SENAI CIMATEC

PROGRAMA DE PÓS-GRADUAÇÃO EM MODELAGEM COMPUTACIONAL E TECNOLOGIA INDUSTRIAL

Doutorado em Modelagem Computacional e Tecnologia Industrial

Tese de Doutorado

Ensaios em Econofísica e Teoria de Redes

Apresentada por: Eder Johnson de Area Leão Pereira
Orientador: Dr. Hernane Barros de Borges Pereira
Co-orientador: Dr. Luiz Carlos de Santana Ribeiro

Outubro de 2020

Eder Johnson de Area Leão Pereira

Ensaios em Econofísica e Teoria de Redes

Tese de Doutorado apresentada ao Programa de Pós-graduação em Modelagem Computacional e Tecnologia Industrial, Curso de Doutorado em Modelagem Computacional e Tecnologia Industrial do SENAI CIMATEC, como requisito parcial para a obtenção do título de **Doutor em Modelagem Computacional e Tecnologia Industrial**.

Área de conhecimento: Interdisciplinar

Orientador: Dr. Hernane Barros de Borges Pereira
SENAI CIMATEC
Co-orientador: Dr. Luiz Carlos de Santana Ribeiro
Universidade Federal de Sergipe

Salvador
SENAI CIMATEC
2020

Ficha catalográfica elaborada pela Biblioteca do Centro Universitário SENAI CIMATEC

P426e Pereira, Eder Johnson de Area Leão

Ensaios em Econofísica e Redes / Eder Johnson de Area Leão Pereira. – Salvador, 2020.

124 f.: il. color.

Orientador: Prof. Dr. Hernane Borges de Barros Pereira
Coorientador: Prof. Dr. Luiz Carlos de Santana Ribeiro

Tese (Doutorado em Modelagem Computacional) – Programa de Pós-Graduação, Centro Universitário SENAI CIMATEC, Salvador, 2020.
Inclui referências.

1. Macroeconomia. 2. Mercados Financeiro. 3. Econofísica. 4. Teoria de Redes I. Centro Universitário SENAI CIMATEC. II. Pereira, Hernane Borges de Barros. III. Ribeiro, Luiz Carlos de Santana. IV Título.

CDD 330

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Doutorado em Modelagem Computacional e Tecnologia Industrial

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HERNANE BORGES DE BARROS PEREIRA:58646450520
Assinado de forma digital por HERNANE BORGES DE BARROS PEREIRA:58646450520
Dados: 2020.10.27 14:30:53 -03'00'

Orientador: Prof. Dr. Hernane Borges de Barros Pereira
Centro Universitário SENAI CIMATEC

Coorientador: Prof. Dr. Luiz Carlos de Santana Ribeiro
Universidade Federal de Sergipe

Membro Interno: Prof. Dr. Marcelo Albano Moret Simões Gonçalves
Centro Universitário SENAI CIMATEC

IVAN COSTA DA CUNHA LIMA:41241703868
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Date: 2020.10.27 15:01:39 -03'00'

Membro Interno: Prof. Dr. Ivan Costa da Cunha Lima
Centro Universitário SENAI CIMATEC

Membro Externo: Prof. Dr. Thadeu Josino Pereira Penna
Universidade Federal Fluminense

Membro Externo: Prof. Dr. Gervásio Ferreira dos Santos
Universidade Federal da Bahia

Dedico este trabalho a Deus todo poderoso, a Dona Maria, a Leo, a Maria Leticia e a Neidinha.

Agradecimentos

Agradeço, primeiramente, a Deus, depois à minha mãe, Maria, e ao meu pai, Eneas, por tudo feito por mim. Quero agradecer à minha esposa, Leonildes, pela parceria, amizade e por ser fundamental neste percurso e à minha filha, Maria Letícia, por ser a grande inspiração para tentar fazer algo diferente. Depois às minhas irmãs, Neidinha, Eronilda, Célia e Netinha, ao meu cunhado, Zé, à minha tia Francisca (*In Memorian*) e a todos os familiares.

Quero agradecer ao meu orientador, professor Hernane, por ter me dado a oportunidade de estar no Cimatec e ter me ajudado muito nessa trajetória. Ao amigo Garcia pelo apoio técnico e ao co-orientador professor Luiz Carlos pela ajuda e parceria. Aos professores do Cimatec Moret, Ivan, Renelson e demais. Aos amigos Paulo Ferreira e Marcus pela colaboração e parceria, aos amigos Anderson, Antônio e William pela ajuda e a todos os colaboradores desse trabalho.

Agradeço também ao Instituto Federal do Maranhão, em especial, ao campus Bacabal pela liberação e apoio nessa empreitada e ao Senai-Cimatec pela excelência, objetividade e por me aceitar.

Salvador, Brasil
dia 27 de Outubro de 2020

Eder Johnson de Area Leão Pereira

Resumo

A aplicação de sistemas complexos na economia tem sido denominada econofísica. A econofísica possibilitaram a aplicação em diversos fenômenos econômicos, principalmente nos mercados financeiros e na macroeconomia. A econofísica e as redes complexas tem dado uma contribuição para o entendimento da macroeconomia e nas finanças, pois elas possuem instrumental teórico para lidar com fenômenos em desequilíbrio, como as crises financeira. Com a possibilidade de analise das relações econômicas e financeiras considerando as redes temporais, é possível verificar o comportamento de sistemas econômicos durante um determinado período de tempo, principalmente, detectando o efeito de choques, como a crise de 2008, nas inter-relações setoriais e nos mercados financeiros. Portanto, esta na Tese defende a importância das redes temporais e da disciplina econofísica para a análise econômica, principalmente, para a análise dos impactos de choques exôgenos nas inter-relações comerciais e financeiras. Os resultados encontrados, com base nas crises, em particular, a crise dos subprime, mostra que a econofísica e a teoria de redes facilitam a percepção dos efeitos exógenos e desvendam a dinâmica de comportamentos de agentes e/ou ativos econômicos (e.g. ativos econômicos e setores da bolsas).
Palavras-chave: Econofísica, Teoria de Redes, Mercados Financeiros, Macroeconomia.

Abstract

The application of complex systems in the economy is called econophysics. Together with complex networks, it has contributed to the understanding of macroeconomics and finance, since they have theoretical instruments to deal with unbalanced phenomena, such as financial crises. With the possibility of analyzing economic and financial relationships considering temporal networks, it is possible to verify the behavior of economic systems over a certain period, mainly by detecting the effect of shocks on sectoral and in the financial markets, such as the 2008 crisis. Therefore, based on the subprime crisis, this thesis highlights the importance of temporal networks and econophysics for the analysis of the economics and the impacts of exogenous shocks on commercial and financial interrelationships. The results showed that econophysics and network theory facilitate the perception of exogenous effects and unveil the dynamics of the behaviors of agents and/or economic assets (e.g., active economic and sectors).

Keywords: Econophysic, Networks, Stock Markets, Macroeconomic, Subprime Crisis.

Sumário

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Lista de Siglas

AEA .... Associação Americana de Economia
DCCA .... Detrended Cross-Correlation Analisys
DFA .... Detrended Fluctuation Analysis
FED .... Federal Reserve System
HME .... Hipótese dos Mercados Eficientes
IP .... Insumo-Produto
OPEP .... Organização dos Países Exportadores de Petróleo
PAPCDAm .. Plano de Ação para a Prevenção e Controle do Desmatamento na Amazônia Legal
PCC .... Coeficiente de Correlação de Pearson
PDCCA ..... DCCA Cross-Correlation Coeficient
PIB .... Produto Interno Bruto
PPGMCTI ... Programa de Pós-graduação em Modelagem Computacional e Tecnologia Industrial
RhoDCCA ... DCCA Cross-Correlation Coeficient
TR .... Teoria de Redes
TVG .... Time-Varying Graphs
WWW ...... World Wide Web

Capítulo Um

INTRODUÇÃO

> Comece fazendo o que é necessário, depois o que é possível, e de repente você estará fazendo o impossível.
>
> (São Francisco de Assis)

Atualmente, as relações nos mercados financeiros, ambientais, na energia e na saúde possuem caracteristicas como: instabilidade, excesso de informação e conectividade. Isso tem gerado a necessidade de uma abordagem sistêmica para a resolução de problemas nessas áreas. Com isso, os sistemas complexos, em especial a Econofísica e a Teoria de Redes (TR) têm disponibilizados um conjunto de ferramentas capazes de solucionar diversos problemas, principalmente em sistemas que os agentes se interagem, são instáveis e cuja a informação desempenha um importante papel, por exemplo, os mercados financeiros, meio ambiente e no mercado de energia.

Nesse contexto, a Econofísica tem dado contribuições em diversos temas da economia, por exemplo, risco financeiro e precificação de ativos (BOUCHAUD; CONT, 1998), predição de crises e quebras dos mercados (SORNETTE, 2017), *agent based modelling* (FARMER; FOLEY, 2009). No entanto, os econofísicos quase sempre tiveram dificuldades de publicar em grandes periódicos econômicos e também estiveram à margem de um debate mais profundo entre os economistas (BALL, 2006). Parece que este cenário está mudando com a adoção de alguns métodos originários na econofísica por partes de alguns economistas, o exemplo que destacamos é o uso de Teoria de Redes (TR).

Com ela é possível análisar dois ou mais ativos interligados através das arestas que podem ser interpretados em Insumo-Produto (IP) como inter-relações setoriais e em finanças como correlações nos retornos de dois ativos. Uma contribuição das redes em finanças é a possibilidade de elas mensurarem a probabilidade de risco sistêmico, que são decorrentes das interligações e da interdependência entre os agentes de um sistema ou mercado, no qual a insolvência ou falência de uma única entidade ou grupo de entidades pode provocar falências em cadeia (BATTISTON *et al.*, 2012).

Na Macroeconomia, a interligação dos vários setores que compõe a economia formando uma rede tem possibilitado a análise das flutuações agregadas que é o efeito de choques exôgenos na redução do PIB per capita de um determinado país. Além disso, o uso da teoria de redes, no âmbito de IP tem proporcionado uma ampliação mais ampliada do sistema econômico. Nesse contexto, com a aplicação dos *Time Varying Graphs*

(TVG) (CASTEIGTS *et al.*, 2012) permitiu analisar as redes considerando a dinâmica dos eventos econômicos. Cabe ressaltar que em economia, o tempo é fundamental, pois as relações entre os diversos agentes econômicos estão em constante mudança, sejam nos mercados financeiros ou na macroeconomia, principalmente após eventos extremos ou choques exógenos como a crise dos *subprime*.

A crise dos *subprime*, ocorrida em 2008, nos Estados Unidos, foi a maior crise nos país desde a "Grande Depressão", em 1929. Ela provocou quedas nas bolsas de valores de diversos países no mundo, além de diminuir a produção industrial nos EUA, durante o seu acontecimento. Após esse evento, diversos estudos foram realizados para mensurar o seu impacto na economia e alguns utilizaram redes complexas. Contudo, com a formulação das redes temporais (CASTEIGTS *et al.*, 2012) e (ROSÁRIO *et al.*, 2015) e das redes multiscala (WANG; XIE; STANLEY, 2018) foi possível captar a magnitude da crise nas inter-relações setoriais e financeiras podendo ser encontrado um padrão nas propriedades das redes que se repete em diversas áreas da economia, como nas finanças e na macroeconomia.

Dessa forma, esta Tese propôs-se encontrar um padrão da conectividade nas propriedades das redes de IP e financeiras, antes e após a crise dos *subprime*. Inicialmente, foi desenvolvida uma revisão sobre Econofísica, mostrando seus aspectos históricos, as principais áreas e a contribuição atual. Em seguida, serão analisados temas envolvendo redes e mercados financeiros em dois ensaios, no primeiro foram analisadas as relações financeiras entre as vinte maiores economias do mundo, utilizando redes multiscala que são múltiplas redes, uma para cada escala de tempo, antes e após a crise de 2008. O segundo ensaio é uma rede dinâmica para analisar as interligações entre os mercados da União Europeia com o objetivo de identificar a influência de crises na estrutura da rede. Por último, foram analisados os efeitos da crise nas inter-relações setorias na economia brasileira utilizando *redes e insumo-produto*, com a finalidade de detectar a influência de choques exógenos nas interrelações setoriais.

Além dos trabalhos que fazem parte da tese, durante o doutorado foram produzidos artigos que utilizam direta ou indiretamente conceitos dos sistemas complexos para a resolução de problemas nas áreas de economia, finanças, meio ambiente e energia ver figura 1.1. Estes trabalhos foram produzidos durante o doutorado com o objetivo de resolucionar problemas em áreas fundamentais para a humanidade como: Energia, Meio Ambiente e Política.

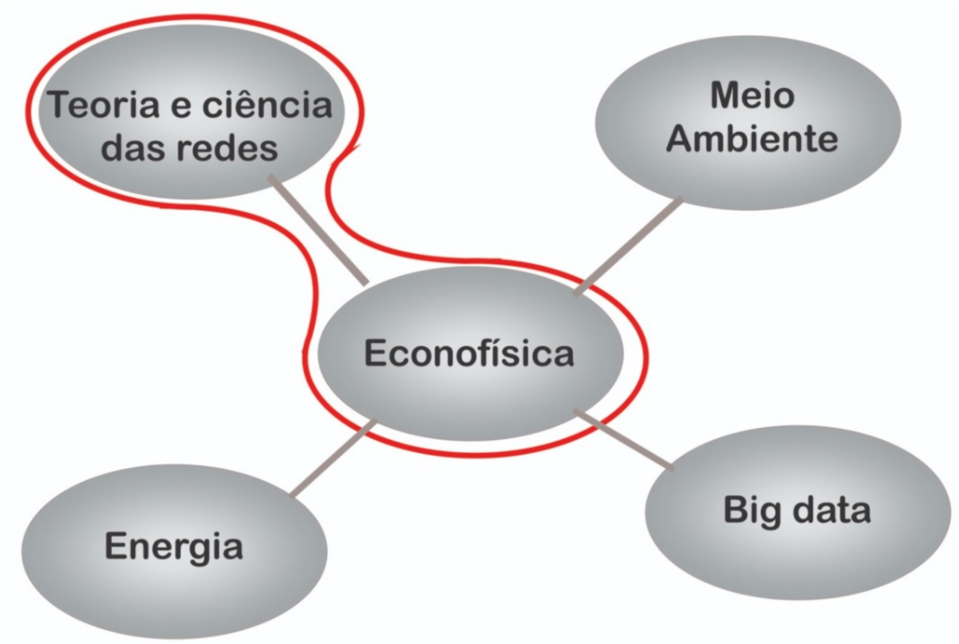

Figura 1.1: Divisão da Tese por tópicos. Fonte: Elaboração própria

Cabe ressaltar que em todos existe a influência da complexidade, colaborando para uma visão sistêmica de alguns problemas como os choques do petróleo, o desmatamento na Amazônia, as flutuações das criptomoedas, as inter-relações setoriais regionais, as margens (rentabilidade do negócio) dos combustíveis e as relações entre o termo Donald Trump e as variações nos mercados de criptomoedas.

Nesse contexto, a complexidade está presente em diversas áreas do conhecimento, facilitando a análise de diversos problemas. De acordo com (HELBING, 2013) com o aumento da conectividade, do risco e da informação, a complexidade passa a ter um papel relevante para a compreensão do risco global. Ainda segundo o autor um problema ambiental pode ocasionar outros problemas, como na saúde, nos transportes, na economia e assim sucessivamente. A dependência dos diversos setores se tornou ainda maior com o aumento da informação e da conectividade. Por esses motivos, fizemos incurssões em outros problemas que envolvem econofísica, energia e ambiente.

Dito isso, a solução de determinados problemas ambientais, como, o desmatamento na Amazônia, atualmente, envolve questões econômicas, sociais e jurídicas. A Amazônia é a maior floresta tropical do mundo, possui mais de 1/3 de toda a biodiversidade global, tem papel fundamental nas mudanças climáticas globais e nos ciclos das chuvas. Além disso, tem um papel estratégico para o Brasil, pois dá ao país uma liderança ambiental global. Por isso, a floresta tropical foi objeto de estudo em três ensaios, tendo como foco o papel das políticas ambientais na sua conservação.

Além do mais, a metodologia baseada na complexidade possibilita analisar a interação entre diversos sistemas e as possíveis consequências dessas conexões ou a falta delas. Outros problemas que os sistemas complexos podem contribuir são os choques do petróleo ou crises na economia. Notamos que choques no preço do barril de petróleo, afetam a economia e as perspectivas de investimento, dado que diversos setores dependem dos derivados do petróleo, por exemplo, o setor químico, automotivo, plásticos e borrachas, setor de alimentos, etc.

Essa relação de causa e efeito, faz com que tanto as quedas como as elevações abruptas do preço do petróleo tenham influência direta na economia brasileira podendo afetar a geração de emprego e renda. Por estes motivos, o petróleo teve uma importância como objeto de estudo secundário nessa tese, sendo analisadas as relações inter-setoriais do setor do petróleo e as influências das variações abruptas do preço do petróleo em tempos de crise em diversos ativos.

Ademais, surgiram outros trabalhos no âmbito da econofísica que foram publicados, o primeiro artigo relacionava às buscas pelo nome do presidente dos Estados Unidos, *Donald Trump*, no *Google Trends* a volatilidade nos mercados de ações. Em outro artigo identificamos os principais setores da economia brasileira de acordo com os conceitos utilizados em TR. E em outros dois artigos foi verificado o efeito contágio nas demais moedas provocadas pelo bitcoin e a hipótese da eficiência de mercado dessa moeda. Esses ensaios foram colocados num apêndice desta tese.

Portanto, a essência da tese foi a aplicação de conceitos oriundos dos sistemas complexos, em particular as redes complexas, para a resolução de diversos problemas, nas áreas econômica, financeira, energética e ambiental. Isso possibilitou a comprovação do estudo e uso da complexidade como um instrumento para o entendimento dessa nova realidade baseada na conectividade, na informação e na instabilidade. Em alguns casos, foi possível a aplicação direta de ferramentas originárias dos sistemas complexos, em outros apenas o uso da metodologia de se trabalhar com diferentes sistemas que estão interligados em termos de organização da narrativa pretendida.

1.0.1 Definição do problema

A crise dos *subprime*, ocorrida em agosto de 2008, trouxe um elevado custo de recuperação econômica para diversos países. Somente nos Estados Unidos, durante os seis anos que seguiram após a crise, o *Federal Reserve Board* (FED) comprou US$ 4,5 trilhões em títulos de dívidas de empresas e mais de 7,3 milhões de pessoas ficaram desempregadas, entre janeiro de 2008 e fevereiro de 2010.

Os efeitos das crise norte-americana contagiaram os mercados financeiros mundiais provocando a queda de diversas bolsas no mundo. Ademais, no Brasil, a produção industrial teve uma queda influenciando outros setores da economia como: agricultura e a metalurgia. Nesses dois eventos podem ser utilizada a TR para mensurar os impactos da crise, já que em ambos diversos agentes estão envolvidos, nas finanças são as bolsas de valores e no Brasil as relações entre os diversos setores da economia. E o uso de redes temporais e/ou rédes multiscala pode auxiliar na percepção da dinâmica das crises nas finanças e em Insumo-Produto.

Na economia, as relações entre os agentes variam no tempo, necessitando de uma abordagem dinâmica para o entendimento da influência de eventos extremos, como a crise de 2008, nos mercados financeiros e nas inter-relações setoriais. Assim, esta pesquisa doutoral pretende responder a seguinte questão de pesquisa: As Teoria de Redes podem identificar uma mudança nas estruturas financeiras e setoriais durante crises econômicas, em particular a crise de 2008?

1.0.2 Objetivo

Identificar mudanças nas estruturas financeiras e setoriais econômicas durantes crises econômicas utilizando econofísica e da Teoria de Redes.

1.0.3 Objetivos específicos

Elaborar o panorama da econofísica;

Analisar a influência da *crise dos subprime* nos principais mercados financeiros;

Analisar a dinâmica na relação entre setores econômicos sob o ponto de vista do Insumo-Produto;

Utilizar os modelos de redes dinâmicas para explicar e predizer crises;

1.0.4 Importância da pesquisa

A presidente do Banco Central Norte Americano, Janet Yellen em seu texto "Interconnectedness and Systemic Risk: Lessons from the Financial Crisis and Policy Implications (YELLEN, 2013) citou dez vezes a expressão "complexity"e dezenove vezes a expressão "complex", defendendo a abordagem dos mercados financeiros como sistemas integrados e interconectados, o que sugere a necessidade da aplicação das TR para a compreensão das instabilidades financeiras.

Sob a análise Insumo-Produto, as redes possibilitaram verificar quais setores são os mais centrais em uma economia, as diferentes comunidades setoriais, etc. A verificação dessas ocorrências no tempo, pode contribuir para várias áreas da economia em especial, a macroeconomia. Já que a análise das flutuações agregadas e das relações inter-setoriais necessitam de uma abordagem dinâmica.

Sendo assim, a Econofísica e a Teoria de Redes podem contribuir para a análise de choques exôgenos nos mercados financeiros e macroeconômicos. Nestes termos, é necessário a consolidação da TR como um importante pilar da Econofísica.

1.0.5 Limites e limitações

A principal limitação foi:

1. A dificuldade de acesso à base de dados relacionados aos indíces financeiros como as cotações das ações, *commodities* ou indíces das bolsas. O problema é que grandes bases de dados, normalmente, possuem um custo elevado de acesso e nem todas as informações estão disponíveis numa única base de dados. Entretanto, durante a tese de Doutorado, foram comprada o acesso às bases de dados para pesquisa.

1.0.6 Suposições

- As redes, em especial as dinâmicas, têm contribuído para a consolidação da econofísica como disciplina;

- As redes multiscala auxiliam na detectação de crises financeiras;

- Os grafos variantes no tempo fornecem novas propriedades para análise dos fenômenos macroeconômicos;

- Os grafos variantes no tempo captam fenômenos exógenos (crises ou elevação no preço de ativos financeiros) nas flutuações inter-setoriais;

- A conectividade das redes antecedem crises financeiras.

Capítulo Dois

CONCEITOS E MODELOS ECONÔMICOS

2.1 Introdução

Essa tese se propôs a analisar identificar padrões em crises financeiras, em especial, na crise dos subprime utilizando econofísica e TR. Com isso, foram utilizados modelos da TR para a resolução dessa questão. A importância dos modelos dá-se pela a capacidade de resolução de problemas que envolvem muitos agentes e se relacionam entre si.

Nesse caso, na análise IP e nos mercados financeiros os agentes se interagem formando diversos padrões que se alteram antes e após as crises financeiras. Esses padrões podem ser utilizados para a análise e predição delas. Para isso, os conceitos e modelos são necessários.

As crises econômicas são eventos importantes na economia. Durante a crise dos *subprime*, foram gastos trilhões com a ajuda do governo norte-americano para salvar a economia e milhões de pessoas ficaram desempregadas. Nesse âmbito, esta tese analisa a crise de 2008, para identificar padrões em modelos de TR na economia ou finanças, pois qualquer percepção mínima de um evento como a crise dos *subprime* pode contribuir para minimizar perdas financeiras. Neste capítulo serão mostrados alguns dos modelos tradicionais usados em economia e finanças. Inicialmente será apresentado a Hipótese dos Mercados Eficientes (HME), uma hipótese tradicional em finanças e amplamente utilizada nos mercados financeiros para, em seguida, serem feitas comparações com os modelos utilizados em econofísica.

Depois, será mostrado o coeficiente de correlação de Pearson e o coeficiente de correlação cruzada ρ_{DCCA}. Por último, será mostrado o modelo Insumo-Produto (IP) que é utilizado em diversas áreas da economia, economia regional e meio ambiente.

2.1.1 Hipótese dos Mercados Eficientes

Os primórdios da Hipótese dos Mercados Eficientes [HME] se deu com a tese de doutoramento em matemática de Louis Bachelier *Theory de La Speculation* (BACHELIER, 1900), na qual ele formulou a hipótese de que os preços dos ativos financeiros se comportavam como um movimento browniano (PEREIRA, 2010).

As ideias de Bachelier foram resgatadas durante a década de 60 pelo economista Paul Samuelson (SAMUELSON, 2016). Contudo, a HME foi formulada definitivamente por Eugene Fama, prêmio Nobel de Economia e orientando de Benoit Mandelbrot, com sua tese de doutorado em Business intitulada *Randon Walk in Stock Price Market* e com a publicação do artigo denominado *Efficient capital markets: a review of theory and empirical work* , em 1970 (PEREIRA, 2010).

