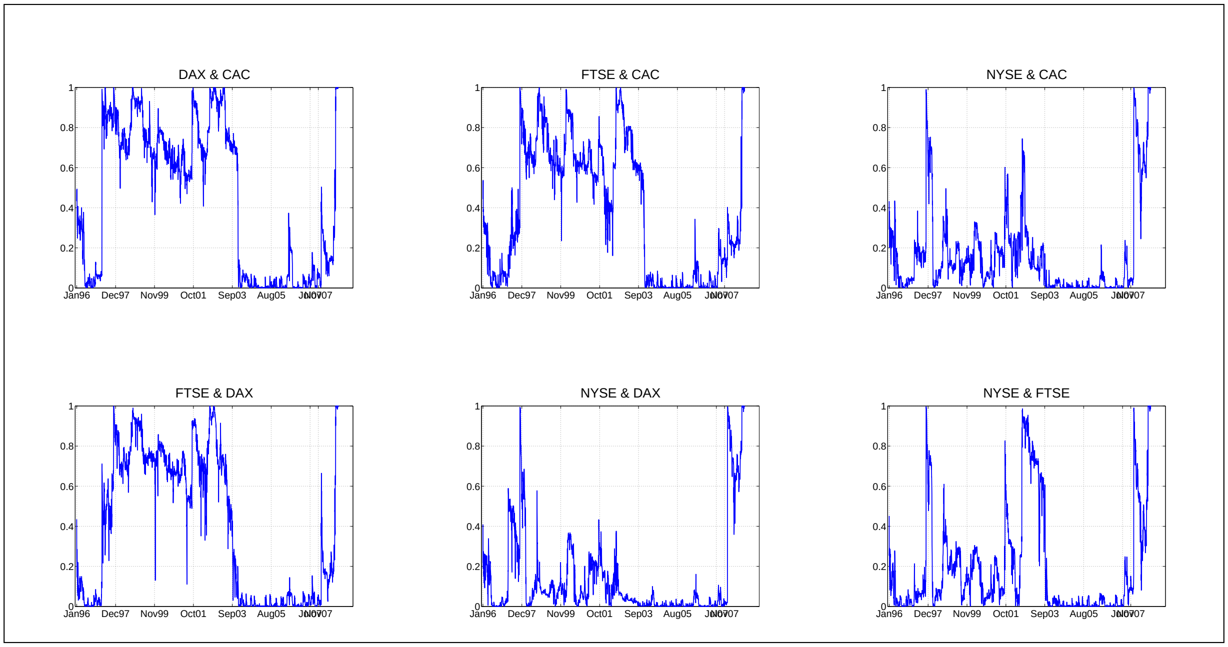


Figure 3-5: Bivariate MSM(3) : Probability of long term high volatility cycle

common low volatility state is high for the period 1996-1997 and 2003-2006. Concerning the NYSE index, cycles are not clearly pronounced in a high or low state. However, the current crisis is the first case where it is obtained a clear long term common high volatility cycle with the European places. This shows the unprecedented extend to how this crisis spreads all over the world and has some long term effects on market risks.

Actually the Asian crisis had launched (with the other successive crises) a long term instability only common to European places. The 2008 crisis, by its nature, extends this phenomenon to the American market, also because the crisis finds its source in the US. It is hard to say before this event that globalization has reduced diversification opportunities, except during very short periods of time, but now it opens a new era where this threat should be taken into account with outstanding long term risk sharing between markets.

3.5 Conclusions

The chapter presents the Multifractal Markov Switching model for index returns on four major places: Paris, Frankfurt, London and New-York. From this empirical model, we define a set of indicators that help understanding the nature of comovements, cycles and correlations. First, state varying correlations between indexes depend on a gradual scale of several volatility horizons. The model exerts three superimposed cycles of heterogeneous lengths. Then, from the probability structure assigned to these volatility states, we propose some new indicators concerning crises and long term cycles. A crisis is considered when as a rise in the joint probability of being in the highest volatility state occurs on all horizons. Extreme high volatility comovements are then defined as a probability of crisis conditional on the high volatility on other markets.

The model has detected several crises (end 1997, August and September 1998, September 2001, July 2002, October 2002, March 2003 and January 2008) occurring during a high long term volatility cycle. It also appears since 2005 that the US market is less isolated from the European places with a higher probability of extreme comovements. Concerning European places, the euro creation had effect inside Europe since 1999 with a high degree of intra-comovements, but this did not decrease the influential role of the US market.

All these indicators also show that the most recent crisis is an extreme case study for several reasons. First of all, during September 2008, all the volatilities on all markets have attained outstanding peaks. They were first observed in the US in 2007 followed in 2008 by European places. Such peaks were only previously seen during the Asian crisis. Before this crisis, the fact that volatilities are not perfectly in phase (due to different cycle lengths) have weakened correlations. The model has shown that considering these cycle heterogeneities between markets is an important fact since diversification has to be considered both in the range of products and in the duration of the positions. Conditioning the correlation definition on the volatility state and resiliency is thus crucial. However, September 2008 is the first time where volatility cycles on every horizons for all markets are in an extreme high state: there is a global transmission of volatility in every market both on the short and long run.

Through a methodological perspective, it would be interesting in further research to recover a stronger time dependency in the correlations to specify the notion of dependent correlation both on time and on the volatility cycle durations. This would lead to an intermediate model coupling time varying correlations and the specification of the returns based on the product of several long lasting components. To summarize, the use of this empirical model gives a set of new indicators about comovements, other than correlations and refine the notion of comovements and diversification both in terms of markets and cycles.

3.6 Appendix

Appendix 3-A. Transition matrix

The probability that one piece of information arrives at the same time on both markets is given by

$$d_{11,k} = \Pr(I^{\alpha}_{k,t} = 1 = I^{\beta}_{k,t}) = \Pr(I^{\beta}_{k,t} = 1 \mid I^{\alpha}_{k,t} = 1).\Pr(I^{\alpha}_{k,t} = 1), \tag{3.30}$$

and similarly for the probability that only one piece of information arrives on one of the two markets, and no information arrival on both markets. This different probabilities give the following d_k matrices, with element $d_{ij,k}$ where $i = I^{\alpha}_{k,t}$ and $j = I^{\beta}_{k,t}$:

$$d_k = \begin{bmatrix} d_{11,k} & d_{10,k} \\ d_{01,k} & d_{00,k} \end{bmatrix} = \begin{bmatrix} [(1-\lambda)\gamma_k + \lambda]\,\gamma_k & (1-\gamma_k)\,(1-\lambda)\gamma_k \\ (1-\gamma_k)\,(1-\lambda)\gamma_k & [1-\gamma_k(1-\lambda)]\,(1-\gamma_k) \end{bmatrix}. \tag{3.31}$$

Since it is considered a bivariate binomial model, it is obtained for each k that the random vector $M_{k,t}$ can take four possible states: $s^k_1 = \left(m^{\alpha}_0, m^{\beta}_0\right)$, $s^k_2 = \left(m^{\alpha}_0, m^{\beta}_1\right)$, $s^k_3 = \left(m^{\alpha}_1, m^{\beta}_0\right)$, $s^k_4 = \left(m^{\alpha}_1, m^{\beta}_1\right)$ with $m^c_1 = 2 - m^c_0$. The d_k matrix allows for the calculation of the transition matrix T_k of the multipliers vector $M_{k,t} = \binom{M^{\alpha}_{k,t}}{M^{\beta}_{k,t}}$ where each element is defined as

$$t_{ij} = \Pr(s^k_{t+1} = s^k_j \mid s^k_t = s^k_i), \tag{3.32}$$

with $i, j = \{1, 2, 3, 4\}$. All calculations give:

$$T_k = \begin{pmatrix} \Psi_k & \Phi_k\text{-}\left(d_{00,k} + \frac{d_{01,k}}{2}\right) & \Phi_k\text{-}\left(d_{00,k} + \frac{d_{01,k}}{2}\right) & \Psi_k\text{-}(d_{00,k} + d_{01,k}) \\ \Psi_k\text{-}\left(d_{00,k} + \frac{d_{01,k}}{2}\right) & \Phi_k & \Phi_k\text{-}(d_{00,k} + d_{01,k}) & \Psi_k\text{-}\left(d_{00,k} + \frac{d_{01,k}}{2}\right) \\ \Psi_k\text{-}\left(d_{00,k} + \frac{d_{01,k}}{2}\right) & \Phi_k\text{-}(d_{00,k} + d_{01,k}) & \Phi_k & \Psi_k\text{-}\left(d_{00,k} + \frac{d_{01,k}}{2}\right) \\ \Psi_k\text{-}(d_{00,k} + d_{01,k}) & \Phi_k\text{-}\left(d_{00,k} + \frac{d_{01,k}}{2}\right) & \Phi_k\text{-}\left(d_{00,k} + \frac{d_{01,k}}{2}\right) & \Psi_k \end{pmatrix}, \tag{3.33}$$

with

$$\begin{aligned} \Psi_k &= d_{00} + d_{01} + d_{11}\left(\frac{1+\rho_m^*}{4}\right) \\ \Phi_k &= d_{00} + d_{01} + d_{11}\left(\frac{1-\rho_m^*}{4}\right). \end{aligned}$$

Finally, depending on the choice of $\bar{k}$, the number of frequencies in the model, the volatility state transition matrix of asset returns A with elements (a_{ij}) with 1⩽i, j⩽$4^{\bar{k}}$ is given by:

$$a_{ij} = \Pr(S_{t+1} = S^j \mid S_t = S^i),$$

with $S = \left(s^1, s^2, ..., s^{\bar{k}}\right)$, the vector of frequency states so that the number of states grows geometrically with the number of frequencies.

Appendix 3-B. Univariate model estimations

	$\bar{k}$ =1	2	3	4	5	6	7	8
m_0^{CAC}	1.694 (0.017)	1.575 (0.016)	1.468 (0.015)	1.427 (0.014)	1.398 (0.019)	1.336 (0.016)	1.400 (0.015)	1.329 (0.021)
σ^{CAC}	1.788 (0.061)	1.615 (0.046)	1.805 (0.072)	2.035 (0.090)	1.729 (0.102)	1.704 (0.088)	1.245 (0.047)	1.808 (0.113)
b^{CAC}	–	0.126 (0.099)	0.329 (0.135)	0.276 (0.086)	0.503 (0.144)	0.581 (0.117)	0.445 (0.111)	0.645 (0.142)
γ_{CAC}	0.022 (0.0047)	0.023 (0.0048)	0.024 (0.008)	0.037 (0.011)	0.026 (0.009)	0.031 (0.0129)	0.028 (0.0094)	0.026 (0.013)
lnL	-5361.7	-5256.1	-5235.2	-5233.2	-5231.4	-5231.3	-5232.9	-5231.2

Table 3-B-1: MSM(k) estimations by MLE for the CAC index

	$\bar{k}$ =1	2	3	4	5	6	7	8
m_0^{DAX}	1.706 (0.015)	1.612 (0.015)	1.488 (0.013)	1.403 (0.0139)	1.371 (0.014)	1.354 (0.019)	1.369 (0.016)	1.355 (0.023)
σ^{DAX}	1.902 (0.059)	1.647 (0.037)	1.819 (0.0625)	1.654 (0.068)	1.480 (0.058)	1.745 (0.084)	1.090 (0.046)	2.716 (0.185)
b^{DAX}	–	0.069 (0.0487)	0.254 (0.097)	0.463 (0.119)	0.560 (0.098)	0.623 (0.116)	0.487 (0.078)	0.5339 (0.0805)
γ_{DAX}	0.014 (0.0038)	0.031 (0.0053)	0.035 (0.0089)	0.036 (0.0125)	0.036 (0.011)	0.031 (0.088)	0.042 (0.0126)	0.038 (0.0154)
lnL	-5553.9	-5424.5	-5409.5	-5407.2	-5405.5	-5404.5	-5407.7	-5406.6

Table 3-B-2: MSM(k) estimations by MLE for the DAX index

	$\bar{k}$ =1	2	3	4	5	6	7	8
m_0^{FTSE}	1.716 (0.013)	1.595 (0.014)	1.501 (0.016)	1.422 (0.016)	1.391 (0.016)	1.393 (0.022)	1.358 (0.019)	1.312 (0.018)
σ^{FTSE}	1.298 (0.039)	1.431 (0.039)	1.584 (0.073)	1.458 (0.066)	1.611 (0.106)	1.098 (0.076)	1.256 (0.064)	1.222 (0.089)
b^{FTSE}	–	0.301 (0.027)	0.323 (0.134)	0.358 (0.102)	0.367 (0.054)	0.576 (0.185)	0.643 (0.142)	0.678 (0.106)
γ_{FTSE}	0.027 (0.0068)	0.021 (0.0058)	0.026 (0.008)	0.046 (0.0143)	0.049 (0.011)	0.029 (0.0168)	0.028 (0.013)	0.036 (0.0158)
lnL	-4642.8	-4512.8	-4492.6	-4487.5	-4090.4	-4486.6	-4482.6	-4483.4

Table 3-B-3: MSM(k) estimations by MLE for the FTSE index

	$\bar{k}$ =1	2	3	4	5	6	7	8
m_0^{NYSE}	1.780 (0.015)	1.619 (0.015)	1.553 (0.014)	1.468 (0.014)	1.427 (0.018)	1.384 (0.019)	1.428 (0.017)	1.401 (0.027)
σ^{NYSE}	1.641 (0.068)	1.597 (0.061)	1.868 (0.078)	1.778 (0.0815)	1.944 (0.184)	1.882 (0.131)	3.042 (0.365)	1.679 (0.158)
b^{NYSE}	–	0.182 (0.09)	0.217 (0.076)	0.274 (0.066)	0.304 (0.082)	0.326 (0.067)	0.290 (0.058)	0.493 (0.104)
γ_{NYSE}	0.027 (0.006)	0.032 (0.008)	0.040 (0.010)	0.058 (0.018)	0.071 (0.023)	0.108 (0.038)	0.072 (0.021)	0.053 (0.014)
lnL	-4514.5	-4407.8	-4369.9	-4362.3	-4360.5	-4361.4	-4361.8	-4359.2

Table 3-B-4: MSM(k) estimations by MLE for the NYSE index

Appendix 3-C. HAC Vuong Test

This test is presented in Calvet and Fisher (2004) and is based on Vuong (1989) likelihood test ratio for nested and non nested hypotheses. We correct the critical value of the test for the autocorrelation in the likelihood addends using Newey and West (1994) for the optimal lag selection.

	CAC			DAX			FTSE			NYSE		
H1	LRstat	c.v	prob	LRstat	c.v	prob	LRstat	c.v	prob	LRstat	c.v	prob
2vs1	1.84*	0.476	0.00	2.26*	0.50	0.00	2.27*	0.57	0.00	186*	0.490	0.00
3vs2	0.35*	0.250	0.00	0.26*	0.26	0.04	0.35*	0.275	0.02	0.66*	0.302	0.00
4vs3	0.043	0.137	0.30	0.041	0.157	0.33	0.088	0.177	0.21	0.133	0.185	0.13
5vs4	0.032	0.101	0.29	0.029	0.082	0.27	0.038	0.090	0.24	0.031	0.093	0.29
6vs5	0.023	0.071	0.48	0.016	0.053	0.30	0.022	0.133	0.59	0.014	0.069	0.37
7vs6	-0.011	0.026	0.47	0.055	0.108	0.20	0.069	0.059	0.28	0.008	0.072	0.43
8vs7	0.029	0.086	0.28	0.020	0.121	0.40	0.014	0.046	0.31	0.045	0.095	0.22
5vs3	0.011	0.101	0.45	0.071	0.154	0.22	0.127	0.163	0.11	0.163	0.172	0.06
6vs3	0.003	0.127	0.52	0.087	0.145	0.16	0.105	0.185	0.17	0.149	0.171	0.08
7vs3	0.012	0.138	0.54	0.031	0.191	0.29	0.174	0.179	0.07	0.141	0.176	0.10
8vs3	0.038	0.110	0.29	0.051	0.143	0.17	0.160	0.173	0.08	0.187	0.180	0.08

$HAC{-}Vuong$ test. Null Hypothesis: models are equivalent against H1.

Appendix 3-D. Bivariate model estimations

	CAC-DAX	CAC-FTSE	CAC-NYSE	DAX-FTSE	DAX-NYSE	FTSE-NYSE
m_0^1	1.576 (0.016)	1.574 (0.015)	1.576 (0.017)	1.610 (0.014)	1.612 (0.014)	1.598 (0.015)
σ^1	1.610 (0.043)	1.622 (0.046)	1.624 (0.046)	1.647 (0.039)	1.651 (0.043)	1.427 (0.044)
m_0^2	1.610 (0.013)	1.596 (0.0137)	1.616 (0.0138)	1.597 (0.0140)	1.618 (0.0161)	1.615 (0.0146)
σ^2	1.646 (0.035)	1.429 (0.0395)	1.587 (0.055)	1.424 (0.039)	1.598 (0.066)	1.581 (0.059)
b	0.088 (0.048)	0.221 (0.099)	0.190 (0.079)	0.144 (0.063)	0.134 (0.056)	0.233 (0.103)
γ_1	0.027 (0.004)	0.022 (0.0041)	0.032 (0.0053)	0.027 (0.0043)	0.035 (0.005)	0.031 (0.0054)
λ	0.949 (0.480)	0.957 (0.482)	0.781 (0.484)	0.746 (0.405)	0.608 (0.412)	0.871 (0.440)
ρ_ε	0.886 (0.069)	0.825 (0.0049)	0.768 (0.0076)	0.7901 (0.0068)	0.748 (0.009)	0.752 (0.0083)
lnL	-8230.5	-7949.1	-8296.1	-8420.2	-8580.9	-7561.3

Table 3-D-1: Bivariate $MSM(2)$

	CAC-DAX	CAC-FTSE	CAC-NYSE	DAX-FTSE	DAX-NYSE	FTSE-NYSE
m_0^1	1.428 (0.016)	1.425 (0.0168)	1.428 (0.0161)	1.462 (0.021)	1.405 (0.0158)	1.424 (0.016)
σ^1	2.04 (0.107)	1.997 (0.105)	2.032 (0.010)	2.259 (0.177)	1.657 (0.070)	1.459 (0.072)
m_0^2	1.485 (0.017)	1.421 (0.016)	1.547 (0.018)	1.422 (0.015)	1.464 (0.014)	1.466 (0.015)
σ^2	2.511 (0.152)	1.481 (0.078)	1.513 (0.063)	1.483 (0.073)	1.784 (0.088)	1.788 (0.098)
b	0.252 (0.051)	0.335 (0.072)	0.280 (0.082)	0.319 (0.060)	0.357 (0.066)	0.312 (0.056)
γ_1	0.036 (0.0061)	0.040 (0.0093)	0.037 (0.007)	0.042 (0.008)	0.045 (0.0102)	0.052 (0.0108)
λ	0.963 (0.473)	0.968 (0.482)	0.901 (0.419)	0.883 (0.454)	0.843 (0.446)	0.859 (0.173)
ρ_ε	0.891 (0.0038)	0.828 (0.0051)	0.774 (0.008)	0.799 (0.006)	0.761 (0.0078)	0.766 (0.0078)
lnL	-8113.5	-7871.6	-8194.2	-8300.2	-8390.5	-7450.2

Table 3-D-2: Bivariate $MSM(4)$

	CAC-DAX	CAC-FTSE	CAC-NYSE	DAX-FTSE	DAX-NYSE	FTSE-NYSE
m_0^1	1.397 (0.019)	1.398 (0.0193)	1.395 (0.019)	1.401 (0.029)	1.371 (0.0163)	1.392 (0.015)
σ^1	1.721 (0.091)	1.729 (0.077)	1.718 (0.082)	2.047 (0.144)	1.485 (0.059)	1.621 (0.083)
m_0^2	1.423 (0.029)	1.419 (0.018)	1.423 (0.016)	1.390 (0.016)	1.413 (0.015)	1.425 (0.017)
σ^2	1.943 (0.120)	1.510 (0.073)	2.019 (0.167)	1.598 (0.085)	1.844 (0.124)	1.962 (0.149)
b	0.490 (0.092)	0.494 (0.098)	0.385 (0.065)	0.405 (0.069)	0.435 (0.063)	0.335 (0.048)
γ_1	0.028 (0.0063)	0.026 (0.0073)	0.042 (0.083)	0.042 (0.009)	0.051 (0.011)	0.058 (0.012)
λ	0.970 (0.47)	0.983 (0.486)	0.913 (0.399)	0.908 (0.443)	0.906 (0.439)	0.890 (0.455)
ρ_ε	0.892 (0.0038)	0.828 (0.0058)	0.765 (0.008)	0.795 (0.0064)	0.756 (0.008)	0.761 (0.0076)
lnL	-8088.3	-7866.5	-8161.7	-8268.4	-8391.5	-7436.7

Table 3-D-3: *Bivariate* MSM(5)

Appendix E. Conditional extreme comovements

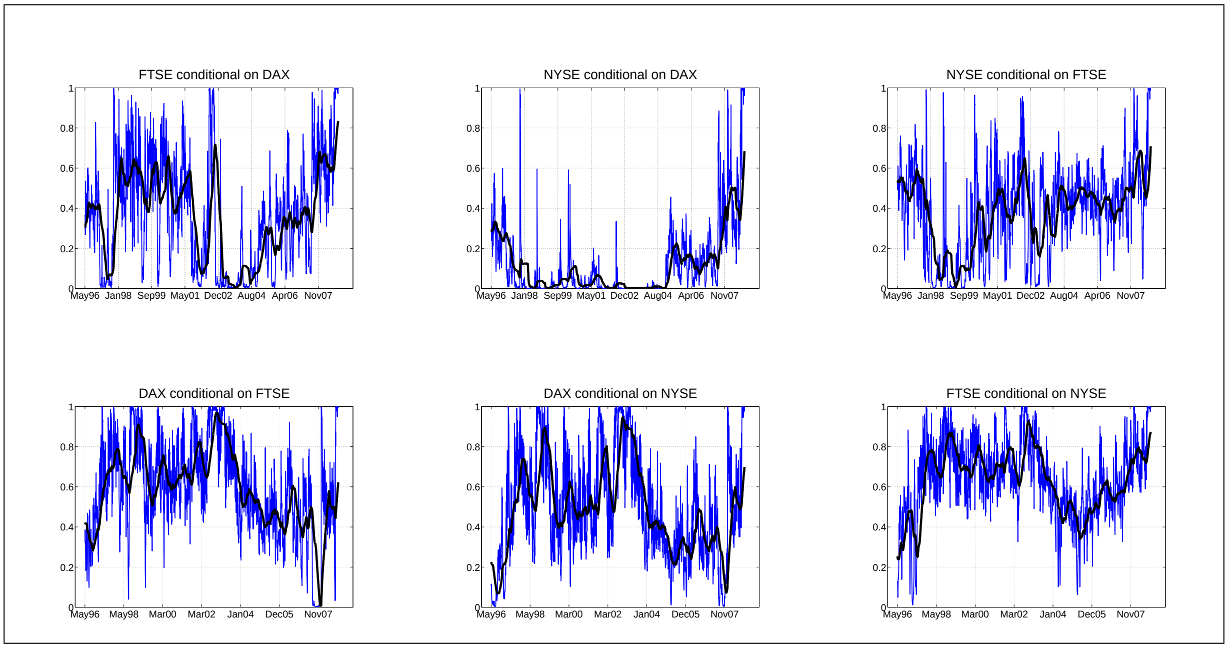


Figure 3-6: Bivariate MSM(3) : conditional probability of extreme comovements

Appendix F. Long run volatility cycles

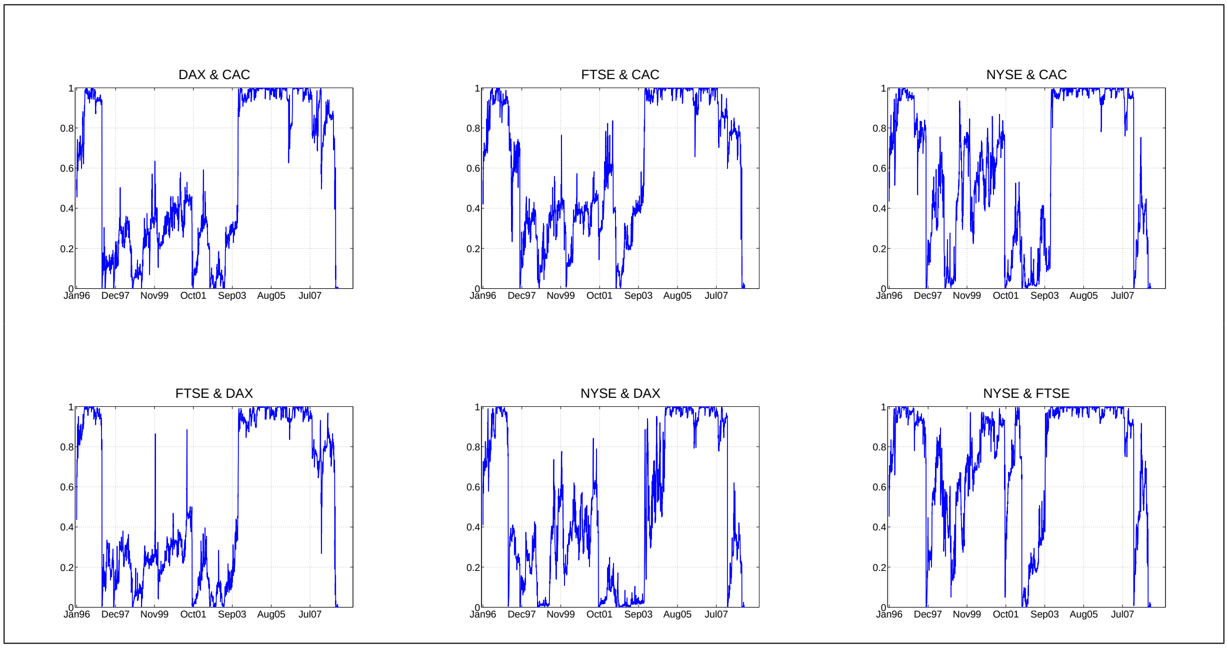


Figure 3-7: Bivariate MSM(3) : Probability of long term low volatility cycle

Chapter 4

A Markov switching multifractal model with time varying correlations

Non Technical summary[1]

This chapter introduces a hybrid model combining a dynamic conditional correlation and a multifractal specification of asset returns. This chapter aims at remedying shortcomings of the MSM model outlined in the previous chapter in terms of correlation. Indeed, the MSM model of Calvet et al. (2006) assume a constant correlation between the residuals. Our contribution is to relax this assumption by using a conditional correlation model, introducing time dependency in the correlation. This extension allows for keeping the benefits of the MSM models described in the previous chapter, and gives some more flexibility to the correlation. In particular, we complete by a DCC model (as in Engle and Sheppard (2002)) the MSM model to improve its performances. Besides, this permits to consider the positive trends that correlations between European markets exhibit.

Precisely, comovements analyses usually focus on the level of correlation. Our approach focuses on the dynamics of the correlations but also in terms of re-correlation.

The re-correlation is the process by which a well diversified portfolio of assets may finally present some strong correlations in times of crisis inducing chain losses. This comes from an underestimation of correlations during periods of low volatility in the markets. However, as widely observed in the late 2008, some assets supposed unrelated were finally highly correlated and induced chain losses.

In our model the re-correlation risk is taken into account by conditioning correlation to the market volatility state. Therefore, the correlation is as a combination of two components. The first one reflects the structural time process of the correlation which represents the highest possible level of correlation. The second component is a scaling factor which moderates correlation when the volatility processes are not perfectly correlated. For example, let considers a common shock in two different markets. If it triggers a simultaneous high volatility then we have some perfect

[1] I thank Laurent Calvet, Phillippe Charlot, Gaelle Le Fol, Valérie Mignon and participants of the "journée d'économétrie" at University Paris X and participants at the 2008 Banque de France-AMF conference for helpful comments and discussions.

spillovers and thus the correlation, depending on the magnitude of the shock, reaches its maximum. If the same shock effects are shifted in time or not transmitted, the scaling factor becomes lower than unity and moderates the level of correlation.

Therefore during crisis, i.e. periods of high and common volatility between places, the scaling factor takes value 1 and induces re-correlation between the prices of assets. The empirical part of this work concerns the same daily data as before: the CAC, DAX, FTSE and NYSE from January 1996 to November 2008. Two major crises have in particular led to re-correlation: the Asian crisis and the crisis started in 2008 referring to a very strong spread of the disturbances. From an econometric point of view it appears that the MSMDCC model beats the MSM and DCC models when the number of frequencies considered in the model is high enough.

4.1 Introduction

In this chapter, we consider the dynamic conditional correlation model [DCC] of Engle and Sheppard (2002)) and a Markov switching multifractal model [MSM] in line with Calvet et al. (2006). This specification [MSMDCC] presents two main advantages:

- the correlation is time dependent in contrast with the original MSM model;
- its parsimonious specification allows for a large number of states.

This new model is a model of state-dependency in the class of DCC. One the one hand, we consider several volatility and correlation states, but on the other hand we also consider time dependency conversely to the original MSM specification by relaxing some assumptions.

In the literature of financial econometrics, several approaches consider the modelling of variance covariance matrices from the class of multivariate GARCH to the class of non-parametric specification of variance-covariance matrices via high frequency data, as presented in Chapter 1. However, a drawback of this class of models is the rapid increase in the number of parameters to estimate with the number of assets or if we introduce some regime switches. Some improvements have been made with the introduction of the DCC of Engle and Sheppard (2002) or that of Tse and Tsui (2002) who consider a fixed number of parameters whatever is the number of assets. Overall, dynamic conditional correlation models, since the work of Bollerslev (1990), have been used, with several specifications to circumvent all these issues. Notably, estimations of such models is quite popular since they characterized both the market risk by the estimation of volatilities and comovements with the estimation of dynamic correlations.

The alternation of low and high volatility periods claims for some switches in DCC models as in Billio and Caporin (2005) or Pelletier (2006). However, regime switches in models of correlation are not easy to implement since it implies once again, an even higher number of parameters. The introduction of state-dependence in tools dedicated to the analysis of financial markets is crucial since the dynamics may be very different if the market is calm or the market is highly volatile (with the occurrence of contagion phenomena as stated in Forbes end Rigobon (2002) or Dungey et al. (2005)).