Dessa forma, a HME influenciou toda uma geração de economistas, um exemplo é que a fórmula Black-Scholes (BLACK; SCHOLES, 1973), famosa fórmula utilizada no mercado de opções, tem como uma de suas condições suficientes que os mercados sejam eficientes.

(MANTEGNA; STANLEY, 2007) definem a HME como a capacidade do mercado em 122 refletir toda a informação disponível no preço dos ativos financeiros. Para que os mercados sejam eficientes é necessário atender algumas condições suficientes (MALKIEL; FAMA, 1970):

1. Não há custo de transação na negociação do ativo;

2. Os agentes reagem de forma homogênea às informações disponíveis e

3. As informações estão disponíveis a todos os agentes.

Na HME a distribuição da frequência dos retornos é próxima a uma curva normal, sendo que ela tem as caldas finas, e isso significa que grandes flutuações nos preços das ações são nulas (MALKIEL; FAMA, 1970). Portanto, na HME as ocorrências de grandes variações nos preços das ações são muito próximas a zero, por conseguinte, as ocorrências de crises financeiras, fenômeno recorrente nos mercados financeiros são praticamente nulas (PEREIRA; URPIA, 2011).

2.1.2 Coeficiente de Correlação de Pearson

Em estatística descritiva, o coeficiente de correlação de Pearson, também chamado de coeficiente de correlação produto-momento ou simplesmente de p de Pearson mede o grau da correlação e a direção dessa correlação se positiva ou negativa entre duas variáveis de escala métrica. O coeficiente de correlação de Pearson não tem esse nome por acaso. A origem desse coeficiente remonta o trabalho conjunto de Karl Pearson e Francis Galton (STANTON, 2001). O coeficiente de correlação de Pearson (r) é uma medida de associação linear entre variáveis.

Ele assume apenas valores entre -1 e 1. Em que: p = 1 significa correlação perfeita positiva entre duas variáveis, p = -1 correlação negativamente perfeita entre as duas variáveis e p= 0 significa que as duas variáveis não dependem linearmente uma da outra.

2.1.3 *Coeficiente de Correlação Cruzada* ρ_{DCCA}

O coeficiente de correlação cruzada é um método para quantificar o nível de correlação cruzada entre duas séries temporais não estacionárias. Ele baseia-se na *detrended fluctuation analysis* (DFA) (PENG *et al.*, 1994) e no *detrended cross-correlation analysis* (DCCA) (PODOBNIK; STANLEY, 2008). Assim, os dois métodos foram juntos e foi formulado o coeficiente de correlação cruzada sem tendência com o objetivo de analisar séries temporais não-estacionárias. Mostraremos as 5 etapas de sua determinação (ZEBENDE, 2011; ZEBENDE; SILVA; FILHO, 2013) a seguir:

Etapa I. Considerando duas séries temporais, $\{x_t\}$ e $\{y_t\}$, com $t = 1, 2, ..., N$, (N é o número total de elementos das séries temporais), integramos as séries temporais obtendo duas novas séries:

$$xx_k = \sum_{t=1}^{k} y_t, k = 1, 2, ..., N \tag{2.1}$$

Etapa II: Dividimos essas duas séries temporais integradas, $\{xx_k\}$ e $\{yy_k\}$, em $(N-s)$ caixas sobrepostas de igual comprimento s , com $4 \leq s \leq {}^{N}/_{4}$.

Etapa III: Calculamos a tendência local de cada caixa pelo ajuste dos mínimos quadrados de cada série, $xP_i(k)$ e $yP_i(k)$. Então, nós calculamos a covariância de resíduos em cada caixa por: .

$$f^2{}_{xy}(s,i) = \frac{1}{s+1} \sum_{k=i}^{i+s} (xx_k - xP_i(k))(yy_k - yP_i(k)) \tag{2.2}$$

Etapa IV: Agora, a média sobre todas as caixas sobrepostas é calculada para obter a nova função de covariância: .

$$F^2{}_{xy}(s) = \frac{1}{(N-s)} \sum_{i=1}^{N-s} f^2{}_{xy}(s,i) \tag{2.3}$$

Etapa V: Finalmente, calculamos o coeficiente de correlação cruzada por: .

$$\rho_{DCCA}(s) = \frac{F^2{}_{xy}(s)}{F_{xx}(s)F_{yy}(s)} \tag{2.4}$$

Onde $F^2xy(s)$ é a função de correlação determinada pelo método de (PODOBNIK; STANLEY, 2008) e $F_{xx}(s)$e $F_{yy}(s)$ são as funções de auto correlação determinadas pelo método de (PENG *et al.*, 1994). O ρ_{DCCA} depende do tamanho de cada caixa s (escala temporal), com isso é possível mensurar as correlações entre duas séries temporais em diferentes escalas de tempo. Além do mais, ele varia no intervalo $-1 \leq \rho_{DCCA} \leq 1$, onde 1 significa correlação cruzada perfeita, -1 anticorrelação cruzada perfeita e 0 não existe correlação.

Desde o surgimento do ρ_{DCCA}, vários trabalhos envolvendo ele foram feitos, entre os mais relevantes, Podobnik *et al.* (2011) formulou o teste de hipótese para o ρ_{DCCA} avaliar o nível de significância dos resultados obtidos. Em seguida, (KRISTOUFEK, 2014b) criou um método alternativo ao ρ_{DCCA} denominado ρ_{DMCA} para avaliar as correlações cruzadas entre suas séries temporais não estacionárias. Em 2016, Silva *et al.* (2016) formularam o $\delta\rho_{DCCA}$ para estudar a ocorrência de efeito contágio entre as bolsas de valores. Em 2017, Kwapień *et al.* (2017) fundiram o cálculo fracionário com o ρ_{DCCA} , criando o qρ_{DCCA} para análise da correlação cruzada entre duas séries temporais não-estacionárias.

2.1.4 *Vantagens do ρ_{DCCA} em relação ao Coeficiente de Correlação de Pearson*

De acordo com Wang *et al.* (2013b), o método do coeficiente ρ_{DCCA} tem algumas boas propriedades como a propriedade não-linear e a resolução da escala, eles demonstraram que o ρ_{DCCA} tem melhores resultados e propriedades do que o PCC (Coeficiente de Correlação de Pearson). Para Kristoufek (2014a), o ρ_{DCCA} é capaz de estimar o verdadeiro coeficiente de correlação sem viés, mesmo para séries fortemente não estacionárias. Ademais, a precisão das estimativas não varia muito com o aumento do comprimento das séries temporais.

A relação entre o ρ_{DCCA} e a análise de correlação cruzada entre as séries temporais financeiras tem sido produtiva para a Econofísica, já que desde o seu surgimento o ρ_{DCCA} tem diversos estudos analisando as correlações cruzadas entre os diversos ativos (SILVA *et al.*, 2016; PEREIRA *et al.*, 2018; FERREIRA *et al.*, 2019; WANG; XIE; CHEN, 2017). As razões para o relativo sucesso da aplicação do ρ_{DCCA}, basicamente, são duas:

I. Possibilidade de analisar séries temporais não-estacionárias. A grande maioria das séries financeiras não são estacionarias (e.g. *commodities*, petróleo, índices financeiros, etc.);

II. Obtenção de várias escalas possibilitando identificar a influência delas na correlação entre duas séries temporais para cada uma das escalas. Com isso, é possível identificar se existe uma correlação de curto, médio ou longo prazo, fato que é relevante para a análise financeira.

Devido a essas propriedades, o coeficiente ρ_{DCCA} foi utilizado para o cálculo das correlações entre ativos financeiros nas redes formando *multiscale networks* (WANG *et al.*, 2013a; WANG; XIE; STANLEY, 2018; PEREIRA *et al.*, 2019b). Isso cria redes a partir das quais que analisamos as correlações entre ativos financeiros em curto, médio e longo prazo.

2.1.5 O modelo Insumo-Produto

O modelo de Insumo-Produto foi elaborado pelo economista Wassily Leontief, Prêmio Nobel de Economia de 1973. O trabalho de Leontief teve como objetivo construir um modelo que representasse as relações técnicas entre as várias atividades produtivas de uma economia. Os modelos de IP possibilitam a melhor compreensão da interdependência entre os setores produtivos de uma economia, bem como permitem a identificação de fragilidades e potencialidades do ponto de vista inter-setorial que podem influenciar o desenvolvimento regional (GUILHOTO, 2011).

A análise de Insumo-Produto representa uma fotografia da economia, nele Leontief mostrou como os setores estão relacionados entre si e com a demanda final e de acordo com Guilhoto (2011, p.11):

> O resultado foi uma visão única e compreensível de como a economia funciona - como cada setor se torna mais ou menos dependente dos outros. Esse sistema de interdependência é formalmente demonstrado em uma tabela conhecida como tabela de insumo-produto; e tais representações demandam grandes investimentos, já que elas requerem uma coleção de informações sobre cada companhia, a respeito dos seus fluxos de vendas e das suas fontes de suprimento.

Enquanto setores compram e vendem uns para os outros, um setor individual interage, tipicamente e diretamente, com um número relativamente pequeno de setores. Entretanto, devido à natureza desta dependência, pode-se mostrar que todos os setores estão interligados, direta e indiretamente.

A equação 2.7 representa a solução do modelo de IP proposto por Leontief:

$$X = (A - I)^{-1} f \tag{2.5}$$

em que X é o vetor de produção setorial total, A é a matriz de coeficientes técnicos e f é o vetor de demanda final. Sendo B a matriz inversa de Leontief, a equação 2.7 pode ser reescrita como:

$$X = B \cdot f \tag{2.6}$$

Na análise IP os preços não se modificam e os coeficientes técnicos são constantes, isso mostra, como já dissemos, uma "fotografia" estática da economia durante um período determinado.

A ideia de que a produção de bens e serviços depende de uma rede complexa de transações entre uma ampla gama de fornecedores e clientes tem uma longa tradição na economia. Na década de 1940, em seu estudo da estrutura da economia americana, Wassily Leontief mostrou que rede de processo de produção poderia produzir distúrbios em certas empresas ou indústrias, consequentemente, tais distúrbios poderiam se espalhar para outras partes da economia por meio de ligações entre os agentes econômicos. Isso possivelmente poderia transformar choques microeconômicos isolados em flutuações macroeconômicas (CARVALHO; GABAIX, 2013).

Na década de 50, Solow, ganhador do prêmio Nobel de economia, também conciliou redes e estruturas produtivas, posteriormente, Bak *et al.* (1993) demonstraram a importância da estrutura de cadeia de insumo e oferta na transmissão do choque entre setores da economia. Nos anos 2000, após a possibilidade de se incorporar a análise de centralidades nas redes contribui para uma visão alternativa de como os setores estão correlacionados.

Nesse contexto, Blöchl *et al.* (2011) analisaram a transação de bens entre setores da economia para diversos países calculando a centralidade pelo método *random walk centrality* encontrando os setores chaves para as economias estudadas, além de compará-las através da centralidades, eles cunharam o termo *Tão Central para Cair* referindo-se a setores que eram centrais demais para caírem. Um exemplo disso, é o setor automotivo nos Estados Unidos, onde empresas como General Motors, Chrysler e Ford desempenham um papel central na cadeia de suprimentos americana, sendo estas centrais em toda a cadeia industrial, dessa forma qualquer choque negativo nelas podem afetar consideravelmente a cadeia de fornecedores nos EUA.

Concomitantemente, Acemoglu *et al.* (2012), detectaram setores “centrais” na cadeia de produção norte-americana, analisando setores fornecedores na rede formada por meio da matriz de IP dos Estados Unidos. Eles identificaram que choques negativos em setores altamente conectados podem gerar efeitos em cascata que são então transmitidos a outros setores da economia. E Gabaix (2011) chegou a uma conclusão semelhante, estudando a cadeia de suprimentos dos Estados Unidos, descobriu que o tamanho da cadeia tinha uma distribuição de probabilidade com "caudas pesadas". Isso implica que um choque negativo em empresas mais conectadas pode afetar toda a rede, já que poucas empresas têm muitas conexões e muitas empresas têm poucas conexões.

Capítulo Três

Econofísica: Passado e Presente

Desde os estudos iniciais de Benoit Mandelbrot, durante a década de 60, a condição de normalidade dos retornos das séries financeiras têm sido rejeitadas "Statistical test that reject the brownian hypothesis that changes, brownian hypothesis price changes are gaussian" (MANDELBROT, 1963, p.336). Porém, as ideias de Mandelbrot sobre a não-normalidade dos retornos financeiros permaneceram no esquecimento, até que Rosario Mantegna ao analisar o mercado acionário italiano, em 1991, (MANTEGNA, 1999) e Eugene Stanley, em 1996, analisando o índice *Dow Jones* encontrou que os retornos das ações não seguiam uma curva normal, contribuindo para o surgimento da disciplina econofísica.

Econofísica é um neologismo usado no campo da Física de Sistemas Complexos que busca fazer um levantamento completo das propriedades estatísticas dos mercados financeiros usando o volume de dados disponíveis e a metodologia de trabalho da física estatística (MANTEGNA; STANLEY, 2007). O termo econofísica surge pela primeira vez com Eugene Stanley, em 1996, desde o surgimento da Econofísica, um número crescente de artigos sobre econofísica foram publicadas em periódicos de Física, várias séries de reuniões dedicadas a esse tópico são regularmente organizadas e várias universidades já têm a disciplina Econofísica em sua grade curricular tanto na graduação como na pós-graduação (SCHINCKUS, 2012).

No início, a econofísica era usada para estudar apenas o formato da distribuição dos retornos dos ativos financeiros (ações, taxas de câmbio, *commodities* e índices de ações), posteriormente, adaptou outras ferramentas originárias da física estatística, como o expoente de Hurst, modelagem cruzada de correlação, modelos baseados em agentes e redes complexas. Nesse contexto, as redes complexas foram estabelecidas como importantes ferramentas analíticas em várias áreas, fornecendo uma nova visão no estudo de alguns problemas econômicos.

Um evento que contribui para comprovar a ideia da econofísica de que os retornos financeiros não seguiam uma curva normal e sim uma lei de potência foi a crise de 2008, quando o principal índice de ações dos EUA, o Dow Jones, perdeu 777,68 pontos em um único dia (29/09/2008), depois da rejeição do plano de resgate financeiro na votação na Câmara dos Estados Unidos. Em termos percentuais, a baixa foi de 6,98% maior desde 17 de setembro de 2001, dia da retomada das operações depois dos ataques de 11 de setembro daquele ano. Nesse cenário, o Nasdaq, indicador de ações na área de tecnologia, caiu 9,14% e o Standard Poor's 500 recuou 8,8% em um único dia.

Após a crise de 2008, as instituições financeiras passaram a aceitar o fato de que os mercados financeiros estão sujeitos a grandes variações e isso pode contribuir para a prevenção dessas instabilidades ou mesmo para evitá-las, pois podem ser incorporadas à análise de risco (SORNETTE, 2017).

Durante os mais de 20 anos de existência, a Econofísica tem dado uma contribuição significativa em diversos temas: risco financeiro e precificação de ativos (BOUCHAUD; MÉZARD, 2000), predição de crises e quebras dos mercados (SORNETTE, 2017), *agent based modelling* (FARMER; FOLEY, 2009). No entanto, os econofísicos segundo Ball (2006) quase sempre tiveram dificuldades de publicar em grandes periódicos econômicos e também estiveram à margem de um debate mais profundo entre os economistas. Contudo, esse cenário pode estar mudando com a adoção de alguns métodos originários na Econofísica por parte de alguns economistas e sua aplicabilidade em algumas áreas da economia. É nesse contexto que esta tese doutoral modestamente pretende contribuir.

A Econofísica ainda passa por um processo de consolidação entre economistas, um exemplo disso, é que as leis de potência passaram a ter um papel importante na economia a ponto de mereceram um extenso artigo no *Journal of Economic Perspective* (GABAIX, 2016), o qual demonstra as aplicações da econofísica nas finanças, tamanho das cidades, salários dos executivos e na macroeconomia.

Em outro exemplo, em Dezembro de 2017, na Associação Americana de Economia (AEA), foi realizado, por um conjunto de físicos e economistas, um seminário sobre Econofísica com a intenção de demonstrar um pouco mais sobre essa disciplina para esta associação. A atitude da AEA é um passo importante para o entendimento de duas áreas, Economia e Física, que sempre estiveram tão próximas, mas somente em pouco mais de duas décadas progrediram na formação de uma disciplina que as juntasse culminando com a Econofísica. Durante o seminário na AEA, alguns dos pesquisadores mais importantes da nova disciplina puderam mostrar alguns dos avanços da econofísica e suas perspectivas.

Atualmente, a utilização da Econofísica em áreas da economia como economia da energia (FILIP *et al.*, 2016), economia regional (GAO; ZHOU, 2018) ou economia ambiental (STOLBOVA; MONASTEROLO; BATTISTON, 2018) demonstra sua importância maior na resolução de diversos problemas econômicos. Assim, em um planeta marcado pelo excesso de informação, conectividade crescente dos diversos sistemas da terra (HELBING, 2013) e fragilidade financeira, a econofísica se fortalece por propor os métodos necessários que auxiliam na compreensão dessa nova economia.

Pela importância do tema, apresentamos, um artigo demonstrando a importância da econofísica para a economia, principalmente após a crise de 2008. Inicialmente, será mostrado os aspectos históricos da relação entre a econofísica e a economia, depois as principais áreas da econofísica e, por último, a consolidação da Econofísica como disciplina (PEREIRA; SILVA; PEREIRA, 2017):

Physica A 473 (2017) 251–261

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Minireview

Econophysics: Past and present

Eder Johnson de Area Leão Pereira [a], Marcus Fernandes da Silva [b,*], H.B.B. Pereira [c,d]

[a] Instituto Federal do Maranhão, Brazil
[b] Instituto Federal da Bahia, Brazil
[c] Programa de Modelagem Computacional, SENAI Cimatec, Av. Orlando Gomes 1845, 41.650-010, Salvador, BA, Brazil
[d] Universidade do Estado da Bahia, Rua Silveira Martins, 2555, 41.150-000, Salvador, BA, Brazil

HIGHLIGHTS

- Brief historical aspects from econophysics.
- Efficient market hypothesis.
- Power laws and the emergence of the econophysics expression.
- Some applications from econophysics.
- Prospects for econophysics.

ARTICLE INFO

Article history:
Received 8 August 2016
Received in revised form 13 December 2016
Available online 9 January 2017

Keywords:
Econophysics
Agents
Memory
Correlation
Complex networks

ABSTRACT

This paper provides a brief historical review of the relationship between economics and physics, beginning with Adam Smith being influenced by Isaac Newton's ideas up to the present day including the new econophysics discipline and some of the tools applied to the economy. Thus, this work is expected to motivate new researchers who are interested in this new discipline.

Contents

* Corresponding author.
E-mail address: marcusfis@hotmail.com (M.F. da Silva).

http://dx.doi.org/10.1016/j.physa.2017.01.007
0378-4371/

1. Introduction

Despite the connection of these two disciplines having already existed for some time, it took more than twenty years for the econophysics name to emerge. According to Schinkus [1], a new discipline has arisen making a contribution to the economy, especially the financial markets. In this paper, we intend to provide a brief discussion of the development of this new discipline from the historical aspects to its future prospects. We hope, therefore, that new researchers become interested in this topic.

The organization of this paper is structured as follows: Sections 2 and 3 provides a brief historical account of the theories of physics being applied to economics and some applications from econophysics, respectively. In Section 4 we show some of the perspectives of econophysics and finally Section 5 presents our final considerations.

2. Brief historical aspects

Econophysics can be considered a new perspective for the economy. According to Gingras and Schinckus [2] econophysics is a new discipline with a different methodology and with new tools that can greatly contribute to the advancement of the economy. However physics, from an early age, has indirectly influenced the economy.

With the discovery of the law of gravity by Isaac Newton (1643–1727), a new method of research arose, not only in physics, but in science in general, based on rationalism, experimentalism and with it an attempt to understand the universe through analysis, synthesis and application of the inductive method. Subsequently, Adam Smith (1723–1790), a philosopher regarded as the founder of economics sciences, was strongly influenced by Newton's ideas. According to Hetherington [3], "Adam Smith's efforts to discover the general laws of economics were directly inspired and shaped by the examples of Newton's success end discovering the natural laws of motion".

Another economist who was influenced by the physical sciences – mainly in relation to the equilibrium of bodies in the constitution of its laws – was Walras. His law of general equilibrium was based on the work of the mathematician Louis Poinsot (1777–1859), who produced his research on the equilibrium of forces before Walras. According to Paula [4],"there is no way to recognize the decisive influence of Poinsot on Walras and not see the Walras book as an application in the field of economy from 'science de l'équilibre des forces"'. Other essential concepts in economics were also strongly influenced by physics. According to Carbonne et al. [5]:

> Adolphe Quetelet (1796–1874) corroborated the idea that physical laws could govern human behavior and also economics. His contemporary philosopher, Auguste Comte (1798–1857), first envisaged the social physics as a scientific discipline alongside astrophysics, geophysics and chemical physics. It is not by chance that these concepts raised in an intellectual climate permeated by the Newtonian ideas. The basic assumptions of neoclassical economics span a wide range of applications and concepts (utility maximization, market supply and demand, equilibrium) and are still influential.

At the beginning of the twentieth century, Louis Bachelier (1870–1940)[1] in his doctoral thesis in mathematics (*Theory de La Speculation*, published in 1900), admitted that the prices of financial assets followed a random walk.[2] She was supervised by the great mathematician Henry Poincaré. Curiously, Bachelier [8] anticipated the ideas from Einstein [9] in five years on the mathematical formalization of *random walk*. Thereby, Bachelier founded the modern theory of finance which gave rise to the efficient markets hypothesis (see [10–12] and the Black–Scholes pricing formula options).

Years later, Fischer Black and Myron Scholes managed to solve the problem of finding pricing formula options that had an application in the stock exchange. It is noteworthy that one of their ideas was to use the heat diffusion equation widely used in physics. Black and Scholes sought to publish their ideas in an article sent in October 1970 to the *Journal of Political Economy* (JPE). Editors promptly rejected the article, claiming that Black and Scholes put too much emphasis on finance while neglecting economics [13]. Another journal, *Review of Economics and Statistics* from Harvard, was also quick to return

1 "Who was under estimated by his supervisors, perhaps because the title of his thesis was not attractive to mathematicians. Unfortunately, certain historical research follows this legend. But our study of documents shows that this simplified story is far from being correct" [6].

2 Regarding random walk, "the best decision is made based on the present and not the past, the best example for random walk is the guy coin game or crown if someone throws a coin twice or a thousand times up the likelihood of having to face in both cases is 50%, that is, they are independent identically as in the first move der face, this does not guarantee that the second will give face again and a thousand plays der face this also does not guarantee that the thousandth first move will give face, making a completely independent event" [7].

it; neither journal bothered to ask an expert to examine it. Finally, the paper was accepted in the May–June 1973 edition in JPE, however, only after the intercession of two members from Chicago University [13].

Therefore, the Black and Scholes equation became a way to determine the "fair" price paid for an option, which from the behavioral point of view, generated greater confidence in investors at the time, since it did not only depend on fundamental analysis, but had a mathematical formula that could carry out such a calculation. Another hypothesis in economics which helps illustrate the relationship between the economy and the physical is the efficient markets hypothesis, as discussed below.

2.1. Efficient market hypothesis

The efficient markets hypothesis is, currently, one of the most discussed and studied topics in Economic Sciences [14–16]. Thus, the importance of understanding this hypothesis is fundamental to understanding the behavior of financial series and, doing so, one can get a sense of how finances work.

This hypothesis originated from the doctoral thesis in mathematics by Louis Bachelier (1870–1947), *Theorie de la speculation*, under the supervision of the eminent mathematician Henry Poincaré. In it, Bachelier [8] compared the prices of financial assets to a *random walk*. However, his thesis remained forgotten until Samuelson [10] discovered the work of the "forgotten" teacher and became fascinated because it was an attempt to give a more scientific character to financial markets.

After that, Samuelson [10] tried to give a more rigorous account of the efficient markets hypothesis. He reformulated the hypothesis of random behavior of prices while supposing that agents are rational. However, only with the help of Eugene [11] and Fama [12] was the hypothesis better developed to define "the market's ability to reflect all available information on the price of financial assets" [17]. Thus, the *random walk* model can be defined as:

> The *random walk* model is based on two different hypotheses: (a) the current price of a savings bond reflects all available information indicating that the price movements over time are a series of random numbers (**serial correlation of errors equal to zero**); and (b) price changes obey the same probability distribution [11].

The motives for economists in the finance would adopt the Efficient Market Hypothesis according to Ausloos et al. [18] Is the possibility of constructing a conceptual framework that tries to reflect the reality from hypotheses previously adopted for the implementation of computerization of financial markets. Another important point for Ausloos et al. [18] is the possibility that economists can use Gaussian stochastic processes to perform statistical tests, this allows for greater scientific rigor And the statistic used by economists was constructed using *Stable Levy Structure*implying the use of the *General Central Limit Theorem*.

A parallel between the hypothesis of efficient and econophysics markets lies in the fact that the formulator of the Eugene Fama hypothesis was guided in his Doctoral Thesis by Benoit Mandelbroat who despite being a mathematician, had a strong connection with econophysics, having started at least two discussions that today are essential to this discipline: the study of longterm memory in financial series and whether the distribution of the financial series returns are in power law format.

2.2. Power laws

According to Jovanovic and Schinckus [19] and Jovanovic and Schinckus [20], In the 60's of the 20th century, Mandelbrot, Samuelson and Fama proposed to study financial markets using non-Gaussian structures inspired by the works of Levy and the stability of the distributions of probability and extension of the central limit theorem proposed by Gnedenko et al. [21]. Mandelbrot [22]. Using two models the M1963 and M1965 initiated two new research themes in statistics applied to finance one related to the independence of information and the other related to stationarity.

According to Jovanovic and Schinckus [19] and Jovanovic and Schinckus [20] In its first model Mandelbrot proposed that the "α stable" Levy processes were entirely suited to abrupt price changes. Mandelbroat showed that the price of cotton for half a century fit a distribution in the power law format. Mandelbroat [23] realized that normal distributions could not explain the high fluctuations in the price of cotton, given that a distribution using the power law format fits the data better. The discovery by Mandelbroat was of vital importance for the emergence of econophysics early on as a large number of the studies involving econophysics are finding power laws in financial series and demonstrating its importance for financial markets.

However, according to Gleria et al. [24], Mandelbrot encountered the problem of infinite standard deviation. More precisely all moments of order greater than two are infinite. And in the financial markets the standard deviation is a measure of the volatility of the variable, Making it difficult to give meaning to this greatness in case it becomes infinite. Only in the 90's of the twentieth century with Eugene Stanley and Rosário Mantegna did Mandelbrot reconsider the possibility that Levy's distributions would again explain fluctuations in assets, This being a fundamental step for the emergence of econophysics. It should be considered that the distributions of Levy are also called Pareto–Levy, being the Pareto law a classical power law.

The power law or Pareto's Law was originally studied by economist Vilfredo Pareto (1848–1923) who was interested in the distribution of income in Italy in 1906. Instead of asking what would be the umpteenth higher income, he asked how many people would have a higher income than x. Thereby, Pareto defined its distribution as follows:

$$P[X > x] \sim (m/x)^{-k} \quad (1)$$

where m represents the lowest salary and $m > 0$, $k > 0$ and $x \geq m$ and k is an inequality index. The lower the index, the more unequal the distribution of income is. This expression attests that there are many millionaires and a few modest people.

For the power law, the relevant information is not how many people have a higher salary than x, but how many people receive exactly x. This is the probability distribution function associated with PDF (Probability Density Function), associated with DFC (Density Function Cumulative) given by Pareto.

$$P[X = x] \sim x^{-(k+1)} = x^{-a}. \tag{2}$$

Note that the exponent of the power law distribution, $a = k + 1$, k is the parameter of the Pareto distribution. According to Gleria [24]:

> Bouchaud and Mezard examined Pareto's law and observed that, if we consider the number of people in the United States who have 1 billion dollars, we find that four times more people have half a billion dollars and four times higher than that will have a quarter of a billion dollars, and so on.

Power laws have the property of being free of scale, they are ideal for measuring phenomena that are susceptible to extreme events, such as financial markets, for example. Therefore, the emerging econophysics gains a relevant dimension in the 90's of the 20th century, by applying power laws in the distribution of stock returns.

2.3. Emergence of the econophysics expression

The econophysics name first emerged with Stanley et al. [25] at a conference held in 1995 in Kolkata. It is a neologism used for the branch of physics of complex systems that seeks to make a complete survey of the statistical properties of financial markets, using the huge volume of data now available and working methods of statistical physics [17].

Econophysics, since its foundation, was intrinsically linked to seeking extreme events in financial series using power laws to describe them. However, this type of study was marginalized or little considered by most economists, since the main economic assumptions were built based on the normal distribution and large deviations were almost impossible. However, the results found by econophysics indicate that such events are not so rare, e.g. the 1987 crisis, where the Dow Jones index fell 22%, or the 2008 crisis.

In the 1990s, a growing number of publications began studying the distribution of financial returns using physics (in particular see [25–28]). This first period was marked, mainly, by the application of power laws in the distribution of financial returns. Other types of studies were the size of cities [29] and executive compensation [30,31].

From the 2000s, econophysics expanded rapidly and began to study various phenomena that occur not only in the financial markets, but in the economy in general; their applications range from the use of fractal analysis of the returns distributions to models based on evolutionary agents.

3. Some applications

3.1. Agentbased models

Econophysics has advanced and is no longer limited to testing financial series, thus embarking on other paths. One example is the Agent Based Model (ABM) which has been used in several areas of the economy. Its main advantages are the use of agents with limited rational adaptive behavior and the possibility of micro and macro interaction. Due to the ABM possessing these characteristics, a workshop was held in Virginia at the end of June 2010, with the organization of America's National Science Foundations and with the presence of many economists including the Fed (Federal Reserve System), Bank of England and some scientists (including physicists, economists and computer scientists), in which they showed how the ABM can be useful to Macroeconomics [32].

3.1.1. Setting agents

An agent is an entity that perceives its environment through sensors and acts on the same using the implementers; for example, on human agents, the eyes and ears are sensitive, hands and mouth are executors [33]. Furthermore, agents can evolve, adapt, learn and still have cognitive abilities [34].

Regarding the interaction between the agents and the environment, when the environment issue encounters a stimulus, the first captures it with its sensors, and then responds with an action using their executioner's elements. Based on this, Russel and Norvig [35] proposed that the basic structure of an agent is very simple: it has an internal data structure that will be updated with the arrival of new insights, this structure is used in decision making procedures, which will generate actions to be executed. Therefore, according to Stefferson Lima and Rosario [33] they have the following characteristics:

1. Agents can operate without direct human control or other agents: they are **selfemployed**.
2. Agents can act in partnership with humans and with other agents: they **communicate**.
3. Agents can react to various forms of stimulation of domains: they are **reactive**.
4. Agents can make decisions for themselves to fit the defined goals:they are **proactive**.

ABM is the creation of a population of agents, with the capacity of perception and action similar to the actual components to be simulated. So they can act as if they own the components of a system, and one should provide them with behaviors and rules that define the possible actions [35–37]. This is done by modeling behaviors, by analyzing the variables of a system and extracting its main features so that they can be incorporated into the respective individuals. According to Pykas and Fagiolo [38], ABM has the following characteristics:

(a) Time: Usually it is a model evolving overtime in discrete steps, $t = 1, 2, \ldots$
(b) Agents (or actors): The system is populated by a number of agents $I_t = \{1, 2, \ldots, N_t\}$. In many examples, but not necessarily all, the population size is assumed to be constant over time ($N_t = N$).
(c) Microstates (or actions): Each agent $i \in I_t$ is characterized by a L vector of Microstates (or variable micro) $X_{i,t} = (X^1_{i,t}, \ldots, X^L_{i,t})$, these variables are easy to handle, can make them endogenous, modifying the agents' decisions (as a product of the company, number of shares that individuals have etc.).
(d) Microparameters: Each agent is also characterized by a microparameter vector H $\theta_i = (\theta^1_i, \ldots, \theta^h_i)$, which are slow variables, that is, they cannot be quantified without a time scale in a dynamic process. Therefore, θ_i typically contains information about the behavior and characteristics of the agents i (Company productivity factors, elasticity of consumption, etc.).
(e) Macroparameters: The system can be characterized as a whole instead of being characterized by an independent technological vector M (macroparameters) $\Theta = (\Theta_1, \ldots, \Theta_M)$ governing all direct attitudes; again, Θ these variables are slow and cannot be modified by agents.
(f) Structure Interaction: In each agent t, the way that information is channeled between agents is governed by a chart (directly and possibly weighted) G_t containing all links ij_t currently in place of an agent for j agent. The existence of a link ij_t means that the agent updates its microvariables $x_{i,t}$. It is affected by the choice made in the past by j agent.
(g) Microdecision rules: Each agent is provided with a set of decision rules $\Re_{i,t} = \{R_{i,t}(\bullet|\bullet),\ b = 1, \ldots, B\}$ mapping the observable variables and the next microchanging period $x_{i,t}$. An example might be: production function, innovation rules.
(h) Aggregate Variables: Clustering (average, sum, etc.) from microvariables can create a vector K macrovariables $x_t = (x_{1t,} \ldots, x_{kt})$ containing all relevant information to analyze in the system. Examples include GDP, aggregate demand, unemployment, etc.

After the definition and characterization of ABM, as already shown, we will show its use in econophysics demonstrating its importance to the economy.

3.1.2. Agent based econophysics and agent based modeling

According to Schinckus [39] *agent-based econophysics*is based on the micro-approach, comes from computational physics and is an area that has developed models of *order-driven markets or models using Kinetic Theory*. Whereas *agentbased modeling*Focuses on the atomistic approach of agents, but is different from the neoclassical approach based on methodological individualism and certain assumptions (utility function, risk aversion and rationality) the *agent-based modeling*Provide microfundamentals for statistical regularities that emerge at a macro level of a socioeconomic system.

3.1.3. The importance of ABM in economics

One of the first studies involving adaptive agents and economic theory was Holland and Miller's [40]. *Artificial Adaptive Agents in Economic Theory* emphasizing the many advantages of applying this new methodology, among which we mention two: the ability to control all system variables and environmental conditions as well as working with adaptive agents. Since that time, this new research agenda has grown considerably and currently the number of publications in economics has been significant in relation to other sciences [41].

In this context, a famous work involving ABM and financial markets was the Santa Fe Artificial Market [42], in which the authors innovated implementing agents that can modify their strategies overtime or had the ability to learning. In Lux and Marchesi [43] heterogeneous agents were used to find high frequency returns of extreme events, *clustered* volatility and power laws.

Using the ABM methodology in the options market has also found anomalies in a study by Suzuki et al. [44] using *traders* with aversion to loss and using the pricing formula of Black–Scholes options. Therefore, ABM studies in finances have found several stylized facts in financial series and it represents a new look, since these anomalies are now treated as events that can occur, approaching most of the stock exchanges, in which there are crises, extreme events and panics, unlike the world of the Efficient Market Hypothesis [11] or the Black–Scholes equation [45] wherein the financial series approaches a normal curve, with the possibility of almost zero crises.

Furthermore, in the words of Le Baron [46] financial markets are particularly attractive for applications based on an agent model for several reasons:

- First, the main debates in finance on market efficiency and rationality are still unresolved.
- Second, financial time series contain many stylized facts that are not well understood.
- Third, financial markets provide a wealth of data volume that can be analyzed.

Use of ABM in macroeconomics is very recent, with a higher frequency in the last decade. In this sense, Le Baron [47], Hodgson [48] and Farmer and Foley [49] have stressed the need for agents to understand the micro and macroeconomic phenomena, because they can interact with each other and the environment, and agents are rationally limited. Due to these characteristics, Colander et al. [50] proposed the use of agents in Macroeconomics; in their words:

> The advantage of Computational Agent economy (Agent Based Models applied economics), in particular, in macroeconomics is that it removes the treated limitations of the analytical limit of macroeconomics. ABM allows researchers to choose the appropriate way to solve problems, including the types of agents, number of each type of agents and the hierarchy of their arrangements. They also allow the researchers consider the interactions between agents simultaneously with their decision, and study the dynamics of macro interaction between them.

Thus, Dosi et al. [51] built a model of evolutionary cycles and managed to reproduce some stylized facts in macroeconomics as the most volatile investment rather than consumption. The investment showed a procyclical growth and the model showed a multiplier equal to the Keynesian accelerator.

Because of the possibility that they may be incorporated into agent's variables such as learning, routines and evolution (somewhat restricted in traditional modeling firm theory), such qualities, according to Pykas and Fagiolo [38], can assist in the proposal of Nelson and Winter [52] to study the firm and Macroeconomics evolution. In this context, Hodgson [48] goes further and proposes ABM as an alternative model for the study of institutions in the twentieth century, since for him the institutions are a set of individuals who are constantly interacting and evolving and not a set of rational and atomized units.

In this way, the contribution of ABM on macroeconomics and/or firm theory is still difficult to measure because the research is fairly recent. However, ABM has been a challenging methodology and can greatly assist in understanding macroeconomic policies.

3.2. Long term memory

One way to characterize the long term memory of a time series is to associate it with a property called persistence. The determination of this property is generally related to a parameter, named H exponent or Hurst exponent. In the literature there are many methods for determining this exponent, but one of the most used is the classic R/S method. Specifically, R/S is a method with empirical bases. It has provided a solution for the problem of a finite reservoir subjected to a random input stream.

The question is based on determining the volume of a reservoir by knowing its water inflow $\xi(t)$, whereas its output flow is equal to the average $\xi(t)$, so that the tank never runs dry or overflows [53].

Considering a time interval τ, the mean inlet flow will be:

$$\langle\xi\rangle_\tau = \frac{1}{\tau}\sum_{i=1}^{\tau}\xi(\tau). \tag{3}$$

Let $X(t)$ be the cumulative difference between the input flow and its average

$$X(t,\tau) = \sum_{u=1}^{t}\left\{\xi(u) - \langle\xi\rangle_t\right\}, \quad (1 \le t \le \tau). \tag{4}$$

The maximum and minimum from (4) represents the minimum and maximum volume of water that passes through the shell in the period τ. Thus, the total volume of the reservoir, so that it never overflows or runs dry, should be the difference between the maximum and minimum from X,

$$R(\tau) = \max X(t,\tau)_{1\le t\le\tau} - \min X(t,\tau)_{1\le t\le\tau}. \tag{5}$$

Obviously $R(\tau)$ depends on the flow $\xi(t)$, which in turn depends on the period considered τ. Hurst investigated many natural phenomena and realized that R depended on the period τ as a power law,

$$R/S = \left(\frac{\tau}{2}\right)^H. \tag{6}$$

In (6) S is the standard deviation of the inflow, defined by:

$$S = \left(\frac{1}{\tau}\sum_{t=1}^{\tau}\left\{\xi(t) - \langle\xi\rangle_\tau\right\}^2\right)^{\frac{1}{2}}. \tag{7}$$

Introduced only for the variable R/S is a dimensionless number making it easier to compare with other phenomena [54]. Although initially for hydrogeological reasons, this method has considerable application in economics. For example, Cajueiro and Tabak [55] proposed testing the assertion found in the literature that emerging financial markets were becoming more efficient over time and checked whether this was true or not. The calculation of the Hurst exponent was proposed from the R/S method over time using a time window of 4 years of data. These data were the stock exchange rates of some emerging countries and Japan and the United States. It was observed that for the latter two $H \approx 0.5$ that is, this market efficiency was related to the value of this Hurst exponent and that emerging countries including Brazil, the Philippines and Thailand had values this H exponent great then 0.5 which showed that these three countries were not following the literature by becoming more efficient over time.

Another application of this method was in Souza et al. [56] where they used the Hurst exponent by R/S method to investigate the long term memory in the transition between the fixed exchange rate regimes and floating exchange rate in Brazil.

Rejichi et al. [57] tested the efficiency of the MENA stock market using a certain Hurst Exponent with the R/S method. Mensi et al. [58] determined the Hurst exponent using the R/S method to measure the degree of long range dependence displayed by crude indexes for measuring the degree of long range dependence exhibited by West Texas Intermediate (WTI) and European Brent.

These and other applications of the classical method R/S are the physical point of view and basically work in autocorrelation time series. The application of these methods to the economy has been growing in the econophysics literature, promising a major evolution of this new area in the future.

This revolution continues when we look at another aspect of time series in econophysics associated with cross-correlations, which is one way to observe the behavior of grip a time series with another. As we are working with econophysics these series include the financial market such as: the foreign exchange market with the benchmark interest rate, country risk with international reserves, etc.

3.3. Cross-correlation

The study of cross-correlation is based on statistics that relates one time series with another. In the literature, a range of theories comprise this analysis. In this article we will focus on the theory [59] measuring the cross-correlation between time series, based on the autocorrelation of them [60] and the study of cross-correlation between time series by power law [61]. In order to improve the understanding of this theory we explore this in more detail below.

The theory of Peng et al. [60] is focused on determining the cross-correlation coefficient without trend, ρ_{DCCA} coefficient, which succinctly forms the 5 steps of his determination. Step I. Considering two time series, $\{x_t\}$ and $\{y_t\}$, with $t = 1, 2, \ldots, N$, (N is the total number of elements of the time series). Then we integrate time series obtaining two new series:

$$xx_k = \sum_{t=1}^{k} x_t \quad \text{and} \quad yy_k = \sum_{t=1}^{k} y_t, \quad k = 1, 2, \ldots, N. \tag{8}$$

Step II: We have divided these two integrated time series, $\{xx_k\}$ and $\{yy_k\}$, in $(N - s)$ overlapping boxes of equal length s, with $4 \leq s \leq N/4$.

Step III: We calculate the local trend of each box by the least squares fit of each series, $xP_i\,(k)$ and $yP_i\,(k)$. Now we calculate the covariance of waste in each box by:

$$f_{xy}^2\,(s, i) = \frac{1}{s+1} \sum_{k=i}^{i+s} (xx_k - xP_i\,(k))\,(yy_k - yP_i(k))\,. \tag{9}$$

Step IV: Now, the average over all overlapping boxes is calculated for the new covariance function:

$$F_{xy}^2\,(s) = \frac{1}{(N-s)} \sum_{i=1}^{N-s} f_{xy}^2\,(s, i)\,. \tag{10}$$

Step V: Finally we calculate the cross correlation coefficient ρ_{DCCA} by:

$$\rho_{DCCA}(s) = \frac{F_{xy}^2\,(s)}{F_{xx}\,(s)\,F_{yy}(s)}, \tag{11}$$

where $F_{xy}^2(s)$ is the correlation function determined by the method from Podobnik and Stanley [61] and $F_{xx}(s)$ and $F_{yy}(s)$ are the autocorrelation functions determined by the method from Peng et al. [60]. This cross-correlation coefficient depends on the size of each box s (time scale). One advantage of this cross-correlation coefficient is measuring the correlation between two time series with different time scales. The ρ_{DCCA} varies in the range $-1 \leq \rho_{DCCA} \leq 1$, where 1 means perfect cross-correlation, 1 perfect anti cross-correlation and 0 there is no correlation.

In conclusion, the determination of the ρ_{DCCA} coefficient has some applications in econophysics. In M. F. da Silva et al. [62] this coefficient was used to measure the correlation between the prices of soybeans and corn in Barreiras/Bahia/Brazil with the Brazilian foreign exchange market. In Wang et al. [63] the ρ_{DCCA} was used to measure the cross-correlation between the larger coins 44 countries on a global network and in Reboredo et al. [64] the ρ_{DCCA} coefficient was used to verify the cross-correlation between the exchange rate and the price of oil in different countries before and after the 2008 economic crisis.

The theory of cross-correlation time series is significantly robust and well applicable in econophysics. There is great potential still to be explored in this area of econophysics and therefore a good opportunity for researchers who want to explore new avenues.

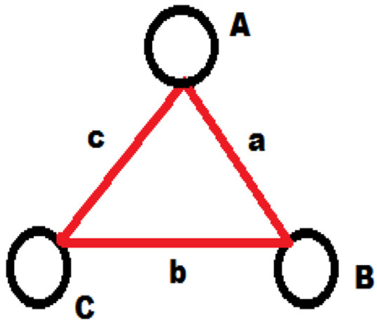

Fig. 1. Network consists of three components A, B and C which represent the vertices (nodes) of the network and a, b, c the edges.
Source: Self elaboration, 2015.

3.4. Complex networks

Complex networks are nodes (vertices) connected by edges, and they can be exemplified by: transport networks (network of airlines in Brazil, networks of roads), social interactions (knowledge networks, scientific collaboration networks), biological networks (regulatory networks of genes and protein interaction networks) and networks in economics (banking networks and networks of exporting countries), etc.

The study of networks began with the resolution of the Königsberg Problem, city of Prussia, currently Kaliningrad, in Russia. After the statement by Leonhard Euler in 1736 that the problem had no solution, mathematics revolutionized not the answer, but the way it was developed. Euler created basic categories like nodes and edges. Two centuries later, mathematicians Paul Erdös and Alfred Rényi, introduced a new concept that allows the study of these networks: the theory of random graphs. The idea was to combine the theory of graphs with the tools of probability theory. Two other fundamental contributions were: the discovery of the small world effect by Milgron [65] and Watts and Strogatz [66] and networks free of scale [67].

The structure of a complex network is represented in the same way as a graph by which a set R, for networks that do not have weights in the links is defined by $R\ (\upsilon, \varepsilon)$, where $\upsilon = \{\upsilon_1, \upsilon_2, \upsilon_3 \dots \upsilon_N\}$ are the nodes (or vertices) and $\varepsilon = \{e1, e2, e3, \dots, eM\}$ are the edges or connections that connect pairs of nodes, considering the number of elements υ and ε, N and M, respectively. To illustrate this complex structure, a simple schematic representation of a network with three edges and three nodes is shown in Fig. 1.

3.4.1. Complex network and financial markets

The use of complex networks in the financial markets has enabled a new view, mainly to measure the financial interaction between the stock exchanges, assets, banks or companies, in this case, the nodes are usually the assets, banks or countries. For financial markets, the greatest contribution of complex networks to date has been to show the financial markets as interdependent and subject to financial fragility. Until the 2008 crisis, the economy predominated the idea of efficient markets proposal by Eugene [11] where the assets reflect all available information. However, after the 2008 crisis, markets are not efficient and the financial interconnection between different assets or banks varies greatly (see [68]). This means that in times of financial crisis, stock markets tend to become more interconnected and can completely change the economic and monetary policy of a country.

3.4.2. Complex networks and production

Currently, to measure the degree of connection between the various export sectors and importers of the economy, noting that in Hildalgo et al. [69], a new idea about the level of economic growth was formulated. For them an important element is connectivity between some sectors, for example, to produce a computer the company must rely on others that will produce the battery, liquid crystal display, chips, mouse, software, etc. In other words, the more complex and interconnected the relations are between the various sectors, the greater the chances of a country to grow economically, because the greater the knowledge produced by the country in question.

This type of research may represent an advance in the theories of economic growth with an analysis of various disaggregated sectors. Usually, economic models tend to consider only two sectors such as assets and capital. In the case of complex networks there is a paradigm shift in that you can see how each sector interfered in another or the probability of developing a new activity or new sector.

4. Prospects for econophysics

The growth of econophysics has been considerable in the last two decades with several indications including the creation of Ph.D. courses in econophysics around the world such as Houston University or creating econophysics as a discipline in various postgraduate courses both in economics and in physics. Moreover, many conferences and meetings have directly and indirectly encompassed econophysics both in Brazil and around the world, with the most well known being the Econophysics Colloquium, which in 2016 will be its twelfth year and has been held in various countries around the world.

The institutionalization of economics is documented in Gingras and Schinckus [2], which uses bibliometric methods to identify scientific publications with the econophysics theme. Have been identified 242 articles on the subject published in the period from 1980 to 2008; 147 Published in scientific journals, 90 of which are published in *Physica A*, 27 in *European Physical Journal B*, and the others in *Physical Review E*, *Quantitative Finance*, and *Journal of Economic Behavior & Organization*.

Some of the most cited economists in the world, according to various indices that measure the number of citations such as *repec*, *Google Scholar* or *webometric*use directly or indirectly the theoretical tools of complex systems. For example, Joseph Stiglitz, Nobel laureate in economics, who has the highest H[3] index of the world according to *webometric* [70] with an $H = 177$ and one of the most cited according to *repec* [71], has several works using complex systems and with physical partnerships (see [72–75]). According to *repec*, two of the fifteen most cited economists in the world in the last ten years use complex systems in their recent works Daron Acemoglu and Xavier Gabaix. In the case of Acemoglu, which is the most cited economist in the world in the last ten years, according to *repec* [71], uses heavy tails to explain the large macroeconomic fluctuations including works with coauthor Eugene Stanley, one of econophysics' founders. And the Xavier Gabaix's relationship is even more directly involved with econophysics, as the winner of several awards in economics and finance including the top award *Fischer Black* of finance, given by the *American Finance Association*. He uses econophysics in several works mainly using power laws [29,32,76,77] and writing several articles with physicists and with Eugene Stanley.