In the class of state-dependent models, the MSM model is very parsimonious and involves a large number of states (Calvet et al. (2006 and 2007), Lux (2008), Lux and Kaizoji (2007), Liu and Lux (2005) or the precedent chapter, among others). This multifractal model considers that the market is heterogeneous (as in Zumbach and Lynch (2001)) and analyzes price movements on the different horizons of the market . This was already done in the class of ARCH models by Müller et al. (1997) or with the HAR model (Heterogeneous Auto Regressive model) of Corsi (2002). However, these two models are not yet suited for correlations.

From a diversification point of view, highly volatile periods are key since they induce fewer diversification opportunities. In the case of dynamic portfolio management, a rise in the correlation between the assets used as portfolio components is a risk. This risk may notably be underestimated when correlations are calculated during low volatility periods. Most of the time, the correlation between prices may be moderate because of some differences in behaviours on the market, some arbitrage opportunities or strategies. However, in times of crisis, recorrelation occurs between markets, so that the linkages between asset prices are finally very strong. As a consequence, investors incur some chain losses. This concept of recorrelation motivates this chapter by introducing a model that takes into account both the various states of market volatility and the classical temporal evolution of the correlation.

By combining the two models mentioned above (DCC and MSM) we capture the specificities of both: the flexibility of the temporal dependence on the one hand and the large number of states induced by a parsimonious specification, on the other one. The aim is to refine our understanding of the price linkages by exploiting the many states of the MSM, without disregarding the time process.

The model MSMDCC appears more flexible than the standard model MSM whose correlation dynamics is only based on the state associated with market volatilities. The correlation obtained from MSMDCC model is the combination of the volatility state and the evolution of the correlation over time.

The chapter is organized as follows. In Section 4-2, the model is presented. The MSM model Calvet et al. (2006) is extended by introducing a model similar to the DCC of Engle and Sheppard (2002). As a result, we derive and discuss the correlations. Section 4-3 introduces the estimation procedures and compare the MSMDCC model with the MSM and DCC models on the basis of the dataset used in chapter 3. Section 4-4 concludes.

4.2 A Multifractal setup with time varying correlations

We refine the concept of comovements of price dynamics assuming two types of comovements usually not handled in a unified framework. To be more precise, methods for measuring comovements are for some of them based on the dynamic of the correlation analyzed in a pure temporal dimension. An exception is the model of dynamic correlation with regime switches of Billio and Caporin (2005) or Pelletier (2006) which consider both the temporal process and regime switches.

The MSMDCC model objective is to improve this by considering two types of dependencies. On the one hand, we have the temporal dimension of the standard dynamic correlation and on the other hand a dependence on market risk (volatility) introduced by the multifractal model (Calvet et al. (1997), Fillol (2003), Calvet and Fisher (2001 & 2002)).

4.2.1 The model

Similarly to the previous chapter, we consider the vector of rates of returns as $x_t = \binom{x_t^\alpha}{x_t^\beta}$ for two assets α and β as this:

$$x_t = \begin{pmatrix} M_t^{\alpha^{1/2}} \\ M_t^{\beta^{1/2}} \end{pmatrix} * \varepsilon_t \tag{4.1}$$

All the variables have been defined in chapter 3 (section 3.3).

This specification, as shown in Calvet et al. (2006), Calvet et al. (2007) or in the precedent chapter has very satisfactory applications with the possible derivation of comovement indicators other than correlations. Its economic interpretation is very simple since the model considers that shocks (represented by the jumps in the volatility components) occur on several heterogeneous horizons. Traders with outstanding positions may launch long periods of high volatility while some others may initiate volatility only for some days. However, this specification has the main drawback to ignore time varying correlations.

Indeed, Calvet et al. (2006) consider the residual vector ε_t to be bivariate Gaussian with constant variance covariance matrix $\Sigma = \begin{bmatrix} \sigma_\alpha^2 & \rho_\varepsilon \sigma_\alpha \sigma_\beta \\ \rho_\varepsilon \sigma_\alpha \sigma_\beta & \sigma_\beta^2 \end{bmatrix}$ where σ_α^2 and σ_β^2 are the respective return variances and ρ_ε the assumed constant correlation between the residuals.

Besides, correlations are not like volatility and usually presents some trends as a result of more interdependence between markets. As a consequence, the new set-up of the bivariate MSM model considers that the vector of residuals $\varepsilon_t \in \mathbb{R}^2$ is bivariate Gaussian $(0,\Sigma_t)$ such that the variance covariance matrix Σ_t is time dependent. This is similar to the specification of multivariate GARCH models.

In the standard DCC models volatilities are specified as GARCH models. In the MSMDCC($\bar{\mathrm{k}}$), volatilities follow a MSM($\bar{\mathrm{k}}$) specification. Their variations over time is due to the heterogeneity in states implied by the multifractal specification. The remaining multifractal specification is similar to the one exposed in the previous chapter (page 142). In this framework, we finally consider $4^{\bar{k}}$ states in the volatility processes and these states then influence the level of the conditional dynamic correlation as follows.

The covariance matrix Σ_t in the spirit of the DCC model of Engle and Sheppard (2002) is defined as

$$\Sigma_t = \begin{pmatrix} M_t^{\alpha^{1/2}} & 0 \\ 0 & M_t^{\beta^{1/2}} \end{pmatrix} D R_t D \begin{pmatrix} M_t^{\alpha^{1/2}} & 0 \\ 0 & M_t^{\beta^{1/2}} \end{pmatrix} \tag{4.2}$$

with $D = diag\{\sigma_\alpha, \sigma_\beta\}$, R_t the correlation matrix further defined and $\begin{pmatrix} M_t^{\alpha^{1/2}} & 0 \\ 0 & M_t^{\beta^{1/2}} \end{pmatrix}$ the diagonal matrix of the product of the components.

One major difference with the usual DCC models is that the matrix D is constant over time. Actually, the dynamics of the volatilities stem from the state dependency. It is not time dependent, as it is in the DCC framework through GARCH models. The expected variance conditional on the state $M_t = m^i$ with a probability of realization $\Pi_{i,t}$ for $i = 1$ to $4^{\bar{k}}$ is:

$$E_t(\Sigma_t) = \sum_{i=1}^{4^{\bar{k}}} \Pi_{i,t} E_t(\Sigma_t \mid M_t = m^i), \tag{4.3}$$

with

$$\begin{aligned} E_t(\Sigma_t \quad | \quad M_t = m^i) = & \\ & E_t\left[\begin{pmatrix} M_t^{\alpha^{1/2}} & 0 \\ 0 & M_t^{\beta^{1/2}} \end{pmatrix} D R_t D \begin{pmatrix} M_t^{\alpha^{1/2}} & 0 \\ 0 & M_t^{\beta^{1/2}} \end{pmatrix} \middle| M_t = m^i \right], \end{aligned} \tag{4.4}$$

so that similarly to Calvet et al. (2006) the filtered variance covariance matrix is

$$E_t(\Sigma_t) = \begin{pmatrix} \sigma_\alpha^2 \prod_{k=1}^{\bar{k}} E_t\left[M_{k,t}^\alpha\right] & \rho_t \sigma_\alpha \sigma_\beta \prod_{k=1}^{\bar{k}} E_t\left[(M_{k,t}^\alpha M_{k,t}^\beta)^{\frac{1}{2}}\right] \\ \rho_t \sigma_\alpha \sigma_\beta \prod_{k=1}^{\bar{k}} E_t\left[(M_{k,t}^\alpha M_{k,t}^\beta)^{\frac{1}{2}}\right] & \sigma_\beta^2 \prod_{k=1}^{\bar{k}} E_t\left[M_{k,t}^\beta\right] \end{pmatrix}, \tag{4.5}$$

where ρ_t is the time varying off-diagonal element of R_t. In this setting, the expectations over time of the standardized residuals η_t are defined as

$$E_t(\eta_t) = \sum_{i=1}^{4^{\bar{k}}} \Pi_{i,t} E_t(\eta_t \mid M_t = m^i), \tag{4.6}$$

with

$$E_t(\eta_t \mid M_t = m^i) = E_t\left(\left[\begin{pmatrix} M_t^{\alpha^{1/2}} & 0 \\ 0 & M_t^{\beta^{1/2}} \end{pmatrix} D \right]^{-1} \varepsilon_t \middle| M_t = m^i \right). \tag{4.7}$$

Following the DCC specification of Engle and Sheppard (2002), the correlation matrix R_t in equation (4.2) is defined as

$$R_t = Q_t^{*^{-1}} Q_t Q_t^{*^{-1}}, \tag{4.8}$$

with

$$Q_t = (1 - \theta_1 - \theta_2)\bar{Q} + \theta_1 E_{t-1}(\eta_{t-1}) E_{t-1}(\eta_{t-1})' + \theta_2 Q_{t-1}, \tag{4.9}$$

where $\theta_1, \theta_2 > 0$ and $\theta_1 + \theta_2 < 1$ and:

(i) the unconditional correlation $\bar{Q}$ is defined as

$$\bar{Q} = \frac{1}{T} \sum_{t=1}^{T} \sum_{i=1}^{4^{\bar{k}}} \Pi_i^0 E_t(\eta_t \mid M_t = m^i) E_t(\eta_t \mid M_t = m^i)', \tag{4.10}$$

so that $\Pi^0 = (\Pi_1^0, \Pi_2^0, ...\Pi_{4^{\bar{k}}}^0)$ is the ergodic distribution of the Markov switching process;

(ii) $Q_t^* = diag\{\sqrt{q_{\alpha\alpha,t}}, \sqrt{q_{\beta\beta,t}}\}$ with $q_{cc,t}$ are the diagonal elements of Q_t for $c = \{\alpha, \beta\}$.

4.2.2 The MSMDCC correlation

From equation (4.5) the conditional correlation between returns is:

$$Corr_t\left(x_t^\alpha, x_t^\beta\right) = \rho_t \prod_{k=1}^{\bar{k}} \frac{E_t\left[(M_{k,t}^\alpha M_{k,t}^\beta)^{\frac{1}{2}}\right]}{\left[E_t(M_{k,t}^\alpha)E_t(M_{k,t}^\beta)\right]^{\frac{1}{2}}}. \tag{4.11}$$

This correlation thus presents some time dependency but the level of correlation is lowered by the fractal components so that the variability of this correlation is higher than the simple MSM. These two dimensions of time dependency and state dependency may be seen in the model by picturing the two components separately of the correlation as

$$Corr_t\left(x_t^\alpha, x_t^\beta\right) = \rho_t s_t, \tag{4.12}$$

with

$$\rho_t = \frac{1}{\sqrt{q_{\alpha\alpha,t}q_{\beta\beta,t}}}\left[(1-\theta_1-\theta_2)\bar{q}_{\alpha\beta} + \theta_1\left(E_t(\eta_{\alpha,t})E_t(\eta_{\beta,t})\right) + \theta_2 q_{\alpha\beta,t-1}\right],$$

$$s_t = \prod_{k=1}^{\bar{k}} s_{k,t} \leq 1, \tag{4.13}$$

with $s_{k,t} = \frac{E_t\left[(M_{k,t}^\alpha M_{k,t}^\beta)^{\frac{1}{2}}\right]}{\left[E_t(M_{k,t}^\alpha)E(M_{k,t}^\beta)\right]^{\frac{1}{2}}}$. This is very useful for example in the case of the European Union and the convergence of stock market indices. For this application, the MSM model is not satisfactory since it does not take into account the positive trend in correlations, but only the heterogeneity of shocks that have occurred in the process of volatility. For similar reasons, the DCC model is also unsatisfactory because it only considers the time dependence without ever considering the heterogeneity of shocks and their resiliencies in the process of volatility. Indeed, the heterogeneity of shocks is considered in the MSMDCC by their size (via the standardized residuals $E_t(\eta_t)$) and by their duration in the $s_{k,t}$ factors.

The first level ρ_t is conditional on time. This is the traditional view of the correlation. The second level of dependency concerns shocks with potential effects on both the short and long term volatilities that influence the process of correlation via s_t.

In addition, the scaling factor may be close to unity in the short term but not in the long term, for example. This dichotomy between the impact of the shocks and their length is similar to that used in the precedent chapter for the derivation of indicators with a MSM model.

Note that s_t is high when the components are high and implies that $Corr_t\left(x_t^\alpha, x_t^\beta\right)$ is then close to its maximum ρ_t. In other cases, the conditional correlation $Corr_t\left(x_t^\alpha, x_t^\beta\right)$ is lowered by s_t. When the volatility processes are less correlated the additional noise makes the returns series less correlated. From equation (4.13), the maximum of s_t is reached when the multifractal components are perfectly correlated on every horizon: this opens a recorrelation period. As a consequence, comovements are the highest between places when the volatilities are also perfectly correlated. This is linked to perfect spillovers between markets.

4.2.3 The Maximum likelihood estimation

The formula used for estimation are similar to the ones of section 3.3 page 148 in the previous chapter. One difference is that the returns at $t+1$ are observed and are assumed to follow a bivariate Gaussian density conditional on the volatility state $f_{x_{t+1}}(x_{t+1} \mid M_{t+1} = m^j)$ with variance covariance matrix $H_{j,t+1}$:

$$H_{j,t+1} = \begin{bmatrix} \sigma_\alpha^2 M_{t+1}^\alpha & \rho_{t+1}\sigma_\alpha\sigma_\beta\left(M_{t+1}^\alpha M_{t+1}^\beta\right)^{1/2} \\ \rho_{t+1}\sigma_\alpha\sigma_\beta\left(M_{t+1}^\alpha M_{t+1}^\beta\right)^{1/2} & \sigma_\beta^2 M_{t+1}^\beta \end{bmatrix} \tag{4.14}$$

Indeed, contrary to the standard bivariate MSM model, the bivariate Gaussian density is time varying, since the variance covariance matrix H is also time dependent. The updated probability is a function of actual returns and the history of past probabilities:

$$\Pi_{t+1}^{j} = \frac{f(x_{t+1}) * \Pi_t A}{[(f(x_{t+1}) * \Pi_t A)\, \iota']} \tag{4.15}$$

with * the Hadamard product, ι a $(1 \times 4^{\bar{k}})$ vector of ones, A the transition matrix and $f(x_{t+1})$ a $(1, 4^{\bar{k}})$ vector of elements $f_{x_{t+1}}(x_{t+1} \mid M_{t+1} = m^j)$.

The set of parameters $\Theta = (\sigma_\alpha, \sigma_\beta, m_0^\alpha, m_0^\beta, b, \gamma_1, \lambda, \rho^*, \theta_1, \theta_2) \in \mathbb{R}^{10}$ is estimated by maximum likelihood similarly to the previous chapter as:

$$l(x_{1...}x_T; \Theta) = \sum_{t=1}^{T} \ln(f(x_t \mid x_{t-1,}x_{t-2}, ...x_1)) \tag{4.16}$$

with

$$f(x_t \mid x_{t-1,}x_{t-2}, ...x_1) = \sum_{j=1}^{4^{\bar{k}}} f(x_t \mid M_{t-1} = m^j) \Pr(M_{t-1} = m^j \mid x_{t-1,}x_{t-2}, ...x_1) \tag{4.17}$$

so that the log likelihood is finally

$$l(x_{1...}x_T; \Theta) = \sum_{t=1}^{T} \ln(f(x_t).\, (\Pi_{t-1} A)). \tag{4.18}$$

A two step estimation procedure is applied as for the original MSM model, and the standard errors are, as a consequence, corrected as in Calvet et al. (2006). The first estimation step is similar for both the MSM and the MSMSDCC. It estimates a combined univariate models as in Calvet et al. (2006) and in the precedent chapter and then the full likelihood is maximized as in equation (4.18). In other terms we implement the following algorithm:

(i) The combined volatility processes for series α and β are implemented so that the two volatilities are specified as a restricted MSM model. This is similar to the first step of the bivariate MSM model introduced by Calvet et al. (2006). It is a restricted model since parameters γ_1 and b are supposed to be the same for both return series.

(ii) The expected value of standardized residuals, conditional on the volatility states are calculated through equation (4.7) by using the estimated parameters of step (i).

(iii) $\bar{Q}$ is then calculated using the ergodic distribution of the Markov switching process and this distribution is also used to initiate the vector of probability states at date zero.

(iv) The standardized residuals in $t-1$ are calculated ex post at date t through equation (4.6) by using the state probabilities prevailing at date $t-1$.

(v) The conditional variance-covariance matrices are calculated at date t by applying equations (4.4), (4.8) and (4.9), using the past values of the correlation matrix and the lag of the standardized residuals calculated in step (iv).

(vi) The likelihood conditional on state m^j is calculated using the Gaussian bivariate distributions with zero mean and conditional variance-covariance matrices obtained from step (v). The probability of state j at date t is calculated for $j = 1$ to $4^{\bar{k}}$ through equation (4.15) and the likelihood at date t is computed as in equation (4.17).

(vii) Finally, we reiterate the algorithm from step (iv) to step (vii) over the entire sample to obtain the complete likelihood as in equation (4.18).

4.3 Empirical illustrations

The linkages between markets have strengthened in recent years due to several factors that have been underlined in the introduction of this thesis. The most obvious concerns the European monetary union that facilitates arbitrages between markets in the Euro zone. Moreover, the spread of financial crisis has increased the correlation risk supported by portfolio supposed to be well diversified. This section provides an analysis of comovements based on four stock indices with the MSMDCC model.

4.3.1 Dataset

This model considers the same dataset as in the previous chapter (see page 149). Bivariate models are estimated so that six couples of series are considered. All the data are index prices at 3 p.m. GMT obtained from Thomson-Reuters.

These graphs show that the stock index returns present some similar clusterings. The picture of the CAC and the DAX are close so that we can expect correlations to be high. It is more heterogeneous with the FTSE and the NYSE. The usual descriptive statistics for the geometric returns are given in appendix 4-A. They show excess kurtosis and negative skewness. The excess kurtosis is due to some large shocks on the data inducing fat tails. It is thus hard to think in terms of unique Gaussian distribution for the returns. Considering a state dependent model clearly improves the fit to the data since we have for each state a different Gaussian distribution and once filtered we finally obtain a mixture of Gaussian distributions for the returns. Then the skewness is negative so that the weight of the return distributions is on the negative side. By considering this dataset, it is interesting to gauge the interactions between the stock markets.

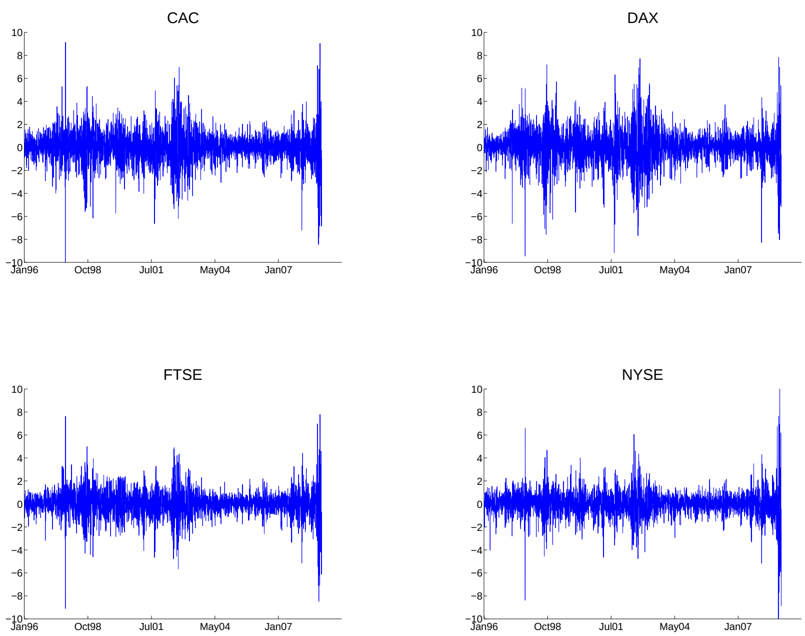


Figure 4-1: Geometric index returns for the CAC, DAX, FTSE and NYSE indexes between 02/01/1996 and 15/11/2008.

4.3.2 Estimations & model comparisons

Appendices 4-B & 4-C present the estimations. Several models are used to calculate the correlations between indexes. The first one is the standard DCC model, the second type of models are MSM models, and the third type is the above defined MSMDCC model. The MSMDCC and MSM models are estimated for $\bar{k} = 1$ to 5.

Estimations provided for the first subset of parameters is similar to the previous chapter as stated in the estimation algorithm exposed in section 4.2.3. The differences between the two models lie in the dependence structure. Concerning both the MSM and the MSMDCC, the correlation between the jumps λ is quite high and pretty stable across models. For the MSM, the correlation between the residuals ρ_{ε}, is quite high and close to the sample correlation. For the MSMDCC, the correlation dynamic exhibits high persistence with $\theta_1 + \theta_2$ close to unity. However, some heterogeneous lasting shocks also occur through the multifractal setup and finally modify the time dependent correlation of the returns.

We focus here on models with three frequencies i.e. $\bar{k} = 3$. The correlation between the jumps (λ) from one volatility state to another is the highest for the couples CAC-DAX and CAC-FTSE so that these places are almost always in the same volatility state. From a time dependency point of view, all the correlations are very persistent. This is confirmed by the estimation of DCC models whose persistence is also close to unity. One key element is that in most cases, the DCC persistence is lower than the MSMDCC one. This clearly comes from the fact that some negative shocks, independent of the time process in the MSMDCC may occur, so that the pure time dependency in this model may be stronger. The time dependency in the MSMDCC thus represents the highest level of dependency that we may observe on the market if all shock impacts are perfectly and instantaneously transmitted between markets. This is key to define the recorrelation phenomenon.

We compare MSM, MSMDCC and DCC using likelihood ratio tests based on Vuong (1989) for nested and non nested hypotheses. All the tests are presented in appendix 4-C with the estimation results of the several models. Three likelihood ratio tests are performed. The first one (as LR1) tests the null hypothesis that MSM and MSMSDCC are equivalent against the alternative that MSMDCC is better than MSM. LR2 tests the null hypothesis that DCC model and MSM model are equivalent against the alternative that MSM is superior to the DCC model. LR3 tests the null hypothesis that the MSMDCC and DCC are equivalent against the alternative that the MSMDCC is superior to the DCC model.

The results show that the MSMDCC models always beat the standard MSM model. In this sense, allowing for a time dimension in the correlation process has clearly improved the fit of the model. Moreover, when we consider a sufficiently high number of frequencies, MSMDCC presents significant higher likelihoods than the standard DCC model. Notably, the MSMDCC is in most cases better than the DCC at the 5% confidence level if $\bar{k} > 3$. Comparing MSM and DCC models the conclusions are not clear so that it claims for the consideration of both models in a unified framework as the MSMDCC.

Figure 4-1 reports the dynamic correlations obtained from the MSM(3), the DCC and the MSMDCC(3) models. The correlations obtained with a MSM model is not appropriate since there is no time dependency and stay close to the sample correlations. Considering the two other models, the correlations obtained from the DCC model is very reactive to shocks, with correlations presenting some transient discontinuities at some point in time. The MSMDCC correlation appears to be an intermediate case. On the one hand, it is more varying than the MSM correlation, but it is more stable than DCC on the other hand. This comes from the multifractal scaling factor that hampers some of the shocks, when the volatility processes of the series are not perfectly correlated (i.e. when shocks occur on different lasting horizons).

4.3.3 Comovements analysis

The convergence of stock markets is clearly observed with more or less instantaneous price adjustments between markets. The usual literature on comovements, transmission and contagion focuses

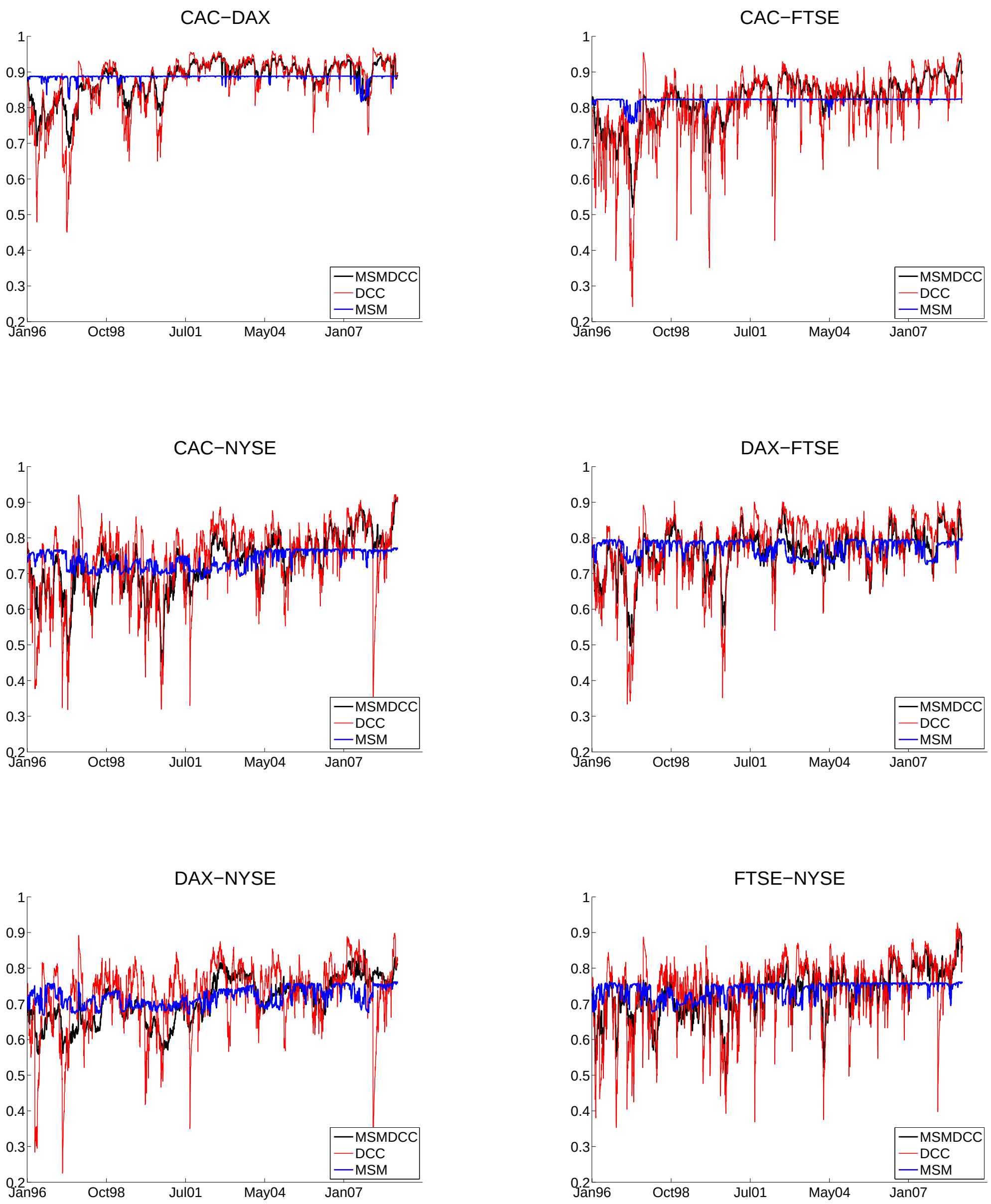


Figure 4-2: Correlations from MSMDCC(3), DCC and MSM(3) models

on a fundamental links between markets and the emergence of some additional channels during crises. Crisis and excess comovements in the framework of MSM model have been studied in the precedent chapter. We improve the approach by introducing a time varying correlation in the MSMDCC. This approach is different in spirit than the usual literature. Indeed, it estimates as seen in equation (4.11) a ceiling correlation that is fundamentally high. This correlation is further moderated by the scaling multifractal factor. It means that the pure time dependence estimated in the model is actually the highest level of transmission observed in the market.

The model thus defines two levels of correlation. The first one is the structural correlation which is the highest possible correlation between prices and is represented by ρ_t. The second level is the multifractal scaling factor s_t that represents some frictions in the market and lowers the first level of correlation. The observed correlation is then the product of these two components $\rho_t s_t$.

Figure 4-2 below represents this two components separately for each considered couple of indexes between 1996 and 2008.

Looking at the ρ_t evolution, almost all correlations rose over the sample. This can be attributed to the increasing commonality in shocks. The CAC-DAX correlation is the highest exceeding 0.9 from 2002 to 2007; it then stabilizes around this level. The CAC-FTSE correlation rose over the entire sample to reach 0.85 by 2008. The CAC-NYSE correlation dynamics is less regular than the previous ones. It rises but we note two decreasing periods: 1999-2001 and 2003-2004. The correlation between the DAX and the FTSE and NYSE are not increasing as it is for the CAC index one. It is more erratic and stays below 0.85. However, a comparison between DAX-NYSE and CAC-NYSE correlations show that the DAX does not really exert any decreasing tendency in correlation as previously highlighted for the CAC. Finally, the FTSE-NYSE correlation has also raised, but with two decreasing periods: 1999-2001 and 2002-2003.