Another point is the creation of the *Institute for New Economic Thinking*, by mega investor George Soros, with the intention of helping the economic sciences to rebuild and put together strategies to prevent possible financial crises. The institute has the participation of physicists such as Doyne Farmer from *Santa Fe Institute* and Dirk Helbing from *ETH Zurich (Swiss Federal Institute of Technology in Zurich)*.

In this context, the financial market has been absorbing physicists to work as *traders* or in providing advice, where they can apply the concepts of physics to complex systems in finance. For that to happen, a great beacon was undoubtedly the 2008 crisis, because while models of physics indicated a likely drop in the North American stock exchange [77], economists were still rooted in the efficient markets hypothesis and that, in addition to physics providing an easier way to deal with complex systems such as the financial markets, it is crucial for greater visibility and application of the concepts or methods of econophysics on stock exchanges [78].

Therefore, economists and physicists are discovering that econophysics can be of great help in modeling various economic problems, leading to a natural process of science that is the consolidation of econophysics, just like mathematical economics, behavioral economics and evolutionary economics.

5. Final considerations

This article explored the contribution physics has had on economics beginning with Adam Smith being influenced by Newtonian mechanics and the concept of utility or the Black–Scholes formula. Additionally, this paper was shown as a one more discussion's alternative about this topic.

Some instruments used by econophysics were presented such as: power laws, ABM, long term memory, cross-correlation and complex networks in order to provide future researchers in this area information about early concepts in some of this field's areas. This, of course, does not exhaust all areas of econophysics that, due to its dynamic behavior, also already have good contributions on literature. Therefore, these areas are considered a sample in a universe of possibilities areas to investigate about this topic.

In summary, the emergence of the expression econophysics opened a new horizon of research and scientific contribution that has grown considerably in the last twenty years. Initially, the research was almost exclusively on financial markets, but with a greater number of researchers and the emergence of new techniques, it has expanded and today, there are applications in macroeconomics, theory of the firm, income distribution, microeconomics, etc. This rapid growth of econophysics has brought many perspectives becoming a new discipline, not to be subsumed by other traditional disciplines within the economy.

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[3] The H Index was created in 2005 by the physicist J. E. Hirsch of the University of California. It is a proposal to quantify the productivity and impact of scientists based on papers most cited. In other words, the H index is the number of papers having greater than or equal to this number of quotes. Examples certainly help illustrate the concept: a researcher with $H = 5$ has 5 papers receiving 5 or more citations; a researcher with H index equal to 30 has published 30 scientific papers, and each received at least 30 citations in other papers. Papers with fewer citations would not be considered.

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Redes

Nesse capítulo, serão revisados os conceitos de redes utilizados nos artigos que utilizam esse instrumental. A estrutura de uma rede complexa é representada da mesma forma que um grafo por meio de um conjunto R , que, no caso de redes que não apresentam pesos em suas ligações, é definido por $\upsilon = \{\upsilon_1, \upsilon_2, \upsilon_{3...}\ \upsilon_N\}$ são os nós (ou vértices) e $\varepsilon = \{e_1, e_2, e_3, ..., e_n\}$ são as arestas ou conexões que conectam pares de nós.

Os números de elementos em υ e ε são denotados por n e m , respectivamente. As redes complexas podem ser exemplificados por: redes de transporte (rede de companhias aéreas no Brasil, redes de estradas), interações sociais (redes de conhecimento, redes de colaboração científica), redes biológicas (redes reguladoras de genes e redes de interação de proteínas) e redes em economia (redes bancárias e redes de países exportadores), etc. Outro conceito importante é o de rede social que é uma estrutura capaz de representar a ligação entre indivíduos, grupos de indivíduos, organizações etc (PEREIRA, 2013). Elas são formas de representação dos relacionamentos efetivos ou profissionais de indivíduos entre si, ou entre seus agrupamentos de interesse mútuos (PEREIRA, 2013).

4.0.1 Conceitos Básicos

A junção da física estatística com a teoria dos grafos permitiu o surgimento das redes complexas e, com isso, diversas propriedades como: as análises de centralidades, comunidades, coeficiente de aglomeração, além da análise dinâmica das redes. Elas em conjunto permitiram pesquisadores de diversas áreas trabalharem com sistemas não lineares e grandes quantidades de agentes permitindo estudar como se comportam os agentes numa determinada rede ou sua evolução no tempo. Iremos ver algumas propriedades das redes com o objetivo de mostrar a importância dessas propriedades para a análise dos problemas que surgiram durante a tese.

4.0.2 Matriz de Adjacência

Um importante conceito que ajuda a representar algebricamente um grafo é a matriz de adjacência pode ser representada por um grafo com n vértices pode ser representado pela sua matriz de adjacência A, de dimensão NXN, cujos elementos a_{ij} essa matriz indicam se há ou não arestas partindo do nó i e chegando ao nó j, de modo que:

$a_{ij} = \left\{X_{ij}\right\}$, tal que:

$$a_{ij} = \begin{cases} 1, & Se\ existe\ aresta\ entre\ o\ vértice\ i\ e\ j \\ 0, & Caso\ contrário \end{cases}$$

Em um grafo não direcionado, A é uma matriz simétrica.

4.0.3 Grau

O grau k_i do vértice i em um grafo não direcionado é o número de arestas que tem esse vértice como extremidade. A partir da Matriz de Adjacência:

$$k_i = \sum_{ji}^{n} a_{ij} \tag{4.1}$$

A soma dos graus de todos os vértices da rede deve ser o dobro do número de arestas, pois cada aresta contribui com uma unidade para o grau de nós que ela conecta.

$$\sum_{j=i}^{n} a_{ij} = 2m \tag{4.2}$$

O grau médio de um grafo é a média aritmética dos graus dos vértices que o compõe:

$$< k >= \frac{1}{n} \sum_{i=1}^{n} k_i = \frac{2n}{m} \tag{4.3}$$

4.0.4 Grau ponderado

Um grafo ponderado $GW = (V, E, W)$ consiste em um conjunto de V vértices, conectados por arestas, cujos pesos W estão associados a cada arestas pertecentes a E e são números reais e indica a força da conexão entre cada par de vértices.

Vamos considerar que $\Gamma(i)$ do vértice i. O grau ponderado do vértice i é dado pela soma dos pesos de todos as arestas ou arcos de entrada e saída conectados ao vértice i, $k_{wi} = \sum_{j \in \Gamma(i)} w_{ij}$.

4.0.5 Rede direcionada

Uma rede direcionada ou grafo direcionado, também chamado de dígrafo, é uma rede em que cada aresta tem uma direção, apontando de um vértice para outro. Tais arestas são denominadas arestas direcionadas ou arcos e podem ser representadas por linhas com flechas neles. Em redes não direcionadas, o grau é apenas um número, mas em redes direcionadas, os vértices têm dois graus diferentes, grau de entrada e grau de saída, correspondendo ao número de arestas apontando para dentro e para fora desses vértices (NEWMAN, 2010).

4.0.6 Centralidade

Uma importante classe de métricas de redes é a centralidade. A centralidade quantifica a importância dos vértices (NEWMAN, 2010; FREEMAN, 1978). De acordo com Newman (2010), existem uma grande variedade de métodos matemáticos e medidas de centralidade de vértices que se concentram em diferentes conceitos e definições do que é ser central numa rede.

Uma medida simples de centralidade em uma rede é o grau de vértice que representa o número de arestas conectadas a ele, sendo considerada uma das mais importantes métrica de redes (NEWMAN, 2010). Em uma rede social, por exemplo, parece razoável supor que indivíduos que têm conexões com muitos outros podem ter mais influência, mais acesso à informação ou mais prestígio do que aqueles que têm menos conexões. Um exemplo de rede não social é o uso de contagens de rotas aéreas em um aeroporto. O número de rotas que um aeroporto possui, que é simplesmente o seu grau na rede aeroportuária, fornece uma medida, a grosso modo, para saber se o aeroporto é ou não importante.

4.0.7 Centralidade de PageRank

O *PageRank* mede a importância de um vértice (setor) contando o número e a qualidade dos arcos (se a rede for direcionada) apontando para ele. O *PageRank* é uma medida de quantidade e qualidade, porque captura o número de arcos que um vértice pode ter e a importância do vétrice na rede; um vértice (setor) pode ser importante se receber um arco de um vértice importante (CERINA *et al.*, 2015).

4.0.8 Centralidade de Intermediação

A centralidade de intermediação mede quantas geodésicas entre todos os pares de vértices do grafo passam através de um determinado vértice, a sua fórmula é a seguinte:

$$BC(V_k) = \sum_{i \neq j \neq k} \frac{b_{ij}(v_k)}{b_{ij}} \tag{4.4}$$

onde BC representa o número total de caminhos mínimos entre i e j e (vk) representa o número de caminhos mínimos entre i e j que passam pelo vértice (vk). O vértice com maior centralidade de intermediação será o mais central da rede (FREEMAN, 1978).

4.0.9 Caminho mínimo médio ou distância geodésica L

$$L = \frac{1}{n(n-1)} \sum_{i \neq j} d_{ij} \tag{4.5}$$

Onde o termo d_{ij} corresponde a distância geodésica entre os vértices i e j, em termos do número de arestas existentes.

4.0.10 Diâmetro

É a maior distância geodésica da rede, calculada da seguinte maneira:

$$D = \max(d_{ij}) \tag{4.6}$$

4.0.11 Modularidade

A Modularidade mede a subestrutura interna das redes necessária à avaliação de blocos fundamentais formados entres os vértices. Ela refere-se à medida de vizinhança, ou seja, de quanto um determinado vértice tende a aparecer dentro de um determinado grupo. Ela pode ser considerada uma medida de comunidade, e identifica quantas comunidades existem numa determinada rede, encontrando grupo de vértices que apresentam alta densidade de arestas internamente, estando assim fortemente conectados entre si e fracamente conectadas a outros agrupamentos existentes (NEWMAN, 2003).

Ela é o número de arestas que caem dentro de grupos menos o número esperado em uma rede equivalente com arestas colocadas aleatoriamente, podendo ser negativa ou positiva, com valores positivos indicando a possível presença da estrutura comunidade. Nesse contexto, a estrutura da comunidade pode ser encontrada precisamente procurando as divisões de uma rede que possuem valores positivos e preferencialmente grandes da modularidade (NEWMAN, 2003).

4.1 REDES DINÂMICAS

4.1.1 Redes Variantes no Tempo

Como a noção de grafo (estático) é o meio natural para representar uma rede estática, a noção de gráfico dinâmico (ou variável no tempo ou em evolução) é o meio natural para representar esses ambientes dinâmicos. Um ponto comum na analíse de redes dinâmicas é que a estrutura do sistema - a topologia de rede - varia com o tempo. Assim, mudanças nos sistemas não são anomalias, mas parte integrante da natureza do sistema (CASTEIGTS *et al.*, 2012).

Para descrever uma TVG usamos o conceito criado por (CASTEIGTS *et al.*, 2012). Um TVG é descrito como $\mathcal{G} = (V,\ E,\ \mathcal{T},\ \rho,\ \zeta)$ onde $V = \{v_1, v_2, ..., v_n\}$ consiste no conjunto de vértices da rede; $E = \ \{a_1,\ a_2,\ ...,\ a_m\}$ é o conjunto de arestas; T é o intervalo de tempo (isto é, $|T|$); $T = \{t_1,\ t_2,\ \ldots, t_i,\ t_{i+1}\}$, P indica a existência ou ausência da relação entre dois nós em um determinado momento. A função latência é caracterizada por ζ. (HOLME; SARAMÄKI, 2012), apresentam uma variedade de exemplos relevantes de redes temporais. Uma TVG pode ser analisado como uma sequência de "fotografias"ordenadas temporalmente para os subintervalos. Assim dado um grafo, todos os parâmetros clássicos da rede (Grau, Diâmetro, Densidade, etc.) podem ser calculados diretamente para cada grafo estático $G = (V, E)$ das sequências dentro de um intervalo determinado.

Essa abordagem permite acompanhar a evolução temporal dos índices ao longo do processo de montagem do TVG, possibilitando verificar mudanças estruturais nos grafos ao longo do tempo.

4.1.2 O método de Motif

O método de Sincronização por Motif foi desenvolvido por Rosário *et al.* (2015). Nele as séries temporais podem ser descritas como uma sequência de padrões com elevações e picos que são chamados de motifs. A sincronização por motif consiste na contagem quase-simultânea desses motifs. De com acordo Rosário *et al.* (2015, p.11):

> Os motifs podem ser geralmente classificados como declives, picos ou valas, dependendo do número de pontos usados para gerar cada motif (grau do motif) e o intervalo entre esses pontos (atraso). Os diferentes tipos de motifs podem ser identificados automaticamente através de uma comparação simples entre os valores dos pontos consecutivos da série temporal. Nosso método de sincronização de motifs (EM) consiste em contar a aparência simultânea desses dados predefinidos.

Segundo Rosário *et al.* (2015) a principal finalidade do método é fornecer informações sobre o grau de sincronização e a direção entre séries temporais que representa vértices de uma rede, contando o número de ocorrências de alguns padrões entre quaisquer duas séries temporais. O método é capaz de identificar similaridades nas séries temporais através de padrões pre-definidos e, com isso, transpor essas informações para a análise das redes temporais, conseguindo analisar diversas redes ao longo do tempo.

Capítulo Cinco

Redes multiscala para 20 mercados usando DCCA

A teoria de redes tem dado uma contribuição para os mercados financeiros, ao propor novos métodos, técnicas ou propriedades. Nesse âmbito, o uso de redes nos mercados financeiros tem sido um dos principais temas de pesquisa da atualidade em finanças (SCHWEITZER *et al.*, 2009).

Dessa forma, a segunda contribuição teórica e prática da tese é a análise dos mercados financeiros utilizando TR. Para isso, serão propostos dois ensaios, o primeiro utilizando redes multiscala e o segundo redes dinâmicas. A ideia é demonstrar com esses dois ensaios a importância do uso de redes para a análise do risco, durante a crise de 2008.

No primeiro ensaio, apresentando a seguir pretendemos aplicar redes multiscalas nos mercados financeiros, com o objetivo de analisar como as relações entre os diversos ativos para várias escalas de tempo se comportaram antes e após a crise dos *subprime* (PEREIRA *et al.*, 2019b). Alem disso, as correlações cruzadas obtidas pelo coeficiente $pdcca$ são mais eficientes para analisar séries não-estacionárias, algo que é inerente da maioria das séries financeiras (KRISTOUFEK, 2014b).

Com a construção das redes foi possível descobrir se houve alterações provocadas pela crise nos mercados mais centrais, nos *hubs* e nas comunidades. Essa informação para fundos *Hedge*, que são fundos multimercados, é importante, já que as relações financeiras estão em constante mudanças, principalmente quando se altera a escala de tempo. Em termos teóricos, esse será o primeiro modelo unindo uma rede financeira multiscala com as analíses de centralidades e comunidade:

Physica A 529 (2019) 121542

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Multiscale network for 20 stock markets using DCCA

Eder Johnson de Area Leão Pereira [a,b], Paulo Jorge Silveira Ferreira [c,d,e,*], Marcus Fernandes da Silva [f], Jose Garcia Vivas Miranda [g], H.B. B. Pereira [a,h]

[a] Programa de Modelagem Computacional, SENAI Cimatec, Av. Orlando Gomes 1845, 41.650-010, Salvador, BA, Brazil
[b] Instituto Federal do Maranhão, Brazil
[c] VALORIZA — Research Center for Endogeneous Resource Valorization, Portalegre, Portugal
[d] Instituto Politécnico de Portalegre, Portugal
[e] CEFAGE-UE, IIFA, Universidade de Évora, Portugal
[f] Instituto Federal da Bahia, Brazil
[g] Universidade Federal da Bahia, Brazil
[h] Universidade do Estado da Bahia, Rua Silveira Martins, 2555, 41.150-000, Salvador, BA, Brazil

HIGHLIGHTS

- We analyze the stock exchanges for 20 countries.
- We build a multiscale network identifying the linkages between markets.
- Results show the central role of European stock markets.

ARTICLE INFO

Article history:
Received 21 September 2018
Received in revised form 6 April 2019
Available online 27 May 2019

Keywords:
Centrality
Community
Cross-correlation
Multiscale networks
Stock markets

ABSTRACT

The aim of this paper is to analyze the stock exchanges for a large set of countries (20 in total) before and after the subprime crisis, identifying which markets are the most central and if the linkage pattern changed after the crisis. We started by calculating the correlations between stock markets' returns, using the ρDCCA, in order to identify if there is some variation in the scale between the links in the different stock markets of the network, in both periods. Additionally, a cross-correlation filtering process will be performed with the intention of identifying which countries have stronger relationships according to the used time scales. The results show the central role of European markets among the world's main financial markets, mainly France, Germany and the United Kingdom. Moreover, after the subprime crisis we find the formation of two large communities, one of European and American countries and the other formed by Asian countries plus Australia, while in the pre-crisis period three communities could be identified. It is possible to conclude that after the 2008 crisis the connectivity and integration of the network for the whole set of analyzed timescales increased.

1. Introduction

Financial markets move trillions of USD annually, and understanding their dynamics is of vital importance to the world economy, for several types of economic agents: actual or potential investors, managers of firms and of mutual funds, for economic authorities and also for policy makers. The fact that any information coming from financial markets could be

* Corresponding author at: CEFAGE-UE, IIFA, Universidade de Évora, Portugal.
E-mail address: pferreira@ipportalegre.pt (P.J.S. Ferreira).

https://doi.org/10.1016/j.physa.2019.121542
0378-4371/

used, for example, to prevent financial crises or to improve the financial system underlines the importance of continuing to study these markets. In the context of financial markets, stock market integration is a much studied topic in the financial literature and also a very broad one, not only with a vast amount of literature but also using different methodologies to assess the evolution of stock market integration. So, it is firstly important to identify a general overview about integration, as well as its advantages and disadvantages.

Stock market integration is a particular aspect of the broader issue of financial integration. As a whole, if markets are more integrated, this is expected to boost countries' growth, allowing citizens to increase their well-being. This is due, for example, to the fact that more integrated markets could cause better savings allocation (see, amongst many others, [1] or [2]). However, authors also recognize that, despite these potential advantages, increased market integration could have a negative effect because this potentiates greater financial instability and financial contagion (see, for example, [3]). The fact that economies increase their interdependence could heighten these effects [4]. Authors such as Bekaert et al. [5] identify a constant increase in international trade, including in financial assets, besides causing instability in macroeconomic variables such as exchange rates, national income or employment, and also affecting governments' capacity in their policy decisions.

Stock market integration could be studied using several approaches, with the use of correlations and cointegration tests probably being the most common. The evolution of methodologies and data availability has led to multiple types of studies, with linear and non-linear methodologies but also in different countries and regions. The use of so many different approaches is seen, for example, in [6] and [7], who report strong evidence of integration over time, mainly in developed markets.

In this paper, to analyze stock market integration, we will use a network of financial indices corresponding to twenty stock exchanges worldwide. We study the periods before and after the subprime crisis to verify how these markets behaved after this important economic event. The subprime crisis began with the real estate bubble in the US in 2006, with the culmination of the crisis being the collapse of the Lehman Brothers Bank in 2008. Subprime loans are high-risk bank loans to clients with a poor or unproven track record. Most of these credits were granted to buy real estate and with a fixed interest rate. With increased interest rates in the United States, many clients became defaulters. Many banks lending to subprime clients automatically went through a difficult situation, some of them becoming bankrupt and others having to go through financial restructuring. This crisis has affected many countries around the world, causing recession in several. Investor mistrust has increased, reducing investment in financial assets and causing instabilities in the financial sector.

Financial markets in general and stock markets in particular are seen as complex systems, due to the large amount of interactions between agents. The use of complex systems in economics has been termed econophysics by Stanley et al. [8] and Mantegna and Stanley [9]. According to Pereira et al. [10], in the beginning econophysics was used to study only the format of the distribution of financial assets' returns (stocks, exchange rates, commodities and stock indexes). Later it adapted other tools originating in statistical physics, such as the Hurst exponent, correlation cross-modeling, agent-based models and complex networks. Complex networks have been established as important analytical tools in several areas, providing a new vision in the study of several problems. The different methods and techniques can be found in classic studies like Barabási and Albert [11], Albert and Barabási [12], Newman [13], Boccaletti et al. [14] or Jackson [15].

The use of complex networks, which allows much information about financial series to be captured, according to Mantegna [16], is a type of approach useful to analyze market integration. Additionally, complex networks allow us to measure characteristics such as centrality, medium degree, network hub and others. Kwapień and Drozdz [17] demonstrate the importance of the application of complex systems in several phenomena, including with the use of econophysics.

Mantegna [16] applied the Minimum Spanning Tree (MST) method between July 1989 and October 1995, using companies listed on the New York Stock Exchange (NYSE) detecting a hierarchical behavior in stock markets. Bonanno et al. [18] used high-frequency data for the major stocks traded in the United States stock markets demonstrating that the degree of cross-correlation varied according to the time horizon used to compute them. Onnela et al. [19] also analyzed the New York Stock Exchange to build hierarchical structures corresponding to the networks. In this context, the use of MST on the stock exchange to demonstrate the hierarchical structure of several financial markets has grown: see, for example, [20–23]. Another application of MST was made by Kristoufek et al. [24], when studying the correlation between biofuels and related commodities before and after the food crisis, finding that correlations are considerably higher in the post-crisis period than in the pre-crisis one. In another study, Kristoufek et al. [24] also use MST and demonstrate there are correlations between food and fuel commodity prices in the United States and the European Union between 2003 and 2008, the interaction dynamics varying according to the weekly, monthly and quarterly data.

Tumminello et al. [25] introduced the concept of the Planar Maximally Filtered Graph (PMFG) as an alternative to MST. Another relationship involving networks and financial markets is the possibility of network theory measuring systemic risk in the banking payment system: see [26–28]. It is also possible to analyze the dynamics of a financial network's connectivity, as a predictor of possible financial crises [29–31]. Other relevant studies involving networks and financial markets are those by Boginski et al. [32], Billio et al. [33], Hautsch et al. [34], Diebold and Yılmaz [35], Wang et al. [36,37].

Rather than using the Pearson's correlation, which is a linear measure of correlation amongst two series, considering a given data sample, an alternative way of calculating the correlation between the nodes of a network is by using multiscale methods. Multiscale methods allow the analysis of different networks for different time scales, allowing the identification of different behavior for each scale. They could be used, for example, to differentiate between the behavior of networks in the short or long-term (considering, for example, lower or higher time scales). A pioneering study was that of Kenett et al. [38], which studied the New York Stock Exchange (NYSE) from 2000 to 2003, using the 300 largest companies and Partial Correlation Network (PCN), and with a dynamic window. The authors checked the persistence of financial sector actions both for a window of one month and for a four-month trading window. Another study was that of Wang et al. [39], which combined ρ DCCA (detrended cross correlation analysis) with MST (Minimum Spanning Tree) obtaining a multiscale network from calculation of the cross correlation, applying 44 different currencies from 2007 to 2012. Following this idea, Wang et al. [40] applied the MST and ρDCCA to analyze the network based on the exchange rate of several countries from 2007 to 2012, finding that the cross-correlation coefficient of the foreign exchange market has a long tailed distribution, and identifying that USD and the euro are the predominant currencies.

Wang et al. [41] analyzed 57 stock markets using the MST Pearson and the MST Partial methods, finding different results in relation to betweenness centrality and closeness centrality. Wang et al. [42] calculated the cross correlation using wavelet cross correlation and Pearson correlation by analyzing 457 shares quoted in the SP 500 during the period 2005 to 2012, finding fat tail distribution with wavelet with clusters formed by the following sectors: Financial, Material and Industrial. Kwapien et al. [43] generalized the Minimum Spanning Tree (MST) concept by introducing the q-dependent minimum spanning tree family. This method allowed them to work with data ranging from one minute to one month, in addition to using the value of the coefficient $q = 2$ and $q \neq 2$, the latter value being more satisfactory. Battiston et al. [28] and Battiston et al. [44] use Debt Rank's concept of centrality, emphasizing that there are "too many core markets not to fall", so the use of centralities in financial networks makes it possible to identify which exchanges or banks are central to a financial network.