These comments apply to the highest level of comovements that market participants may expect during periods of high transmission. However, there are some frictions on the market that make

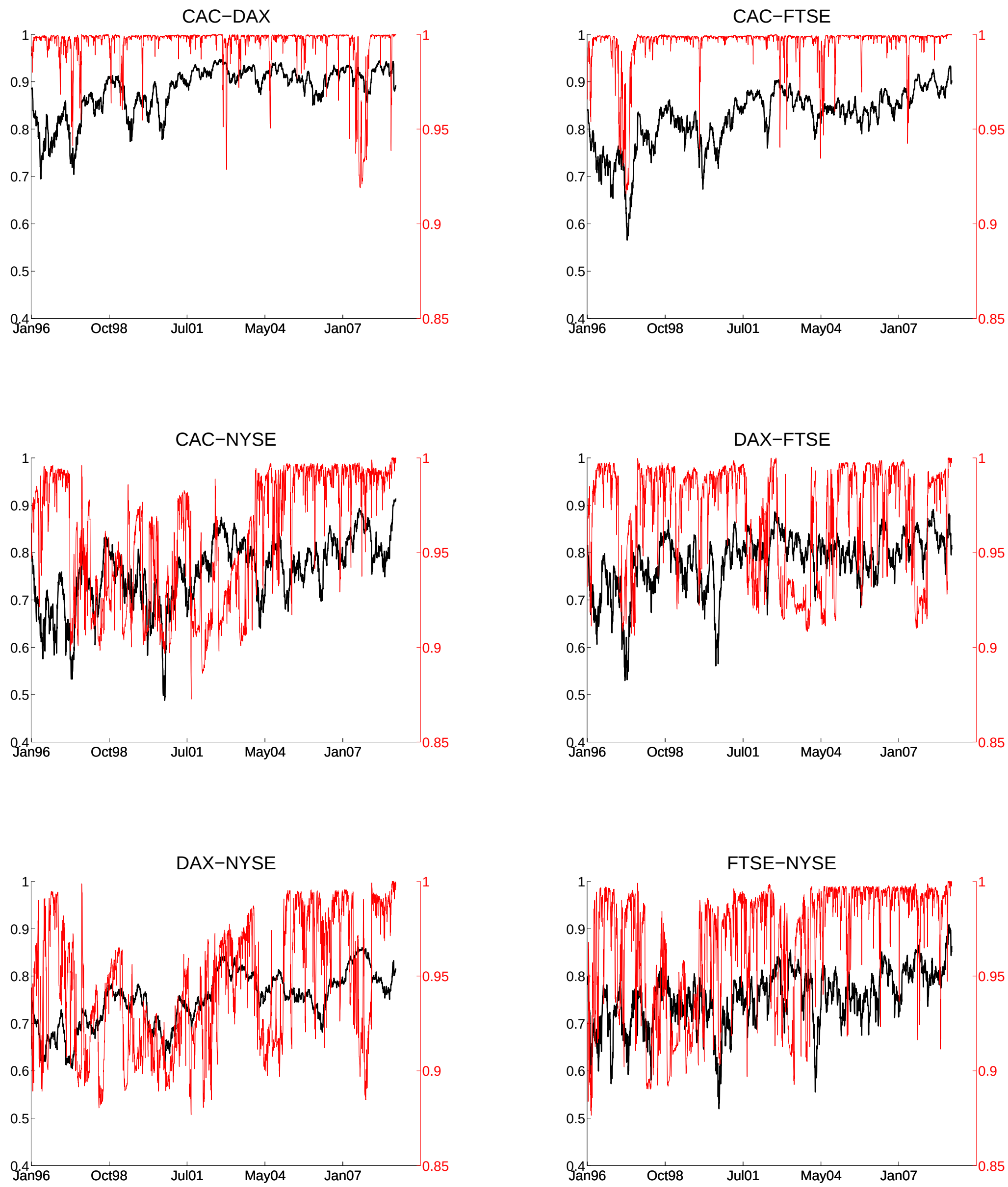


Figure 4-3: Correlation decomposition MSMDCC(3)

arbitrages imperfect so that it is interesting to look at the scaling factor s_t, representing the heterogeneous shocks that impact the price dynamics.

The level of the scaling factor for the CAC-DAX is quite high and stable (except during the end of 2007 and the beginning of 2008). This is also the case between the CAC and the FTSE with more heterogeneous shocks in 1997 and between 2003 and 2006 and lower the correlation. The FTSE-NYSE case is intermediate even if the scaling factor is most of the time close to unity. Then, for the other pairs, the scaling factor is less stable : CAC-NYSE, DAX-NYSE and DAX-FTSE. The DAX-NYSE is the one with the most unstable scaling factor.

As seen before, comovements are at the highest level, when $s_t = 1$, i.e. when the volatility components are perfectly correlated. This is referred as (re)correlation and is associated with perfect spillovers between markets. The following table gives the number of occurrences for $s_t > 0.9999$ over the sample.

	$\#(s_t > 0.9999)$
CAC-DAX	37
CAC-FTSE	26
CAC-NYSE	11
DAX-FTSE	5
DAX-NYSE	4
FTSE-NYSE	11

Table 4-1: Recorrelation occurrences by pair of indexes between 1996 and 2008.

Perfect spillovers are observed more often between the CAC and the DAX, and only four times, for example, between the DAX and the NYSE. These four occurrences appeared on the 27/10/1997 during the Asian crisis and then three times in October 2008 (the 9th, 14th and 29th). Concerning the CAC-NYSE, perfect spillovers happened eleven times. One important thing is that on these 11 days of recorrelation, 8 of them are in October and November 2008 while the three other ones are during the Asian crisis. This exerts how the spread and global impact of the 2008 crisis has no precedent.

The FTSE and NYSE are in this situation eleven times on the sample with the same remarks as previously: 9 of them are in October and November 2008 while the two first dates of recorrelation correspond to the Asian crisis. Concerning the linkages between the CAC and respectively the DAX and the FTSE, many dates appear relevant : it includes the Asian crisis in October 1997, the Russian crisis from August 1998 to October 1998, 21/09/2001 with the re-opening of the US market, July 2002, October 2002, January 2008 and predominantly days in October and November 2008.

To sum up this comovement analysis, if the commonality of shocks between markets has increased, there only exists punctually some perfect transmission of shocks, and the majority of the market movements are not perfectly transmitted. Moreover, the perfect transmission of shocks have mainly occurred during the very last crisis showing the increasing vulnerability of markets to share crisis. This would confirm the dark side of globalization so that arbitrage opportunities are finally disappearing when agents need it the most.

The analysis exerts a ranking of transmission which is higher inside the Euro area, then lower in Europe, and even lower between Europe and the US. This differs from other papers comparing the level of correlation directly since these levels are structurally different between assets. Recorrelation may occur between assets during trouble periods (i.e. $s = 1$) even if the correlation level is structurally low (low ρ_t).

4.4 Conclusion

In this chapter, we develop a hybrid model to analyze the correlations involving a Markov switching multifractal model as in Calvet et al. (2006) and a model of dynamic correlation as in Engle and Sheppard (2002). The contribution is to relax some assumptions of the MSM bivariate model by introducing a time process. Both the regime switches in volatility and the dynamic correlation contribute to specify the nature of comovements. The model is specified in a bivariate form due to the increasingly large number of states induced by the multifractal specification when the number of assets is high. The new model (as MSMDCC) has significantly improved the adjustment to the data on the sample particularly when the number of frequencies considered is at least three. It outperforms both the standard MSM model and the DCC model.

The introduction of a temporal process and the consideration of a variety of shocks in the volatility states refine the standard interpretation of the correlation. The model considers the pure dependence over time interpretable as the level of comovements between two prices when there is no friction. However, the scaling factor, from the multifractal specification moderates this relationship, and represents the imperfect degree of comovements when the processes of volatility are not perfectly correlated.

This heterogeneity introduced a number of negative shocks affecting the correlations over several horizons. Recorrelation is observed when the volatilities are perfectly correlated between markets. Thus comovements are not only measured and compared in terms of level but also through the possibility for the correlation to attain its highest level of correlation at some specific dates.

Our results show that the crisis of 2008 is unprecedented in that it involves a large number of days where this phenomenon of recorrelation between markets was observed.

4.5 Appendix

Appendix 4-A. Descriptive statistics for geometrical returns of CAC, DAX, FTSE and NYSE

	CAC	DAX	FTSE	NYSE
CAC	1.0000	0.888	0.847	0.783
DAX	0.888	1.0000	0.809	0.742
FTSE	0.847	0.809	1.0000	0.786
NYSE	0.783	0.742	0.786	1.0000

Table 4−*A*−1: Sample Correlations 1996-2008

	CAC	DAX	FTSE	NYSE
mean	0.013	0.018	0.001	0.009
std.err	1.422	1.537	1.170	1.148
skew	-0.365	-0.445	-0.405	-0.597
kurtosis	8.056	7.255	9.498	15.333

Table 4−*A*−2: Descriptive statistics 1996-2008

Appendix 4-B. Estimation results for DCC

	CAC-DAX	CAC-FTSE	CAC-NYSE	DAX-FTSE	DAX-NYSE	FTSE-NYSE
μ_0^α	0.013 0.000	0.013 0.000	0.013 0.000	0.015 0.0001	0.015 0.0001	0.0099 0.0001
μ_1^α	0.083 0.000	0.083 0.000	0.083 0.000	0.089 0.0001	0.089 0.0001	0.098 0.0001
μ_2^α	0.913 0.0000	0.913 0.0001	0.913 0.0001	0.907 0.0001	0.907 0.0001	0.898 0.0001
μ_0^β	0.015 0.0000	0.0099 0.0001	0.017 0.0001	0.0099 0.0001	0.017 0.0001	0.017 0.0001
μ_1^β	0.089 0.0001	0.098 0.0001	0.097 0.0001	0.098 0.0001	0.097 0.0001	0.097 0.0001
μ_2^β	0.907 0.0001	0.898 0.0001	0.891 0.0001	0.898 0.0001	0.891 0.0001	0.891 0.0001
θ_1	0.039 0.000	0.058 0.000	0.051 0.000	0.0357 0.0000	0.0376 0.000	0.0313 0.000
θ_2	0.954 0.000	0.921 0.0001	0.930 0.0001	0.951 0.0001	0.954 0.0001	0.962 0.0001
lnL	−8146.0	−7899.3	−8300.7	−8351.2	−8583.4	−7568.9

Estimation results for bivariate DCC as in Engle and Sheppard (2002)

for the mentioned stock indexes

between 1996 and 2008 at daily frequency (std errors are given below the coefficients)

Appendix 4-C. Estimation Results for MSMDCC

	k=1		k=2		k=3		k=4		k=5	
	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC
m_0^α	1.694 0.017		1.576 0.016		1.471 0.0175		1.428 0.016		1.397 0.019	
σ_α	1.794 0.063		1.611 0.043		1.782 0.084		2.04 0.107		1.721 0.091	
m_0^β	1.706 0.015		1.610 0.013		1.488 0.0152		1.485 0.017		1.423 0.029	
σ_β	1.889 0.063		1.646 0.035		1.828 0.0759		2.511 0.152		1.943 0.120	
b	-		0.088 0.048		0.272 0.0628		0.252 0.051		0.490 0.092	
γ_1	0.017 0.003		0.027 0.004		0.031 0.0062		0.036 0.0061		0.028 0.0063	
λ	0.972 0.453	0.994 0.0199	0.949 0.480	0.998 0.016	0.981 0.483	0.968 0.022	0.963 0.473	0.976 0.013	0.970 0.47	0.967 0.015
ρ_ε	0.894 0.003	-	0.886 0.069	-	0.888 0.0036	-	0.891 0.0038	-	0.892 0.0038	-
θ_1	-	0.009 0.0023	-	0.018 0.0042	-	0.021 0.006	-	0.014 0.004	-	0.018 0.043
θ_2	-	0.990 0.0030	-	0.976 0.0056	-	0.975 0.0077	-	0.984 0.0048	-	0.979 0.005
lnL	-8408.7	-8332.4	-8230.5	-8171.1	-8158.3	-8087.3	-8113.5	-8026.8	-8088.3	-8014.8
$LR1$	1.31 (0.03)		1.03 (0.01)		1.23 (0.01)		1.51 (0.01)		1.28 (0.01)	
$LR2$	-4.63 (0.99)		-1.52 (0.99)		-0.27 (0.640)		0.52 (0.24)		0.95 (0.09)	
$LR3$	-3.30 (0.99)		-0.49 (0.72)		0.97 (0.09)		2.03 (0.00)		2.24 (0.00)	

Table 4-C-1: CAC DAX estimations results for MSM (1 to 5) MSMDCC(1 to 5) with std errors below the coefficients. The time dimension is restricted to one lag in the MSMDCC as in the DCC. LR1 tests Ho: MSM=MSMDCC against H1: MSM<MSMDCC; LR2 tests DCC=MSM against H1: DCC<MSM. LR3 tests DCC=MSMDCC against H1: DCC<MSMDCC. All the likelihood ratio tests are based on Vuong (1989) and corrected for autocorrelation in the likelihood addends. It is reported the LR statistics and the t-prob in parentheses.

	k=1		k=2		k=3		k=4		k=5	
	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC
m_0^α	1.695 0.017		1.574 0.015		1.469 0.0186		1.425 0.0168		1.398 0.0193	
σ_α	1.783 0.059		1.622 0.046		1.801 0.082		1.997 0.105		1.729 0.077	
m_0^β	1.714 0.013		1.596 0.0137		1.501 0.0177		1.421 0.016		1.419 0.018	
σ_β	1.291 0.030		1.429 0.0395		1.583 0.07821		1.481 0.078		1.510 0.073	
b	–		0.221 0.099		0.323 0.102		0.335 0.072		0.494 0.098	
γ_1	0.023 0.004		0.022 0.0041		0.025 0.0065		0.040 0.0093		0.026 0.0073	
λ	0.975 0.492	0.970 0.017	0.957 0.482	0.962 0.035	0.984 0.488	0.971 0.023	0.968 0.482	0.947 0.0023	0.983 0.486	0.967 0.022
ρ_ε	0.838 0.005	-	0.825 0.0049	-	0.824 0.0056	-	0.828 0.0051	-	0.828 0.0058	-
θ_1	-	0.069 0.0035	-	0.012 0.0025	-	0.017 0.006	-	0.012 0.003	-	0.024 0.008
θ_2	-	0.923 0.0053	-	0.986 0.0031	-	0.977 0.087	-	0.984 0.004	-	0.970 0.011
lnL	-8190.8	-8177.1	-7949.1	-7900.5	-7893.9	-7831.7	-7871.6	-7826.4	-7866.5	-7805.9
$LR1$	0.24 (0.03)		0.84 (0.01)		1.08 (0.00)		0.79 (0.00)		1.05 (0.00)	
$LR2$	-5.13 (0.99)		-0.91 (0.92)		-0.05 (0.57)		0.44 (0.22)		0.53 (0.18)	
$LR3$	-4.89 (0.99)		-0.06 (0.54)		1.14 (0.02)		1.23 (0.01)		1.59 (0.01)	

Table 4-C-2: CAC FTSE estimations results for MSM (1 to 5) MSMDCC(1 to 5) with std errors below the coefficients. The time dimension is restricted to one lag in the MSMDCC as in the DCC. LR1 tests Ho: MSM=MSMDCC against H1: MSM<MSMDCC; LR2 tests DCC=MSM against H1: DCC<MSM. LR3 tests DCC=MSMDCC against H1: DCC<MSMDCC. All the likelihood ratio tests are based on Vuong (1989) and corrected for autocorrelation in the likelihood addends. It is reported the LR statistics and the t-prob in parentheses.

	k=1		k=2		k=3		k=4		k=5	
	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC
m_0^{α}	1.695 0.016		1.576 0.017		1.471 0.0182		1.428 0.0161		1.395 0.019	
σ_{α}	1.783 0.062		1.624 0.046		1.774 0.091		2.032 0.010		1.718 0.082	
m_0^{β}	1.781 0.019		1.616 0.0138		1.551 0.0151		1.547 0.018		1.423 0.016	
σ_{β}	1.654 0.067		1.587 0.055		1.861 0.084		1.513 0.063		2.019 0.167	
b	-		0.190 0.079		0.251 0.061		0.280 0.082		0.385 0.065	
γ_1	0.023 0.004		0.032 0.0053		0.033 0.007		0.037 0.007		0.042 0.083	
λ	0.927 0.442	0.976 0.024	0.781 0.484	0.778 0.057	0.845 0.332	0.842 0.046	0.901 0.419	0.874 0.044	0.913 0.399	0.906 0.031
ρ_{ε}	0.778 0.007	-	0.768 0.0076	-	0.771 0.0092	-	0.774 0.008	-	0.765 0.008	-
θ_1	-	0.009 0.0036	-	0.015 0.0048	-	0.023 0.0068	-	0.023 0.0049	-	0.024 0.0061
θ_2	-	0.990 0.0049	-	0.981 0.0064	-	0.972 0.0098	-	0.974 0.0056	-	0.972 0.009
lnL	-8397.9	-8367.9	-8296.1	-8259.3	-8200.4	-8151.5	-8194.2	-8153.9	-8161.7	-8118.9
$LR1$	0.86 (0.00)		0.64 (0.00)		0.85 (0.00)		0.70 (0.00)		0.74 (0.00)	
$LR2$	-2.60 (0.99)		0.04 (0.51)		1.70 (0.04)		1.81 (0.03)		2.38 (0.01)	
$LR3$	-1.74 (0.99)		0.67 (0.25)		2.56 (0.00)		2.51 (0.00)		3.12 (0.00)	

Table 4-C-3: CAC NYSE estimations results for MSM (1 to 5) MSMDCC(1 to 5) with std errors below the coefficients. The time dimension is restricted to one lag in the MSMDCC as in the DCC. LR1 tests Ho: MSM=MSMDCC against H1: MSM<MSMDCC; LR2 tests DCC=MSM against H1: DCC<MSM. LR3 tests DCC=MSMDCC against H1: DCC<MSMDCC. All the likelihood ratio tests are based on Vuong (1989) and corrected for autocorrelation in the likelihood addends. It is reported the LR statistics and the t-prob in parentheses.

	k=1		k=2		k=3		k=4		k=5	
	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC
m_0^α	1.706 0.015		1.610 0.014		1.488 0.0145		1.462 0.021		1.401 0.029	
σ_α	1.873 0.065		1.647 0.039		1.827 0.0702		2.259 0.177		2.047 0.144	
m_0^β	1.713 0.013		1.597 0.0140		1.503 0.018		1.422 0.015		1.390 0.016	
σ_β	1.287 0.032		1.424 0.039		1.581 0.0801		1.483 0.073		1.598 0.085	
b	-		0.144 0.063		0.281 0.0689		0.319 0.060		0.405 0.069	
γ_1	0.020 0.004		0.027 0.0043		0.031 0.0063		0.042 0.008		0.042 0.009	
λ	0.907 0.423	0.928 0.033	0.746 0.405	0.797 0.066	0.851 0.227	0.851 0.042	0.883 0.454	0.881 0.036	0.908 0.443	0.901 0.029
ρ_ε	0.802 0.008	-	0.791 0.0068	-	0.797 0.0079	-	0.799 0.006	-	0.795 0.0064	-
θ_1	-	0.0047 0.003	-	0.017 0.0103	-	0.029 0.0064	-	0.020 0.0062	-	0.028 0.007
θ_2	-	0.989 0.008	-	0.979 0.0136	-	0.957 0.0078	-	0.971 0.099	-	0.953 0.015
lnL	-8642.1	-8640.7	-8420.2	-8379.2	-8324.5	-8292.3	-8300.2	-8272.7	-8268.4	-8236.7
$LR1$	0.03 (0.58)		0.30 (0.08)		0.56 (0.00)		0.48 (0.00)		0.55 (0.00)	
$LR2$	-5.13 (0.99)		-1.25 (0.99)		0.42 (0.28)		0.84 (0.12)		1.39 (0.02)	
$LR3$	-5.10 (0.99)		-0.95 (0.99)		0.97 (0.08)		1.32 (0.03)		1.95 (0.00)	

Table 4-C-4: DAX FTSE estimations results for MSM (1 to 5) MSMDCC(1 to 5) with std errors below the coefficients. The time dimension is restricted to one lag in the MSMDCC as in the DCC. LR1 tests Ho: MSM=MSMDCC against H1: MSM<MSMDCC; LR2 tests DCC=MSM against H1: DCC<MSM. LR3 tests DCC=MSMDCC against H1: DCC<MSMDCC. All the likelihood ratio tests are based on Vuong (1989) and corrected for autocorrelation in the likelihood addends. It is reported the LR statistics and the t-prob in parentheses.

	k=1		k=2		k=3		k=4		k=5	
	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC
m_0^α	1.706 0.014		1.612 0.014		1.488 0.0143		1.405 0.0158		1.371 0.0163	
σ_α	1.871 0.058		1.651 0.043		1.815 0.075		1.657 0.070		1.485 0.059	
m_0^β	1.781 0.013		1.618 0.0161		1.552 0.0152		1.464 0.014		1.413 0.015	
σ_β	1.662 0.063		1.598 0.066		1.865 0.0857		1.784 0.088		1.844 0.124	
b	-		0.134 0.056		0.236 0.074		0.357 0.066		0.435 0.063	
γ_1	0.021 0.003		0.035 0.005		0.037 0.007		0.045 0.0102		0.051 0.011	
λ	0.777 0.417	0.911 0.023	0.608 0.412	0.745 0.065	0.777 0.436	0.774 0.054	0.843 0.446	0.858 0.0338	0.906 0.439	0.905 0.026
ρ_ε	0.739 0.0078	-	0.748 0.009	-	0.762 0.0088	-	0.761 0.0078	-	0.756 0.008	-
θ_1	-	0.0179 0.0023	-	0.017 0.0047	-	0.009 0.0027	-	0.018 0.0061	-	0.014 0.005
θ_2	-	0.959 0.0028	-	0.979 0.0063	-	0.989 0.0033	-	0.976 0.0089	-	0.984 0.061
lnL	-8785.2	-8789.5	-8580.9	-8569.6	-8440.6	-8421.7	-8390.5	-8374.4	-8391.5	-8368.6
$LR1$	-0.07 (0.98)		0.19 (0.85)		0.33 (0.02)		0.29 (0.03)		0.39 (0.00)	
$LR2$	-3.57 (0.99)		0.01 (0.49)		2.44 (0.03)		3.31 (0.00)		3.30 (0.00)	
$LR3$	-3.65 (0.99)		0.19 (0.55)		2.77 (0.02)		3.59 (0.01)		3.69 (0.01)	

Table 4-C-5: DAX NYSE estimations results for MSM (1 to 5) MSMDCC(1 to 5) with std errors below the coefficients. The time dimension is restricted to one lag in the MSMDCC as in the DCC. LR1 tests Ho: MSM=MSMDCC against H1: MSM<MSMDCC; LR2 tests DCC=MSM against H1: DCC<MSM. LR3 tests DCC=MSMDCC against H1: DCC<MSMDCC. All the likelihood ratio tests are based on Vuong (1989) and corrected for autocorrelation in the likelihood addends. It is reported the LR statistics and the t-prob in parentheses.

	k=1		k=2		k=3		k=4		k=5	
	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC	MSM	MSM-DCC
m_0^α	1.716 0.013		1.598 0.015		1.504 0.0177		1.424 0.016		1.392 0.015	
σ_α	1.297 0.029		1.427 0.044		1.579 0.0827		1.459 0.072		1.621 0.083	
m_0^β	1.779 0.014		1.615 0.0146		1.551 0.0158		1.466 0.015		1.425 0.017	
σ_β	1.641 0.065		1.581 0.059		1.861 0.0939		1.788 0.098		1.962 0.149	
b	-		0.233 0.103		0.259 0.0802		0.312 0.056		0.335 0.048	
γ_1	0.027 0.004		0.031 0.0054		0.033 0.006		0.052 0.0108		0.058 0.012	
λ	0.728 0.456	0.821 0.033	0.871 0.440	0.920 0.0335	0.894 0.429	0.869 0.0329	0.859 0.173	0.858 0.035	0.890 0.455	0.875 0.038
ρ_ε	0.757 0.0060	-	0.752 0.0083	-	0.761 0.0083	-	0.766 0.0078	-	0.761 0.0076	-
θ_1	-	0.0576 0.0167	-	0.013 0.0063	-	0.028 0.0121	-	0.028 0.009	-	0.014 0.011
θ_2	-	0.921 0.141	-	0.982 0.0103	-	0.958 0.023	-	0.954 0.018	-	0.982 0.020
lnL	-7833.4	-7826.5	-7561.3	-7545.1	-7503.6	-7474.8	-7450.4	-7427.2	-7436.7	-7410.4
$LR1$	0.12 (0.87)		0.28 (0.02)		0.50 (0.00)		0.40 (0.00)		0.45 (0.00)	
$LR2$	-4.66 (0.99)		0.09 (0.66)		1.09 (0.07)		2.03 (0.00)		2.26 (0.00)	
$LR3$	-4.54 (0.99)		0.37 (0.68)		1.60 (0.02)		2.43 (0.00)		2.72 (0.00)	

Table 4-C-6: FTSE NYSE estimations results for MSM (1 to 5) MSMDCC(1 to 5) with std errors below the coefficients. The time dimension is restricted to one lag in the MSMDCC as in the DCC. LR1 tests Ho: MSM=MSMDCC against H1: MSM<MSMDCC; LR2 tests DCC=MSM against H1: DCC<MSM. LR3 tests DCC=MSMDCC against H1: DCC<MSMDCC. All the likelihood ratio tests are based on Vuong (1989) and corrected for autocorrelation in the likelihood addends. It is reported the LR statistics and the t-prob in parentheses.

Chapter 5

Central liquidity and market liquidity: the role of ECB collateral policy on the market for French government debt securities

Non-technical summary[1]:

Since the beginning of the crisis in August 2007, the European Central Bank has managed numerous operations for refinancing the banking system that had great liquidity needs. This loose liquidity in refinancing operations takes several forms: (i) an increase of allotted amounts during the main refinancing operations [MRO], (ii) a rise of the number of special refinancing operations and (iii) an increase of operations with a maturity greater than two weeks (the standard duration of MRO). These measures were necessary to preserve the financial stability but we address, in this chapter, the possible adverse effects of such modifications of the operational framework in these times of turmoil.

In particular, we look at the impact of refinancing operations conducted by the ECB on asset markets that can serve as collateral. Indeed, to limit credit risk, the central bank attached to these operations some clauses to ensure any loss related to these transactions. Thus, it settled rules on the eligibility of collateral during the refinancing operations.

Here, we focus on two rules that can be sources of instability namely: (i) the valuation rule of collateral on a marked to market basis and (ii) the variable margins.

Any eligible and marketable collateral for refinancing operations is priced according to its market value. Therefore, the value of the collateral varies during the operation. In this sense, the central bank is no longer exposed to credit risk but to a market risk. This risk is all the more important if the ECB multiplies refinancing operations and extends their maturities.

To limit this market risk, the central bank applies throughout the duration of the refinancing operation a rule of variable margins: if the asset depreciates, banks are required to correct this gap by providing cash to the central bank whereas any increase in the value of collateral implies a corresponding compensation from the central bank.

[1]This is a joint work with Sanvi Avouyi-Dovi. We thank Caroline Jardet, Gaelle Le Fol and Vladimir Borgy for valuable comments and discussions.

To confirm the consideration of market risk, the central bank implemented rules including a criterion for evaluating the collateral in terms of liquidity: it defines liquidity classes for eligible assets to then apply a variable haircut to the less liquid assets.

However, we believe that these rules can be a source of instability in the markets for collateral. The vicious circle of adverse effects is as follows: by increasing refinancing operations, the central bank requires a raising immobilization of collateral and therefore less liquidity in the involved market. This lack of liquidity implies a deterioration of the market with a higher associated risk. If this deterioration is confirmed with a loss in the value of the assets, the variable margin rule applies and, as a consequence, bank liquidity needs intensify. This induces new pressures for refinancing operations and thus self-sustaining needs of liquidity.

We examine this possibility on two segments of the French public negotiable debt securities for 3 months and 10 years widely used as collateral in ECB tender procedures. These two segments are characterized by a different degree of liquidity and thus two classes of eligibility.

We use high-frequency data of these two contracts to calculate indicators of market liquidity (bid-ask spread) and volatility (bipower variation from Barndorff-Nielsen and Shephard (2003)). We study the dynamics between the two maturity rates, their liquidity and volatility associated in a stationary regime switching VAR (Krolzig (1997)) from 2003 to 2008.

We identify a significant impact of the announcement of refinancing operations on the market for the collateral. The impact spreads to liquidity when special operations are conducted by the ECB while it is usually only on the volatility. Under this regime, the comovement dynamics in volatility and liquidity, combined with liquidity and volatility premia present evidence of the above cited vicious circle. According to these results, it appears necessary for the ECB (and has already begun to be done by the end of 2008) to extend the range of eligible collateral to other asset classes.

5.1 Introduction

This chapter provides an empirical analysis of the impact of open market operations [OMOs] on the market for collateral underlying these operations. The conduct of the ECB monetary policy is ruled by two main interventions: the interest rate setting and the provisions of liquidity to the banking system. As in any credit operations, the OMOs conducted by the central bank are subject to credit risk (Stiglitz and Weiss (1981)), so that some collateral rules have been implemented to ensure the central bank against any failures in the OMOs process.

This collateral policy is key for several aspects. First, collateral used during OMOs concerns marketable assets which are marked to the market on a daily basis. Indeed, the value of the collateral is provided by the market, so that the value of the collateral retained by the central bank during the credit duration is not constant. This exposes the central bank not to the credit risk but to a market risk.

One way to circumvent this problem is the already implemented system of variation margins: if the value of the collateral varies, banks are imposed to compensate with cash the potential losses. As a matter of fact, the marked to market value of collateral may finally create what we call in this chapter the undesirable spiral of OMOs. When the ECB multiplies OMOs and increases their durations, the immobilization of collateral induces a decrease in the associated market liquidity with higher volatility. As a consequence, banks incur losses in the value of their collateral and have to respond to margin calls with cash. This finally induces some new needs of refinancing, new OMOs and even more scarcity for liquidity on the market for collateral.

Then, by considering this market risk, market liquidity becomes a key factor to determine the value of the collateral and the associated risk (Manning and Willison (2006)). Market liquidity is the ability to fairly determine a price for an asset given that enough agents are participating to the market. It has been widely studied in the microstructure literature via spread measures, resiliencies, transaction costs etc. (Amihud and Mendelson (1992), Huang and Stoll (1997) or

Biais et al. (2005)). In an illiquid market, any movement has huge consequences on the price and induces losses in the collateral value with volatility. For example, Green (2005) finds evidence that assets eligible as collateral present lower rates of returns than the non eligible ones incurring an opportunity cost to detain them.

In this respect the ECB has introduced rules to mitigate this market risk by reducing the pool of marketable assets used as collateral to the postulated most liquid assets. However, this asset classification is not directly based on a standard indicator of market liquidity (as bid-ask spread or number of transactions) but on a "type of asset" criteria. For example, all government debt instruments belong to the same liquidity class for the ECB, while there exist some important differences in terms of market liquidity between these assets.

This liquidity criteria is thus doubtful for two main reasons: first, by reducing the pool of marketable assets (mainly government and central bank debt securities) the ECB may impact directly market liquidity on some more concentrated market segments. Second, by multiplying OMOs and extending their durations, the ECB may exacerbate this impact on market liquidity and increases the market risk associated with collateral. The aim of the paper is to gauge these potential adverse effects.

Some papers (e.g. Diaz et al. (2006) etc.) have focused on the impact of the EMU integration on market treasury liquidity and volatility. Fleming (2003) or Goldreich et al. (2005) focus on the liquidity of the US treasuries and its impact on rates. Chakravarty and Saskar (1999) also compare different segments of bonds in terms of bid-ask spreads.

In our analysis we focus on the market for French government debt security market that is widely used by banks as collateral in OMOs. Moreover, this market by the multiplication of tradable assets has clearly developed for the last ten years to a major market with international investors. Our approach is different from the above cited papers since we focus especially on bonds as collateral, on its liquidity at the transaction level and on the market risk associated using high frequency data.