In this paper we propose to build a network based on Zebende's [45] method, calculating the correlation coefficient for multiple scales. Zebende [45] developed a method to investigate the cross-correlation power laws between two simultaneous time series, called Detrended Cross Correlation Analysis (DCCA). According to Pereira et al. [10], the analysis of cross-correlations between time series has been a new frontier in economics since the study by Podobnik and Stanley [46] when they created the DCCA, extending the methods to analysis of cross-correlations between different variables, including economic assets, such as the correlations between trade volume and share prices. Podobnik et al. [47] and Gvozdanovic et al. [48] applied the DCCA between the Dow Jones index and 30 constituent companies.

Some variations of DCCA can be found in the literature, with Horvatic et al. [49] proposing the DCCA-ℓ (n) or Duan et al. [50] using the random matrix theory of modified time lag to study time-delay cross correlations in several time series in several countries. Another variation was proposed by Kristoufek [51]. Duan and Stanley [52] combined DCCA with support vector machines (SVM) to predict returns from financial series. Podobnik et al. [53] introduced a new test to quantify the long-range cross-correlations, observing the effects of trends in the series, and Podobnik et al. [54] used time lag cross correlation in several phenomena.

Thus, this article has the following objectives: (i) to develop a model of financial networks with the calculation of correlations from Zebende [45], since this is an established method in the literature allowing the use of different time scales; (ii) analyze the behavior of the main stock exchanges in the world ten years after the subprime crisis with the purpose of identifying which markets are the hubs, i.e., have the most central markets according to the indicated time scale; (iii) identify the main communities formed among the stock markets of the countries studied; and (iv) analyze the hypothesis that after the subprime crisis the market became strongly connected. Therefore, this article is divided as follows: in the next section we present the data (Section 2), followed by the methodology (Section 3). Section 4 presents the results and Section 5 concludes.

2. Data

The data was retrieved from the ADVFN and yahoo finance platforms and correspond to the period from 2nd February 2001 to 18th January 2017. We split the sample in two subsamples, considering the pre and post-subprime crisis periods. The division was made in January 2009, with this date corresponding to the moment in which the Dow Jones index (index of the American stock market) comes out of a downtrend and moves on to a bullish sequence and the period after the subprime crisis. The period under analysis includes the Eurodebt crisis and the political crisis caused by the Brexit referendum, which could give us interesting results. The 20 stock markets used are those included in Table 1. It considers 19 of the most relevant stock markets, according to data availability, as well as the Eurostoxx50, representing the Eurozone as a whole.

The descriptive statistics of the return rates are presented in Table 2. A brief reading reveals that 6 of the 20 indices had negative means in the period considered. Curiously, 4 of those countries are European and the Eurozone is also in this situation. Remember that in the European Union, after the subprime crisis, countries faced the Eurodebt crisis, which also affected stock markets generally. The other country with a negative mean was Brazil, which also experienced a severe economic crisis as well as a political one.

From the remaining indicators, the negative skewness for almost all indices stands out, meaning that for most of them, higher losses are more frequent than higher gains (the exception is the Indian index). Furthermore, and regarding kurtosis, all the indices but Taiwan show levels higher than the normal distribution benchmark, meaning that return rates should suffer from fat tails, which is a well-known stylized fact in the financial literature.

Table 1
Country and corresponding stock market index.

Country (region)	Stock market index
Argentina	Merval
Australia	SandPASX200
Austria	ATX
Brazil	Ibovespa
Canada	SandPTSX Composite index
Chile	IPSA
China	SSE Composite index
Eurozone	Eurostoxx50
France	Euronext 100
Germany	DAX
India	SandPBSE SENSEX
Indonesia	Jakarta Comp index
Israel	TA-100
Italy	MIB
Japan	Nikey 225
Mexico	IPC
South Korea	Cospi
Taiwan	TSEC
United Kingdom	FTSE 100
United States	Dow Jones

Table 2
Descriptive statistics for the return rates of the considered indices.

	Mean	Std. dev.	Minimum	Maximum	Skewness	Kurtosis
Argentina	0.00036	0.0217	−0.1215	0.1749	−0.0117	4.7726
Australia	0.00019	0.0100	−0.0705	0.0579	−0.3028	4.1863
Austria	0.00024	0.0147	−0.0974	0.0910	−0.5510	5.3184
Belgium	−0.00002	0.0129	−0.0736	0.0978	−0.0273	5.3258
Brazil	−0.00002	0.0178	−0.1139	0.1343	−0.1690	3.2679
Canada	0.00002	0.0110	−0.0932	0.0982	−0.3416	9.9282
Chile	0.00039	0.0098	−0.0698	0.0590	−0.4597	5.0761
China	0.00016	0.0206	−0.1324	0.1478	−0.3704	6.2255
Eurozone	−0.00019	0.0151	−0.0786	0.1035	−0.1052	3.3232
France	−0.00017	0.0135	−0.0856	0.0884	−0.1623	4.1702
Germany	−0.00004	0.0152	−0.0707	0.1128	−0.0482	3.7702
India	0.00045	0.0151	−0.1114	0.1734	0.1263	10.9177
Indonesia	0.00073	0.0140	−0.1038	0.0792	−0.6347	6.0060
Israel	0.00017	0.0110	−0.1000	0.0541	−0.7575	6.9863
Japan	0.00028	0.0158	−0.1141	0.1415	−0.1116	7.7960
Mexico	0.00040	0.0126	−0.0701	0.1031	−0.0868	4.6911
South Korea	0.00046	0.0139	−0.1057	0.0614	−0.5199	4.5341
Taiwan	0.00029	0.0128	−0.0651	0.0577	−0.2090	2.5397
UK	−0.00017	0.0121	−0.0785	0.0805	−0.2998	4.8025
USA	0.00005	0.0112	−0.0993	0.1104	−0.5194	10.3279

3. Methodology

The basis of the network is built using the detrended cross-correlation analysis (DCCA) coefficient correlation to study the cross-correlation dependence between series. DCCA was created by Podobnik and Stanley [46] and is performed according to the following steps. It considers two different datasets x_k and y_k with $k = 1, \ldots, t$ equidistant observations. Based on those variables, DCCA starts by integrating both series, i.e., calculating $(t) = \sum_{k=1}^{t} x_k$ and $y(t) = \sum_{k=1}^{t} y_k$. The next step is to divide the whole samples into boxes of equal length, of dimension n and divide into N-n overlapping boxes. For each box, a local trend ($\tilde{x}_k$ and $\tilde{y}_k$) is considered, using ordinary least squares. The detrended series are calculated, based on the difference between original values and the previously calculated trend. The covariance of the residuals in each box is calculated, given by $f_{DCCA}^2 = \frac{1}{n-1} \sum_{k=i}^{i+n} (x_k - \tilde{x}_k)(y_k - \tilde{y}_k)$. Finally, the detrended covariance is calculated summing all boxes of size n, i.e., $F_{DCCA}^2(n) = \frac{1}{N-n} \sum_{i=1}^{N-n} f_{DCCA}^2$. The process is repeated for all length boxes, allowing identification of the relationship between the DCCA fluctuation function and n. The long-range cross correlation $F_{DCCA}(n)$ is given by the power law: $F_{DCCA}(n) \sim n^{\lambda}$, with the λ parameter as the parameter of interest which quantifies the long-range power-law cross-correlations.

The DCCA method measures the covariation between series. However, to understand the degree of the relationship it is more suitable to use the correlation coefficient created by Zebende [45], given by $\rho_{DCCA} = \frac{F_{DCCA}^2}{F_{DFA\{x\}} F_{DFA\{y\}}}$, where $\text{DFA}_{\{xi\}}$

and $DFA_{\{yi\}}$ represent the DFA method [55] for the series {xi} and {yi}, respectively. This has had several applications in economics and finance [56–60].

That coefficient, which is considered efficient by Kristoufek [61], has the desired properties of a correlation coefficient: $-1 \leq \rho_{DCCA} \leq 1$; $\rho_{DCCA} = 0$ when there is no cross-correlation between series; a positive or negative value meaning evidence of cross-correlation or anti cross-correlation and Kwapień et al. [62] propose the q-dependent detrended cross-correlation coefficient, i.e., ρ_q (q ∈ R) based on the so-called q-dependent fluctuation functions.

The Podobnik et al. [63] procedure is used to test the significance of this correlation coefficient, considering the different sample sizes used in this study. Besides that, based on Silva et al. [64], we consider a high degree of ρ_{DCCA} correlation coefficient ≥ 0.66. In this study, we consider the existing network connection in significant correlations and the correlation grades already mentioned. A variation of ρDCCA is the ΔρDCCA introduced by Silva et al. [65], which is used to measure the contagion effect, with the work of Wang et al. [66] or Ferreira et al. [58] applying that new concept. Additionally, Balocchi et al. [67] reconcile the ρDCCA with ARFIMA models and Kristoufek [68] shows that the DCCA coefficient is more efficient than the Pearson coefficient in measuring the cross correlation between two non-stationary series.

For the analysis of communities, we then apply the Louvain method for community detection to identify closely interconnected stock markets within the graphs proposed by Blondel et al. [69], named modularity.

To analyze centrality we will consider the weighted degree and the PageRank. Regarding the weighted degree, let us consider that $\Gamma(i)$ is the neighborhood of vertex i. The weighted degree of vertex i is given by the sum of the weights of all in-or-out arcs connected to vertex i, $k_{wi} = \sum_{j\in\Gamma(i)} w_{ij}$.

PageRank measures the importance of a node (sector) by counting the number and quality of arcs (if the network is addressed). PageRank is a measure of quantity and quality because it captures both the number of arcs a node can have and the importance of the node in the network. A node (stock market) can be important if it receives an arc from an important node, according to Page et al. [70], PageRank is defined as:

1. At t = 0, an initial probability distribution is assumed, usually $PR(i;0) = 1/N$, where N is the total number of nodes;
2. At each time step, the PageRank of node i is computed as $PR(i;t+1) = \frac{1-d}{N} + d\sum_{j\in M(i)} \frac{PR(j;t)w_{ij}}{S(j)}$, where M(i) are the in-neighbors of i, w_{ij} is the weight of the link between the nodes i and j, S is the sum of the weights of the outgoing edges from j, and the damping factor d is set to its default value, 0.85.

4. Results

Firstly, we build the network formed by the values of the significance test of Podobnik et al. [63], linking the edges for a ρDCCA ≥ 0.66. The objective of using a ρDCCA ≥ 0.66 is to propose a filtering method to verify which edges remained even for a high ρDCCA value. So we can verify which stock exchanges are most influential. For this, the total value of the weighted degree of a given market together with the ρDCCA filtering will be used.

Fig. 1 shows the example of the networks for a time scale of 4 days, considering the values of ρDCCA and using the significance test of Podobnik et al. [63], with the top panel representing the period before the crisis and the bottom panel the period after the crisis. The larger the node size and the darker the blue tint, the greater the weighted degree value. This helps in visualizing the most important nodes corresponding to the financial indices of the respective countries. We can see that the larger knots in darker blue are European markets, mainly France, Germany, Belgium, the Eurozone as whole and UK. In the background, American countries and China predominate.

During the pre-crisis period, the agglomeration coefficient of the network was 0.48 and the density coefficient 0.47, while after the crisis our network has higher coefficients: 0.98 for the agglomeration and 0.97 for the density. This shows that during the period analyzed, the twenty stock exchanges maintained relationships with each other, for a time scale of 4 days. Regarding the analysis for a time scale of 28 days and 135 days, the results are similar (see appendix 1, which shows the results of the correlation coefficient for all pairs of indices, for both subperiods).

Fig. 2 reveals the communities extracted with the modularity property, using the modularity algorithm of Blondel et al. [69]. For the period before the crisis (upper panel), the algorithm retrieved three communities: one formed by European stock markets, another formed by American markets and the third formed by Asian countries and Australia. Regarding the post-crisis period (lower panel), just two communities were formed: one by European and American stock markets and another formed by Asian markets and Australia. This does not mean that the stock markets of a given community do not influence one belonging to the other community. The algorithm only divides the stock markets that correlate most with each other. For example, in the period after the crisis, there is a notable influence of European markets on American markets and a community representing Asian countries, with the Chinese stock exchange being dominant, since this has the highest weighted degree among the Asian markets.

Combining both subperiods, the reduction from three to two communities means that stock markets seem to increase their levels of integration, since American and European indices now form just one community. This is not a new result: for example, Ang and Chen [71] and Ang and Bekaert [72] found an increase in correlations between financial assets' returns across international markets after a shock. The fact that Asian markets and the Australian one remain in a different community means those markets are not fully integrated with the others.

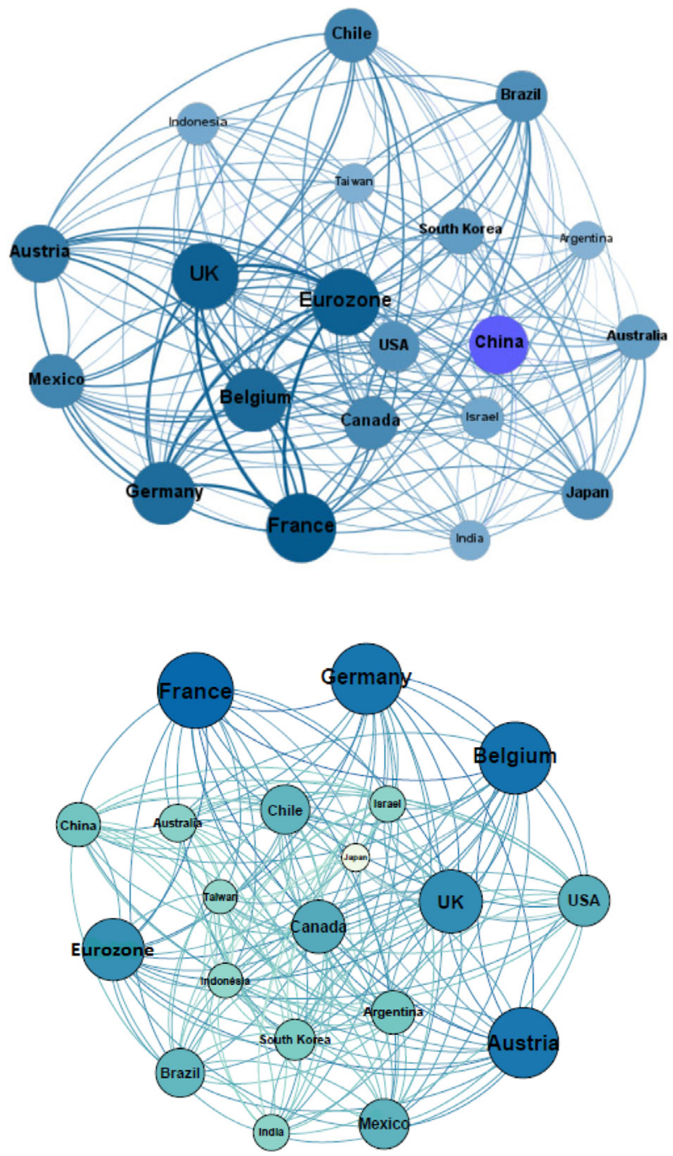

Fig. 1. Networks constructed for a time scale of 4 days and considering the significance test of Podobnik et al. [63]. Note that the larger the knot and the darker the blue the larger the weighted degree. The upper panel is for the pre-crisis period and the lower panel for the period after the crisis.

Considering a higher level of correlation (ρDCCA > 0.66), it is natural that the size of the network is smaller, since a correlation with a more demanding level is being considered. It is noticeable that the longer the time scale, the more integrated the market is, and there are more connections between the corresponding stock markets. In the scales of n = 4, n = 14, n = 28 and n = 60 (Figs. 3–6), the clear predominance of the European markets is noted. Thus, considering a higher level of integration (measured by a higher level of correlation), European markets are not only among the most integrated, but also those that can be considered as influencing other markets. Fig. 7, representing a time scale of n = 135, shows the participation of several stock markets in different continents, emphasizing the European markets. The strong connectivity of European countries was detected before and after the subprime crisis. The crisis had two effects on the network: an increase in the connectivity in the network with the presence of a larger number of countries for all scales and an increased presence of South Korea and Taiwan. Additionally, the network remained practically the same before the crisis for smaller scales, having a change in scales 60 and 135 (see Figs. 3–5).

Tables 3 and 4 identify country rankings, for both subperiods, according to the centrality of Page Rank and the Weighted Degree, considering the different time scales under analysis. In the period before the crisis, the results show that the Eurozone as a whole has in important role in the network. France and the UK are other European countries prominent in almost all time scales, in both the indicators used in the analysis. The US stock market appears in the lead of the network for shorter time scales, when considering the Page Rank. A brief note for the presence of Mexico in the table in the pre-crisis period, for higher time scales. And according to the centrality of the weighted degree and Page Rank, shows the predominance of European markets, mainly the French, British, German, Belgian and Austrian ones and the Eurozone

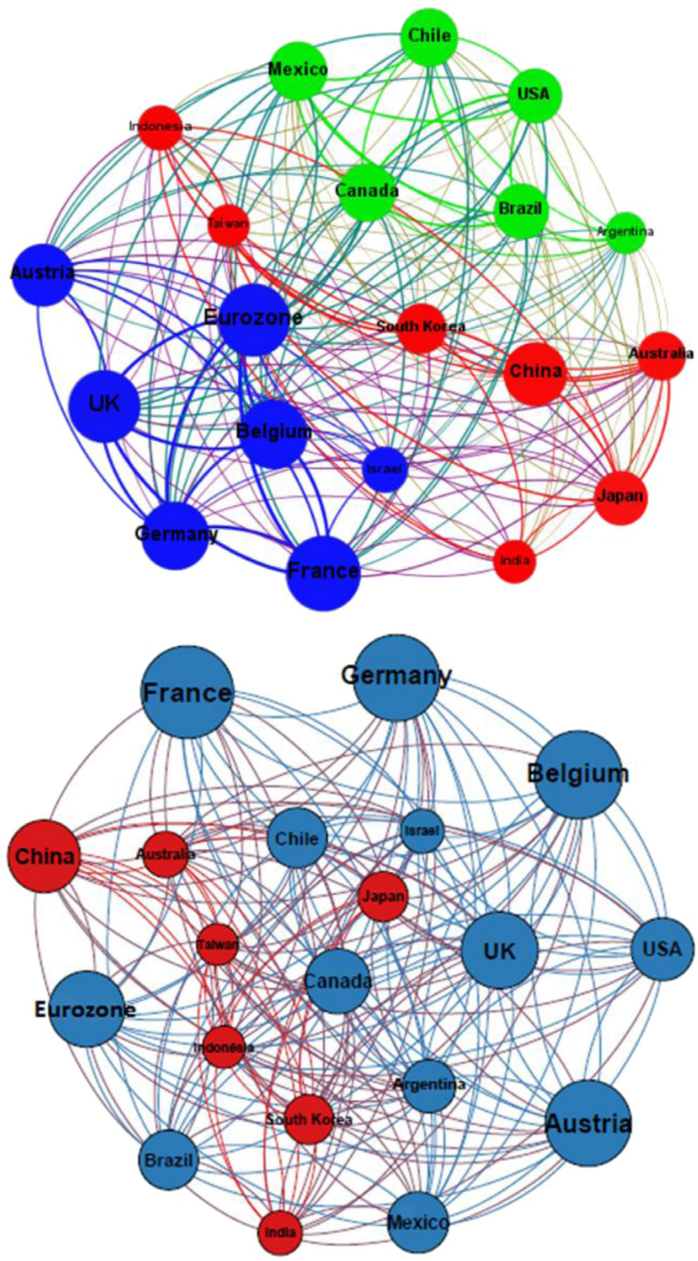

Fig. 2. Communities extracted with the modularity property. The upper panel is for the period before the crisis and the lower panel for the period after the crisis.

as a whole. Few variations among the first five positions are noted. This really shows the predominance of the European stock markets when compared with the remaining countries under analysis. The fact that in recent years the European Union in general and the Eurozone in particular suffered a severe financial crisis could be one of the explanations of these results.

5. Concluding remarks

The subprime crisis was the biggest crisis since 1929, and has caused the fall of several stock exchanges worldwide, increased unemployment and reduced Gross Domestic Product (GDP) all over the world. In the ten years since its outbreak, other financial phenomena such as the Eurodebt crisis and the United Kingdom's decision to leave the European Union (Brexit referendum) have taken place and this has affected the dynamics of the world financial markets. Therefore, this work analyzed twenty world stock exchanges using a multiscale network with the intention to verify how these stock markets are related after those ten years, compared to the situation in the pre-crisis period.

During the pre-crisis period, European and North American indices show predominance in the network, despite the main role of the European markets. In the post-crisis period, European stock exchanges are predominant. The importance

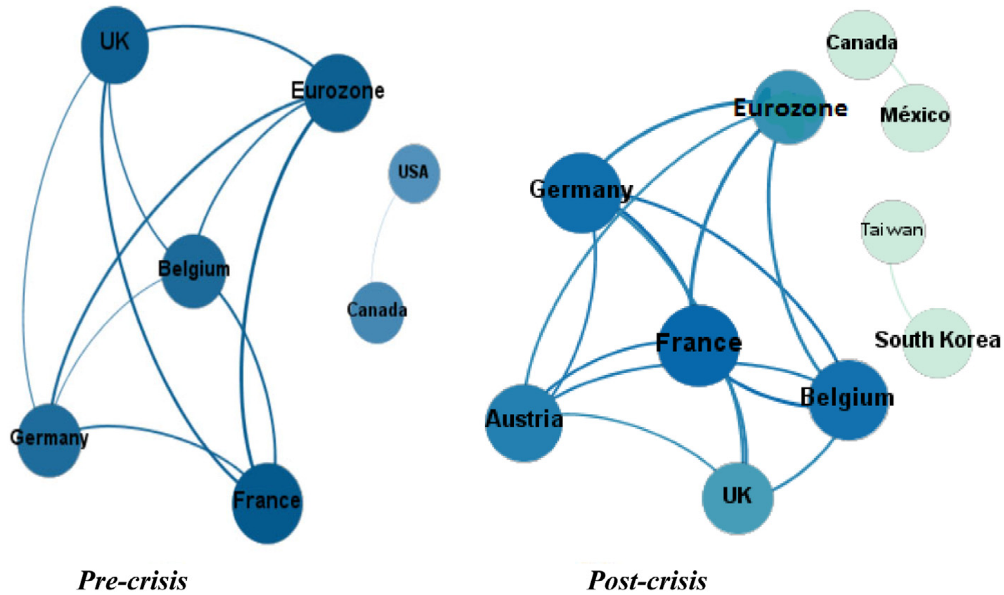

Fig. 3. Relationships with $\rho_{DCCA} > 0.66$ for a time scale of n = 4. In this network, the darker blue represents the higher weighted degree of the respective stock market. On the left the pre-crisis period and on the right the post-crisis one.

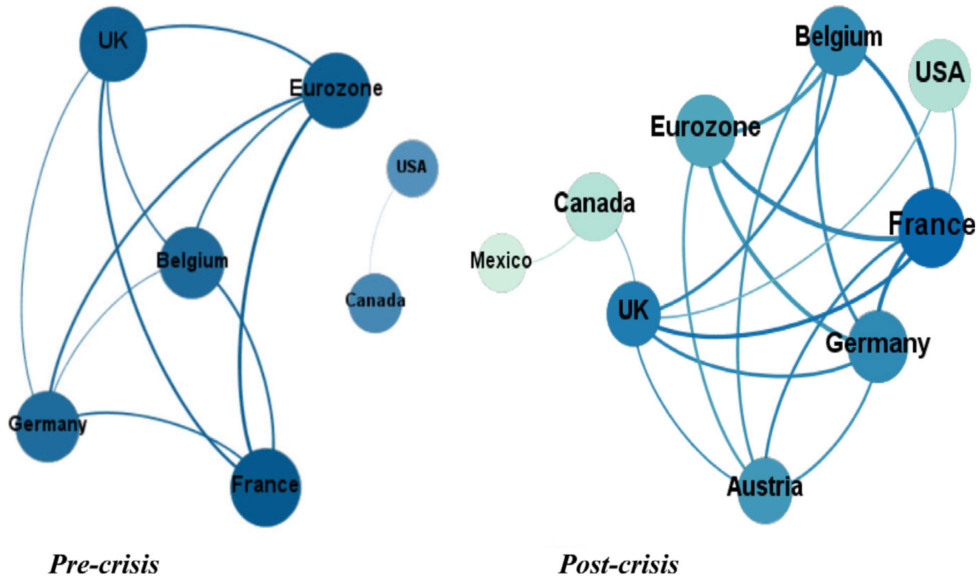

Fig. 4. Relationships with $\rho_{DCCA} > 0.66$ for a time scale of n = 14. In this network, the darker blue represents the higher weighted degree of the respective stock market. On the left the pre-crisis period and on the right the post-crisis one.

of the Eurozone in the network is noticeable, namely in the lower scales. This means that, in the short run, the Eurozone is an important market regarding the connection with others. The difference between the subperiods, namely the fact that in the post-crisis period North American markets lost importance, could be justified by the crisis itself, because it caused some decrease in stock market integration with European markets. However, and considering the number of communities retrieved, it is possible to conclude on increased integration of European and American markets, after the crisis.

If the network is considered for a value of ρDCCA $\geq$ 0.66, again European stock markets predominate for all the time scales analyzed. As for the variation of time in the scales, the larger the time scale analyzed the greater the financial integration of the stock markets studied and for a time scale of 135 days, the markets of several countries in several continents maintain a strong financial integration.

The number of communities extracted from the network changed from three (European, American and Asian plus Australia) to two communities, with the joining of European and American markets as a single community. Therefore, the analysis of financial networks that vary with time scale can contribute to financial risk containment policies both for financial funds, where the time scale is important and also for hedge funds, helping to control financial stability.

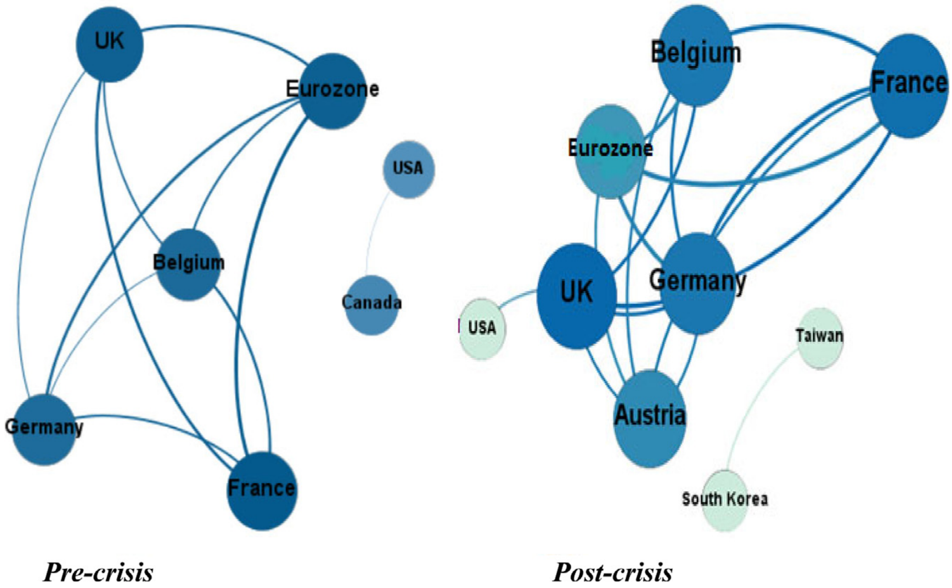

Fig. 5. Relationships with $\rho_{DCCA} > 0.66$ for a time scale of n = 28. In this network, the darker blue represents the higher weighted degree of the respective stock market. On the left the pre-crisis period and on the right the post-crisis one.

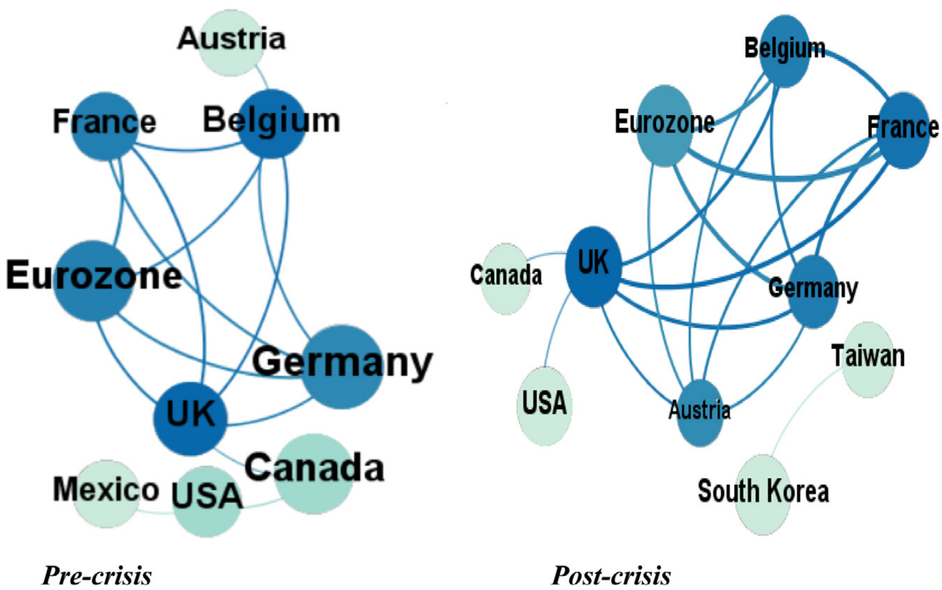

Fig. 6. Relationships with $\rho_{DCCA} > 0.66$ for a time scale of n = 60. In this network, the darker blue represents the higher weighted degree of the respective stock market. On the left the pre-crisis period and on the right the post-crisis one.

The results could also be an alert as they could be used for financial risk prevention, in the sense that any crisis in the European Union, mainly in countries like France, Germany, Belgium or Austria, could have a negative influence on several financial markets. The UK also has a relative predominance, which is very important in the current context of Brexit. Therefore, for hedge funds it is vitally important to monitor the economic situation of this region.

Acknowledgments

Paulo Jorge Silveira Ferreira is pleased to acknowledge financial support from Fundação para a Ciência e a Tecnologia (grant UID/ECO/04007/2013) and FEDER/COMPETE (POCI-01-0145-FEDER-007659).Eder Johnson de Area Leão Pereira, is pleased to acknowledge financial support from Fundação de Amparo e Pesquisa do Estado da Bahia - FAPESB, Brazil (grant number BOL 0261/2017).

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.physa.2019.121542.

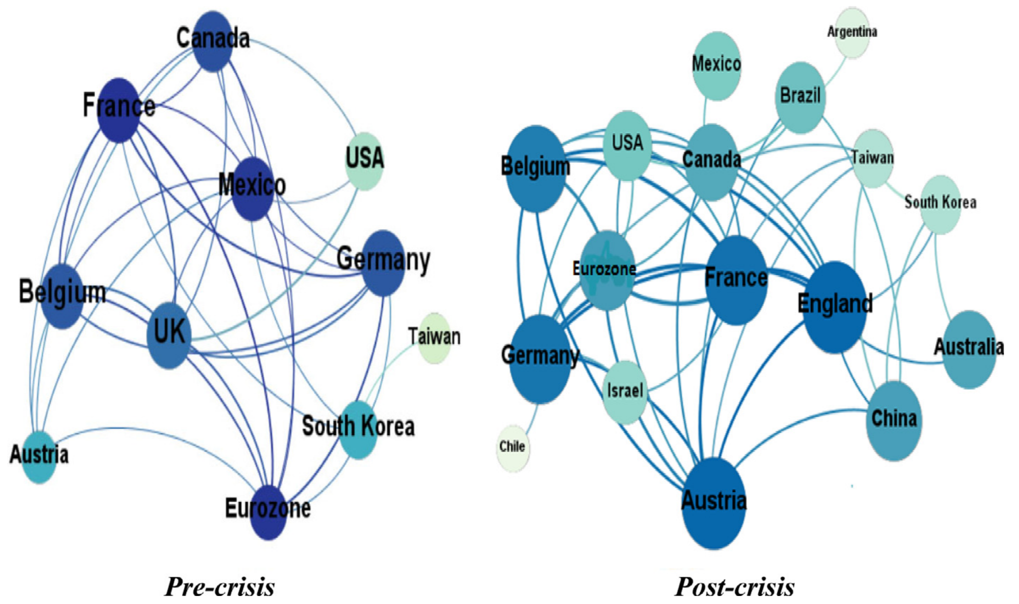

Fig. 7. Relationships with $\rho_{DCCA} > 0.66$ for a time scale of n = 135. In this network, the darker blue represents the higher weighted degree of the respective stock market. On the left the pre-crisis period and on the right the post-crisis one.

Table 3
Country ranking according to the centrality of Page Rank and Weighted Degree, considering different time scales (post-crisis period).

Weighted Degree ranking	Scale 4	Scale14	Scale 28	Scale 60	Scale 135
1	France	France	France	UK	France
2	Eurozone	Eurozone	Eurozone	France	Eurozone
3	UK	UK	UK	Belgium	Mexico
4	Belgium	Germany	Germany	Eurozone	Canada
5	Germany	Belgium	Belgium	Germany	Germany
Page Rank ranking	Scale 4	Scale14	Scale 28	Scale 60	Scale 135
1	Eurozone	Eurozone	Eurozone	Eurozone	Eurozone
2	UK	UK	UK	UK	Mexico
3	USA	USA	USA	Mexico	UK
4	France	France	France	Belgium	France
5	Belgium	Belgium	Belgium	France	Canada

Table 4
Country ranking according to the centrality of Page Rank and Weighted Degree, considering different time scales (pre-crisis period).

Weighted Degree ranking	Scale 4	Scale14	Scale 28	Scale 60	Scale 135
1	France	France	UK	UK	France
2	Germany	UK	Eurozone	France	Eurozone
3	Belgium	Germany	Germany	Germany	Germany
4	Austria	Belgium	Belgium	Belgium	UK
5	Eurozone	Austria	Austria	Austria	Belgium
Page Rank ranking	Scale 4	Scale14	Scale 28	Scale 60	scale 135
1	France	UK	UK	UK	France
2	Germany	France	Eurozone	France	Austria
3	Belgium	Germany	Germany	Germany	Germany
4	Austria	Belgium	Belgium	Belgium	UK
5	Eurozone	Austria	Austria	Austria	Canada

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Capítulo Seis

Redes Dinâmicas e Estabilidade na União Europeia

6.1 Sobre o artigo

Neste ensaio envolvendo finanças e redes, foi aplicado o método de motif (ROSÁRIO *et al.*, 2015) que possibilitou identificar a dinâmica da conectividade de uma rede financeira, construída utilizando os retornos dos índices de diversas bolsas europeias. Com isso, foi possível analisar o efeito de choques nos mercados financeiros como, por exemplo, crises. A hipótese é que a variação das propriedades da rede podem dar sinais de possíveis crises financeiras, podendo a estabilidade da rede ser utilizada para a prevenção de crises financeiras (PEREIRA *et al.*, 2019b).

Associar a análise de redes financeiras a previsibilidade de crises é uma campo de pesquisa relativamente novo, mas de muito interesse (MINOIU *et al.*, 2015; TABAK *et al.*, 2014a; YAN; XIE; WANG, 2014a; YAN; XIE; WANG, 2014b). Entretanto ainda não existem estudos envolvendo os mercados europeus que estão entre os mais importantes do mundo.

Portanto, foi analisado sobre a dinâmica dos mercados europeus, entre 1988 a 2017, isso conseguiria captar o efeito de aproximadamente 30 anos de choques exógenos sobre esses mercados, captando a interferência de turbulências nas propriedades das redes como o maior evento econômico desse século, a crise dos *subprimes* em 2008.

Network Dynamic and Stability on European Union

Hernane Borges de Barros Pereira[1,2,*,+], **Raphael Silva do Rosário**[3,+], **Eder Johnson de Area Leão Pereira**[1,4,+], **Davidson Martins Moreira**[1,+], **Paulo Ferreira**[5,6,7+], **and José Garcia Vivas Miranda**[3,+]

[1]Programa de Modelagem Computacional, SENAI Cimatec, Salvador, 41.650-010, Brazil
[2]Universidade do Estado da Bahia, Salvador, 41.150-000, Brazil
[3]Universidade Federal da Bahia, Brazil
[4]Instituto Federal do Maranhão, Brazil
[5]VALORIZA - Research Center for Endogenous Resource Valorization, Portalegre, Portugal
[6]Instituto Politécnico de Portalegre, Portalegre, Universidade de Évora, Portugal
[7]CEFAGE, Universidade de Évora, Portugal
[*]hbbpereira@gmail.br
[+]these authors contributed equally to this work

ABSTRACT

This paper proposes an analysis of the financial market of 14 countries of the European Union, under the vision of the dynamic networks using the motif-synchronization method. It is found that the countries of Central Europe (France, the Netherlands, Germany, and the UK) are the most influential in the remaining exchanges of the European Union countries. They were also found as hubs during and after the subprime crisis in Ireland and Greece. The network formed between the indices of the countries in the European Union increased its connectivity constantly from 1988 up to 2008 and 2009, years in which the subprime crisis occurred, and after 2008–2009 the connection gradually decreased until the year 2017, revealing behavior before and after the crisis. The results corroborate the thesis that strongly connected financial networks are more susceptible to exogenous shocks than sparse networks.

Introduction

Since its creation, the European Economic Community, now the European Union (EU), had the objective of increasing economic integration between countries. Initially, it was created with the objective of fostering international trade, but it always had the expectation of increasing the level of integration. Thus, the integration of a number of new countries into the EU was not unexpected, neither was the deepening of the integration, with the creation of the single market, which expanded the free circulation not only of products but also services, citizens, and capital. Later, the establishment of a common currency for the majority of EU countries followed the objective of increased integration.

In particular, the free flow of capital and the creation of a common currency should have a major impact on the integration of financial markets, namely the stock markets. Because integration in general and stock market integration in particular could have important effects on economies, studying this feature continues to be important. In fact, it is expected that a deeper market integration could promote economic growth, because it would improve savings allocation and investments. However, it could also have negative impacts, such as the possibility of increasing risks and a faster spread of negative shocks.

In this context, it was found that as a result, there is a strong connection between EU stock markets, both before and after the 2008–2009 crisis, as well as a change in the connectivity pattern of the network once it turned sparser after the subprime crisis. This result reinforces the idea that connected networks are more sensitive to exogenous shocks than sparse networks, mainly in the EU, where historically strong financial integration exists.

Thus, we focused our analysis on the study of stock market integration in the EU, based on a network formed by stock market indices before and after the crisis using the theory of time-varying graphs (TVG) and the motif-synchronization method. We create dynamic networks that will allow us to identify those markets that are more influenced by and have more influence on other markets. Our proposal has two main advantages: (i) as we use a network, we can investigate which are the most important stock markets in that network; (ii) as our methodology can be studied dynamically, we can study the evolution of the network over time showing that when a network tends towards stability, this can be indicative of financial crisis.

Owing to data availability, our sample starts in 1988. Because we are interested in studying how the network developed, we split our sample into several subsamples, all of them with a two-year dimension. This will allow us to study the evolution of the network over time.

The remainder of this paper is organized as follows. In the second section, we present a review of the literature on stock market integration, first identifying some advantages and disadvantages and, second, centered on the analysis of how the stock market evolved in the EU. In the third section, we present the data and the methodologies used in this paper. In the fourth section, we present the results and discuss on them, and, in the fifth section, we present our conclusions.

Literature review

The amount of literature on stock market integration is huge, which makes a complete analysis difficult. Furthermore, as we also have to make some reference to the use of networks in previous works, we provide only a brief review of this topic, but make a distinction between several important issues in the theoretical aspects of our approach. Thus, we first present a general overview of stock market integration, identifying expected advantages and disadvantages, and, second, we identify different methodologies to measure stock market integration that were applied to the EU. Finally, we present some studies applying networks.

Stock markets are very important markets that are used not only for financing firms but also for investment (both by persons and firms), thus maintaining the interest in analysis. One motive is the rapid increase of international trade, not only of goods and services but also for financial assets. Another motive is that markets are now much more inter-related than in previous years, which could have benefits but also possible contagion effects (see, for example, Bekaert et al.[1]). This increase in stock market integration makes markets more interdependent and could also have effects on how governments design their policies, because that integration has direct impacts on variables such as exchange rates, national income, or even in employment (see, for example, Kearney and Lucey[2]).

Theoretically, it is expected that more integrated markets will have a positive impact on the welfare and growth of countries, because it promotes a certain investment specialization that as consequence will have a better allocation of savings (see, among others, Obstfeld[3] and Bekaert et al.[4]). In the case of the EU, this was the expectation of all countries when they pursued their initiatives of increasing economic integration (remember that stock market integration is just a part of the whole process of integration). In addition to the advantages for the countries, it could also be of benefit for potential investors because more integrated stock markets would increase returns and reduce costs. This important factor was raised, for example, by Lemmen[5] and was empirically confirmed by Hardouvelis et al.[6]. Although these positive effects, it is also recognized that an increase in market integration (mainly in the case of the financial market) could have a negative effect on financial stability, mainly if capital inflows are not used efficiently. In addition, the risks of the existence of financial contagion increase, in particular when economies are more interdependent, i.e., when they are more integrated (see, for example, Beine et al.[7]).

In addition, it is possible to find studies that identify that increased integration in financial markets could reduce the possibility of gains due to the increase of correlation among assets, as stated by Famá and Pereira[8]. Similarly, it is possible to find that strategies using models of portfolio optimization in countries with low levels of financial integration could minimize risks and maximize returns (see, for example, Coroa et al.[9]).

Furthermore, in the context of the EU, the increase in this interdependence when financial integration is not complete (not only stock market integration, but other issues of financial integration, such as money markets, banking or bond market integration) could have very nefarious effects. In fact, the increased exposure to risk and the possibility of emergence of a global crisis are among the possible risks that could not be solved in each country due to the impossibility of implementing some types of economic policies to combat possible asymmetry (see, for example, Lemmen[5]).

There are plenty of studies using several methodologies and countries, but, as stated previously, we focus on studies including EU countries. Owing to data restrictions, it is difficult to find many studies including only EU countries before the 1990s. Normally, they also include other non-EU countries (mainly Canada, Japan, and the USA) and most of these studies do not provide a direct analysis of EU-only countries. Although, for example, Ayuso and Blanco[10] concluded that there has been an increase in the degree of integration in the large EU countries (and also with Japan). However, even at that time the authors were warning that the situation could be problematic if there was a continued lack of supervision, because the political capacity to intervene when problems in the financial markets appear may be lost in the context of the EU.

Rangvid[11] analyzed data for France, Germany, and the United Kingdom, with a long sample (from 1960 to 1999), searching for common trends. Their results showed evidence of an increase in stock market integration, especially after 1982. Rangvid concluded that periods with greater integration are those immediately following the lifting of restrictions. Yang et al.[12] used data before and after the creation of the Euro and found evidence of a general increase in stock market integration after the establishment of the single currency, which could be a result of the faster transmission of information, technological advances, and the existence of mergers of stock indexes. Cerný[13] also showed that the transmission of information is a cause of the increase in integration, but also concluded that it is more evident in more developed markets. Yang et al.[12] identified that the levels of integration are different if they analyzed the largest Eurozone markets (Germany, France, Italy, and the Netherlands) or smaller markets (including Portugal, Spain, and Ireland) that are more isolated.

Although most studies found evidence of an increase in stock market integration, it is also possible to find some studies pointing to some contrasting evidence, mainly when smaller markets are investigated, as stated previously. For example, Rouwenhorst[14] identified that the integration levels are lower than the expected, which could be explained by the existence of home bias (a higher weight of domestic assets in investors' portfolios). The fact that countries have different answers in the case of asymmetric shocks is presented as another possible explanation of the results.

With the increase of in the number of countries in the EU and with the increase of available data, it is possible to find more studies, inclusively with newer EU countries[1]. Scheicher[15] found that Hungary, Poland, and the Czech Republic (countries which entered in the EU in 2004) had increased integration levels between themselves and also with other EU countries. Fratzscher[16] also found an increase in market integration in Europe and, in addition, showed that the EU gained importance in relation to the American markets. In studies that also included countries that entered in the EU in 2004, Pungulescu[17] and Voronkova[18] showed an increase in stock market integration, even controlling for structural changes. Regarding the Euro, it is also possible to find several studies studying the direct impact of the creation of the common currency in the increase of stock market integration; examples include those of Baele et al.[19], Kim et al.[20], Hardouvelis et al.[6], Cappiello et al.[21], Bartram et al.[22], and Bley[23].

However, both the subprime crisis and mainly the Eurodebt crisis altered how stock market integration was viewed. First, it increased the debate about the fact that deep integration could have a negative impact, mainly with contagion effects, even in smaller countries such as Greece (see, for example, Beirne and Fratzscher[24] and Samitas and Tsakalos[25]). Second, it drew attention to the necessity of a more homogeneous EU and greater supervision (as stated previously). Thus, to measure the effects of integration during the subprime crisis, we use the theory of networks.

The use of networks in financial markets could actually be considered as one of the main topics of research in finance. According to Schweitzer et al.[26], the networks allow the analysis of two or more interconnected assets in a system. Battiston et al.[27] stated that networks can measure the likelihood of systemic risk arising from interconnections and interdependence between agents of a system or market in which insolvency or bankruptcy of a single entity or group of entities can lead to bankruptcy of the whole network.

Mantegna[28] in one of the first studies involving networks and financial markets applying the minimum spanning tree (MST) method between the periods from July 1989 to October 1995 using companies listed on the New York Stock Exchange (NYSE). Mantegna detected that time series could pass on valuable information to the financial markets. Mantegna's study has practically revolutionized the way in which financial relationships between financial assets can be perceived, ranging from the network of shares in a given stock exchange to the financial relationship between stock exchanges in different countries.

Onnela et al.[29] also analyzed the NYSE to build hierarchical structures corresponding to the networks. Bonanno et al.[30] used high-frequency data for the major stocks traded in US stock markets and found that the degree of cross-correlation varied according to the time horizon used to compute them.

Sandoval-Junior and França[31] used random matrix theory (RMT) to analyze the correlation of the returns of various country indices to demonstrate that periods of strong volatility are associated with strong correlations between the world financial indices. Sandoval-Junior[32] set up the complex network of companies comprising BM & F-Bovespa (São Paulo Stock Exchange, Futures and Commodities Exchange) using MST, concluding that they were clustered by sector. Huang et al.[33] analyzed the return of companies forming Hong Kong's financial market between November 2011 and February 2015 and found a distribution in the power law format for the network formed by the correlation between them. Liu and Tse[34] analyzed the complex network of 32 market indices for several countries finding a strong correlation between volatilities with the exception of developing countries. Matesanz et al.[35] applied complex networks in the commodities market and found a similar dynamic between commodities of the same sector (metals, oils, and grains) but did not observe an increase in the co-movements between them over time with the exception of the years of 2008 and 2009. There are also applications of financial networks in the foreign exchange market, e.g. Wang and Xie[36], Wang et al.[37] and Wang et al.[38]; biofuels, e.g. Kristoufek et al.[39] and Filip et al.[40]; and commodities Tabak et al.[41].

An important link has been found between the connectivity of a financial network and a crisis in the stock market. Some authors have found this relationship can be used in predicting crises or as a sign of financial market instability. In general, before a crisis the network for stock exchanges tends to become more connected or tends to a small world topology, however after the crisis the network becomes less connected. A pioneering study in this area was presented by Minoiu and Reyes[42] analyzed the properties of networks formed by banks from 184 countries between 1978 and 2009 and found that connectivity tends to fall during and after a financial crisis. They also found that 2009 had a strong impact on the network.

Tabak et al.[43], Minoiu et al.[44], and Bardoscia et al.[45] found a relationship between banking system connectivity and systemic risk. Acemoglu et al.[46] found a financial network such as a highly connected banking network has contributed to spreading an exogenous shock (such as a crisis) making the system more unstable than a sparse network. For them, sparser financial networks are less prone to systemic risk than highly connected networks.

[1]Recall that 10 extra countries joined the EU in 2004, followed by three more countries in 2007 and 2013, but the UK is currently in the process of leaving.

Regarding the relation between the connectivity of stock exchanges and financial crises, we mention the study of Yan et al.[47] who analyzed 710 companies from the Chinese stock market from 2005 to 2011, dividing the period analyzed into three parts: before the subprime crisis, during the subprime crisis, and after the subprime crisis. They presented some robustness tests to verify whether the network topology changed during the analyzed period, concluding that the network is sensitive to the failure of the nodes being unstable and that before the crisis the financial market had a strong robustness against intentional attacks. According to Yellen[48], complex interactions between market actors can serve to amplify the frictions in the market, information asymmetries, or other externalities, generating more instability than stability.