To analyze the role of the ECB collateral policy, we use two different maturities: the three month rate on treasuries and the 10 year rate for notes. The analysis is based on the use of high frequency data referencing all the quotations of on the run contracts for three month and ten year maturities between 2003 and 2008. This set of high frequency data allows us to analyze the ECB policy both on liquidity (bid-ask spreads) and on realized volatilities (precisely bipower variations form Barndorff-Nielsen and Shephard (2003)). We introduce all these indicators in a Markov switching Vector Autoregressive model (Krolzig (1997)) to analyze the modifications in the different regimes of transmission channels between daily rate variations, volatility and liquidity for the two considered segments.

The main results are the following. First, there is a significant impact of OMOs announcements in the market used as collateral. This impact in normal time (identified as regime one in the model) is only on volatilities while when the ECB conducts special additional operations, this impact also appears on liquidity of the ten year notes market. Second, the conduct of special operations leads to new transmission channels between the two considered market segments with higher liquidity and volatility comovements associated with liquidity and volatility premia. The resulting political implications, that have effectively been followed by the ECB in the last (and current) crisis is thus to extend the collateral pool of marketable assets when the amounts and durations of ongoing OMOs is significantly rising, as it was observed by the end of 2008.

The chapter is organized as follows. In the following section, we review the concepts of market liquidity and central liquidity, by focusing on the links between collateral rules and market dynamics. We notably present the vicious circle of OMOs and focus on the recent developments on the market for French sovereign bonds and the monetary policy conduct during the 2007-2008 crisis. In the third section, we define the liquidity and volatility indicators and present the MSVAR model. The fourth section displays the empirical results. Section five concludes.

5.2 Liquidities

In this section, we present the two liquidity concepts before examining the linkages between them via the ECB collateral rules for OMOs.

5.2.1 Central bank liquidity and collateral policy

The central bank provides liquidity to banks through several channels. A majority of these operations are main refinancing operations (as MRO) with a weekly frequency. The central bank also uses some long term refinancing operations (LTRO) and some other punctual operations: fine tuning operations (as FTO) and structural operations. A detailed description of this primary channel of central liquidity is discussed in Idier and Nardelli (2008) with a focus on the March 2004 reform for liquidity management. A second channel for providing liquidity is the use of standing facilities. Any bank may ask the central bank for refinancing at any time at a penalty rate. This penalty is such that few banks usually use these standing facilities. There exist a "standing facility stigma" since banks are usually reluctant to use them: it is usually a weak signal provided to the market for the bank using the facilities (even if it is theoretically confidential). One salient example is the 2008 Lehmann Brother case in the US: before going to bankruptcy, this bank did not go to the standing facilities provided by the Federal Reserve scared to be penalized by the market.

All these operations managed by the central bank induce some collateral immobilization on which we focus here. To prevent the ECB (and more generally any central bank) from losses due to open market operations, some guaranties (called collateral) underline the operations. In case of credit failure, this collateral, may be liquidated by the central bank to get its money back. The assets used as collateral must meet some criteria to be eligible by the ECB during its refinancing operations (see "The implementation of monetary policy in the euro area", November 2008). These rules have been modified in the early 2007 with the introduction of the single list of eligible assets. Notably, the ECB considers collateral eligibility for marketable and non marketable assets.

Concerning marketable assets, are eligible debt instruments with high credit standard denominated in euro, traded on regulated markets[2] so that the issuer is an EEA member or a G10 member. The non marketable assets (credit claims and retail mortgage-backed debt instruments) must be issued by credit institutions located in the euro area, with high credit standards and denominated in euro. However, in the ECB monetary policy framework, the collateral policy is generally restricted to marketable assets for outright transactions.

To ensure the quality of the collateral the ECB uses two additional measures: the haircut and the variation margins. The haircut is a percentage discount applied to the value of the collateral used in open market operations. The value of the collateral is thus calculated as the market value of the asset less the haircut applied to this category of assets. One important thing is that the value of the asset is marked to market so that the ECB is exposed to a downward variation of the collateral value during the period of the credit. As a consequence, the counterparties (banks) must provide additional cash to maintain the value of the asset (called a margin-call). Obviously, these variation margins are symmetric and if the value of the asset rises above a certain level, the counterpart retrieves the corresponding cash.

As we see, the value of the collateral highly depends on the market dynamics. The ECB have integrated this market dependency in its rule so that the level of the haircut is based on a liquidity criteria. However what is denominated liquidity class by the ECB does not correspond to a standard measure of market liquidity but on some categories of assets grouped together. There exist five denominated categories of liquidity for the assets used as collateral. The first class is supposed to be the more liquid, and the liquidity is decreasing along the four other classes. Table 5-1 sums up these categories concerning marketable assets.

[2] There exist some exceptions in published lists of non regulated markets accepted by the ECB.

Category I	**Category II**	**Category III**	**Category IV**	**Category V**
Central government debt instruments Debt instruments issued by CB	Local and regional government debt instruments Jumbo covered bank bonds Agency debt instruments Supranational debt instruments	Traditional covered bank bonds Debts instruments issued by corporate and other issuers	Credit institution debt instruments (unsecured)	Asset back securities

Table 5-1: Liquidity categories for marketable assets (source: ECB)

In each of these categories and depending on the residual maturity of the considered debt instruments, the haircut is varying from 0.5% to 20% depending on the maturity and the coupon. As we see, collateral best choice for participating to OMOs in the euro area are the government debts instruments. They usually meet high credit standard, liquidity and are exchanged on organized markets.

This addresses several questions. First of all, the liquidity categories for collateral are not based on a standard criterion of market liquidity (bid-ask spread range, number of transactions, traded volumes) but, in fact, on a "class of asset" criteria. However, there exists some heterogeneity in government bonds market liquidity and thus the criteria "type of asset" may not be enough to characterize the liquidity risk associated. Second, the monetary policy framework of the ECB may not be neutral in terms of liquidity. By multiplying market operations, the central bank imposes the mobilization of collateral, dries up the market for such bonds and creates volatility. This auto generated process may then have consequences for banks if the central bank is not willing to extend its list of eligible collateral. The following graph presents the vicious circle of such a mechanism:

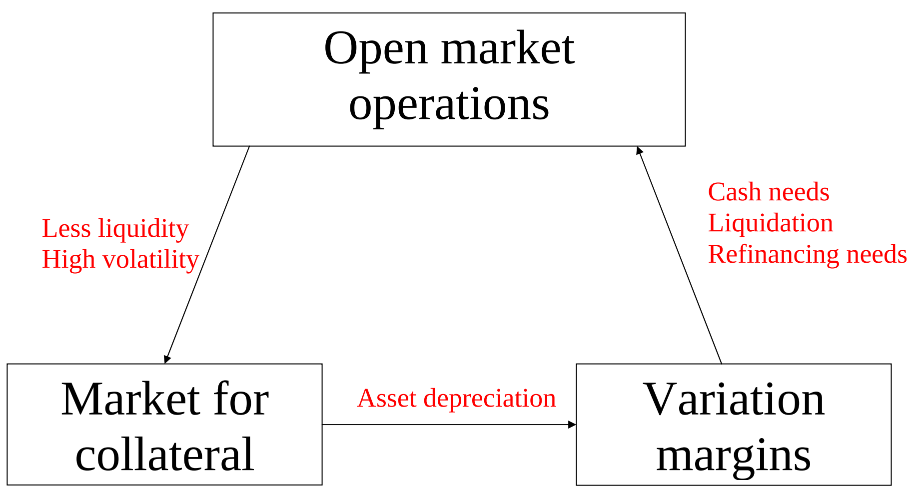


Figure 5-1: The vicious circle of OMOs and collateral markets

To sum up, by setting a collateral policy to hedge credit risk, the central bank may generate a spiral transferring risk from credit market to the market for collateral (via liquidity and volatility risks) for the whole set of investors and generates the above illustrated mechanism.

5.2.2 The French market for sovereign bonds

How to characterize liquidity in the French sovereign bond market due to the particular changes that have occurred during the last ten years? The amount of the negotiable debt for the French government has almost doubled between 1998 and 2008 reaching 988 billions euro at the end of September 2008. This upward trend has been possible by the introduction of marketable products grouped in three categories based on their initial maturities. The first category comprises the short term bond class with maturities less than one year. In this category, three month maturity bonds are typically issued weekly and respond to short term needs in financing. The second category concerns bonds with two or five year maturities with a new adjudication per month. The last category concerns long term bonds with maturity from seven to 50 years with one adjudication per month.

After these regular pre-scheduled adjudications, securities are actively traded on the secondary market where transactions are not centralized. This secondary market is an Over The Counter market [OTC] and bilateral transaction details are partially known.

One main development of this market is its internationalization. An increasing share of the negotiable French debt is actually hold by foreign investors. By the end of 1998, it represented 18.8% of the negotiable debt to reach 62% by mid-2008. In particular, this internationalization is a certainly a vector of increasing liquidity on the market with a wider pool of market participants.

5.2.3 The 2008 crisis implications for liquidities

As previously mentioned, the multiplication of OMOs may have consequences on the liquidity and volatility of assets used as collateral. The 2008 crisis has remarkably impacted the interbank market with the impossibility for banks to find funding on this market. The ECB thus decided to provide huge amounts of liquidity to the banking system through regular and special OMOs.

Considering regular open market operations, the ECB first has increased the level of allotment to respond to liquidity needs of the banks through MROs and LTROs. Due to the high demand for liquidity and the "close" of the interbank market, the ECB decided to use a fixed rate tender for MRO in order to completely respond to bank liquidity needs. During a fixed tender rate, the ECB gives the level of the rate applied to the MRO and banks are asked to give the corresponding amount of liquidity they are willing to obtain at this price. In this way, their needs are completely fulfilled given the level of the rate. It is opposed to variable tender rates, during which banks provide ten rates and ten corresponding amounts of liquidity that they are willing to obtain with no guaranty on the final amount allotted. In this way, the ECB limits tensions on the interbank market, but provides important amounts of liquidity to the banking system, and this implies higher amounts of collateral. This has also been coupled with the multiplication of special operations as reported in figure 5-2.

Figure 5-2: proportion of ECB liquidity operations by types

The proportion of operations other than MRO and LTRO has largely increased during the recent period[3]. Moreover, between 2000 and July 2007 the mean amount per operation of allotted liquidity

[3]We restrict here the operations to the liquidity provisions.

during special operations is around 17 billions euros, versus around 40 billions between August 2007 and October 2008. On the collateral side, the ECB took several measures to ensure the soundness of the open market operations in the late 2008 (directives ECB/2008/15 and ECB/2008/18). They have especially extended eligibility (with higher haircuts) to some other classes of assets (asset back securities, syndicated loans for a given period, Japanese, US and UK credit claims for example).

Concerning the recent bond market developments, there are some appealing issues. Typically, it has been observed, on the European market as a whole, a high volatility on bond yields for the short and long term maturities since August 2007. Moreover, the gap between the short term and the long term yields raised. Finally, the bid-ask spreads have also started to widen (see ECB monthly Bulletin, October 2008).

Due to the commitment of government budget in solving the crisis and a general rise of credit risk premium, risk aversion on bonds over the long term have increased. This is now reflected in the yields for long term securities. However, this does not occur to all government bonds inside the euro area. One the one hand, bonds are actually suffering from a flight to quality phenomenon where investors report their trades on traditional strong government debt securities (typically the German of French ones). One the other hand, there is also a flight to liquidity issue with investor willing to invest in liquid markets. In a period where refinancing is difficult on the interbank market, it is clear that banks are mitigating their risk by investing in markets where funds may be withdrawn rapidly. As a consequence, some bond market liquidity dries up (for instance the greek market for bonds) and reports on other bonds markets. This association of flight to quality and flight to liquidity may have remarkable consequences for markets, and may be worsen and selfsustained by the collateral policy of the central bank.

In the next section, we focus on the French government debt security market to exert whether the monetary policy framework have some adverse effects for this market. Our goal is to assess if the collateral policy does generate a liquidity risk that all market participants, then, have to bear.

5.3 An empirical assessment of the vicious circle

5.3.1 Dataset and market indicators

Our dataset consists in high frequency quotes for French debt securities with 3 month and 10 year maturities from Reuters Data Tick History ranging from October 1st, 2003 to November 1st, 2008. We construct on the run series by always considering the last adjudications that have occurred for the corresponding assets.

5.3.1.1 Liquidity indicators

We construct an average daily bid-ask spread for each rate. The bid-ask spread reflects many factors (see (Roll (1984), Glosten (1987), Glosten and Harris (1988), (1991), Huang and Stoll (1997), Hasbrouck and Seppi (2001)). A main component is the transaction cost on the buy side and on the sell side. The larger the spread the higher the transaction cost (see Harris and Piwowar (2005) for bond markets). Assuming that the true value of the asset is in between ask and bid prices, the larger the spread, the higher the potential gap between this true value and the price investors have to bear for buying or selling it. Fleming (2003) assesses in particular that spreads are good measures to track liquidity on treasuries. This measure is used in many markets and allows for comparisons as in Chordia et al. (2003). In usual market the price is defined as the difference between the ask price and the bid price. Here, since we consider the bid-ask spread for rates, inversely related to the prices, the spread is defined as:

$$S_{i,t} = r_{i,t}^{bid} - r_{i,t}^{ask} \tag{5.1}$$

for the i^{th} transaction of day t. The daily liquidity indicator is then the mean over the day of all relative spreads:

$$S_t = \frac{1}{N}\sum_{i=1}^{N} S_{i,t}$$

Due to the partial information available on our dataset (e.g. no details about transaction volumes), we restrict our analysis to this quite standard indicator as suggested by Fleming (2003).

5.3.1.2 Volatility measures

Since the seminal paper of Merton (1980) realized volatility has been widely used in the literature. Typically, it uses the intraday returns of an asset to calculate daily volatility measures by approximation of the quadratic variation. There exist several realized volatility estimators (see Avouyi-Dovi and Idier (2008)), but here is calculated the bipower variations from the work of Barndorff-Nielsen and Shephard (2003). First let consider a partition Ψ of the day retaining the last transaction of equal subintervals of time (one hour in our case study). Then, the day t volatility estimator is defined as:

$$RV_t = \sum_{i \in \Psi} |r_i r_{i^-}| \tag{5.2}$$

where r_i and r_{i^-} are subsequent returns for the considered subintervals of day t. The rationale for this choice comes from its ability to remove the jump component. These jumps may be quite usual during the day for liquidity reasons typically. This is not the case for the standard realized volatility estimator of Merton (1980) defined as the daily sum of squared returns (see Andersen et al. (2007), Barndorff-Nielsen and Shephard (2005), Barndorff-Nielsen et al. (2006), Huang and Tauchen (2005), Tauchen and Zhou (2004)).

The bipower variations are applied to bond yields. Due to some liquidity problems on the three month maturity (especially less active than the longer term maturity bonds) we restrict our volatility indicator to be computed on a one hour basis frequency.

5.3.1.3 Monetary policy indicators

To consider monetary policy, we construct several indicators representing the operational framework of the ECB policy. First of all, we consider a set of dummy variables for OMOs, and their type MRO, LTRO or Other. We also retain the allotted amount of OMOs and the cover ratios of these operations. This bid cover ratio is the supply-demand ratio for liquidity. It summarizes some tensions about refinancing between banks. All these indicators give the intensity with which market participants are refinancing from the central bank and how the collateral market, as a consequence, may be impacted by these operations. As we will further see in the chapter, all these indicators show that there are some tensions in the process of OMOs (see below).

5.3.2 Liquidity and volatility of the French sovereign bond market

The following figures display the daily evolution of the bond rates, liquidity and volatility for the two segments considered on the French bond market. While the short term rate is anchored to the evolution of the minimum bid rate of the ECB, 10 year rates are more independent to the rise in interest rates occurring from the end of 2005. As a consequence, the bond spread is shrinking until spring 2008. From September 2008, the financial crisis and the ECB monetary decision to cut interest rates have clearly increased this bond rate spread with a huge drop in short term maturity rates (see figure 5-3).

In terms of liquidity, figure 5-4 presents the bid-ask spread for the two bonds during the last five years. It clearly shows that the short term maturity bond is much less liquid than the longer term one over the sample. The average bid-ask spread for three month maturity rates is around 3 bp while it falls 0.8 bp for the 10 Year one. This difference may come from the greater dispersion in investors for the short term with more contracts than for the 10 year bonds[4].

[4] This is also confirmed by the relative bid-ask spreads.

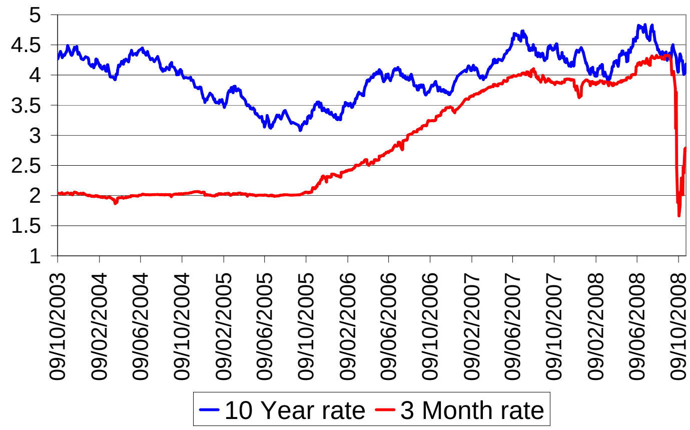


Figure 5-3: daily rate for French bonds

Broadly on the sample, the bid-ask spread for short term maturity fell except during the crisis of 2008 where it jumped twice in September and October. Moreover, the volatility has also jumped during this period. We note that the impact is stronger than for 10 Year bonds. Indeed, volatility for long term bonds has raised but did not explode and the impact mainly appears on the bid-ask spreads which has tripled in the 2008 year (fig. 5-5).

There are several things to investigate in this domain. First, liquidity and volatility may not have the same interactions depending on the market segments. The market impact on a liquid market may not impact that much the price dynamics and so the volatility. However, a deterioration of liquidity on a market where it is already scarce for several reasons, may have a huge impact on price dynamics and volatility. Moreover, the monetary policy framework may impact these indicators, as we mentioned earlier, so that some markets may be more vulnerable than others, even if they belong to the same liquidity class of collateral considered by the ECB.

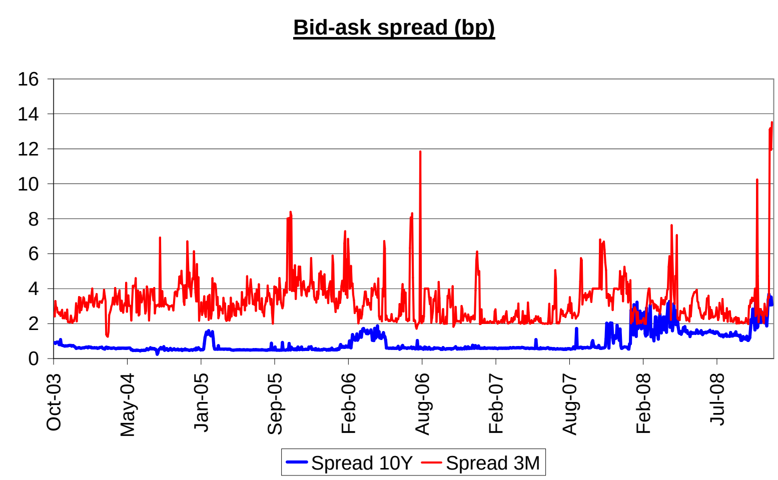
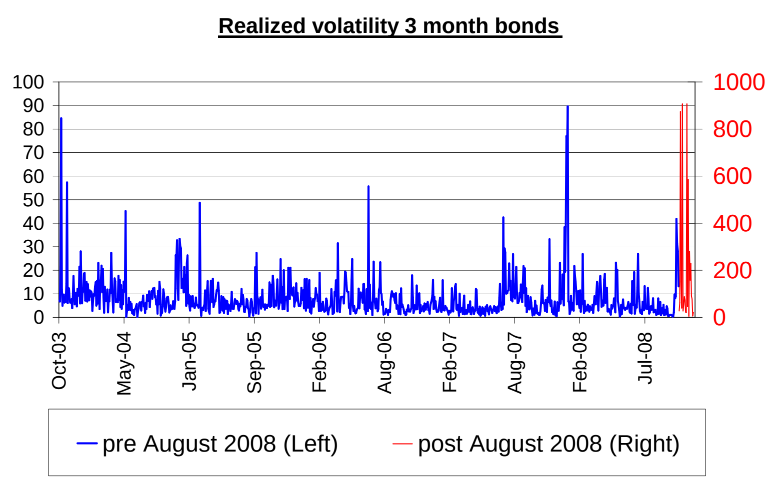


Figure 5-4: market liquidity



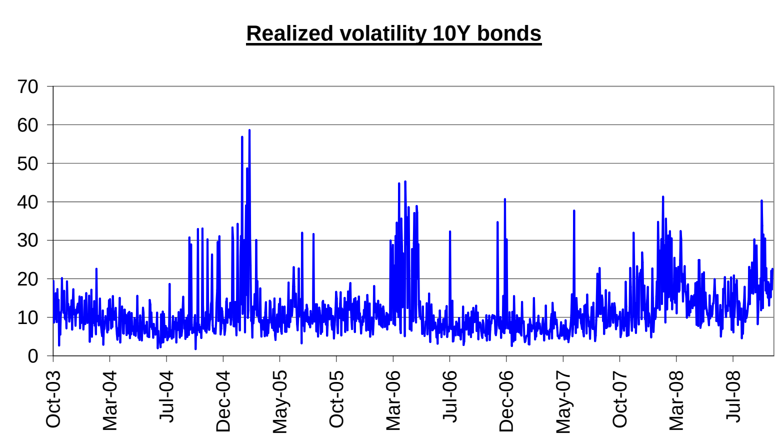


Figure 5-5: realized volatilities

Another issue could be related some flight to liquidity phenomena: it appears on these graphs that liquidity has slowly decayed on the long term bond market since 2007, while this is not so clear considering the three month maturity market over the sample (except at the very end).

Looking at the OMOs conducted by the ECB, the duration (maturity) of the OMOs has been increasing for the last two years (except at the end of the sample with the multiplication of special short term maturity operations). These longer durations in average, imply longer immobilization of collateral and thus less liquidity on the market for collateral. In average, the duration of OMOs

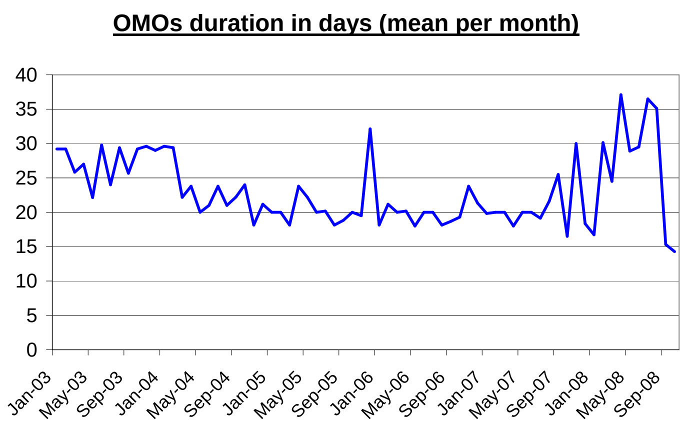


Figure 5-6: OMOs durations

is around 20 days except during 2007 and 2008 when they last in around 30 or 35 days.

These longer durations are coupled with the multiplication of operations as underlined in the previous section and the augmentation of allotted amount during operations. This clearly responds to some stronger liquidity needs and is confirmed by the bid to cover ratio. In 2007, it appears that

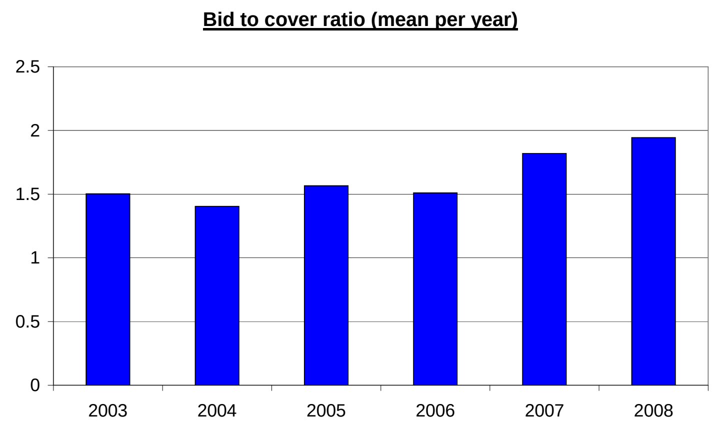


Figure 5-7: bid to cover ratio for ECB OMOs

the demand for liquidity was in mean 82% higher than the amount supplied which even attained 94% in 2008.

We question how the market for collateral is impacted by such developments in monetary policy operations, i.e. an higher competition for liquidity, even if the amount allotted are increasing? Moreover, is the ECB creating some comovements between assets used as collateral even if their evolution linked to different fundamental factors are originally different?

5.3.3 The Model

We consider a general Vector Auto-Regressive [VAR] stationary process including variables such as: the daily variation in bond yields; log realized volatility calculated on the basis of the work of Barndorff-Nielsen and Shephard (2003); the bid-ask spread variation. We complete this set of variables with a monetary policy operation announcement indicator (as defined in appendix 5-A).

Let consider a VAR model with P lag [VAR(P)] as :

$$X_t = \sum_{p=1}^{P} \Phi_p X_{t-p} + \gamma D_t^{OMO} + \mu + \varepsilon_t, \tag{5.3}$$

where X_t is the vector of variables of interest as yield variations ($\Delta r_{3M,t}$, $\Delta r_{10Y,t}$), volatilities ($\sigma_{3M,t}$, $\sigma_{10Y,t}$) and liquidities ($S_{10Y,t}$, $S_{3M,t}$), and D^{OMO} a dummy variable taking value 1 on OMO announcement days and zero otherwise. In addition, we consider a Markov switching VAR to catch the dynamics on the variable of interests[5]. Conditional on $\{X_t\}_{t=1:N}$, the history of past variables, we consider a two state model for $s_t = 1, 2$ similar to Krolzig (1997) such that

$$E(X_t \mid s_t) = \sum_{p=1}^{P} \Phi_p(s_t) X_{t-p} + \gamma(s_t) D_t^{OMO} + \mu(s_t), \tag{5.4}$$

and

$$X_t - E(X_t \mid s_t) = u_t,$$

with u_t follows a Gaussian distribution with zero mean and $\Sigma(s_t)$ state dependent variance-covariance matrix. By considering the state dependent variance, we obtain a mixture of two Gaussian distributions allowing to replicate the skewed and leptokurtotic distribution of bond yield variations (see Idier et al. (2008)).

The state process is generated by a homogeneous Markov chain with two states so that the transition probabilities are defined by:

$$p_{ij} = \Pr(s_t = j \mid s_{t-1} = i) \text{ with } \sum_{j=1}^{J} p_{ij} = 1,$$

[5] The model is a stationary VAR since no cointegration relationship has been validated by usual tests.

for $i, j = \{1, 2\}$. In this setting, the Markov chain admits a transition matrix T such that:

$$T = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix}.$$

In this framework, one interesting output is the regime dependent impulse response functions (IRF). Here we follow the methodology by Hermann, Ellisson and Valla (2003) with the additional feature that we consider generalized impulse response function as in Pesaran and Shin (1998) since we do not have any a-priori on the ordering of the variables. One important feature is that the IRF calculated this way are defined *within* a regime such that the responses are consistent if the horizon of the IRF is shorter than the duration of the regimes.

All the variables used in the model are stationary, tests are reported in appendix 5-B.

5.3.4 Results

The model is estimated between the 1^{st} of October 2003 until the 30^{th} of October 2008. The two regimes are statistically identified and the expost regime probabilities are presented below.

The estimated transition matrix T is

$$T = \begin{bmatrix} 0.931 & 0.069 \\ 0.103 & 0.897 \end{bmatrix}$$

so that the first regime is more persistent than the second one. The respective durations of the regimes 1 and 2 are 15 and 10 days respectively. All the tests clearly reject the linearity of the model and account for a two state Markov chain. The second regime is, in particular, the regime prevailing since the beginning of the crisis in the late 2007. It is thus interesting to gauge the dynamics of the model conditional on each of these regimes. Given the duration of the regimes,

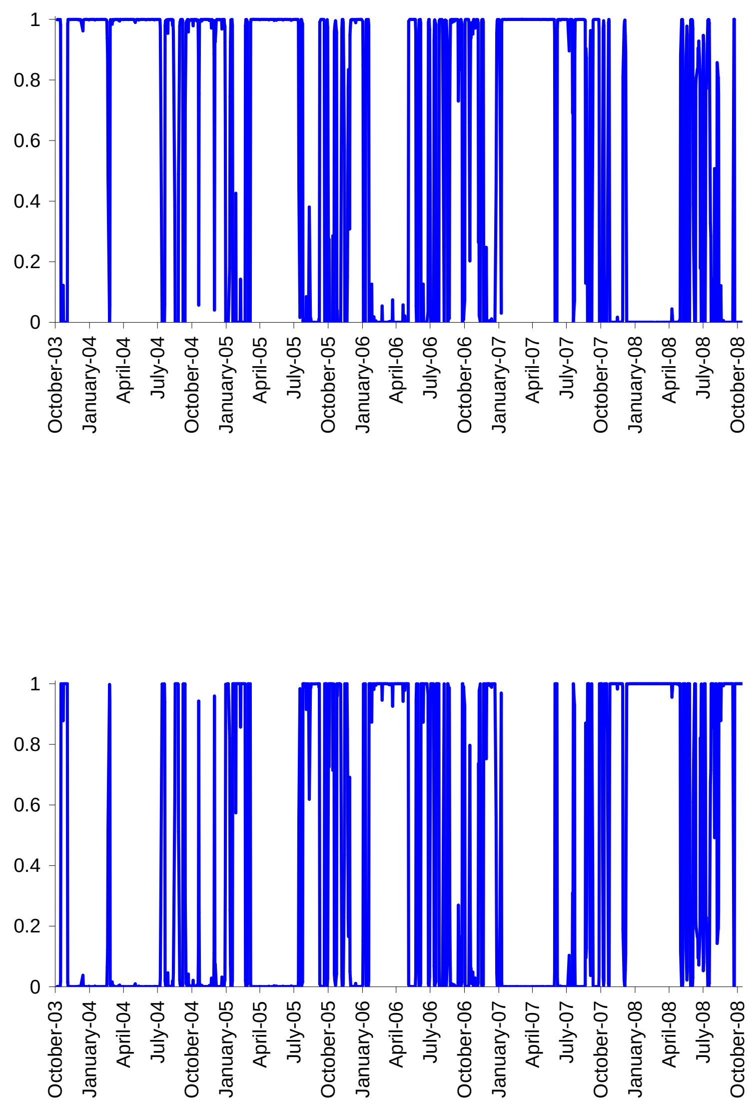


Figure 5-8: regime 1 (top) and regime 2 (bottom) probabilities

the estimated *within* IRFs are limited to ten days. All the estimation results are reported in appendix 5-C.