Materials and Method

The EU is formed by 28 countries (including the UK at the time of writing), 19 of which share the Euro as their common currency. Our objective is to provide a deep analysis, including as many countries and as long a sample as possible. However, not all countries have a long sample of data available: some of them only joined the EU recently, others are relatively new countries, and some simply do not have data available. Thus, with these objectives, we retrieved data for 14 EU countries, from January 1988 to June 23, 2017. The database includes a total of 7404 observations for each country. The countries used are Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain (with the Euro as their currency), Denmark, Sweden, and the UK (non-Eurozone countries). For each country, we retrieved prices for the Morgan Stanley Capital International (MSCI) indexes. In addition to the availability criteria (some of the national indexes were not available at the same time), this allowed us to have comparable indexes. Data was retrieved from Datastream.

Because our objective is to analyze the evolution of the network, we split the whole sample into subperiods of 2 years. This allowed us to have a good sample size in each subperiod (of about 1000 observations). Thus, the first period is from the beginning of 1988 to the end of 1989, the second period from 1990 to 1991, and so forth.

Considering the price level P_t, we calculated return rates using the difference of consecutive logarithms, i.e., $r_t = \ln(P_t) - \ln(P_{t-1})$.

TVG and dynamic networks

When networks refer to real systems, it is difficult to find relationships between elements of the system that are persistent over time. In many cases, a static interpretation of these relations is just a simplifying approach. The notion of TVG is a common method to represent such dynamic networks (Holme and Saramäki[49]).

The simplest way to describe a TVG is as an ordered sequence of static graphs $G = \{G_t\}$, $t = 1, 2, ..., T$, where each G_t represents the configuration of the network edges at a given time t, with T the total observations of time of the system under analysis.

Formally, according to Casteigts et al.[50], a TVG can be defined as a quintuple function $G = (V, A, T, \rho, \zeta)$, where:

- V represents the set of vertices of G;
- A represents the set of edges of G;
- T is the lifetime of the system;
- $\rho(A, T)$ is a function that indicates the existence of a given edge at a given time;
- $\zeta(A, T)$ is a latency function that indicates the lifetime of a given edge.

Motif synchronization

Motif synchronization is a method of association proposed by Rosário et al.[51], as a more efficient method to build dynamic brain networks. A more in-depth discussion of the efficiency of the method can be found in (Rosário et al.[51]).

The MSCI time series can be described as a sequence of micro patterns such as slopes, peaks, and ditches in a given order of occurrence. These patterns are called motifs. In general, motif synchronization consists of counting the quasi-simultaneous occurrence of those motifs.

For the description of the method, let us assume two time series X and Y, recorded simultaneously from different countries. The first step is the translation of these time series into two new series X_M and Y_M, sequences of motifs. We then define $c(X_M; Y_M)$ as the largest number of times that the same motif was found in Y_M shortly after being found in X_M, within a delay τ, that is,

$$c(X_M; Y_M) = c_{XY}$$
$$c_{XY} = \max\left(\sum_{i=1}^{L_m} J_i^{\tau_0}, \sum_{i=1}^{L_m} J_i^{\tau_1}, ..., \sum_{i=1}^{L_m} J_i^{\tau_n}\right) \tag{1}$$

being

$$J_i^\tau = \begin{cases} 1 & \text{, if } M\#_{x_i} = M\#_{y_{i+\tau}} \quad \text{or} \\ 0 & \text{, otherwise} \end{cases} \tag{2}$$

where $\#_{x_i}$ is the motif of the country x at time i and L_m the total size of the motifs series. The time delay τ varies between $\tau_0 = 0$ and τ_n, where τ_n is the maximum value considered. In an analogous manner, we define c_{XY}. Finally, we define the degree of synchronization Q_{XY} and the direction of synchronization q_{XY}, given by

$$Q_{XY} = \frac{\max(c_{XY}, c_{YX})}{L_m} \tag{3}$$

and

$$q_{XY} = \begin{cases} 0 & \text{, if } c_{XY} = c_{YX} \quad \text{or} \\ signal(c_{XY} - c_{YX}) & \text{, otherwise} \end{cases} \tag{4}$$

The degree of synchronization Q_{XY} would be between 0 and 1 and the index q_{XY} assumes a value of 0 for a synchronization with no preferred direction between X and Y, assumes a value of 1 when X precedes Y, and assumes a value of –1 when Y precedes X.

Building a network

In this work we use as nodes, for the dynamic networks, the 14 EU countries mentioned previously. For each node, a time series of MSCI indices is associated, $f(t)$, $t \in [0;T]$, where T is the total time of the period considered.

We apply the motif-synchronization method to the time series of each pair of nodes, and the connectivity index generated for each edge is subjected to a significance test. The significance test consists of comparing the synchronization generated with a threshold value Q_{th}. For example, if the degree of synchronization Q_{XY} between countries X and Y is equal or greater than the Q_{th}, this edge will be considered, that is, $a_{xy} \equiv 1$; otherwise, $a_{xy} \equiv 0$. At the end of this process, we obtain the adjacency matrix of the network.

This process is performed for a mobile time window W. When moving the window over the signal period the process repeats itself by generating new networks, thereby building the time-varying networks. Figure 1 illustrates the process.

The threshold synchronization value Q_{th} was obtained by the randomization process as defined in (Rosário et al.[51]).

Hub distribution

Hubs are the nodes that present their degree higher than the average of the network $\langle k \rangle$ by twice the standard deviation σ, or more precisely,

$$x^{hub}, \text{ if } k_x \geq \langle k \rangle + 2 \times \sigma \tag{5}$$

In financial networks, hubs can represent countries with the greatest influence in the whole financial market. In directed networks, hubs can also represent two important characteristics: the receiving and generating countries. Fostering countries are those that, during the dynamics of the system, receive more information flows and consequently are highly influenced by the market. Generating countries, on the other hand, have the flow of information in the opposite direction, thus exerting more influence on the global network. As the TVG method generates several networks over time, it becomes possible to check the number of times a node was a hub and thus generate the hub distribution.

Aggregated static network

Dynamic networks generate a huge amount of data from which we can extract information about the dynamics of the studied system. To extract the main characteristics and to optimize the statistical analysis of these data, some methods from the theory of TVG and complex networks are necessary. One of the most important and efficient approaches is the aggregated static network (ASN).

Let $G = \{G_t\}$ where $t = 1, 2, ..., T$ be a TVG and $A_G = \{A_t\}$ for $t = 1, 2, ..., T$ is the set of adjacency matrices of each graph G_t. The ASN of G is given by

$$A_G^{ASN} = \sum_{t=1}^{T} A_t \tag{6}$$

That is, the ASN is the network resulting from the sum of all adjacency matrices generated by the TVG method. Thus, A^{ASN} represents a weighted network whose edge weights w_{xy} denote the number of times the countries x and y were significantly synchronized along the TVG period T.

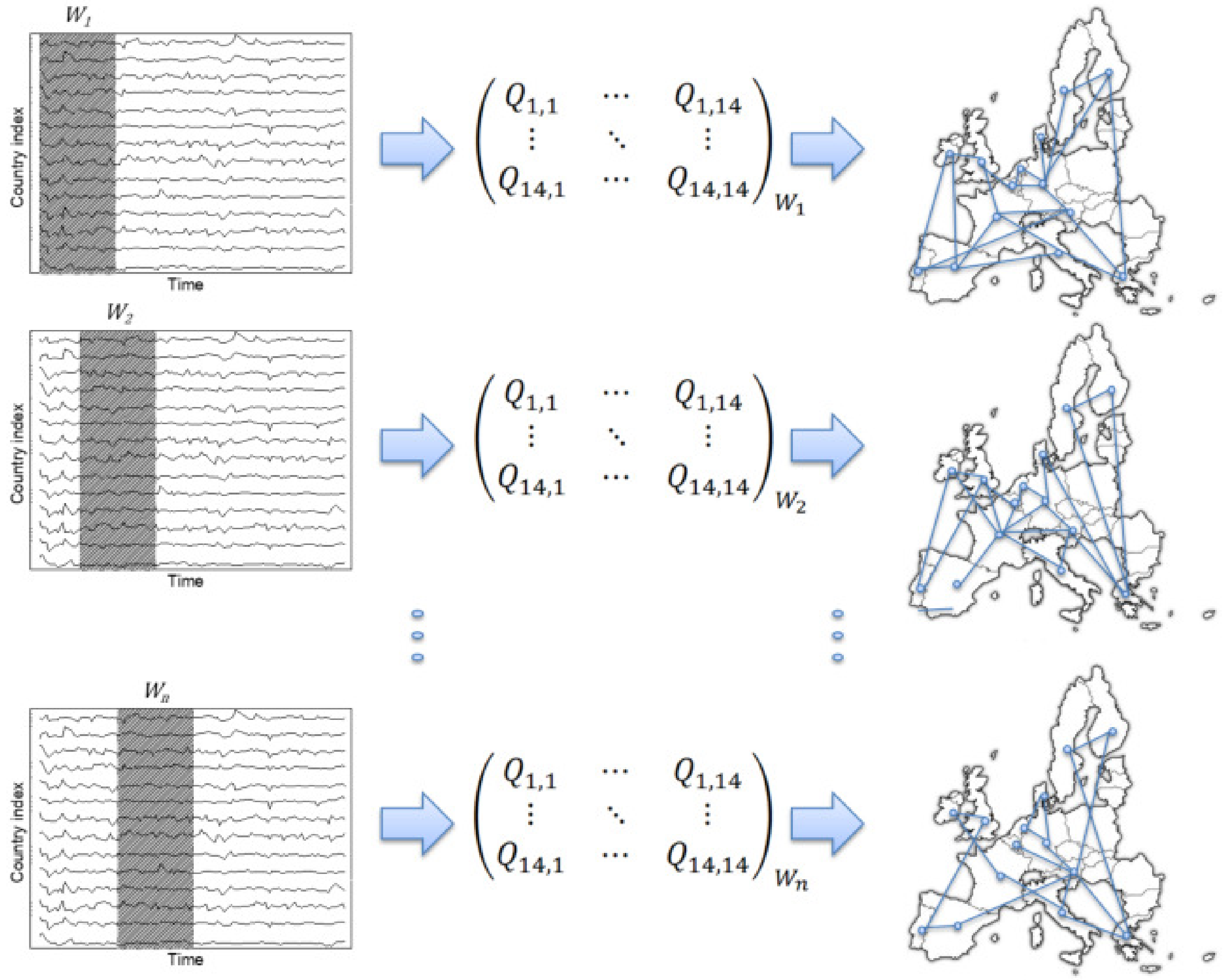

Figure 1. Application of the motif-synchronization method. For each window W_i, the method is applied, building a network for a given instant of time. By moving the window along the time series, the process repeats itself, thus generating the TVG.

Results

All networks were built for a temporal window W of fixed size equal to 7 days and with a threshold of $Q_{th} = 0.90$. In the motif-synchronization method, we adopted motifs of degree $n = 3$, lag $\lambda = 1$, and the delay time used was $\tau_n = 7$ days.

Three types of analyses were performed. First, we attempted to study the distributions of hubs to evaluate the countries that presented the greatest structural importance exercised in the dynamically constructed networks. Second, we compared the weighted degrees (level of temporal connectivity of each country) of the ASNs constructed. Finally, we used the indices, average degree, average clustering coefficient, average minimal path length, density, efficiencies, and their respective coefficients of variation to characterize the temporal evolution of the system throughout the evaluated period.

ASN results

We built an ASN for each analyzed period and we calculated the weighted degree of all the nodes of the network. Figure 2 shows the hub and weighted degree of each country for the different periods.

In Figure 2, we can observe that, according to the hub, before 2006-2007, although no particular pattern could be found, most of the predominance in the network is from Central and North European countries. Interestingly, during the 1990s, Portugal appeared several times in the top ranking, probably because of its recognized good economic performance. Greece also appears in the end of the 1990s and the beginning of the new century, after its acceptance on the Eurozone. Since 2008-2009,

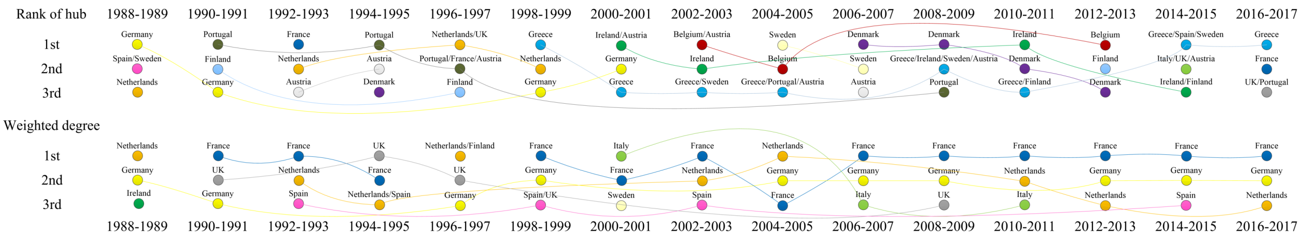

Figure 2. Hub and weighted degree in descending order.

the Greek stock market is the one which appears most times in the top of the hub, and in this case accompanied by other countries which were most affected by both crisis: Ireland and Portugal with major problems and Spain with minor ones. In relation to the weighted degree, the predominant stock markets are mostly Central European countries, like France, the Netherlands, and Germany.

These results are certainly related to the economic and financial situation of the EU in recent years, in particular the sovereign debt crisis that mostly affected the Eurozone. After the creation of the single currency, countries that are generally small will begin to have a greater presence in the remaining network; see, for example, the continuous rise in weight, as an influencer, of the Greek and Portuguese stock markets. The sovereign debt crisis had a major impact on the way that stock markets networked, with Greece and Portugal clearly emerging.

Network general indices

For the characterization of the dynamic networks throughout the considered periods, we calculated the time averages of the global and local efficiency, the average degree, the clustering coefficient, and the minimum mean path. Figure 3 shows the temporal evolution of global and local efficiency.

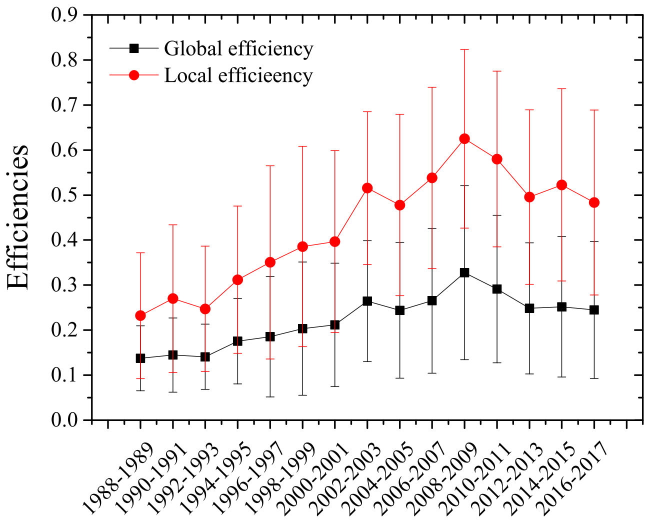

Figure 3. Global efficiency (black) and local efficiency (red) throughout each analyzed period. The error bars represent the standard deviation of the index.

Figure 4 shows the temporal evolution of the clustering coefficient and the average path length. Figure 5 shows the temporal evolution of the average degree.

As can be observed, both global and local efficiency, the clustering coefficient, and the average degree showed a very similar behavior, demonstrating an increase in the network connectivity up to a peak in the period 2008–2009, declining in the following periods. Comparing this increase in connectivity with the evolution of the average minimal path length in Figure 4, we can observe a network trend to a small-world topology, that is, a typical community network of high robustness and transitivity. To better analyze this effect, we can observe the phase space between the average clustering coefficient (C) and the average minimal path length (L) in Figure 6.

Figure 6 shows that with the growth of C, in general, L decreases. Although small, there is a tendency against this effect

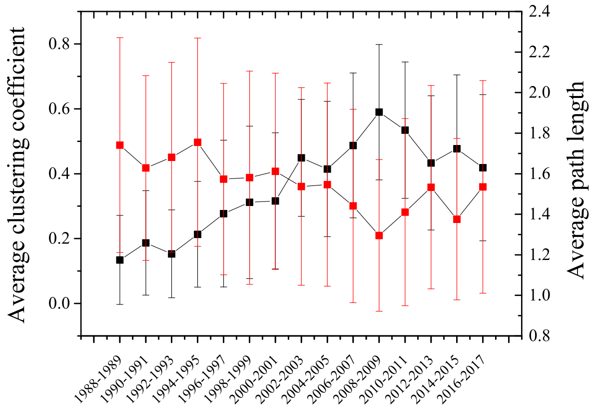

Figure 4. Average clustering coefficient (black) and average minimal path length (red) throughout each analyzed period. The error bars represent the standard deviation of the index.

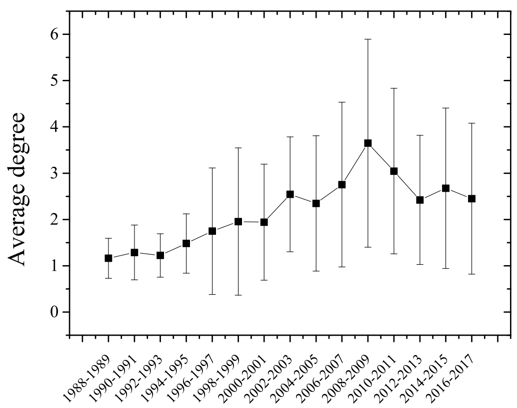

Figure 5. Average degree over each analyzed period. The error bars represent the standard deviation of the index.

in the periods 1992–1995 and 2000–2003, which may represent a qualitative influence of some important historical facts on the evolution of the network. Historically, the first period is related to the signing of Maastricht Treaty in 1993 and thus the formation of the single market in the EU, which has made Europe a market with free movement of capital with a direct influence on stock markets. On the other hand, the following time period coincides with the moments immediately following the creation of the single currency in 1999.

To analyze the stability of the network, under different issues, we calculated the coefficient of variation of each index for all periods, which can be observed in Figure 7.

The coefficient of variation of the degree (K_{cv}) and the global efficiency (GE_{cv}) presented a similar behavior, with a peak in the period 1996–1999 and values, in periods from 2000, higher than the average from 1988 to 1995. It is important to note that even though the behavior of K_{cv} and GE_{cv} varies, the coefficient of variation of local efficiency (LE_{cv}) also shows a visible peak of instability in the period 1996–1999, which may be associated with the period before the creation of the Euro. The coefficient of variation of the average minimal path length (L_{cv}) does not show large changes, being approximately constant over time. A reduction of the average clustering coefficient (C_{cv}) and the local efficiency variation (LE_{cv}) can be observed until the period 2008–2009 and then an increase of both, demonstrating that the network was in a tendency to increase connectivity and change after the crisis of 2008–2009, reducing its connectivity later.

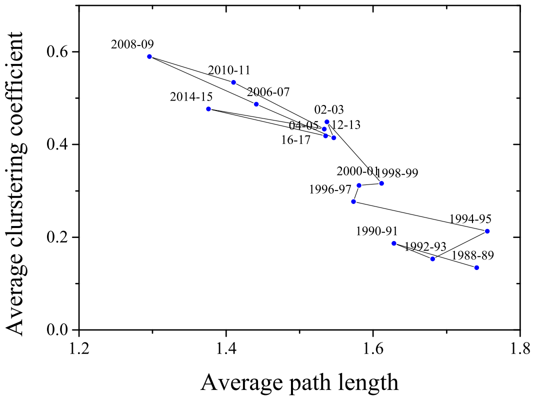

Figure 6. Evolution of the system from the perspective of the average clustering coefficient and the average minimal path length.

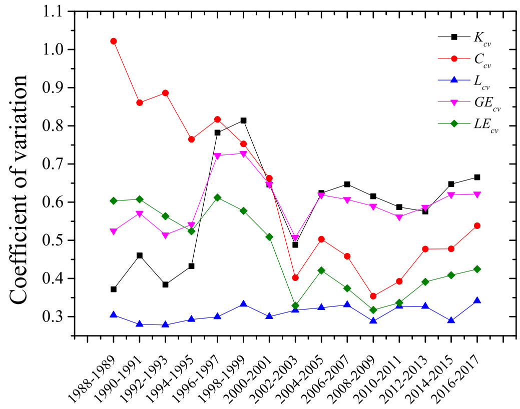

Figure 7. Coefficients of variation by period of the indices evaluated: K_{cv}, average degree; C_{cv}, average clustering coefficient; L_{cv}, average minimal path length; GE_{cv}, global efficiency; and LE_{cv}, local efficiency.

Conclusions

This paper has proposed an approach to analyze EU stock markets using dynamic networks. The application of TVG, jointly with motif synchronization, has enabled the characterization of the level of connectivity of each index of the network. We found that France, the Netherlands, Germany, and the UK were the countries that presented the highest weighted degree in the majority of the ASN, that is, they remained synchronized with the remaining network countries most of the time.

In particular, the results allow us to conclude that the countries of Central Europe (France, the Netherlands, Germany, and the UK) have the highest weighted degree of the network. Regarding countries that have become hubs, it is worth mentioning the change pattern in the hubs, passed mainly from Central European countries before the crisis to countries which are in the most affected ones after the subprime crisis and those which are in the origin of the Eurodebt crisis. In fact, since 2008-2009 Greece dominates the rank of hub, with some relevance for Ireland and Portugal.

Another result is that the network formed between the indices of the countries in the EU increased its connectivity constantly from 1988 up to 2008 and 2009, years in which the subprime crisis occurred and, following this, the connection diminished, indicative of contagion as there was a change in properties (clustering coefficient, path length, and local efficiency). This result is in line with that found by Tabak et al.[43] and Yan et al.[47], demonstrating that an exogenous shock tends to make the network less dense, and with that of Acemoglu et al.[46], who found that a connected financial network is more susceptible to exogenous shocks than a sparse network.

Therefore, this paper intends to collaborate with the study of financial interconnections in the EU from 1988 to 2017, observing its dynamics and stability. In this sense, the stability of the financial network of the main exchanges in this region can help in macroprudential policies, as there is a monitoring of the financial interconnections between the different markets that make up the EU by the agents that make up the financial system. This area is an essential region for the solvency and liquidity of financial markets and any instability that may occur in it can have a major effect on international finances.

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Acknowledgements (not compulsory)

Paulo Ferreira is pleased to acknowledge financial support from Fundação para a Ciência e a Tecnologia (grant UID/ECO/04007/2013) and FEDER/COMPETE (POCI-01-0145-FEDER-007659). We are grateful for the financial support granted by the Fundação de Amparo a Pesquisa do Estado da Bahia – FAPESB (Termo de Outorga de Bolsa N^{o} BOL 0261/2017. JGVM was supported by a CNPq Research Grant (no. 306571/2011-0).

Author contributions statement

HBBP, RSR, EJALP, DMM, PF and JGVM contributed equally (i.e. conceived and conducted the experiment, and analyzed the results) to this work.

Additional information

The author(s) declare no competing interests.

Capítulo Sete

Redes e Insumo-Produto

7.1 Sobre o artigo

Ao analisarmos as inter-relações setoriais estaticamente, perdemos informação relativa à tendência, influência de choques exógenos ou predição de possíveis comportamentos. Nesse sentido, foi encontrado na literatura uma falta de estudos envolvendo grafos variantes no tempo e análise Insumo-Produto. Com isso foi proposto um modelo de análise de grafos variantes no tempo e IP. Com eles foi possível identificar os impactos de choques exógenos nas inter-relações setoriais brasileiras, podendo ser identificados quais setores são os mais centrais ao longo do tempo e como se comportaram as inter-relações setoriais antes e após a crise de 2008.

A quarta contribuição da tese foi a aplicação das redes variantes no tempo construídas a partir da matriz de insumo-produto para analisar os efeitos da crise de 2008 nas inter relações setoriais na economia brasileira. Segue o artigo (PEREIRA HERNANE BORGES DE BARROS, 2020):

Assessing productive structures in Brazil with dynamic time varying graphs

Hernane Borges de Barros Pereira[1], Luiz Carlos de Santana Ribeiro[2*], Eder Johnson de Area Leão Pereira[3], Roberto Luiz Souza Monteiro[1], Valter de Senna[4&].