5.3.4.1 The role of monetary policy and regime identification

Looking at the estimated regime probability, the second regime is a special regime in the sample that contains the 2007-2008 period of high market perturbations. However, it also catches the early 2005 and 2006 when special OMOs on the interbank market were conducted by the ECB following the implementation of the new operational framework in March 2004.

The OMOs announcement in the MSVAR has different effects depending on the two regimes. In the first one, there is only a volatility effect. The announcement of OMOs increases volatility on long term market and decreases volatility for shorter term maturities. $\sigma_{3M,t}$ decreases by 2 percentage points while $\sigma_{10Y,t}$ increases by 1.35 percentage points.

In the second regime, the effect on $\sigma_{10Y,t}$ vanishes while remaining on $\sigma_{3M,t}$. This effect is strong on the volatility rising from 18 to 25% (annualized values). However, there is a new effect on $S_{10Y,t}$, the liquidity of long term bonds: during a day with OMOs announcement the bid-ask spread for such a security ($S_{10Y,t}$) increase by 0.27 bp which is important compared to the size of this bid-ask spread without OMO announcement that is around 1.18. Table 5-2 summarizes the effects on volatility and liquidity of OMOs announcements in each regime and segment.

	$S_{10Y,t}$	$\sigma_{10Y,t}$	$S_{3M,t}$	$\sigma_{3M,t}$
regime 1 with OMOs	0.61bp	11.05%	3.05bp	8.2%
regime 1 without OMOs	0.61bp	9.70%	3.05bp	10.2%
regime 2 with OMOs	1.45bp	14.7%	3.47bp	25%
regime 2 without OMOs	1.18bp	14.7%	3.47bp	18%

table 5–2: mean effect of OMOs in the two regimes obtained from the VAR estimations (appendix 3)

5.3.4.2 Market dynamics

In the first regime, comovements are significant and positive both from long to short term rates and conversely[6]. This illustrates a French sovereign bond market dynamics as whole. However, this is no longer true in the second regime.

A large part of the literature has focused on returns or volatility comovements. Concerning liquidity commonality, it has been mainly studied in the microstructure literature as in Chordia et al. (2000) or Hasbrouck and Seppi (2001)).

Looking at the volatilities there is only few volatility comovements from $\sigma_{3M,t}$ to $\sigma_{10Y,t}$ in regime 1 while liquidity comovements are strong from $S_{10Y,t}$ to $S_{3M,t}$ even if this effect is significantly oscillating around zero. This is a major founding since $S_{10Y,t}$ is directly impacted by OMOs and may then perturb the market dynamics as a whole. Moreover, we obtain a strong significant liquidity effect on the volatility: when liquidity decreases ($S_{10Y,t}$ widens) the volatility increases and this relationship is reciprocal, i.e. when volatility increases there is persistent and strong effect on the spread so that liquidity becomes scarce.

5.3.4.3 The vicious circle, mainly explained by volatility and liquidity premia

Many studies have been interested in the volatility and liquidity premia that interest rates may account for as in Diaz et al. (2006) for the Spanish treasury market or Longstaff (2004) on US markets.

There appears a volatility premium in regime 2 for $\Delta r_{3M,t}$. This effect could be compared with a GARCH in mean effect with an increase in the rate coming from a rise in volatility. This increase in the rate reflects less demand for the short term security market in regime 2. As mentioned before, the second regime corresponds to the periods of special monetary ECB operations and market tensions. This temporary volatility premium on the short term rate may be a consequence of these

[6] All the IRF graphes are reported in appendix 5-D.

operations linked to the uncertainty concerning the ECB monetary policy during the turmoil since the three month rate is close to the ECB rate.

Moreover, the announcement of OMOs in regime 2 has a strong effect on the volatility of the short term rate so that it can be transmitted to the level of the rate itself via the premium. In this case, the mentioned above circle applies: an increase in OMOs leads to volatility on the three month market that decreases demand and price (via the volatility premium) so that a margin call has to be done for banks using treasuries as collateral.

In addition to this volatility premium, the liquidity premium is a factor that have shown to be of interest in the determination of the corporate and sovereign bond market dynamics (Amihud and Mendelson (1991), Chakravarty and Saskar (1999), Elton and Green (1998) or Fleming and Remolona (1999)). Indeed, investors prefer to invest in markets where liquidity is abundant if they are willing to find a counterparty for trading the liquidation of their portfolios without incurring losses. On the treasury market, Longstaff (2004) shows some flight to liquidity phenomena in the bond markets that potentially affect the levels of the yields. Kamara (1994) or Goldstein et al. (2005) notably make the bridge between market transparency, liquidity and price on bond markets.

Concerning $r_{10Y,t}$, we do find a price for market liquidity even with ambiguous effects since different in the two regimes. In the first regime, a deterioration of market liquidity, with higher spreads, implies a decreasing demand for long term bonds and thus higher rates. This is what it is usually observed in other markets since illiquidity is priced as a risk. On the contrary, the second regime shows that if liquidity is decreasing, the rate is decreasing as a first effect. This clearly shows that the second detected regime in our Markov switching model is a non standard regime: the absence of liquidity implies higher demand for long term security. One possible reason for this is the punctual strong incentive to trade these assets due to their use as collateral in OMOs that generates aggressive market participants behaviors. Moreover, the second regime is characterized by a significant positive impact of OMOs announcement on $S_{10Y,t}$ that generate even more aggressive trading behavior of investors during this punctual period of time.

This opposite impact of the liquidity premium in regimes 1 and 2 is not observed for the three month rate. However, in regime two, the first positive effect of $S_{3M,t}$ on $\Delta r_{3M,t}$ exerts less demand for the short term security when the market liquidity is scarce. This first effect is then oscillating around zero which is consistent with the Acharya and Perdersen (2005) model of asset pricing with liquidity risk since liquidity affects differently contemporaneous returns and expectations of returns.

5.4 Conclusions

This chapter considers the impact of ECB collateral policy and OMOs on the market for French government debt securities. In particular, we focus on the three month and ten year rates in terms of price, volatility and liquidity comovements. This has been made possible via the analysis of all transaction data of on the run bonds to compute the bipower variations of the rate dynamics and their respective market liquidity via the analysis of bid-ask spreads. The interactions between these several indicators have been done via the estimation of a Markov switching VAR model and interpreted via the impulse response functions and variables used to clarify the role of the monetary policy in the market perturbations.

The MSVAR detects two regimes in the data, and one of them (regime two in the maintext) comprises the market perturbed periods and the periods where special open market operations have been conducted. The results show that the announcement of OMOs impacts globally (whatever the regime is) the dynamics of the French sovereign bond market. Precisely in regime two, whom the last crisis belongs to, the announcement of OMOs deeply impacts the liquidity of the ten year notes with a widening of the spread and an increase of the volatility of the three month rate.

In the second regime we observe that even if the spread is widening the demand for the 10 year notes is not impacted (no liquidity premium in the rate while there is one in the first regime) which may be a consequence of forced demand for this asset due to its use as collateral.

Concerning the three month rate, the liquidity premium is important in the second regime and the liquidity on the ten year note is a strong perturbing factor. Comovements are thus more complex than expected by usual models only considering linkages between returns or between volatilities. There exist some cross premia effects between assets that pricing formula usually ignore. In particular for the less liquid market, we obtain that volatility and liquidity premia validate our hypothesis of undesirable spiral of OMOs with a global impact of the central bank on the markets eligible for collateral. This circle may only be broken by policy decisions to extend for example the pool of collateral by accepting other assets as it has been decided in the late 2008 by the ECB.

5.5 Appendix

Appendix 5-A: Open market announcements, timing and definition.

The ECB and the national central banks announce publicly the open market operation one day before the deadline for bid submissions of eligible counterparties (banks). This public announcement is then follows by 5 subsequent steps:

1. tender announcement: (a) announcement by the ECB through public wire services and (b) announcement by the national central banks through national wire services and directly to individual counterparties (if deemed necessary);

2. counterparties' preparation and submission of bids;

3. compilation of bids by the Eurosystem;

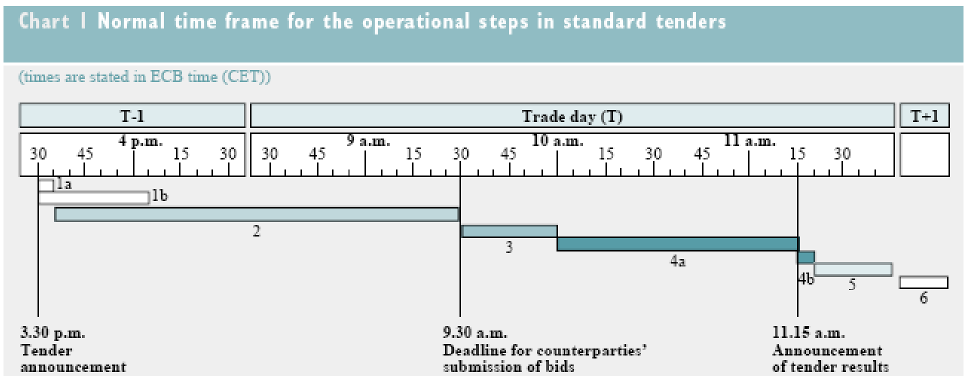
4. tender allotment and announcement of tender results: (a) ECB allotment decision and (b) announcement of the allotment result;

5. certification of individual allotment results;

6. settlement of the transactions.

This is summarized in the following graphs for standard and quick tenders

In particular, the ECB announcement delivers publicly the following information: the reference number of the operation, the date of the operation, the type of operation, the maturity of the operation, the type of auction, the allotment method, the intended operation volume, the fixed rate (only for fixed rate tenders), the min/max interest rate, the currency of the operation, the exchange rate (in case of foreign exchange swaps), the maximum bid limit, the minimum individual allotment (if any), the minimum allotment ratio, the time schedule of the submission.



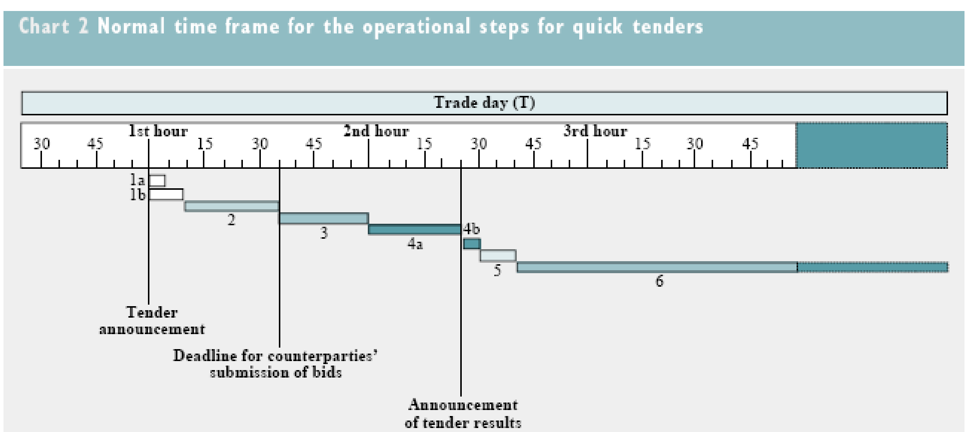


Figure 5-9: Tender procedure for standard and quick tenders (Source ECB)

Appendix 5-B: Stationary tests

Augmented Dickey Fuller test and Kwaitowski, Phillips, Schmidt and Shin (1992) tests are performed and reported with intercept.

The stationary results are confirmed with trend and intercept in the two test procedures.

	ADF	KPSS
$\Delta r_{10Y,t}$	-28.4*	0.125*
$\Delta r_{3M,t}$	-10.5*	0.141*
$ln(\sigma_{10Y,t})$	-6.59*	0.797
$ln(\sigma_{3M,t})$	-7.17*	0.426*
$\Delta S_{10Y,t}$	-26.8*	0.243*
$\Delta S_{3M,t}$	-19.8*	0.22*

ADF and KPSS tests statistics

($*$) validates the stationary hypothesis at the 5% level

Appendix 5-C: MSVAR estimations.

Estimations are performed using the MSVAR package of Krolzig (1997) with Ox. $\Delta r_{10Y,t}$, $\Delta r_{3M,t}$, $\Delta S_{10Y,t}$ and $\Delta S_{3M,t}$ are expressed in basis points and $\sigma_{10Y,t}$, $\sigma_{3M,t}$ are annualized value of volatility. The number of lags is chosen via the Akaike and Schwarz criteria.

	$\Delta r_{10Y,t}$	$\Delta r_{3M,t}$	$ln(\sigma_{10Y,t})$	$ln(\sigma_{3M,t})$	$\Delta S_{10Y,t}$	$\Delta S_{3M,t}$
$\Delta r_{10Y,t-1}$	0.204 0.037	0.018 0.026	0.0036 0.004	-0.018^{**} 0.009	0.0006^{**} 0.0003	-0.0036 0.0066
$\Delta r_{10Y,t-2}$	-0.105^{**} 0.0366	-0.017 0.0265	-0.0014 0.0048	0.014 0.009	0.0002 0.0003	0.0089 0.0066
$\Delta r_{3M,t-1}$	0.057^{**} 0.0295	0.116^{**} 0.021	-0.012^{**} 0.004	-0.023^{**} 0.007	-0.0038^{**} 0.0002	0.0117^{**} 0.0052
$\Delta r_{3M,t-2}$	-0.035 0.0063	-0.460^{**} 0.046	-0.007 0.0028	-0.027^{**} 0.015	0.0004 0.0005	-0.031 0.011
$ln(\sigma_{10Y,t-1})$	-0.020 0.266	0.020 0.193	0.172^{**} 0.034	0.089 0.066	0.0031 0.00053	-0.0307 0.0113
$ln(\sigma_{10Y,t-2})$	-0.523^{**} 0.259	-0.325^{*} 0.188	0.214^{**} 0.034	-0.0084 0.064	-0.0029 0.0022	0.0372 0.0463
$ln(\sigma_{3M,t-1})$	-0.144 0.145	-0.230^{**} 0.0022	0.038^{**} 0.019	0.407^{**} 0.036	0.0008 0.00121	-0.0063 0.0259
$ln(\sigma_{3M,t-2})$	0.214 0.144	-0.285^{**} 0.104	0.0001 0.01	0.164^{**} 0.035	-0.0001 0.00120	0.035 0.0257
$\Delta S_{10Y,t-1}$	0.740 3.49	39.64^{**} 2.53	-1.58^{**} 0.458	0.735 0.869	-0.471^{**} 0.029	3.53^{**} 0.62
$\Delta S_{10Y,t-2}$	3.442^{*} 2.06	61.76^{**} 1.49	-0.654^{**} 0.027	-1.843^{**} 0.512	-0.092^{**} 0.0171	1.86^{**} 0.367
$\Delta S_{3M,t-1}$	-0.191 0.163	-0.686^{**} 0.118	0.077^{**} 0.020	0.0186 0.041	-0.00005 0.001	-0.331^{**} 0.029
$\Delta S_{3M,t-2}$	-0.140 0.142	-0.677^{**} 0.103	0.0017^{**} 0.018	-0.023 0.035	-0.0030^{**} 0.0012	-0.183 0.0254
D_t^{OMO}	-0.350 0.249	-0.165 0.181	0.133^{**} 0.032	-0.138^{**} 0.062	-0.0036^{*} 0.002	-0.075^{*} 0.044
μ	1.05 0.72	1.936 0.528	1.224^{**} 0.095	0.680^{**} 0.181	-0.0022 0.006	0.0546 0.130
R^2	0.08	0.83	0.19	0.30	0.47	0.28

Table 1: results under regime 1

($*$) indicates significance at 10%

($**$) indicates significance at 5%

standard errors are provided below the estimated coefficients

	$\Delta r_{10Y,t}$	$\Delta r_{3M,t}$	$ln(\sigma_{10Y,t})$	$ln(\sigma_{3M,t})$	$\Delta S_{10Y,t}$	$\Delta S_{3M,t}$
$\Delta r_{10Y,t-1}$	0.253^{**} 0.0450	0.0016 0.0721	0.0096 0.006	0.0118 0.0116	0.0022 0.0048	0.0138 0.018
$\Delta r_{10Y,t-2}$	−0.011 0.0466	0.075 0.073	−0.004 0.007	−0.0104 0.0118	-0.015^{**} 0.004	-0.039^{**} 0.0184
$\Delta r_{3M,t-1}$	-0.065^{**} 0.02886	0.021 0.0453	−0.004 0.004	0.041^{**} 0.007	0.0059^{**} 0.003	−0.0132 0.0114
$\Delta r_{3M,t-2}$	−0.001 0.0215	-0.228^{**} 0.033	0.0039 0.0032	0.013^{**} 0.0054	0.0018 0.0022	0.0016 0.0085
$ln(\sigma_{10Y,t-1})$	0.276 0.302	0.199 0.476	0.283^{**} 0.0459	0.0956 0.0769	−0.0408 0.032	0.188 0.119
$ln(\sigma_{10Y,t-2})$	0.0263 0.310	-1.028^{**} 0.488	0.145^{**} 0.047	−0.062 0.078	−0.0075 0.228	−0.148 0.122
$ln(\sigma_{3M,t-1})$	-0.417^{**} 0.174	0.712^{**} 0.275	0.0118 0.0265	0.344^{**} 0.0444	−0.0085 0.018	0.102 0.0692
$ln(\sigma_{3M,t-2})$	0.375^{**} 0.173	−0.172 0.272	0.0131 0.0262	0.261^{**} 0.0439	0.0210 0.0183	−0.0025 0.068
$\Delta S_{10Y,t-1}$	0.783^{*} 0.420	-2.379^{**} 0.662	0.119^{*} 0.0683	0.0486 0.107	-0.417^{**} 0.044	−0.0011 0.166
$\Delta S_{10Y,t-2}$	0.759^{*} 0.426	−0.19 0.670	0.092 0.064	0.0057 0.108	-0.271^{**} 0.045	0.0436 0.168
$\Delta S_{3M,t-1}$	0.131 0.127	0.147 0.201	−0.013 0.019	−0.026 0.0324	0.0047 0.0135	-0.464^{**} 0.050
$\Delta S_{3M,t-2}$	0.107 0.139	−0.168 0.219	−0.0046 0.0216	−0.045 0.035	0.0107 0.0147	-0.168^{**} 0.055
D_t^{OMO}	−0.385 0.332	−0.565 0.523	0.047^{**} 0.050	0.264 0.084	0.105 0.0351	0.1099 0.131
μ	−0.487 0.910	1.524 1.446	1.381^{**} 0.139	0.656^{**} 0.233	0.0776 0.097	−0.312 0.363
R^2	0.10	0.16	0.15	0.35	0.22	0.18

Table 2: results under regime 2

(∗) indicates significance at 10%

(∗∗) indicates significance at 5%

standard errors are provided below the estimated coefficients

Appendix 5-D: *Within regime* Impulse response functions *à la* Pesaran and Shin (1998)

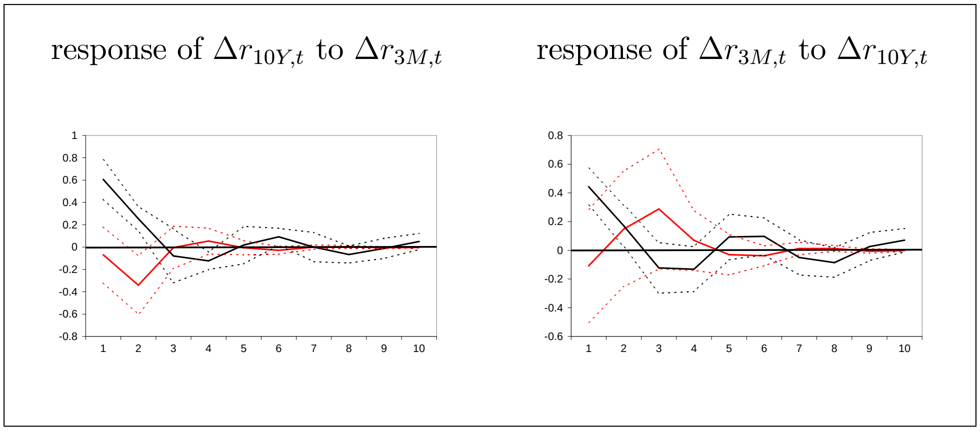


Figure 5-10: IRF for the mentioned variables

Note: The regime 1 IRFs are in black and the Regime 2 IRFs in Red
It corresponds to one std error positive shock
Are presented the 5 percent confidence intervals (bootstrap)

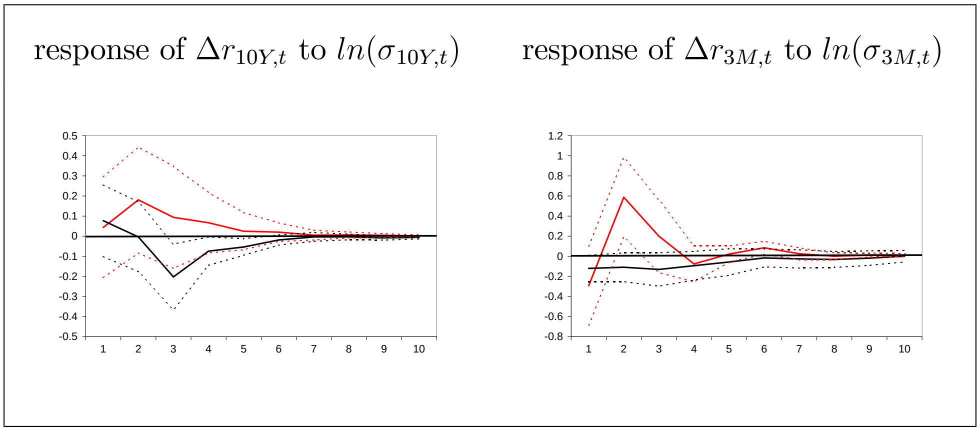


Figure 5-11: IRF for the mentioned variables
Note: The regime 1 IRFs are in black and the Regime 2 IRFs in Red
It corresponds to one std error positive shock
Are presented the 5 percent confidence intervals (bootstrap)

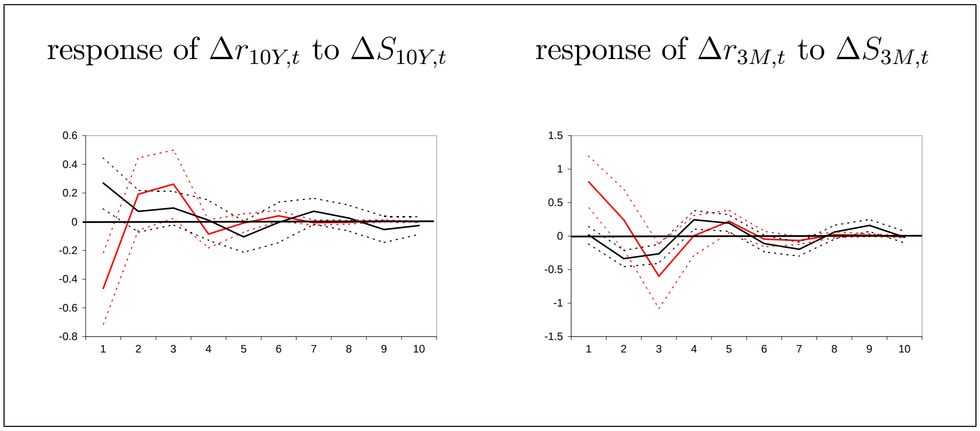


Figure 5-12: IRF for the mentioned variables
Note: The regime 1 IRFs are in black and the Regime 2 IRFs in Red
It corresponds to one std error positive shock
Are presented the 5 percent confidence intervals (bootstrap)

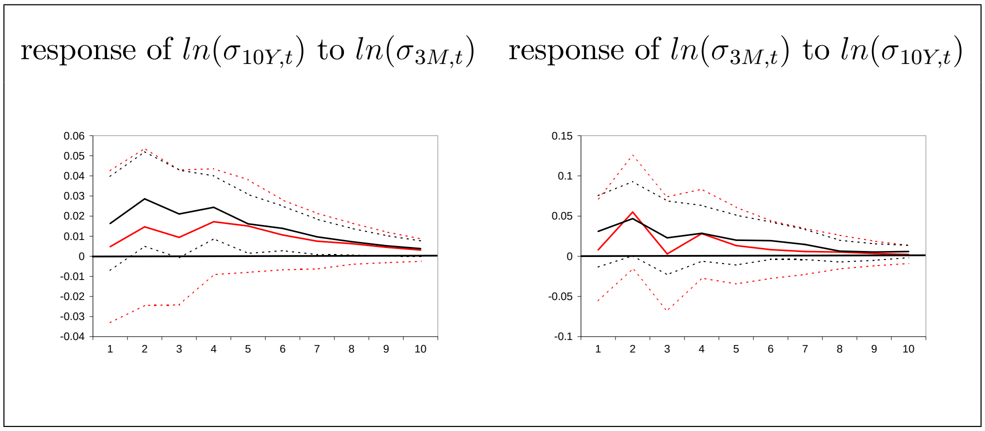


Figure 5-13: IRF for the mentioned variables
Note: The regime 1 IRFs are in black and the Regime 2 IRFs in Red
It corresponds to one std error positive shock
Are presented the 5 percent confidence intervals (bootstrap)

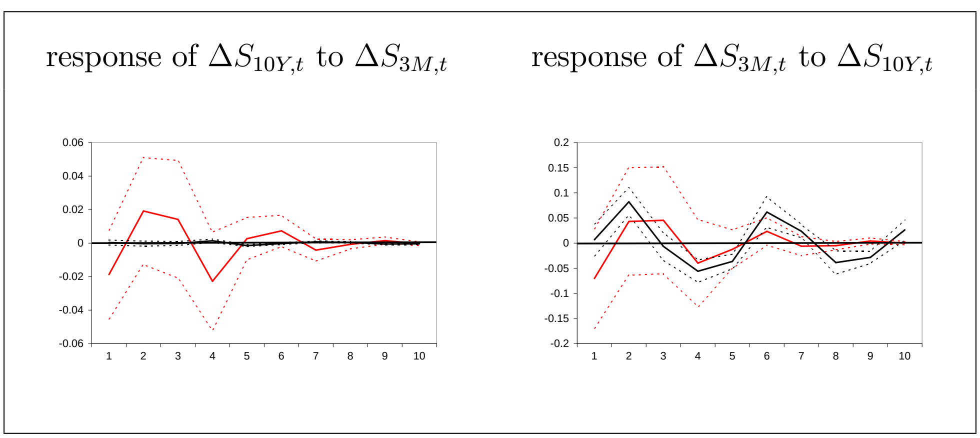


Figure 5-14: IRF for the mentioned variables
Note: The regime 1 IRFs are in black and the Regime 2 IRFs in Red
It corresponds to one std error positive shock
Are presented the 5 percent confidence intervals (bootstrap)

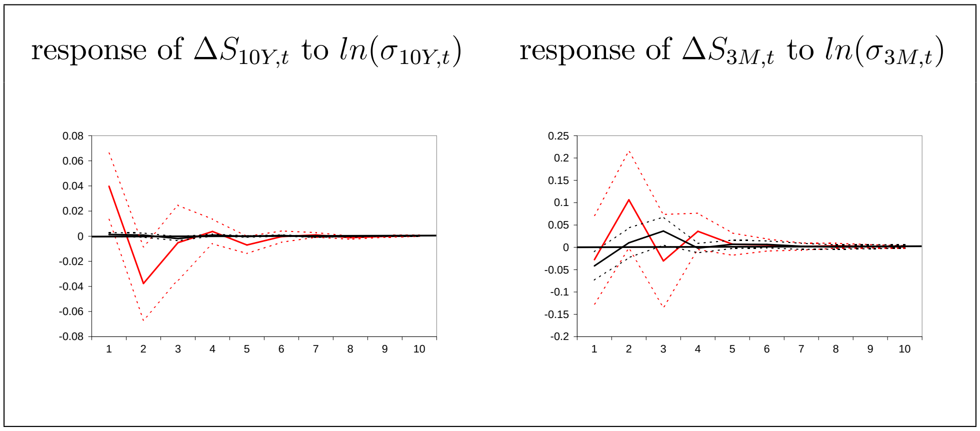


Figure 5-15: IRF for the mentioned variables
Note: The regime 1 IRFs are in black and the Regime 2 IRFs in Red
It corresponds to one std error positive shock
Are presented the 5 percent confidence intervals (bootstrap)

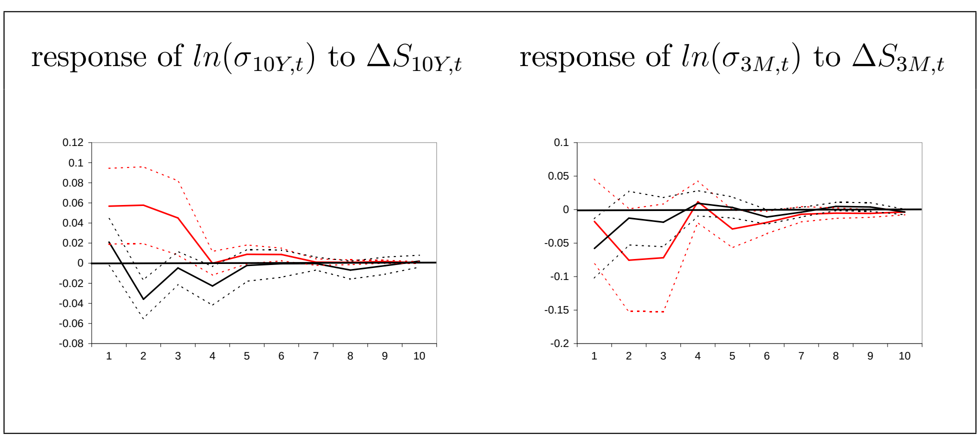


Figure 5-16: IRF for the mentioned variables
Note: The regime 1 IRFs are in black and the Regime 2 IRFs in Red
It corresponds to one std error positive shock
Are presented the 5 percent confidence intervals (bootstrap)

Chapter 6

Probability of informed trading on the euro overnight market rate: an update

Non technical summary[1]

In December 2007, in a speech about the financial market turmoil Mr. González-Páramo, member of the Executive Board of the ECB, gave the following comment: «when talking about information in the context of the financial turmoil, a key dimension of interest regards the role of informational asymmetries in the money markets», introducing in this way an interesting perspective in the context of the discussions not only about the turmoil but also for money markets. The role of information which is widely acknowledged, has been investigated extensively in financial markets such as stock markets. However, despite the role played by money markets for monetary policy, this dimension has been almost ignored or addressed rather marginally in the academic literature.

Focusing on euro money markets, information asymmetries may actually play a significant role on various dimensions related to how private banks refinance their short-term liquidity needs. Generally speaking, the central bank represents the main source which provides the liquidity which is necessary for this market to work. Banks, however, have two alternative channels to fulfil their liquidity needs (mainly stemming from required reserves and autonomous factors), namely relying on central bank's open market operations and/or on the interbank market.

As regards the first channel, liquidity is supplied directly by the central bank through auctions at which banks can participate by submitting bids generally consisting in a certain amount of demanded liquidity at a certain price which cannot be lower than a rate decided by the monetary authority. These operations, which may have various maturities, are secured and banks must possess adequate collateral in proportion to the amount of liquidity received from the central bank.

[1]This is an updated version of the ECB working paper No 987, and the Banque de France WP No 171, a joint work with Stefano Nardelli. The two authors would like to thank those who contributed to improve previous versions of the paper with their valuable comments. In particular, the authors would like to thank Natacha Valla for her comments at the internal seminar of the Banque de France in July 2007 and Gunther Wuyts and Frederic Boissay for their discussions at the ECB Workshop on "The analysis of the money market: role, challenges and implications from the monetary policy perspective" in November 2007. We also thanks the participants of the Bank of Finland seminar in 2008 and particpants of the European Economic Association meeting 2008.

As a consequence, the existence of these provisions aimed at covering risks may be discriminatory as they may exclude some banks which do not possess enough collateral or the collateral does not fulfil some 'quality' criteria. Moreover, banks are allowed to submit bid schedules which may (and often do) reflect strategic behaviours aimed at obtaining the necessary liquidity at the minimum price. In this respect, both the existence of rules and behaviours introduce discrimination among the population of banks which gives scope for the use of private information.

As regards the second channel, normally indicated as interbank market, it represents the market where most transactions take place. Moreover, a significant amount of transactions are unsecured, i.e. it takes place through bilateral transactions without collateral. Transactions in the interbank market are typically not centralized and a significant proportion of contracts are traded over the counter. Market reputation for a bank is thus key to be able to get the necessary liquidity. Moreover, prices at which liquidity is traded may be rather different according to the typology and size of banks involved. In general, population heterogeneity appears to be central when one wants to analyze market price dynamics.

While auction behaviours and the role of private information have been investigated especially in a number of theoretical papers, very scarce papers (if any) have analyzed the role of information asymmetries in the price formation mechanism in the secondary market. This chapter represents an attempt to address the relevance of this issue in the euro overnight market. More concretely, the Probability of INformed trading (PIN) is estimated on data from the euro overnight market. Originally developed on the model by Easley and O'Hara (1992), the PIN has been initially estimated on stock markets and subsequently applied to a variety of financial markets (e.g. forex and bond markets) but never to money markets. This chapter fills this gap and proposes an estimate of the standard PIN measure calculated on a high frequency dataset spanning most of the history of the single currency money market, i.e. the years between 2001 and 2008.

In this chapter, various estimates are presented, including an estimate based on rolling samples to give an historical perspective and to assess the impact of some institutional changes on population heterogeneity especially after the 2004 reform.

As concerns the results presented in the chapter, the steady increase of the PIN measure between 2000 and 2003 points to the fact that a heterogeneous learning process of market mechanisms within participants took place. However, a transition phase characterized by a stabilization of the estimated share of informed trading, followed the announcement of the operational framework reform and the actual implementation of the changes in March 2004. This reform appears to have modified the informational patterns of order flow in the euro area money market as informed trade has become more predominant especially between the last main refinancing operations and the end of the reserve maintenance period than it was before. A further turning point coincides with the increased frequency of FTOs at the end of reserves maintenance periods but especially after the ECB decided to allot consistently liquidity above the benchmark since October 2005. These measures appear to have reduced the impact of information asymmetries by reducing opportunities for strategic trade.

Finally, the PIN evolution is analyzed after the events which started in late summer 2007 and mainly affected money markets. As regards the evolution of information asymmetries, the progressive decline of banks' information heterogeneity started in 2004 came to a halt in April 2007, i.e. about four months before the emergence of the most visible effects of the turmoil (suggests a potential leading property of this index). Afterwards, it declined likely in response to the generous liquidity supplied by the European Central Bank until May 2008. The decision to inject a massive amount of liquidity in the money market visibly reduced, among other effects, the potential for a strategic use of private information by banks until April 2008. Then our market liquidity indicator clearly crashed to its lowest level in the sample indicating important tensions and a new rise in information asymmetries.

6.1 Introduction

> "*When talking about information in the context of the financial turmoil, a key dimension of interest regards the role of informational asymmetries in the money markets*"
> José Manuel González-Páramo, member of the Executive Board of the ECB (December 2007)

The turmoil in late summer of 2007 triggered by US sub-prime mortgage crisis, produced many negative effects on the smooth functioning of various markets and on the financial stability of monetary and financial institutions. It attracted the attention of the community of both academicians and economic analysts onto a market which traditionally was either ignored or did not have great prominence in financial studies: the money market. During the turmoil, disruptions mainly affected the shortest maturities of the yield curve and caused swift interventions of major world central banks that tried to avoid severe financial market disruptions and provide the necessary financial support to limit negative effects to real economy. Overall, the main trigger was a massive confidence crisis among credit institutions, caused by a substantive lack of knowledge about liquidity or credit risks of potential partners in financial transactions, in particular on some crucial segments of money markets such as the overnight segment.

The goal of this chapter is to shed some light on this market for the euro area and, in particular, to analyze empirically the role of information on pricing the asset traded in this market, i.e. the central bank's liquidity, using tools that have been developed in the context of the microstructure analysis.

Central banks regulate and influence the functioning of the money market owing to the special role this market plays for the implementation of monetary policy. As a matter of fact, institutional rules of the money market have a strong influence both on available liquidity in the money market and on the trading mechanisms between agents (banks).

In the euro area, the money market is key since it represents the cornerstone of the architecture of the whole Eurosystem's operational framework and is crucial for the process of steering interest rates along the yield curve and then transmitting the monetary policy impulse to the euro area economy.

This chapter focuses on the euro overnight interbank market. The central bank is the primary source of its liquidity supplied through open market operations (OMOs). However, most transactions take place in the secondary market which is normally referred to as "interbank market". In this way, banks can actually fulfil their appetite for liquidity through two main channels: directly from the central bank at the OMOs, or from bilateral transactions with other banks.

In the academic literature on the euro money market, research mainly focused on aspects related to ECB's auctions and their design to supply liquidity to the banking system. For example, in Ewerhart et al. (2005) banks' bidding behavior in the Eurosystem's main refinancing operations (MROs) is analyzed in connection with the situation in the secondary market. Other papers analyzed empirically the effects of the changes introduced to the operational framework in 2004 on various dimensions, in particular on bank's bidding behavior and on money market rates' level and volatility.[2]

In general, heterogeneity in banks' behaviors is only addressed from a theoretical perspective, while empirical studies are still very scarce, especially for the euro area. This chapter tries to fill this gap and analyses the effects of heterogeneous information on trade behavior in the interbank market. In the academic literature, several models has been proposed, all based on either stock or exchange rate markets. One of the first model addressing information asymmetries in a stock market is the sequential trade model of Glosten and Milgrom (1985). Based on this seminal model, Easley and O'Hara (1992) developed their probability of informed trading (PIN) model to measure information heterogeneity in populations of traders and to study its impact on price formation and market liquidity. The PIN model is built on the pattern of buy and sell orders,

[2] See Neyer (2004), Durré and Nardelli (2007), Jardet and Le Fol (2007).

which is interpreted as stemming from heterogenous information flows in the market. The approach by Easley et O'Hara has inspired a relatively rich set of papers, most of which focuses on equity markets.[3] In this chapter, a PIN model is applied for the first time to the money market to analyze the euro overnight interest rates and consider information flows, heterogeneity in population and market rules. Empirical results are derived from data publicly available to market participants over a time horizon spanning almost the entire history of the single currency money market including the recent financial turmoil in 2007-2008. A simple PIN model is estimated to identify the nature of market belief over time and the days when informed trades are more likely to have occurred in the market. Moreover, some organizational aspects of the market - e.g. occurrence of MROs, periodicity of maintenance periods - are linked to order flows and the nature of days (whether informed or not). Finally, the historical evolution of the PIN is reviewed against the March 2004 reform and other significant events.

The chapter is structured as follows. In Section 6-2, some features of the euro money market organization, market participants and the evolution of the operational framework are discussed. In Section 6-3, the microstructure model used to analyze the overnight market and the econometric application are presented. In Section 6-4, data and empirical results are illustrated. In Section 6-5, the historical evolution of the PIN is reviewed in particular against some significant events between the end of 2000 and the end of 2008. Finally, Section 6-6 concludes.

6.2 The euro money market structure

The euro money market is characterized by the existence of an important institutional player (i.e. the central bank), a set of rules decided by this player based on its strategic objectives, and

[3] See Easley Kiefer O'Hara and Paperman (1997a, 1997b), who relate the PIN to the volume traded ; Easley Kiefer and O 'Hara (19976 use the PIN to test "cream skimming" between places in a fragmented market ; Grammig Schiereck and Theissen (2001) who relate the PIN measure to the trading rules of the equity market ; Easley Hvidkjaer and O'Hara (2005) use the PIN measure as a factor in the Fama-French model.

specific traders, i.e. banks. The amount of assets available in this market is supplied through OMOs conducted at a regular frequency by the central bank to meet demand and, in this way, to ensure an equilibrium price (interest rate) compatible with its monetary policy objectives.[4]

In the euro area, the size of operations and, then, the amount of financial assets (liquidity) consists of two main elements which concur to define the so called "liquidity deficit" of the Eurosystem, i.e. required reserves and autonomous factors. While the size of required reserves is decided by the central bank, autonomous factors include items which have an impact on the total liquidity amount but are not controlled by the central bank. Among these items, there are bank notes in circulation, domestic and foreign assets possessed by national central banks, deposits of governments in national central banks' accounts and other financial assets.

Banks can fulfil their liquidity needs through two main channels: (1) participating to central bank's refinancing operations [5] and/or (2) bilateral transactions in the interbank market.

6.2.1 Refinancing operations design

The two main instruments are the MROs and longer-term refinancing operations (LTROs) which differ for the maturity of refinancing.[6]

Banks can participate to OMOs by submitting bids, i.e. requesting a certain amount and offering a price (interest rate) which cannot be lower than the interest rate set by the monetary authority (i.e. the minimum bid rate). Bids are served starting from highest offered interest rate

[4]For more details on the operational framework principles, rules and available instruments see European Central Bank (2006).

[5]In the Eurosystem, banks can also get liquidity at any time by borrowing funds directly from the central bank. Marginal lending and deposit are the two standing facilities The interest rates applied to these facilities the two other policy rates set by the monetary policy authority of the euro area.

[6]Until 2007, the bulk of liquidity (i.e. around 75%) used to be injected through weekly MROs, whereas the remaining quantity (i.e. around 25%) through monthly LTROs having a maturity of three months. Following the financial turmoil in the late summer of 2007, the share of longer-term liquidity significantly increased over time to above 50% of the total amount of outstanding liquidity. Moreover, longer-term refinancing operations with six-month maturity were also conducted.

to the *marginal interest rate* resulting from the total amount of liquidity supplied by the central bank. At this rate, liquidity is distributed *pro rata* to bidders all offering the same interest rate based on shares computed on the basis of individual demanded amounts.

To be able to participate to central bank's auctions, banks must comply with requirements on their financial soundness. Banks must possess adequate collateral in proportion to the amount of liquidity received from the central bank.[7] From the perspective of participation to direct refinancing, the existence of these provisions may actually be discriminatory, as banks not having sufficient or low quality collateral are excluded. In other words, existing rules that aimed at ensuring financial soundness may actually represent a barrier for some banks.

In addition to these two types of operations, another one has recently become rather frequent: fine-tuning operations (FTOs). FTOs are generally conducted at the end of reserve maintenance periods to resolve significant liquidity imbalances and to avoid marked departures of the overnight rate from the minimum bid rate or excessive volatility.

Unlike the previous two operations, FTOs can be conducted to either supply or withdraw liquidity, depending on the sign of the liquidity imbalances. Because of the need to act rapidly, the list of banks eligible to participate is more restricted, and participation is normally rather limited (between ten and fifteen banks usually participate). Efficiency, therefore, creates another potential barrier for the participation to this type of refinancing. In addition to operational rules, administrative costs may in some cases represent a disincentive, if not an obstacle, to participation in this primary channel of refinancing.

[7] Financial assets must fulfil some criteria to be eligible as collateral. Criteria for eligibility impose that credit rating of certain type of assets must be above a threshold decided by the central bank. These criteria have also an impact on the amount of collateral which is requested as a consequence of the "haircut" imposed by the central bank which increases with the riskiness of the asset. The amount of collateral requested by the central bank is equal to the nominal value of liquidity received by the bank plus the interest rate plus the haircut.

6.2.2 The interbank market

A secondary source of refinancing is represented by the interbank market. Liquidity in the interbank market is typically not centralized and banks deal on this market in various ways. A significant amount of transactions are unsecured, i.e. without exchange of collateral and central bank's liquidity is distributed across banks through bilateral transactions. In this way, all banks – including those not possessing adequate collateral or not able to get liquidity in weekly auctions – may satisfy their liquidity needs. As pointed out in Hartmann and Valla (2007), this market is characterized by both – and mainly – direct dealing (i.e. over-the-counter or OTC market) and electronic centralized platforms (e.g. eMiD). Being less regulated, the interbank market is therefore less discriminatory; nonetheless, there may be situations in which sophisticate agents are able to exert some market power, either because they can access various refinancing sources or because they can exploit more efficiently the information on aggregate liquidity conditions.

The euro money market has experienced a huge expansion since its creation in 1999.[8] This market is mainly organized around four main segments: (i) unsecured market; (ii) secured market; (iii) OTC derivatives swaps; and (iv) short-term securities.

The two first segments are particularly interesting. The unsecured market allows to trade lending and borrowing uncollateralised contracts. Since no collateral is requested for contracts, maturities are concentrated on the very short term to minimize default risk: in 2006, 96% of the contracts were less than one month, and 70% on the overnight as indicated in European Central Bank (2007). By contrast, the secured market requires that contracts are backed by collateral. Since banks have a guarantee on the subscribed contracts, the maturity breakdown of this market is less concentrated on the very short-term maturity: only 13% are overnight maturities while "tomorrow/next to one month" of this market accounts for 77% of total transactions. Recently, electronic platforms have started taking on an increasing market share for both secured and unsecured trade and, today,

[8]For more details on the characteristics of the euro money market see European Central Bank (2007).

they account for around 17% of the unsecured and around 49% of the secured market. However, it appears more difficult to implement an electronic platform on the unsecured market.

"Reputation" is a key difference between secured and unsecured market. Unsecured contracts are traded over the counter on a direct basis. Since counterparties do not have any guarantee (i.e. contracts are not collateralized), it is crucial to know whom a bank is trading with. The anonymity of electronic platforms does not allow any control procedure on contracts, which may explain the different developments of electronic platforms between secured and unsecured market. In this respect, even if analyzing market behavior in an OTC market is more difficult as prices and volumes of transactions are only partially observed, the information from OTCs is undoubtedly more accurate from the point of view of representativeness[9].

A first element of heterogeneity is certainly the size of banks. Usually, big banks can trade more easily than small banks on the unsecured market.

A second element is the discrimination of counterparties induced by rules on the participation to the Eurosystem's liquidity auctions. As illustrated before, banks' eligibility is based on requirements on financial soundness that impose to possess adequate collateral. Since not all banks can participate to these operations, aggressiveness may arise on the secondary market from banks excluded from central bank's refinancing or may offer opportunities to only few banks to trade strategically in the secondary market.

A third factor is the location of the bank. Notwithstanding the fact that all banks in the euro area are entitled to participate to ECB's OMOs, a country bias can still be observed in trading activities in the sense that only 25% of transactions are still made between banks within the same country, while only 55% are cross-border transactions. As large market participants play the role of

[9] Tipically, the rules regulating the access to trade in e-MiD exclude many banks by imposing a net asset worther than USD 10 millions, which prevents smaller banks from becoming market participants and avoids any potential reputation problems.

liquidity providers at a country level, uneven liquidity distribution affecting in particular countries traditionally less active in the weekly MROs may actually occur.[10]

Overall, several elements in the functioning of the euro money market are sources of asymmetries between agents. These asymmetries may stem either from the rules governing the functioning of the market or from factors characterizing individual banks (size, access to direct financing, geographical location). An attempt to reduce these asymmetries by increasing the amount of information disclosed to market participants and then reducing the scope for manipulation and strategic use of private information took place in 2004 when the operational framework of the Eurosystem underwent a reform. The detailed measures and their rationale are described in detail in appendix 6-A. This heterogeneity between banks has crucial effects on market dynamics as it is illustrated in the following sections.

6.3 The model

The empirical model presented below considers market information and the fact that traders (banks) do not perceive price signals in the same manner. To treat heterogeneity in terms of the characteristics outlined above, two groups of banks are considered: big banks are defined as informed bank, and small banks as uninformed banks.

The framework used for the empirical analysis is the same as in Easley and O'Hara (1992), adapted to fit some specific characteristics of the money market. In the next sections, the main features of the model are first illustrated together with some parameters derived from the basic model, i.e. the probability of informed trading (PIN) and the market liquidity. Then, a likelihood function is derived from the model and estimated on high frequency data.

[10] An example is represented by Portuguese banks, which never participates to weekly MROs.

6.3.1 Model Structure

To qualify the model used for the exercise developed later in the chapter, the most relevant features of the seminal model by Easley-O'Hara (referred to as EO model thereafter) are first discussed and transposed to the money market.

6.3.1.1 Assets

In the unsecured overnight market, assets are peculiar compared with other financial markets, since they are represented by contracts. Unlike in stock markets, it is not traded the property of a share value of a firm with some fundamental factors, but rather a cash transfer from one party to another. This transfer is negotiated at a certain interest rate, whose level determines the value of the contract and characterizes, at an aggregate level, trade patterns in the market. The value of the contract reflects the availability of the underlying asset in the market (i.e. market liquidity) but also individual knowledge about future developments of the asset and the central bank's liquidity management.

Money contracts are assumed to be underwritten at a fair value. In traditional applications of the EO model, the true unobservable value is the fundamental value of a financial asset. It may be more contentious to define the true value of the overnight interest rate. However, this value can be assumed to reflect in normal circumstances the aggregate liquidity needs in the money market.

6.3.1.2 Information on assets

On the role of information, two dimensions can be considered. First, a good knowledge of aggregate liquidity conditions in the money market gives an insight on central bank's expected supply and thus of the value of the asset. Second, most active banks may determine, or at least, influence demand because:

- the bigger the needs of liquidity are for a bank, the larger its share in global liquidity needs is;
- the more active a bank is, the better the tools it should have to perceive market information;
- the more active a bank is, the more orders it centralizes.

As a consequence, if a bank has an active role in the market, its knowledge about market needs should be enhanced and, thus, its information.

A market signal can be defined as a piece of information that allows traders to update their beliefs on the true value of (overnight) liquidity, and to make the decision on whether to trade or to wait. If there is a signal, the type of the signal is assumed to be known by the pool of informed banks, and to remain constant during a given day. A signal can be classified as "high" (H) if contracts would be negotiated at a higher interest rate during the day, or "low" (L), if contracts would be negotiated at a lower rate. The model considers also days without signal (O).

6.3.1.3 The population of traders

The population of traders is characterized by information heterogeneity. In the money market, traders are banks which can be classified as "informed", "uninformed" and "market makers". As in Neyer (2004), banks are motivated to trade mainly to comply with institutional rules (i.e. fulfillment of reserve requirements) and minimize the cost of handling liquidity.

Efficiently-informed banks meet two criteria. First, they have superior information and trade on the basis of this information. They represent the most active pool of banks: they acquire, understand and use market information. Second, they are supposed to have fulfilled their reserves requirements or to be not too far from the fulfillment of their reserves. Actually, a bank may interpret a liquidity deficit on the market but may not be able to trade on this information since it may still need to fulfil its reserve requirements. Unlike in the standard EO model interpretation, in this special case, trades opposite to the market signal might be rational, but are however considered as non informed trade. This is comparable to an opportunity cost for immediacy as discussed in Foucault et al. (2003), but in the case of limit order books.

Uninformed banks have no piece of information to trade. Their trade is mainly motivated by inventory constraints, i.e. reserves requirements imposed by the central bank.

Finally, the market-maker pool is assumed to be composed of banks which fulfil their liquidity needs mainly directly from the central bank. These banks provide liquidity to the secondary market and are assumed to be competitive. They set quoted spreads and the best quoted spread, i.e. the narrowest spread, is displayed publicly to the market.

6.3.2 A sequential trade model

As in the EO model, banks arrive to the interbank market sequentially and make their decisions on whether to trade or not. Trade in the interbank market is motivated essentially by shocks in autonomous factors which may change individual positions with respect to reserve requirements. Due to the typical pattern in the fulfilment of reserves, the days between the last MRO and the end of the maintenance period appear crucial.[11] During these days, banks appears very active and information on aggregate liquidity has usually strong effects on the overnight interest rate.

The liquidity necessary to fulfil required reserves can be obtained in two ways, i.e. trading in the interbank market or making use of the existing central bank's standing facility (marginal lending). However, the latter alternative is more expensive (100 basis points above the minimum bid rate[12]) than trading in the interbank market. As a consequence, the increased activity in the interbank market during this period can be expected to reveal market participants' aggregate liquidity needs, and so imperfect information signals through price dynamics. More specifically, all banks observe the type of trade prevailing in the interbank market so that they can assign a probability to the

[11] The typical pattern observed since 1999 was altered after the emergence of financial turmoil in August 2007 and the frontloading policy conducted by the ECB.

[12] Except during the late 2008 and early 2009 when the corridor was temporarily reduced to 50 bp around the minimum bide rate.

type of order (i.e. whether it is more likely that some order comes from informed or uninformed banks) and, in case of informed trade, on the type of signal (high or low). As seen before, these signals are mainly driven by the aggregate liquidity situation which may only be witnessed by a pool of banks. The set of options for market agents can be summarized in a standard tree representing the trade process.

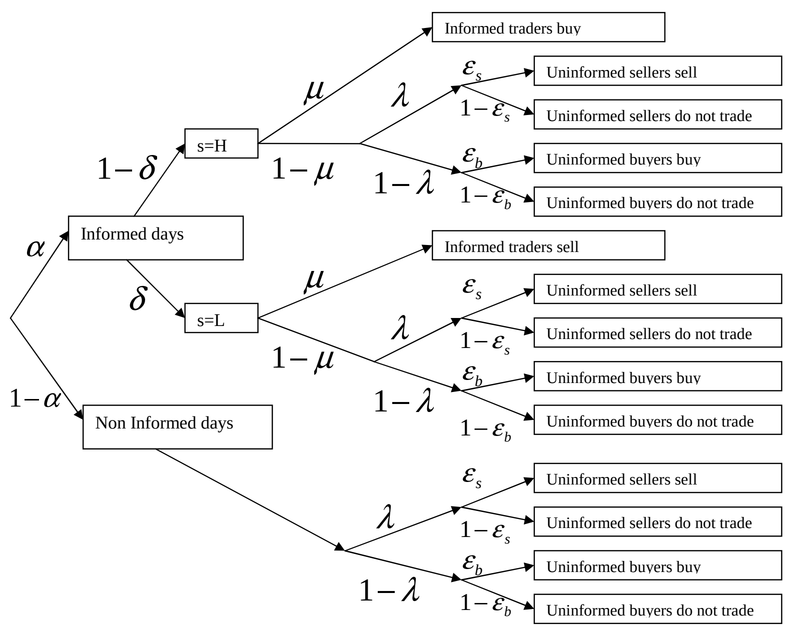


Figure 6-1: tree trade process

The structure of this market is characterized by the set of parameters P=$\{\alpha, \delta, \mu, \lambda, \varepsilon_s, \varepsilon_b\}$. The α parameter represents the probability that information occurs on the market during a given day.[13] In days with a signal (informed days), this information is expected to be linked with the direction of the interest rates on the borrowing (buy orders) or on the lending side (sell orders) of the market. The δ parameter measures the probability that signal is low, i.e. that information be perceived as driving the price lower than it actually is. Finally, the μ, λ, ε_s and ε_b parameters characterize the structure of the population of banks acting in the money market and their propensity to sell or buy given the nature of the day and the type of signal.

6.3.3 Informed trade vs. uninformed trade

Assuming that sequential trade models represent adequately the trading mechanism in the money market, it is possible to calculate the probability of being in an informed day with a low or a high signal, or the probability to be in a day without signal.

Large banks give information to the market about the interest rates they practice either on the lending or on the borrowing sides. However, a bank playing the role of market maker, adapts its bid and ask prices to comply with its own inventory constraints.[14] On the other side of the market, orders are lending-initiated (or a sell order if the counterpart hits the bid price) or borrowing-initiated (or a buy price if the counterpart hits the ask price). Based on the tree in Figure 6-1, the probability to observe B borrowing orders, S lending orders and N no trades, conditional to the

[13] Typically α is always quite high in financial markets. Easley Kiefer and O 'Hara (1997) estimate α to be around 0.75 for an asset traded on the AMEX, which indicates that very few days are non informed.

[14] The level of liquidity possessed by a bank in this context is assimiled to inventory constraints. It supposes it exists an optimal level of liquidity for banks to comply with reserve requirements and autonomous factors. The constraint represents the desire not to be too far from this optimal level.

intensity of the signal during a given day, are respectively:

$$\Pr(B, S, N \quad | \quad s = H) = (\mu + (1-\mu)\,\lambda\varepsilon_b)^B \cdot ((1-\mu)\,\lambda\varepsilon_s)^S \\ \cdot ((1-\mu)\,\lambda\,(1-\varepsilon_s) + (1-\mu)\,\lambda\,(1-\varepsilon_b))^N \tag{6.1}$$

$$\Pr(B, S, N \quad | \quad s = L) = ((1-\mu)\,\lambda\varepsilon_b)^B \cdot (\mu + (1-\mu)\,\lambda\varepsilon_s)^S \\ \cdot ((1-\mu)\,\lambda\,(1-\varepsilon_s) + (1-\mu)\,\lambda\,(1-\varepsilon_b))^N \tag{6.2}$$

$$\Pr(B, S, N \mid s = O) = \lambda^{B+S+N}[(\varepsilon_b)^B \cdot (\varepsilon_s)^S \cdot ((1-\varepsilon_b) + (1-\varepsilon_s))^N]. \tag{6.3}$$

Compounding these probabilities:

$$\Pr\left[(B, S, N) \mid \alpha, \delta, \mu, \lambda, \varepsilon_b, \varepsilon_s\right] = \alpha\,(1-\delta)\Pr(B, S, N \mid s = H) \\ + \alpha\delta\Pr(B, S, N \quad | \quad s = L) + (1-\alpha)\Pr(B, S, N \mid s = O). \tag{6.4}$$

Finally, considering a sequence of T days and assuming that days are independent from each other,[15] the likelihood of observing B buys, S sells and N no trades is:

$$\Pr\left[(B_t, S_t, N_t)_{t=1}^{T} \mid \alpha, \delta, \mu, \lambda, \varepsilon_b, \varepsilon_s\right] = \prod_{t=1}^{T} \Pr\left[(B_t, S_t, N_t) \mid \alpha, \delta, \mu, \lambda, \varepsilon_b, \varepsilon_s\right] \tag{6.5}$$

Some restrictions can be imposed to the set of parameters to simplify the model and to focus on the ability of banks to incorporate information. First, uninformed traders (sellers or buyers) are supposed to have the same intensity, i.e. $\lambda = 0.5$. A second restriction is to consider that being an uninformed seller has the same probability as being an uninformed buyer, i.e. $\varepsilon_s = \varepsilon_b = \varepsilon$. In this way, the set of parameters reduces to only four, i.e. $(\alpha, \delta, \mu, \varepsilon)$.

Based on the reduced form, the maximum likelihood function is as:

$$L(\alpha, \delta, \mu, \varepsilon) = \Pr\left[(B_t, S_t, N_t)_{t=1}^{T} \mid \alpha, \delta, \mu, \varepsilon\right] \tag{6.6}$$

$$= \prod_{t=1}^{T} \left[(1-\varepsilon)^N (1-\mu)^N A^{B+S}\right] \tag{6.7}$$

$$.[\alpha\,(1-\delta)\left(\frac{\mu}{A}+1\right)^{B} + \alpha\delta\left(\frac{\mu}{A}+1\right)^{S} + (1-\alpha)\left(\frac{1}{1-\mu}\right)^{B+S+N}]$$

where $A = \frac{(1-\mu)\varepsilon}{2}$.

To estimate these parameters, it is necessary to derive the structure of the trade flows i.e. the number of buy (borrowing), sell (lending) and no trade orders on a given day. Section 6-4 presents

[15] Imposing this simplification prevents from analysing the effects of the averaging mechanisms of reserve requirements in the operational framework after the changes to the operational framework. However, since the paper is primarily focused on aspects related to information disclosure, this simplification does not appear to limit the validity of the results.

standard estimation procedures using a classification of trades which has been adopted, given the only partial information on the available dataset on the overnight interbank market.

6.3.4 Asymmetric information and market liquidity

To understand how banks consider the institutional framework, how they use the information disclosed by the central bank and how this influences their behaviors, it is interesting to calculate from the model the probability γ that trade is informed for any given day. The probability of informed trading (PIN) represents the implicit risk that a bank faces when trading with a better informed bank on the direction of the interest rate. The PIN depends crucially the total probability of trade during informed days (i.e. market liquidity), defined as Ψ. Based on the tree describing the trade process in Figure 1, the parameter Ψ is equal to ε in non-informed days, and during informed days:

$$\Psi = (1 - \mu)\,\varepsilon + \mu \tag{6.8}$$

hence the PIN is defined as:

$$\gamma = \frac{\mu}{\Psi}. \tag{6.9}$$

As in the classical EO model, the PIN γ measures the implicit risk for some banks to (unintentionally) create trade opportunities for other banks, because they are less informed than their counterparties. The PIN is low when Ψ is high, and inversely it is high when Ψ shrinks. During informed days, the parameter Ψ is key to measure asymmetric information but also the impact of ECB interventions when, for instance, liquidity is scarce.

From a time-varying perspective an increase in the PIN indicates a heterogenous learning process among banks. For instance, this would be the case of an increasing number of banks having fulfilled their reserve requirements knowing how to use information on the expected path of overnight interest rates. By contrast, a decline in the PIN indicates that opportunities to trade on individual information decline. In this case, the learning process among banks would be increasingly homogeneous with less opportunities on trading on information, and, therefore, a decreasing risk in trade.

6.4 Data and results

6.4.1 Dataset

As already described, the overnight unsecured market is mainly an OTC market, and therefore interest rates at which overnight contracts are actually traded are unavailable in general. An exception is represented by the electronic trading platforms such as eMiD, which, for instance, provides volumes and prices of each transaction between banks. This platform, however, only includes a limited set of large banks and, as such, it has severe limitations as far as generality of results is concerned.

As an alternative, data from Reuters have been used. Reuters provides best bid and ask quotes in real time that are known to the market, but actual transaction prices are not available. When financial markets are very liquid as it is the case of the overnight market, however, effective prices can be assumed to be very close to quotes prevailing before transactions.[16] This gives to all market participants the prevailing levels of proposed rates and, mainly for this reason, was preferred to the eMiD database. The available dataset used for the application presented in this chapter, contains date, time and best bid/ask in the market at a 5-minutely frequency between December 2000 and December 2008 as displayed in Reuters' screen.

[16] See Brousseau (2006).

6.4.2 Trade classification

The second problem to solve was the identification of buy orders, sell orders or no orders for each day included in the sample to determine the order flow. Techniques such as in Lee and Ready (1991) are usually applied. Typically, if only transaction prices are known but not spreads, a spread is constructed following Roll (1984) and then every price is compared with the midpoint of the derived spread to determine whether market orders are buy- or sell-initiated.

To be able to apply this procedure, however, transaction prices must be known, whereas only spreads were available from the Reuters' dataset. To overcome this limitation, the following solution is adopted. In the literature,[17] quoted spreads are assumed to be made of three components: trading costs, information asymmetries and inventory constraints.[18] Due to the existence of reserve requirements, the inventory constraint component was assumed to be predominant. Hence, the classification of trade was based on the assumption that banks cannot be too far from their optimal inventory level and, therefore, movements of quoted spreads can be assumed to mainly reflect this fact.

Under this assumption, orders are classified analyzing changes in the bid and ask prices according to the following rules represented in figure 6-2.

- A common rise in the ask and bid price suggests that the price of the previous transaction was at the ask, and that dealers are willing to sell the asset at a higher price. On the bid side, no revision or an increase indicates that the dealer offers a best price to buy the asset. This case represents the dynamics following market "buy orders", i.e. a borrowing unsecured overnight contract has been initiated in the market (case 1 in Figure 6-2).

- A common decline in the ask and bid price represents the opposite situation. Dealers are willing to sell the asset at a lower price to the market and worsen the bid price to limit the market

[17] See, for instance, Ho and Stoll (1997), George, Kaul and Nimalendran (1991) or Harris (2003).

[18] This is a simplified view since many other factors on this special money market may influence the quoted spread.

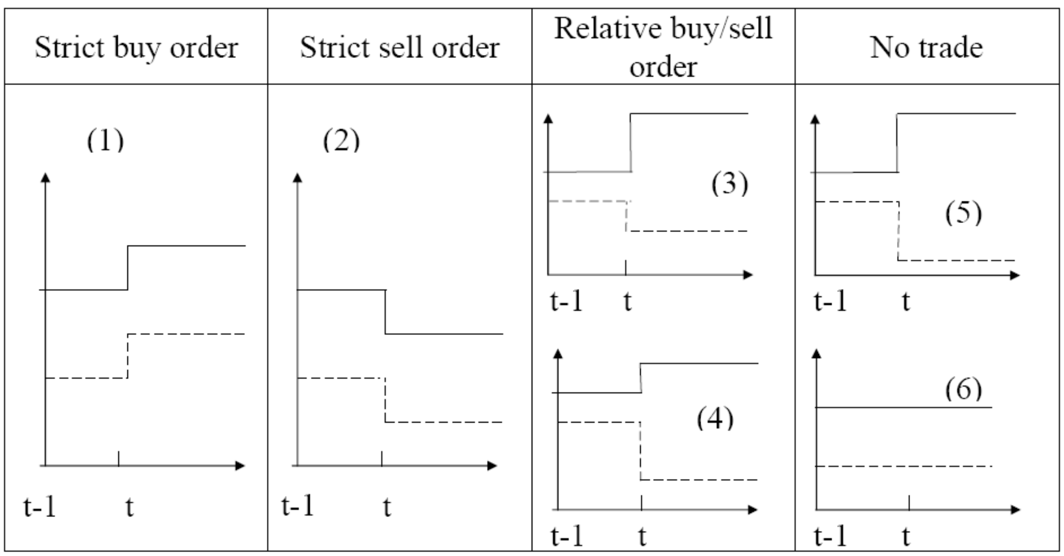


Figure 6-2: Classification of trades based on bid and ask variations

sell orders. This can be interpreted as a market "sell order", i.e. a lending contract has been initiated in the market (case 2 in Figure 6-2).

- An increase in the ask and a decrease in the bid is interpreted as a "buy order" for bigger positive jumps in the ask (case 3 in Figure 6-2) or a "sell order" for bigger negative jumps in the bid (case 4 in Figure 6-2).
- A decline in the ask and an increase in the bid, comparing absolute moves on each side, is classified as "buy order" if the increase in the bid is bigger than the decrease of the ask (these cases do not appear in Figure 6-2).
- Steady bid and ask prices or symmetric revisions characterize the absence of trade. This may only occur because of a change in market liquidity due to large volatility or to an increase in uncertainty (case 5 and 6 in Figure 6-2).

This classification is applied to more than 200,000 available quoted spreads. Daily sum of sell orders, buy orders and no trade orders are computed. Figures 6-3 shows the resulting distributions.[19]

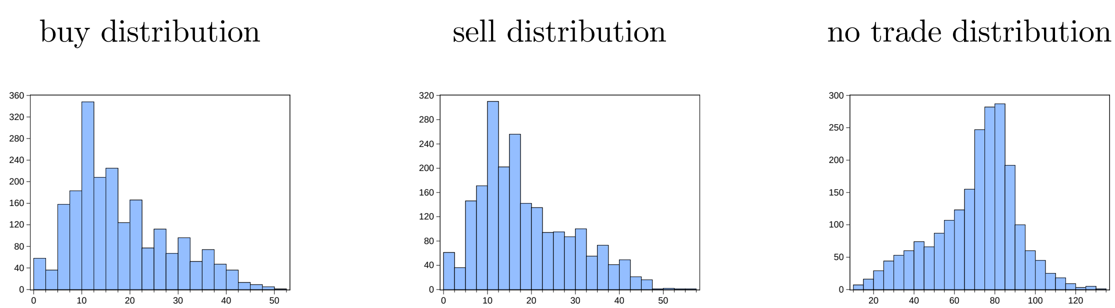


Figure 6-3: distributions of buy, sell and notrade per day

Some stylized facts emerge from the results:

[19] In the whole sample, about 2/3 exhibited pure movements (i.e. common increase or common decrease in ask or bid quotes) and 1/3 relative movements (i.e. opposite movements for the ask and bid quotes).

1. in the euro overnight market, a trade takes place every 20 minutes on average;

2. all distributions (including that for no-trade days) are skewed and leptokurtotic, which indicates that trade intensifies on some special days, namely during the last week of maintenance periods;

3. a slight bimodality is evident for all distributions, which points to a possible mixture of distributions in all cases. This latter aspect is captured by the parameter α, which represents in concrete terms the mixture between informed days (the most active ones) and uninformed days.

6.4.3 Maximum likelihood estimation

The maximum likelihood estimation (equation 6.6) conducted on the complete sample gives the following results:

	Parameter	*Standard error*	*t-Prob*
α	0.235	0.014	0.00
δ	0.617	0.027	0.00
μ	0.203	0.002	0.00
ε	0.306	0.001	0.00
Likelihood	-192254.1		

Table 6-1: MLE estimation, 01/12/2000-01/12/2008

First, the estimate for the parameter α (i.e. 0.235) indicates that on average 1/4 of the days are information driven. Considering the average duration of a maintenance period (i.e. around four weeks), this corresponds to around 4 or 5 informed days in a maintenance period.

Second, during informed days, the signal is low [high] with probability δ $[(1-\delta)]$. Results suggests that a low signal is observed with an estimated probability of 0.61, which means that orders are more likely to be sell-initiated (i.e. lending contracts during excess liquidity period on the market are relatively more frequent) than buy initiated. In other words, banks tend to believe that information-driven orders reveal excess liquidity supply on the market, rather than the opposite. This result confirms that banks are more exposed to risk when the liquidity is scarce than when liquidity is abundant.

Third, μ=0.203 suggests that banks tend to believe that observed orders are information-driven with a probability of only 20%: 1/5 of orders observed in the market are deemed to come from efficiently informed banks. For the money market, the interpretation of the μ parameter is more restrictive than in the standard PIN model, since it only takes into account the banks that are informed and which have efficiently fulfilled their reserve requirements.

Fourth, ε=0.306 indicates that the probability of liquidity trade is only around 30%. During informed day, this parameter represents market liquidity which comes from uninformed banks, while during uninformed days, it coincides with total liquidity available in the market (because only uninformed traders are active on the market).

From Equation 6.8 the probability of trade during informed days is $\Psi = 0.44$, i.e. a new quote every 10 minutes. From Equation 6.9 the probability of informed trade, PIN, is $\gamma = 0.45$ on the complete sample. This result suggests that a bank involved in an overnight contract faces a 45% probability to be trading with a counterparty which is better informed on the direction of interest rates.

6.5 Market learning and the role of information in a historical perspective

The next step is to analyze how some events which have taken place in the overnight market (including changes to the rules of the operational framework) may have affected the trading pattern.

In particular, in order to assess the evolution of informed trades over time, the model parameters are estimated on rolling samples made of 200 overlapping days.

6.5.1 A break in the learning process?

The four panels of Figure 6-4 present the results of the parameter estimates computed from the rolling samples described before.

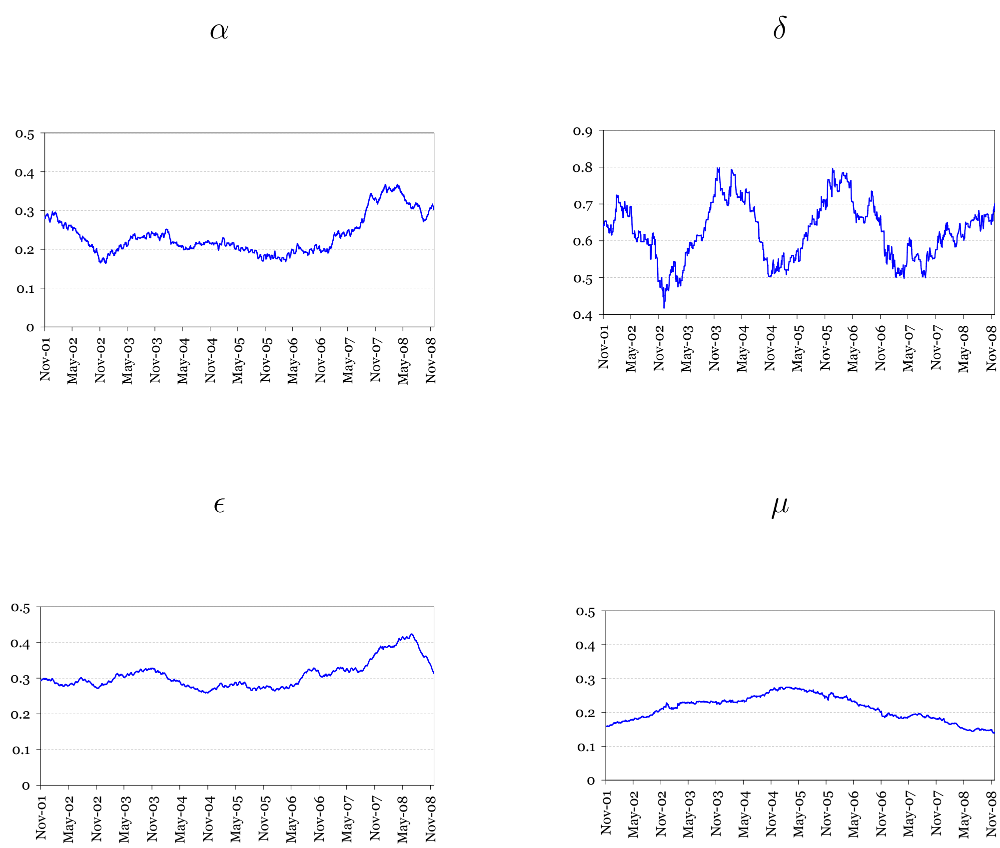


Figure 6-4: Rolling estimates of the PIN model parameters

After an initial decline, the fraction of informed days (α) broadly stabilized at around 0.2 (corresponding to about 5 days in a maintenance period) until the end of 2006. In 2007, however, this parameter rose pointing to an increase in the share of informed days, in particular after May 2007, i.e. shortly before the onset of the financial turmoil. It is interesting to note that this parameter sharply rose in August and broadly stabilized at around 0.35 thereafter. The probability of low signal on overnight rate (δ) has been generally above 0.5 except between November 2002 and January 2003, between October 2004 and January 2005 and after December 2006. Since then, the trend is upward oriented. The share of informed banks (μ) grew until November 2004 and has declined steadily thereafter, including during the financial turmoil phase in the second half of 2007 (with only local peak in August 2007). After December 2006, however, the negative trend appears to have stabilized at a level slightly below 0.2. The share of non-informed trades ε has remained at around 0.3 for a relatively long period, with a significant decline between end-2004 and end-2005. This parameter increased towards the end of 2006 and accelerated after August 2007, i.e. after the response of the ECB to the turmoil and the increase in liquidity allotment. However, from May 2008 the parameters fell to a lower level, indicating a decrease in non informed trades.

Finally, the historical evolution of the PIN γ is shown in Figure 6-5. In the same figure, some landmarks of the Eurosystem's operational framework are also indicated to assess whether some turning points in the trend of the PIN can be associated with major events which took place in the euro money market.

Overall, an increasing trend is observable between 2001 and 2004, which reversed after 2004 and accelerated from the end of 2005. This negative trend came to an end towards the end of 2006 and it reversed again afterwards to reach a peak in the summer of 2007, i.e. at around the onset of financial market turmoil. It is interesting to observe that the reaction of PIN started well before the outbreak of the turbulence in the euro money market, thereby suggesting a possible leading property of the index which would deserve further research. This is also observed in 2008 with an increase in the PIN started in July while real tensions were considered only in September.

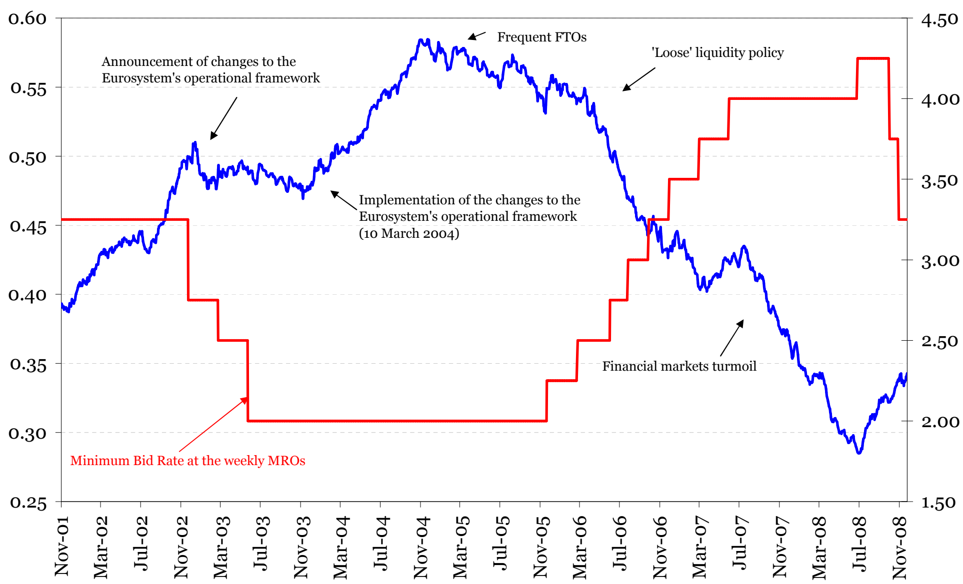


Figure 6-5: historical evolution of the PIN and MBR.

Five particular events appear to have exerted some influence on the historical developments of the PIN. The first coincides with the announcement made by the ECB on 23 January 2003 on the forthcoming changes to the operational framework. Following the period characterized by an increasing PIN, which mirrors the increasing heterogenous knowledge of the operational framework by market participants, the announcement of the new rules discontinued this process and the share of informed trade broadly stabilized.

This can possibly be related to the fact that most expert traders modified their trading behavior to anticipate and exploit some forthcoming rules of the reformed framework. From March 2004, i.e. from the actual implementation of the new rules, heterogeneity increased, possibly reflecting a different degree of assimilation of the new rules in the community of traders and the relative advantage in trade of informed banks. From the perspective of the enhanced information provided to the market after the reform,[20] a possible explanation is that some traders' could better understand market mechanisms in some cases, whereas in many other cases banks were not fully able to process the information delivered to the market. This is especially evident until November 2004, i.e. six or seven months after the implementation of the new framework. After November 2004, the changes to the operational framework have helped attaining a critical mass of informed banks or, in other words, have reduced information asymmetries.

The effects of FTOs, from early 2005, may be twofold. On the one hand, FTOs involve a limited pool of banks and such operations may have increased banks' heterogeneity and increased opportunities to trade strategically to banks which can access to this channel. On the other hand, the need of fulfilling required reserves may be a disincentive to strategic trading, since the price to pay in liquidity withheld at the end of the period may be excessively high. In fact, looking at the developments after November 2004, this second effect seems to have prevailed which would explain the declining trend. An acceleration of the decline of heterogeneity is visible in coincidence with the start of relatively long phase started in October 2005, during which the ECB allotted

[20] See Annex for more details.

systematically an amount of liquidity above the benchmark in response to the widening of the spread between EONIA and minimum bid rate. The explanation can be related to the fact that the increased in the liquidity supplied to banks reduced the margins for a strategic trading on information and, in this sense, decreased heterogeneity in the population of banks.

A discontinuity with respect to recent dynamics occurred in 2007 and then in 2008 with the materialization of the money market turmoil. Given its relevance also in explaining the recent dynamic in the model parameters, this event is analyzed separately in the remainder of this chapter together with a closer look at the effects of the reform of the Eurosystem's operational framework.

Finally, an additional interesting parallel may be drawn between the evolution of the PIN and the cycle of monetary policy interest rate over the period considered (i.e. the red line in Figure 6-5). The increase in the PIN is associated to a stable period for the policy rates. By contrast, when the rate starts decreasing between 2002 and 2003, the PIN broadly stabilizes. This decline is possibly explained to the role of asymmetric information in particular on the uncertainty related to monetary policy decisions prior to the introduction of the March 2004 changes. In fact, the non perfect insulation of the overnight interest rate movements from ECB's decisions on key policy rates could have offered opportunities for informed trading as it is also witnessed by the strong link between expectations and MRO tender results on occasions. This link seems to have been broken in particular after 2005.

6.5.2 The impact of the 2004 reform of the Eurosystem operational framework

This section offers a closer look at the effects of the changes to the Eurosystem's operational framework of March 2004 and of the other measures which followed, namely the conduct of almost systematic FTOs at the end of reserve maintenance periods and the loose liquidity policy conducted since October 2005. To do that, two non overlapping subsamples are considered : from December 2006 to March 2004 and from March 2004 until the end of 2006.[21]

Table 6-2 & 6-3 shows the estimates obtained for the four parameters on the two subsamples.

	Parameter	Standard error	t-Prob
α	0.272	0.028	0.00
δ	0.652	0.042	0.00
μ	0.152	0.002	0.00
ε	0.272	0.028	0.00
Likelihood	-75579.04	#obs	855

Table 6-2: Estimates prior to the reform of the operational framework (sample: 29/11/2000 to 9/3/2004)

	Parameter	Standard error	t-Prob
α	0.209	0.018	0.00
δ	0.585	0.031	0.00
μ	0.210	0.001	0.00
ε	0.279	0.001	0.00
Likelihood	-61722.83	#obs	722

Table 6-3: Estimates after the reform of the operational framework (sample: 10/3/2004 to 31/12/2006)

The results indicate that the probability of being in an event day declines after the 10 March 2004, as indicated by the decline of the α parameter from 0.27 to 0.20. This is in line with one of the goals of the reform, i.e. to insulate money market rates (in particular, the overnight rate)

[21] The second subsample does not include 2007 and 2008 data to avoid any possible influence of the financial turmoil on the paramater estimates and to give a less blurred assessment of the effect of operational changes on the estimates of the model paramaters.

from non-technical factors related to liquidity or reserve management. The probability of being in a low signal day (δ) has declined : the parameter decreases from 0.65 in the period preceding the changes, to 0.58 after. The remaining parameters do not change significantly over the sample. Turning to the PIN γ, it has already been stressed before that information asymmetries appears to have declined after the introduction of the changes to the operational framework and, in particular, after the almost systematic conduct of FTOs at the end of the reserve maintenance period and the loose allotments.

Finally, a simple method to identify when exactly informed trading occurs within reserve maintenance periods has been applied. Such method consists in selecting the most-active days based on the estimate obtained for the parameter α. First, days are ranked in a decreasing order with respect to the observed number of contracts in every specific day and then a total of 230 days (or 150 after 10 March 2003) are selected and labelled as informed. As dates are known, the next step is to associate informed days to their occurrence within a reserve maintenance period using their position in the maintenance period (figure 6-6) before and after the 2004 reform.

The information flow is relatively less concentrated on specific days before 10 March 2004, which might be explained by the fact that some events affecting the expected developments in the overnight interest rates lose their influence during the reserve maintenance period (e.g. monetary policy decisions). By contrast, informed days tend to be relatively more concentrated on fewer days after 10 March 2004, with a noticeable peak 7 days before the end of the period. This peak generally corresponds to the day preceding the last MRO of the reserve maintenance period and is likely to be related to increased importance of the last MRO for the fulfilment of individual liquidity needs after the changes.[22]

[22] This is also visible in a more marked tendency of banks to bid more aggressively at the weekly MROs and, in particular, at the last refinancing operation of the maintenance period.

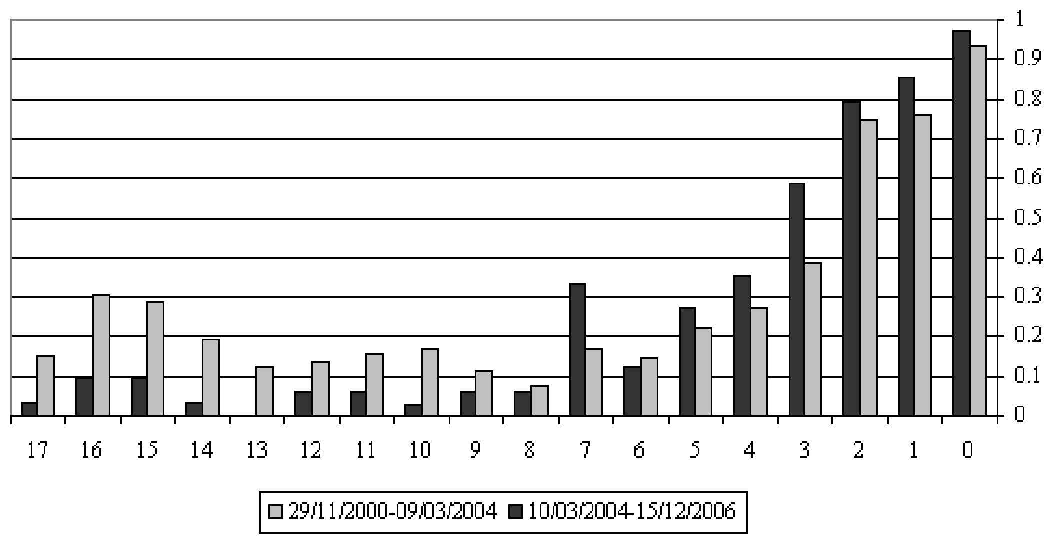


Figure 6-6: Information flows within maintenance periods

6.5.3 The financial market turmoil

This turmoil mainly affected money markets and materialized in a marked and sudden reduction of market liquidity. As an immediate consequence, short-term interest rates rose by several basis points above policy rates and major central banks intervened with a number of exceptional measures to provide the necessary liquidity and thereby to avoid severe disruptions which could ultimately have economic detrimental effects.

At the microstructural level, a sudden lack of confidence among banks raised from a substantive lack of knowledge about the financial soundness of trading partners (namely, banks most exposed in terms of derivatives instruments backed by sub-prime mortgage securities), affecting transactions on very short maturities such as overnight deposits. Central banks' response to counter the adverse effects of the turmoil was very swift. The ECB was very active to provide an extremely generous amount of liquidity through operations at various maturities.[23] Over the course of the following months, the ECB liquidity policy changed significantly with respect to the past in particular as regards two aspects: (i) a significant shift in the liquidity maturity from short-term (one week) to longer term refinancing (three months or more); (ii) a frontloading policy consisting on injecting a considerable amount of liquidity above the benchmark in the first MRO of the reserve maintenance period linearly reduced in the subsequent operations; (ii) an aggressive an cooperative with the US Fed cut in interest rates to sustain the financial soundness of banks.

The effects of this policy are visible in the marked increase of the parameter Ψ reflecting the market liquidity after September 2007, as shown in Figure 6-7. This parameter broadly stabilized after January 2008, i.e. when operations tended to become more regular and so did the provision

[23] Limiting to the sole euro area, starting from 9 August the ECB decided to conduct the following operations: three FTOs on 9, 10, 13 and 14 August of EUR 95 bn, EUR 61, EUR 48 bn and 8 bn respectively. On 6 September EUR 42 bn were allotted in another FTO. Moreover, the ECB allotted a significant amount above the benchmark in the first MROs of each reserve maintenance period as of August. Finally, in December 2007 a new set of operational measures was decided to contrast expected adverse effects ahead of the turn of the year. However, a significant amount of the liquidity injected in the banking system in the first weeks of December was absorbed in various FTOs which took place between 17 and 28 almost on a daily basis to prevent a marked decline of overnight interest rates below the ECB's minimum bid rate.

of liquidity to the money market. However, from May 2008 this liquidity parameter clearly crashed to its lowest level in the sample due to a high decrease in operations on this interbank market.

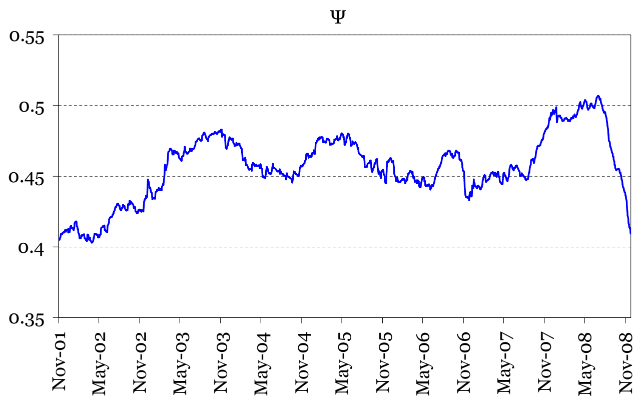


Figure 6-7: Market liquidity Ψ between 2001 and 2008

As regards the evolution of the PIN between January 2007 and December 2008 (Figure 6-8), the progressive decline of banks' information heterogeneity, which started in 2004, came to a halt in April 2007, i.e. about four months before the emergence of the most visible effects of the turmoil. Then the higher liquidity provided by the ECB performed pretty well in reducing information asymmetries. However, from July 2008, i.e. 2 months before the tensions were considered by authorities, the PIN already started to increase indicating some information problems in this market.

The decision to supply a massive amount of liquidity in the money market visibly reduced, among other effects, the potential for a strategic use of private information by banks in the early 2008. However, from May 2008 the situation clearly deteriorated and the functioning of the market itself was difficult due to the start of scarce liquidity period that came back to its 2001 level.

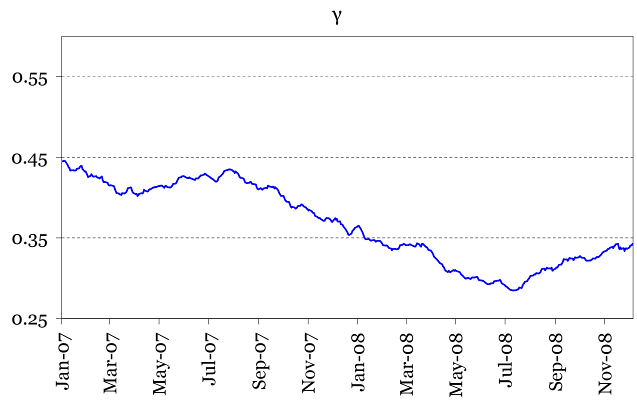


Figure 6-8: Evolution of the PIN in 2007-2008

To conclude, a possible interpretation based on the PIN measure is that the ECB's response to the turmoil has apparently decreased the asymmetric information risk on the money market by easing transactions among banks but this had a limited effect in 2008.

6.6 Conclusion

The chapter presents an empirical microstructure analysis of the euro overnight unsecured market based on the model of Easley and O 'Hara (1992). This is the first attempt to apply a simple sequential trade model to the money market to analyze the reaction between information asymmetries and the effects of the operational framework. The existence of institutional rules which are conditioning factors for trade makes our application somewhat original. In the money market, trades are mainly initiated owing to the existing requirements on reserves which drive banks' liquidity needs more than profit making considerations. Traders are also special. Banks are obliged to trade in a given time period (the reserve maintenance period) and have very strong "inventory constraints", since they face the threat of sanctions from the central bank or reputation issues if they do not fulfil reserve requirements. Finally, another peculiar aspect of this market is the presence and the role of the central bank. This institutional player has objectives different from those of commercial banks: monetary policy objectives are behind decisions on liquidity provision to the market through open market operations, which have an obvious influence on trade behavior.

The high-frequency data used in this analysis spans almost the entire history of the euro money market. Some significant changes have been introduced in the operational framework, and a *tâtonnement* process in the market, through modifications of rules, have influenced market conditions for trading over time. These changes are analyzed from various angles: market behavior, population of banks, information delivery and operational framework rules.

The conclusions are threefold. First, even if market rules on liquidity provisions exclude a pool of banks from participating (due to collateral requirements), heterogeneity has been decreasing since 2004 hence the smallest banks appear less marginalized, and do not trade overnight contracts on disadvantaged grounds. Second, the March 2004 changes of the operational framework appear to have improved market signals. By reducing both market tensions and opportunities for strategic trade, the increased frequency of FTOs at the end of reserve maintenance periods and the ECB's policy of allotting consistently liquidity above the benchmark amount since October 2005 have reduced the impact of information asymmetries.

Finally, the use by the ECB of the available instruments during special events (as in the 2007-2008 financial turmoil) have shown to be partially efficient in reducing information asymmetries. However, since May 2008 the market liquidity on the interbank overnight unsecured market has really deteriorated attaining its lowest level on the sample 2001-2008.

In conclusion, empirical microstructure considerations may help to understand monetary policy issues and financial stability from a new perspective. In this sense, this chapter is just a first step in this direction, but may motivate further research to assess the implementation of monetary policy rules from a microstructural point of view.

6.7 Appendix

Appendix 6-A. The 2004 reform of the Eurosystem's operational framework

Focusing on the history of the Eurosystem after 1999, the most notable changes were introduced to overcome some issues emerged in the mechanisms in place to supply liquidity and to ensure a smooth liquidity provision to banks. Two elements were decisive to motivate the changes: overbidding, i.e. the tendency of banks to submit bids of increasingly sizeable amount at the weekly tender to avoid (liquidity) rationing, and underbidding, i.e. a phenomenon which took place when bids did not entirely cover the liquidity amount which the central bank intended to allot.

To stop overbidding, fixed rate tenders - i.e. tenders in which banks only requested quantities since the price was decided by the central bank - were abandoned in June 2000. They were replaced by variable rate tenders, i.e. auctions where banks offer a price in addition to the demanded amount of liquidity. This change did actually succeed in stopping overbidding and, with few exceptions. The rates resulting from weekly tenders have turned to be well anchored to the minimum bid rate. In this sense, the change to a variable rate system was successful since it has never hindered the transmission mechanism even if the ECB lose the direct control on prices (interest rates) paid for its liquidity. However, a new issue emerged: underbidding. Whenever the ECB failed to inject the liquidity necessary to the banking system, short-term money market interest rates reacted by rising markedly above the EONIA and increasing volatility. Before March 2004, underbidding took place 8 times and it was generally related to expectations on key ECB rate cuts.[24]

To overcome the occurrence of underbidding in weekly refinancing operations and, in this way, to stabilize money market rates, three major changes were introduced in the operational framework in March 2004:

[24] Before March 2004, underbidding took place before interest rate cuts in three occasions, namely on 6 November 2001, 3 March 2003 and 3 June 2003. In the other cases, underbidding was caused by expectations on policy rate cuts or other technical reasons.

1. The bulk of liquidity is supplied in only one operation and no longer in two outstanding operations. At the same time, the maturity of each main refinancing operation was shortened from two to one week.

2. Conditions on monetary policy interest rates are applied as of a new reserve maintenance period and no longer immediately after the decision is made.

3. The start and the end of reserve maintenance period is related to the date of the Governing Council meeting in which monetary policy decisions are made (i.e. normally on the first Thursday of each month), while before the change they always started on day 24 of each month and ended on day 23 of the following month.

In this way, reserve maintenance period resulted better segmented and any interference of monetary policy decisions on liquidity management was removed and so were conditions for underbidding to take place.

These changes however have had some side effects which were addressed by other ad hoc measures. One effect is related to an expected increase of errors in autonomous factor forecasts due to the increase in the number of days between the last MRO and the end of the reserve maintenance period (normally five trading days after the changes, and on average three days before). To limit the impact on the expected higher uncertainty on autonomous factors' developments in the last days of the reserve maintenance period, it was decided to increase the information disclosed to the market before the weekly MRO. This change was also intended to reduce counterparties' uncertainty about the ECB liquidity management and to increase transparency vis-à-vis market participants. More precisely, the changes implied the publication of:

1. the benchmark allotment on the announcement day of the MRO;[25]

[25] The benchmark amount is broadly defined as the sum of (net) liquidity absorbing autonomous factors, reserve requirements and excess reserves.

2. the updated benchmark allotment on the allotment day of the MRO (after making the decision on the amount of liquidity to inject);

3. the updated autonomous factor forecasts on the allotment day of the MRO after the allotment decision and

4. benchmark allotment and actual allotment amounts of the MRO

In practice, the information disclosed by the ECB changed from Figure 1.1 to Figure 1.2 (appendix 6-B), which implied a substantive enhancement. In this way, at least in principle, ECB's decisions on allotment became fully transparent.[26]

A second measure was a marked increase in the frequency of fine-tuning operations conducted at the end of reserve maintenance periods to re-establish neutral liquidity conditions. From a microstructure perspective, these two events may explain more a discontinuity in the amount of informed trade as it will be shown in the empirical section of the chapter. Unfortunately, due to the almost concomitant occurrence of these changes, it is difficult to analyze their effects separately on actual trade.

[26] The new information complemented the formula for the calculation of the benchmark published in the ECB Monthly Bulletin Box entitled "Benchmark allotment rule normally applied by the ECB in its main refinancing operations" (May 2002). Combining the enhanced information with the formula, market participants were able to calculate exactly the benchmark.

Appendix 6-B. Reuters Screen ECB40

08:09 08FEB00 EUROPEAN CENTRAL BANK, FRANKFURT a.M. GE66608 ECB40
Current account holdings of counterparties with the Eurosystem
Including holdings to fulfil reserve requirements. In million of euro.

As at 07/02/2000
(Maintenance period: 24/01/2000 to 23/02/2000)

Current account holdings (*)	109,057
Estimated reserve requirements (**)	107,500
Average current account holdings in current maintenance period (*)	108,689

Use of the standing facilities of the Eurosystem:

Use of marginal lending facility	11
Use of deposit facility	61

(*) Including minimum reserve holdings. For historical data see ECB41.
(**) Preliminary estimate of reserve requirements for the current MP

Figure 1.1: ECB40 screen before March 2004

```
ECB40  show  do
09:21 17APR07    EUROPEAN CENTRAL BANK, FRANKFURT a.M. GE66608          ECB40
Information on liquidity conditions in the euro area (in millions of euro).

Reserve maintenance period (MP): 14/03/2007  to 17/04/2007
Average reserve requirements for the current MP                    181,839

Estimate on 17/04/2007 of average daily autonomous factors:
for the period 18/04/2007 to 24/04/2007                            248,000


Figures as at 16/04/2007
Average current account holdings in the current MP (1)             183,130

Outstanding open market operations                                 430,002
Use of marginal lending facility                                     1,976
Use of deposit facility                                                 97
Autonomous liquidity factors                                       244,076
Current account holdings (1)                                       187,805
Please see page "Announcements on Operational aspects"


(1) Including minimum reserve holdings. Historical data on subsequent pages.
European Central Bank, Frankfurt, + 49 69 1344 8577
```

Figure 1.2: ECB40 Screen after March 2004

Conclusion Générale

Comme annoncé dans l'introduction, l'objectif de cette thèse était d'étudier à la fois les comouvements entre les prix des actifs ainsi que l'impact de la BCE sur les comouvements et les dynamiques de certains marchés particuliers. Nous avons raffiné la notion de comouvement sur des horizons hétérogènes ainsi que proposé des extensions grâce l'utilisation de données haute fréquence. Ces dernières furent en particulier utilisées pour étudier l'impact du cadre opérationnel de la BCE sur le marché de la dette souveraine négociable française et sur le marché européen interbancaire.

Dans le premier chapitre une revue de littérature sur les comouvements a permis de faire le point sur les méthodes économétriques permettant d'appréhender les comouvements. Force est de constater qu'il existe des différences importantes selon les méthodologies utilisées notamment en ce qu'elles ne se situent pas sur une perspective identique de la mesure des comouvements.

L'approche dite de « cointégration » envisage des relations d'équilibre de long terme entre prix d'actif. Ces relations sont fragiles notamment lorsque l'on veut mesurer les comouvements avec des données à fréquence journalière. En particulier, la diversité des chocs et des résiliences de marchés ne permet pas de capter de façon très robuste une relation d'équilibre entre prix d'actifs. Ceci est d'autant plus vrai depuis 1997 avec une succession de crises majeures pour les marchés financiers atteignant son paroxysme avec la crise de 2008.

L'utilisation de modèles multivariés hétéroscédastiques permet, elle, d'extraire des mesures dynamiques des corrélations journalières qui prennent en compte l'évolution temporelle des liens qui existent entre les processus de prix. Cette approche permet en particulier d'analyser le timing des crises et les modifications, qui en résultent, des comouvements entre les marchés. D'un point de vue méthodologique, ces modèles posent toujours le problème de l'estimation pour de large portefeuille d'actifs. En effet, leur spécification entraîne un grand nombre de paramètres à estimer. L'on note cependant des améliorations en cette voie avec par exemple le modèle à corrélation dynamique d'Engle et Sheppard (2002) avec un nombre limité de paramètres indépendant du nombre d'actifs considérés, pour définir la matrice des corrélations. Néanmoins, ceci se fait au détriment d'une certaine précision dans la définition de la dynamique.

Enfin une dernière approche envisagée dans cette revue de la littérature concerne l'utilisation des données à haute fréquence. En premier lieu, ces données permettent la caractérisation des variances et des corrélations de façon non paramétrique. Ceci permet alors une certaine flexibilité dans l'analyse de leurs dynamiques, permettant ainsi d'y associer des variables d'intérêt pour en expliquer les variations. En second lieu, ces données permettent de compléter l'analyse des comouvements sur les prix par des analyses de comouvements sur des variables dite de liquidité : volumes, temps d'échange, fourchettes de cotations etc. C'est autour de cette revue de la littérature que les cinq chapitres empiriques suivants vont s'articuler.

Dans le chapitre deux, nous avons proposé comme première étape pour l'analyse des comouvements de coupler à la fois une relation d'équilibre de long terme de type cointégration avec un modèle multivarié hétéroscédastique. L'objectif de ce premier travail était de comprendre à la fois la dynamique de long terme, dite « moyenne », et la dynamique de court terme qui en résulte sur le deuxième moment des séries de prix via un modèle VECM-GARCH.

Il apparaît clairement qu'une relation de long terme ne permet pas de capturer et d'expliquer le degré de comouvements entre les prix d'actif. Les résidus d'une simple relation de cointégration présentent des corrélations élevées, voire avec tendance en ce qui concerne l'Europe, traduisant une étroitesse croissante des liens entre les prix d'actifs, également sur le court terme. Ceci est d'autant plus vrai pour la zone euro et l'Europe en général. Nous remarquons également que les dynamiques de corrélation et de variance apparaissent instables et plus ou moins résilientes suite aux crises financières qui ont frappé les marchés depuis 1997.

Le chapitre trois a permis de répondre à certaines questions soulevées lors du précédent chapitre. Il existe effectivement un ensemble de comouvements de plus ou moins long terme qui s'établissent entre les dynamiques de prix d'actifs sur les marchés. Pour cela nous avons utilisé et transposé le modèle multifractal des rendements d'actifs de Calvet et al. (2006) pour analyser les comouvements entre marchés d'actions entre 1996 et décembre 2008. Nous montrons qu'il est optimal de considérer au moins la superposition de trois cycles de volatilité pour rendre compte de façon efficace des comouvements entre les indices boursiers CAC, DAX, FTSE et NYSE. Ces trois cycles superposés sont hétérogènes pour chacun des indices considérés indiquant notamment des degrés hétérogènes de résilience suite à des chocs. Il apparaît que l'indice associé à la place américaine est le plus résilient avec un cycle court de l'ordre de 20 jours en moyenne contre 40 jours pour le CAC. Les cycles de moyen terme s'établissent entre 100 et 120 jours et les cycles de long-terme sont entre 350 jours pour le FTSE et 500 jours pour le NYSE. Nous avons également développé un ensemble d'indicateurs pour raffiner la notion de comouvement sur des horizons hétérogènes entre places financières. La probabilité de crises montre ainsi que deux crises ont été majeures sur l'échantillon considéré : la crise asiatique de fin 1997 et la crise de 2008 qui suit la faillite de Lehman Brother. Ces périodes de turbulences sont associées avec des probabilités de comouvements extrêmes très fortes sur l'ensemble des cycles de la volatilité.

Néanmoins, ces améliorations se sont faites au détriment de la modélisation de l'indicateur classique de comouvement : la corrélation. En effet, la dynamique de la corrélation expost est seulement obtenue via les probabilités de la chaîne de Markov associée au modèle, sans dimension temporelle comme dans un modèle à corrélation dynamique conditionnelle.

Le chapitre quatre complète le modèle multifractal des rendements d'actifs en introduisant une dimension temporelle dans la corrélation similaire à un modèle DCC de type Engle and Sheppard (2002). Nous montrons notamment que l'adéquation aux données est largement améliorée dans le modèle en introduisant cette dynamique et en gardant la possible dérivation des indicateurs définis dans le chapitre précédent. Nous avons également mis en évidence dans le modèle la prise en compte du risque de Re-corrélation largement révélé par la crise de 2008.

En effet, en période calme de marché, i.e. avec une faible volatilité, la corrélation peut-être sous estimée. Dans ces conditions, toute arrivée de chocs engendre une perturbation de la dynamique de corrélation et peut entrainer des pertes en chaîne dans des portefeuilles supposés diversifiés. Cette re-corrélation a été effective principalement entre places de la zone euro et plus marginalement pour les liens transatlantiques pendant les périodes de crises.

Ce chapitre quatre ainsi conclue la première partie de la thèse sur les méthodologies employées pour l'analyse des comouvements. Nous avons analysé ensuite les dynamiques de certains autres marchés que marchés d'actions, via l'utilisation de données haute fréquence. En particulier nous nous focalisons sur l'impact possible du cadre opérationnel de la BCE sur deux marchés bien particuliers que sont : (i) le marché de la dette négociable française et (ii) le marché interbancaire au jour le jour du refinancement.

Le chapitre cinq a permis de mettre en évidence l'impact du cadre opérationnel de la BCE sur les comouvements et les dynamiques du marché de la dette négociable française. En particulier, nous montrons qu'il peut exister sur des marchés d'actifs qui servent de collatéral une spirale aux effets indésirables liée à l'augmentation du nombre d'opérations de refinancement collatéralisées par la banque centrale et de l'augmentation des durations liées à ces opérations.

Pour cela nous avons utilisé les variations bipower de Barndorff-Nielsen and Shephard (2005) et des indicateurs de liquidité de marchés dans une modèle VAR à changement d'état. Ceci a permis de révéler l'existence de prime de volatilité sur les taux des obligations souveraines françaises et des comouvements en termes de liquidité et de volatilité, comouvements perturbés par la multiplication des opérations de refinancement indiquant notamment la possibilité d'une demande dite « forcée » sur les OAT à dix ans liés à des comportements d'achats plus agressifs de la part des banques désireuses d'investir dans des actifs liquides pouvant servir de collatéral.

Enfin le chapitre six continue sur les comportements d'échanges des agents sur le marché interbancaire du refinancement. Comme mentionné dans le chapitre précédent, l'ensemble des règles de collatéral peut exclure des opérations de refinancement un certains nombre de banques qui doivent ensuite répondre à leur besoin de liquidité via le marché interbancaire. Nous nous sommes donc intéressés au marché interbancaire du refinancement non collatéralisé.

Nous avons notamment transposé le modèle de la probabilité d'échange informé d'Easley et O'Hara (1992) à ce marché pour analyser l'asymétrie d'information et l'hétérogénéité des banques participant à ce marché. Nous montrons que la réforme du cadre opérationnel intervenue en Mars 2004 et associée à une politique plus laxiste de la liquidité de la part de la BCE a permis une réduction des échanges informés sur ce marché. Une des mesures principales ayant un impact est l'absence de toute modification des taux pendant une période de maintenance. En effet, avant 2004 les décisions concernant le niveau des taux d'intérêt pouvaient être annoncées durant une période de maintenance alors qu'après Mars 2004 (sauf raison exceptionnelle) un même taux s'applique sur la durée totale de la période de maintenance. Ceci a supprimé une asymétrie majeure d'information entre les banques et diminué la possibilité d'échanges stratégiques en facilitant la stabilité du marché.

Nous avons également constaté que la PIN a rendu compte pendant l'été 2008 des tensions sur le marché interbancaire qui ont commencé dès 2007. Les injections de liquidité opérées par la BCE jusqu'en novembre 2008, fin de notre échantillon, ne permettaient toujours pas de retrouver un niveau de liquidité acceptable sur ce marché interbancaire du refinancement, la source principale de liquidité étant la BCE.

Pour conclure l'ensemble des travaux de cette thèse, il est intéressant de recadrer les possibles extensions avec les derniers développements concernant la crise financière majeure que nous connaissons aujourd'hui. La crise financière provient du couplage de trois inefficiences majeures des marchés :

L'inefficience de l'allocation a généré la mobilisation de ressources consacrées à des projets d'investissements insoutenables qui se sont traduits en pertes importantes. Cette inefficience de l'allocation des ressources a conduit, comme souvent, à la création de bulles spéculatives sur certains segments de marchés voués à la correction. La politique de liquidité de la BCE ainsi que des taux d'intérêt bas ont permis une sous estimation des risques et une surestimations de certains actifs.

L'inefficience de l'information : l'information incomplète liée aux actifs financiers a également permis cette sous estimation des risques sous jacents tant que l'information n'était pas incorporée dans les prix, engendrant une large crise de confiance sur l'ensemble des marchés, avec des forts phénomènes de comouvements entre les actifs lors de la deuxième vague de la crise en octobre 2008 (la première vague de la crise étant celle cantonné aux actifs qui lui sont directement liés, à savoir certaines classes de produits structurés). Ce manque de confiance s'est en particulier traduit par un assèchement du marché interbancaire face au risque de contrepartie.

L'inefficience opérationnelle : la crise a révélé que certains marchés supposés immunes à tous dysfonctionnement peuvent présenter des lacunes graves, notamment en termes de liquidité. Toute détermination du prix d'actif suppose qu'il existe un prix de marché : que ce soit la politique d'évaluation du collatéral de la BCE qui est marqué au marché ou toute valeur des bilans des institutions financières. Effectivement, l'intégration financière se traduit par un ensemble de liens très étroits à la fois entre les marchés mais également entre les investisseurs et/ou Institutions financières pouvant impliquer des besoins synchrones de liquidité et donc des ventes forcées et massives d'actifs.

Ces trois inefficiences relevées dans la crise courante peuvent guider de nombreuses extensions aux travaux présentés dans cette thèse.

Tout d'abord en termes d'applications, les méthodes de comouvements peuvent s'appliquer à des pools plus grands d'actifs afin d'étudier les allocations d'actifs, c'est-à-dire comouvements et arbitrages entre différents segments de marchés, entre différents pays ou zones économiques. D'un point de vue méthodologique, la crise courante par son ampleur va nécessiter la prise en compte de changements structurels dans les modèles avec une application de méthodologies plus adéquates permettant d'en rendre compte : cointégration avec changements de régimes, corrélations avec changements de régimes ou breaks, mesures des comouvements au sortir de la crise etc. Nous manquons encore de recul pour implémenter l'ensemble de ces méthodologies mais leur nécessité est indéniable. L'approche introduite dans le chapitre deux et trois, via les propriétés fractales est certainement la bienvenue en ce qu'elle va permettre de clarifier les impacts de cette crise majeur sur des horizons hétérogènes, et des marchés, ou segment de marchés, aux résiliences hétérogènes à la crise actuelle. Il sera notamment intéressant de comparer les propriétés de prévisions du modèle MSMDCC pour voir s'il permet d'améliorer les modèles existant hors échantillon.

Les résiliences des différents marchés vont notamment dépendre de l'hétérogénéité des mesures prises dans les différents pays et de l'impact de la législation (MiFID par exemple) sur la sortie de crise. Le cadre opérationnel de la BCE a notamment subi de profondes modifications au cours des derniers mois. Comme mis en exergue dans le chapitre cinq, il s'est avéré essentiel d'élargir le pool de collatéral accepté lors des opérations de refinancement et l'impact de ces mesures sur les dynamiques de marché en général va devoir être surveillé, notamment en ce qui concerne l'arbitrage entre risque de crédit (avec du collatéral plus risqué) et risque de liquidité (sur les marchés du collatéral en général). Les méthodologies en ce sens devront être raffinées et des travaux sont actuellement en cours sur la définition de la liquidité et du risque de liquidité sur des marchés de négociation aux structures diverses (organisés, OTCs, avec carnet d'ordres, etc.).

Ce risque de liquidité devra en particulier au sortir de la crise être surveillé de façon précise sur le marché interbancaire du refinancement, et des méthodes devront être définies afin de le permettre, comme introduit dans le chapitre six. Il sera notamment intéressant d'appliquer les méthodologies axées sur les comouvements de prix, aux comouvements de liquidité pour donner une nouvelle approche de l'intégration financière et des mouvements internationaux sur les marchés de capitaux.

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General Conclusion

As announced in the introduction, the objective of this thesis was to study both the comovements between asset prices and then, the impact of the ECB on comovements and dynamics of some specific markets. We specified the concept of comovements on heterogeneous horizons and proposed extensions through the use of high frequency data. The latter in particular were used to study the impact of the operational framework of the ECB on the French market for sovereign negotiable debt and on the European interbank market.

In the first chapter, is provided a survey of the literature to review some econometric methods to apprehend comovements. It must be noted that there are considerable differences between the methodologies since they are not gauging comovements on an identical perspective.

The cointegration approach considers long-term equilibria between asset prices. These relationships are particularly weak when comovements are assessed with daily frequency data. In particular, the diversity of shocks and resiliencies of markets is not robustly captured by a long run relationship between asset prices. This is especially true since 1997 with a succession of major crises for financial markets reaching its climax with the crisis of 2008.

The use of multivariate heteroskedastic models allows the extraction of dynamic measures of daily correlations to take into account the temporal evolution of the linkages between the price processes. This approach makes it possible to analyze the timing of crises and changes that result on comovements.

From a methodological point of view, these models are still heavy to estimate for wide portfolio of assets. Indeed, their specification implies a large number of parameters to be estimated. However, it is worthy of note that some improvements in that way have been done with models such as the Dynamic conditional correlation model of Engle and Sheppard (2002) with a limited number of parameters independent of the number of assets considered. However, this comes to the detriment of some precision in the definition of the correlation dynamic.

Finally, a last approach concerns the use of high frequency data. First, these data support a non-parametric characterization of variances and correlations. This allows for more flexibility in the analysis of their dynamics with potential variables of interest to explain their variations. Secondly, these data can be used to complete the analysis of price comovements relying on liquidity indicators: volume, frequency of exchange, bid-ask spreads. The five chapters of this thesis revolve around this literature review.

In chapter two, we propose to combine both a long-term equilibrium with a multivariate heteroskedastic specification. The first objective of this work is to understand the long-term dynamics, so-called "mean" effect, and the dynamics of short-term residuals on the second moment via a VECM-GARCH model.

It is clear that a long-term relationship is not sufficient to capture and explain the degree of comovements between asset prices. The residuals of a simple VECM model present high correlations, even trends with regards to Europe, reflecting closer links between asset prices, also on the short term. This is especially true for the Euro area and Europe in general. We note also that the dynamics of correlations and variances present some shocks more or less resilient following the financial crises that hit the markets since 1997.

Chapter three helps to answer some questions addressed in the previous chapter. There exist actually a set of heterogeneous horizons for comovements established between the dynamics of asset prices on the markets. In this direction, we use and implement the multifractal model of asset returns of Calvet et al. (2006) to analyze comovements between stock markets between 1996 and 2008. We exert, at least, three superimposing cycles of volatility to efficiently gauge volatility comovements between stock indexes (CAC, DAX, FTSE and NYSE). These superimposed cycles are heterogeneous due to heterogeneous market resiliencies against shocks. It appears that the U.S. index is the most resilient with a short cycle of about 20 days on average against 40 days for the CAC. The medium-term cycles are between 100 and 120 days and the long-term one between 350 days for the FTSE and 500 days for the NYSE.

We also develop a set of indicators to precise this concept of comovements on heterogeneous horizons. The probability of crisis shows that two major crises have occurred on the sample: the Asian crisis of 1997 and the crisis started in 2008 following the bankruptcy of Lehman Brother. These periods of turbulences are notably associated with high probabilities of extreme comovements.

However, these improvements come to the detriment of modelling accurately the classic indicator of comovements: the correlation. Indeed, the expost dynamic of the correlation is only obtained through the probabilities associated with the Markov chain in the model, without temporal dimension as it is usually done in a dynamic conditional correlation model.

Chapter four thus completes the multifractal model of asset returns by introducing a time dimension in the relationship similar to a DCC model. We show the particular relevance to fit the data of the temporal dimension. Moreover, we keep this way the possible derivation of indicators defined in chapter three. We also highlight the ability of the model to take into account the risk of Re-correlation widely revealed by the 2008 crisis.

Indeed, in times of calm markets, i.e. with low volatility, the correlation may be underestimated. In these circumstances, any shock arrival causes disturbances on the dynamics of the correlation and can cause chain losses in supposed diversified portfolios. In our application, this re-correlation was mainly effective between places in the Euro area and more marginally for transatlantic linkages during periods of crisis.

This chapter four concludes the first part of the thesis on the methodologies used to analyze comovements. We then analyze the dynamic of some other markets, through the use of high frequency data. In particular we focus on the possible impact of the operational framework of the ECB on two particular markets that are: (i) the market for the French negotiable debt and (ii) the interbank overnight market for refinancing.

Chapter five highlights the impact of the operational framework of the ECB on comovements and market dynamics of the French negotiable debt market. In particular, we show that it can exist in markets of assets that serve as collateral a vicious circle related to the increase of OMOs by the central bank and the associated increase in their durations.

In this direction, we use bipower variations of Barndorff-Nielsen and Shephard (2005) and some indicators of market liquidity in a Markov switching VAR model. This reveals the existence of volatility premia on the rate of French sovereign bonds and comovements in terms of liquidity and volatility between rates at different terms. In particular, comovements are disturbed by the increase in refinancing operations including the possibility of a forced demand on long term bonds related to the more aggressive behaviours from banks willing to invest in liquid assets that can serve as collateral.

Finally, chapter six continues on the behaviours of agents on the interbank market for refinancing. As mentioned in the previous chapter, all the collateral rules may exclude from refinancing operations a number of banks that then must comply with their liquidity needs through the interbank market.

In particular, we implement the model of the probability of informed trade of Easley and O'Hara (1992) in this market to analyze the information asymmetries linked to the variety of banks participating in this market. We show that the reform of the operational framework intervened in March 2004 and associated with a more loose liquidity policy from the ECB, has reduced the probability of informed trade on this market.

One of the main measures that had an impact is the move of any policy rate announcements out of maintenance periods. Indeed, before 2004 decisions on the level of interest rates could be announced during a maintenance period while after March 2004 (excluding exceptional circumstances) the same rate applies to the entire maintenance period. This removed a major information asymmetry between banks and decreased the possibility of strategic trades to improve market stability.

We also fiund that the PIN illustrates the tensions on the interbank market mainly due to the fast decrease in the market liquidity during 2008. The liquidity injections by the ECB made until November 2008, the end of our sample did not always re-established an acceptable level of liquidity on the interbank market, the main source of liquidity scarcity being the lack in confidence.

To conclude the work compiled in this thesis, it is interesting to frame the possible extensions with the latest developments of the 2008 major financial crisis. Clearly, the financial crisis stems from the coupling of three major market inefficiencies:

The allocation inefficiency has generated the mobilization of resources for unsustainable investment projects resulting in significant losses. The inefficiency of resources allocation has led, as often, in creating speculative bubbles in some market segments doomed to a huge correction. The policy of the ECB with loose liquidity and low interest rates may have partially resulted in an underestimation of risk and an overpricing of some assets.

The information inefficiency comes from the opacity of information related to financial assets that has allowed this underestimation of risk as the underlying information was not included in the price, generating a large crisis of confidence in all markets with strong comovements during the second wave of the crisis in October 2008 (the first wave of the crisis being confined to assets from some classes of structured products). This lack of confidence, in particular, resulted in liquidity scarcity in the interbank market.

The operational inefficiency during the crisis revealed that some supposedly immune segments against any market failure may have serious shortcomings, particularly in terms of liquidity. Any valuation of asset price implies that there is a market price, even for the collateral used during ECB OMOs which is marked to market. Financial integration leads to a set of very close linkages between markets but also among investors and financial institutions that may involve synchronous liquidity needs and also synchronous forced and massive portfolio liquidations.

These three inefficiencies related to the current crisis can guide many extensions of the work presented in this thesis. In terms of applications, comovements methods can be applied to larger pools of assets to study the allocations of resources, i.e. comovements and arbitrages between different market segments in different countries or economic area. From a methodological point of view, the current crisis, by its extent, will require taking into account structural breaks in models with application of more appropriate methodologies: cointegration with regime switching, correlation with breaks and state dependencies, new comovement models following the crisis and so on. We are still short, in terms of sample, to implement all these methods but their need is undeniable.

The approach introduced in chapters two and three, via fractal properties is certainly welcome because it will help to clarify the impact of this major crisis on heterogeneous horizons, on different markets or market segments, with heterogeneous resiliencies. It will thus be interesting to compare the properties of the MSMDCC model in terms of predictions to see if it improves the existing models in out of sample forecasts and if it is robust to the current major turbulences. In particular, the resiliencies of markets will depend on the heterogeneity of measures taken in different countries and the impact of the legislation (e.g. MiFID) on country recoveries.

Moreover, the operational framework of the ECB suffered from extensive changes in recent months. As highlighted in chapter five, it was essential to expand the pool of collateral accepted in refinancing operations and the impact of this measure on market dynamics in general will have to be monitored, particularly concerning the trade-off between credit risk (with riskier collateral) and liquidity risk (of collateral markets in general).

Methodologies, in this regard, will be refined and some work is currently underway on the definition of liquidity and liquidity risk in markets with various structures (organized, OTC, with order books, etc.). This liquidity risk should, particularly at the end of the crisis, be closely monitored on the interbank market, and some methods needs to be specified, as preliminary introduced in chapter six.

It will notably be interesting to apply the methodologies based on asset price comovements, to liquidity comovements on these markets directly impacted by the monetary policy framework.

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