[1] Programa de Modelagem Computacional, SENAI Cimatec, Av. Orlando Gomes 1845, Salvador, BA, Brazil. Universidade do Estado da Bahia, Rua Silveira Martins, 2555, Salvador, BA, Brazil.

[2] Departamento de Economia, Universidade Federal de Sergipe, Avenida Marechal Rondon, s/n, São Cristóvão, SE, Brazil.

[3] Programa de Modelagem Computacional, SENAI Cimatec, Av. Orlando Gomes 1845, Salvador, BA, Brazil. Departamento de Ensino Profissional, Instituto Federal do Maranhão, Bacabal, MA, Brazil.

[4] Programa de Modelagem Computacional, SENAI Cimatec, Av. Orlando Gomes 1845, Salvador, BA, Brazil.

[*]Corresponding author. Email: ribeiro.luiz84@gmail.com.

[&] These authors contributed equally to this work.

Abstract

This paper proposes a different view based on time varying graphs to evaluate productive structures in Brazil. We use annual Brazilian matrices from the World Input–Output Database for the period 1995–2011. The main results show two different macroeconomic effects: (i) possible positive impacts of macroeconomic policies and higher commodity prices on increased network connectivity between 2002 and 2003; and (ii) the negative influence of the 2008 crisis, which resulted in decreased network connectivity. In the first period, the beginning of the commodity cycle associated with new macroeconomic policies may have positively influenced, in part, Brazil's intersectoral dynamics. In contrast, in 2009, the deleterious effects of the global economic crisis of 2008 may have contributed to a reduction in intersectoral relations in Brazil.

Keywords: Brazilian economy; input–output network; time-varying graph.

1. Introduction

Econophysics is the use of complex systems in economic studies (Carbonne et al., 2007; Jovanovic and Schinckus, 2017; Mantegna and Stanley, 1999; Pereira et al., 2017; Schinckus, 2013). It is an approach that has advanced both the identification of economic problems and attempts to solve them. According to Pereira et al. (2017), network theory is among the subareas that have contributed to econophysics. Schweitzer et al. (2009) defined the importance of network theory to the economy, since in networks, it is possible to study properties such as time and space, structure identification, and systemic feedback, providing a novel approach to assessing the productive structure of countries or regions.

The seminal study of network theory and production was conducted by Solow (1952), who analyzed aggregate fluctuations. Bak et al. (1993) later showed the importance of inputs and the supply chain in diffusing shocks between aggregate sectors. In the last two decades, interest in network theory and improvements in computation have enabled the development of several network analysis methods and the discovery of new network properties.

In the input–output (IO) field, a recent advance that has allowed hypotheses to be more flexible and has reinforced results is integration with other models, such as linear programming (Hristu-Varsakelis et al., 2012; San Cristóbal, 2012; Souza et al., 2016), econometric models (Kim et al., 2015; Kratena and Temursho, 2017) and complex networks (Carvalho and Gabaix, 2013; Cerina et al., 2015; Tsekeris, 2017). Specifically, Acemoglu et al. (2012) and Carvalho (2010) have used network theory to analyze the problem of aggregate fluctuations in macroeconomics. Cerina et al. (2015), using a world IO database, analyzed the inter-industry relations of several countries through calculations of PageRank centrality and community coreness. In addition, Río-Chanona et al. (2017) evaluated trade relations among 40 economies, and found a strong correlation between the three major economies (United States, China and Germany), indicating a high centrality between trade relations.

Recent research involving trade relations between several countries has used networks that emphasize the role of centrality (Blöchl et al., 2011; Xing et al., 2017) and country-specific assessments (He et al., 2017; Tsekeris, 2017; Xu et al., 2011). It is important to highlight that other studies have also analyzed production, but not necessarily using IO matrices (Atalay et al., 2011; Hidalgo and Hausmann, 2009; Ohnishi et al., 2010; Xiao et al., 2017).

Integrating IO models into network theory is even more interesting when applied to complex productive structures, as seen in Brazil. Moreover, results improve considerably if the database used covers a long period of time, because it can account for important factors, such as structural and governmental changes. This study intends to develop an analysis of Time Varying Graphs (TVG) to evaluate the evolution of the Brazilian productive structure, considering the varying sector relationships over time. As far as to our knowledge, this type of approach has never been applied before in this context. Thus, it is possible to measure the impacts of economic events such as financial crises or macroeconomic policies on the properties of the networks or the interconnection between economic sectors. To this effect, we use a network analysis of annual Brazilian IO matrices for the period 1995–2011.

Brazil had suffered many important changes in terms of economic and political perspectives in the analyzed period. The 1990s were marked by many profound changes in the Brazilian economy, including trade and financial openness at the beginning of the decade, the privatization of public companies, and price stabilization in 1994, ending with a new macroeconomic policy resulting from an exchange rate crisis (Moreira and Ribeiro, 2013). In the 2000's, neoliberalism began to weaken, and public investments in strategic infrastructure sectors resumed. Furthermore, income-transfer-based social programs, in conjunction with other measures, had a positive impact on decreasing regional inequalities in Brazil (Ribeiro et al., 2018; Silveira-Neto and Azzoni, 2011; 2012).

Since there are no annual input-output tables available from the national statistical offices, we are using the national WIOD table for Brazil. The Brazilian statistical office has published IO matrices for the following years: 1995, 2000, 2005, 2010 and 2015. However, these matrices are not compatible because their construction is based on different methodologies of the System of National Accounts (SNA).

The main contributions of this paper are: (i) a novel method for evaluating productive structures using TVG; (ii) an assessment of the macroeconomic policies introduced by different governments over time; and (iii) a contextualized analysis of strongly linked sectors. All of these topics could be generalized to any other country. The remainder of this paper is organized as follows. The next section presents fundamental concepts of the IO model and network. The third section explains our proposed method, and the fourth contains our main results and discussion. The last section includes our final remarks and future research agenda.

2. Fundamental concepts of input–output models and networks

2.1. The input–output model

The IO model, developed by Leontief (1966), represents a snapshot of the economy at a given moment (Miller and Blair, 2009). More specifically, according to Prado (1981), an IO model is a linear production model in which an economic system is simplified into matrices of intersectoral flows of inputs and outputs. In summary, traditional IO analysis considers a system of linear equations, where each sector combines a set of inputs from other economic sectors to produce a given output. We must obtain a vector x_j that indicates the total production value of each sector j. For that, we use the equation $x = Bf$, where B is a Leontief inverse matrix and f is the final demand vector.

The Leontief inverse matrix is calculated by the equation $B = (I - A)^{-1}$, where A is the technical coefficient matrix given by $A = a_{ij} = \frac{z_{ij}}{x_j}$ and z_{ij} is the trade between sectors i and j. Each element of the Leontief inverse matrix b_{ij} should be interpreted as the total output of sector i that is required for producing a final demand unit of sector j. Once obtained, we interpret the IO matrices (supposing we have T matrices, one for each time $t = 1, 2, 3, \dots, T$) as weighted matrices and use them to build IO networks that vary over time. An IO network can describe the connection weights between sectors of the economy.

We use IO tables at current basic prices, because the construction of our time varying graphs is based on the Leontief Inverse coefficients. The main point of our work is to capture the structural relationship in a given year, therefore the use a price index could affect these relationships.

When we use Structural Decomposition Analysis (SDA), for instance, we have variables interaction for at least two different years and, because of that, it is important to use constant prices instead of current prices (Miller and Blair, 2009, p. 307-308). According to these authors, there are two main reasons we can justify the use of current prices: i) if prices of all (or most) inputs to j has increased between two time periods it is expected the output of sector j also increases, which implies a compensation movement between numerator and denominator of the coefficient a_{ij}. Therefore, current price coefficients tend to be more stable than constant price coefficients (Tilanus and Rey, 1964; Miller and Blair, 2009; Shishido et al., 2010); and ii) due to the sectoral aggregation, i.e., sectors produce a wide range of goods. Thus, it would be very difficult to have a sectorial deflator so good as to ensure that the structural relation at constant prices was maintained.

Dietzenbacher and Temurshoev (2012) have shown for Denmark economy that current and constant prices methods provide very similar results in an aggregate level such as gross output and employment. In a sectoral level, however, the differences were large.

2.2. Graphs and networks

In general, a nondirected graph or network consists of a set of vertices and a set of edges that connect the vertices. Mathematically, we can use the following notation to describe graph $G = (V, E)$, where V is a finite and nonempty set of vertices, and E is a set in which binary relations on V are defined. Thus, an edge can connect one or two vertices. Nevertheless, when an edge is directed, we have an arc or an ordered pair of vertices. Our IO networks are directed networks. In this case, we have a directed graph or digraph $G = (V, A)$, where V is a finite and nonempty set of vertices, and A is a set of ordered pairs of vertices of V. A weighted and directed network can be represented by an $n \times n$ cost matrix $W = \{w_{ij}\}$. If $w_{ij} = 0$, there is no directed connection between *i* and *j*, but a directed connection between *j* and *i* may exist, if $w_{ji} \neq 0$. The weighted and directed IO networks used in this paper are composed of positive weights; thus, $w_{ij} > 0, \forall\ i, j$. According to Carvalho and Salehi (2018, p. 3):

> The input-output linkages between various industries can alternatively be represented by a weighted and directed graph on *n* vertices. Each vertex in this graph — which we

> refer to as the economy's production network —corresponds to an industry, with a directed edge with weight $a_{ij} > 0$ present from vertex *j* to vertex *i* if industry *j* is an input-supplier of industry *i*.

Due to the lack of standardization in the formalization of some network properties, we present a short glossary of properties used in this paper:

- The number of vertices $n = |V|$ is given by the cardinality of the set of vertices.
- The number of arcs $m = |A|$ is given by the cardinality of the set of arcs.
- The degree of vertex i is denoted by k_i and consists of the number of edges connecting vertex i.
- The average degree of a directed network is given by $\langle k \rangle = \frac{1}{n}\sum_{i=1}^{n} k_i$. For directed networks, we calculate the average of the input and output degrees.
- Let us consider that $\Gamma(i)$ is the neighborhood of vertex i. The weighted degree of vertex i is given by the sum of the weights of all in-or-out arcs connected to vertex i, $k_{wi} = \sum_{j \in \Gamma(i)} [w_{ij} + w_{ji}]$.
- The weighted average degree is given by $\langle k_w \rangle = \frac{\sum_{i=1}^{n} k_{w_i}}{n}$
- The average clustering coefficient of the network vertices is $C = \frac{1}{n}\sum_{i=1}^{n} C_i$. C_i is the clustering coefficient of vertex i and measures the proportion of existing edges between neighbors of vertex i, denoted by E_i. The maximum possible number of edges is $\frac{n(n-1)}{2}$.
- Average minimal path length is the average geodesic distance and is given by $L = \frac{1}{n(n-1)}\sum_{i \neq j} d(i,j)$, where $d(i,j)$ is the shortest path between vertices i and j.
- The diameter is the longest shortest path between two vertices in a network, denoted by max $d(i,j)$.

- The density of a directed network is given by $\Delta = \frac{m}{n(n-1)}$ and consists of the total existing arcs *m*, divided by the maximum possible number of arcs $n(n-1)$.
- Global efficiency is defined by Latora and Marchiori (2012) as $E(G) = \frac{1}{n(n-1)} \sum_{i \neq j \in G} \frac{1}{d(i,j)}$, where $d(i,j)$ is the average minimal path length between *i* and *j*. Local efficiency is defined as $E_{local} = \frac{1}{n} \sum_{i \in G} E(G_i)$, where $E(G_i)$ is the efficiency of the local subgraph G_i (i.e. neighborhood of i) with $i \notin G_i$.

In order to avoid any confusion with the use of variables, we recall the use of L as a variable of the average minimal path length and B as Leontief inverse matrix.

2.3. Time-Varying Graphs and Networks

Time Varying Graphs (TVGs) or graphs that evolve over a specific period are also called dynamic networks, in which edges or arcs appear and disappear over time for a set of vertices. This kind of network shows relationships that change over time; we can therefore capture the dynamics of the network and model them using "time-ordered sequences of graphs over a set of nodes" (Nicosia et al., 2013). In other words, such as in Ferreira (2004), the dynamics is viewed by a sequence of static graphs.

We use the formalism for TVGs proposed by Casteigts et al. (2012). A TVG is described as $\mathcal{G} = (V, A, \mathcal{T}, \rho, \zeta)$, where *V* is the set of vertices, *A* is the set of arcs connecting pairs of vertices of *V*, $\mathcal{T}$ is the time interval used to analyze the system, ρ is the presence function ρ: $A \times \mathcal{T} \rightarrow 0, 1$, and ζ is the latency function that indicates the time required to form arcs.

Within this context, $\mathcal{G}$ is the time-varying IO network $\mathcal{G} = (V, A, \mathcal{T}, \rho, \zeta)$, where $V = \{v_1, v_2, \ldots, v_n\}$ consists of the set of sectors of the Brazilian productive structure based on IO models; $A = \{a_1, a_2, \ldots, a_m\}$ is the set of IO relationships between Brazilian economic sectors at a given time; $\mathcal{T}$ is the time interval starting in 1995 and ending in 2011 (i.e. $|\mathcal{T}| = 17$), $\mathcal{T} =$

$\{t_1, t_2, \ldots, t_i, t_{i+1}, \ldots, t_{|\mathcal{T}|}\}$; ρ indicates the existence or absence of the IO relationship between two sectors at a given time ($t_i \in \mathcal{T}$) and the IO relationships that can be removed or included according to the use of a filter associated with the arc weights; in this work, we ignore latency function ζ because the IO arcs possess null latency. Finally, it is important to highlight that all sectors are present during time interval $\mathcal{T}$.

A filter is just a criterion adopted in order to make the network less polluted and improve the analysis. Economically speaking, we are taking into account the most important relationships between sectors. Otherwise, the network would have all possible arcs.

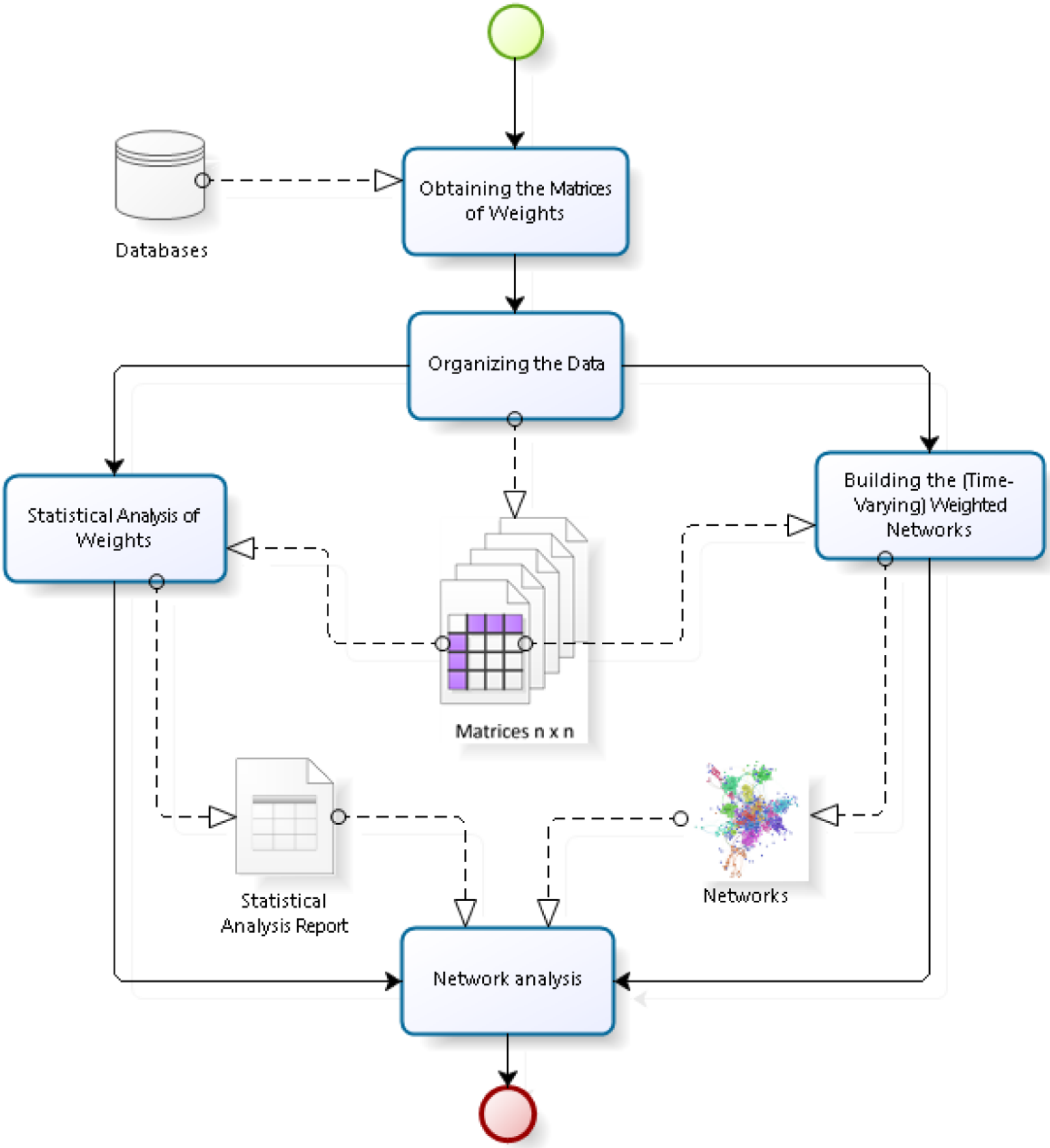
Because TVG can describe several different scenarios, from transport networks (Santos et al., 2018) to neural networks (Rosário et al., 2015), we have used its formalization to model and analyze the Brazilian productive structures in a TGV perspective. Some works, such as Holme and Saramäki (2012), present a variety of relevant examples of temporal networks.

3. Materials and proposed methods

In this work, we use annual Brazilian IO matrices. Fig 1 summarizes the general framework of the proposed method, which consists of five processes. The processes will be described in detail below:

- Obtain the weight matrices
- Organize the data
- Statistically analyze the weights
- Build the (time-varying) weighted networks
- Analyze the networks

Fig 1. General framework of the proposed method for building and analyzing a time-varying weighted network



The first process in the general framework for building and analyzing a time-varying weighted network is obtaining the weight matrices. We use the annual Brazilian IO matrices obtained from the World Input–Output Database (Timmer et al., 2015) for the period 1995–2011 with 35 economic sectors [http://www.wiod.org/database/wiots13]. We have aggregated Sector 35, “Private Households with Employed Persons,” into Sector 34, “Other Community, Social, and Personal Services”. The main advantage of this database is the availability of compatible annual matrices for a group of 40 countries during this period. In our case, each year is equivalent to an instance of time *t*. We are doing a national analysis using a global database because there are no national and annual IO matrices available in Brazil for the period 1995-2011.

The second process is organizing the data. Here, we consider the statistical and network tools used to perform our analysis and build the IO networks, from yearly IO matrices for the analyzed period.

We define the filter to be used in IO networks in the third process based on a statistical analysis of the weights.

In the fourth process, we build the (time-varying) weighted networks, using the IO matrices mentioned in the second process.

Finally, in the fifth process, we carry out the network analysis to find the network properties and characterize the topology of Brazilian economic sectors given economic and political events.

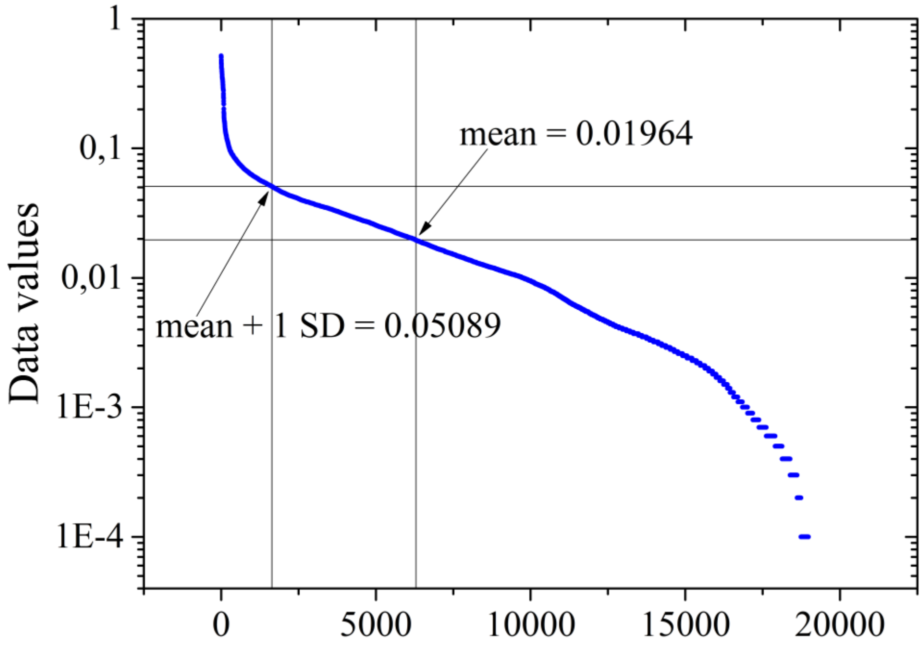
3.1. Statistical analysis of weights

An IO Network is associated with a specific IO matrix. In this context, for each year, we have an $n \times n$ IO matrix with which we build a time varying network based on the annual tables. Let us consider that each static IO network is nonsymmetric (i.e., $w_{ij} \neq w_{ji} \geq 0$). Although there are loops in the IO network, we do not consider them. That is we exclude intrasectoral relations (i.e., all elements on the main diagonal of each matrix). In addition, it is important to highlight that the weighted and directed IO networks used in this paper are composed of positive weights (i.e., $w_{ij} > 0$).

Various approaches have been used to establish a filter, i.e., the edges or arcs that are considered in network analysis. For example, Carvalho (2010) summed the total transactions of a single sector and considered only relations greater than 1%, whereas Blöchl et al. (2011) considered transactions greater than 1 billion and 500 million USD, respectively. Acemoglu et al. (2012) and Tsekeris (2017) used the mean and the mean plus one standard deviation, since they believed that standard deviation would capture the volatility or aggregate shocks in the economy.

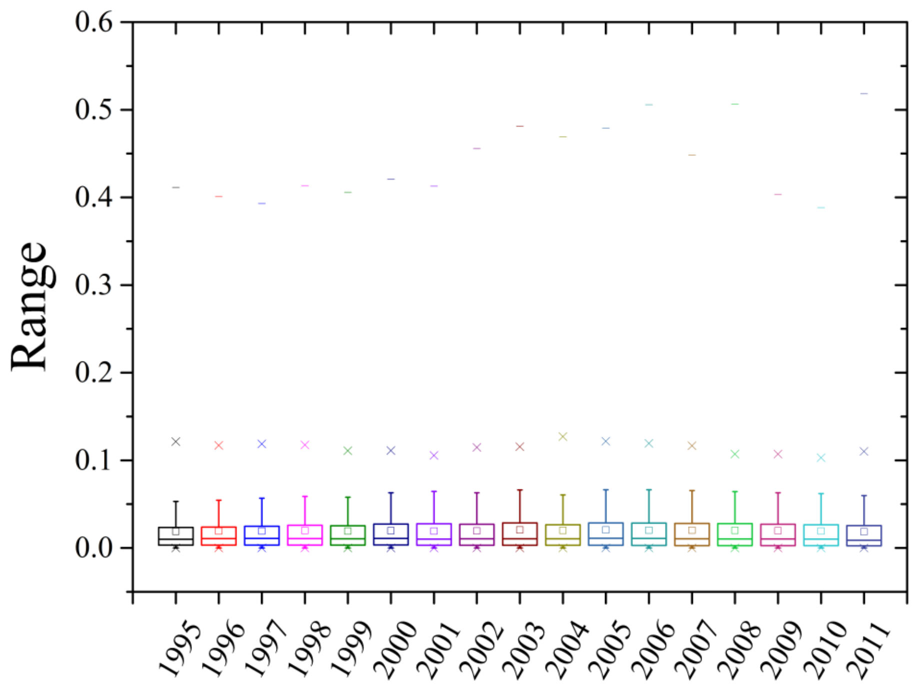
In our case, we chose to adopt the mean plus one standard deviation as this would discard mostly irrelevant information. In Fig 2, we show a histogram of 19,074 weights (i.e., the Leontief inverse coefficients between sectors i and j for $i \neq j$) of Brazil's IO matrices. As indicated with arrows in Fig 2, we found $\langle w \rangle = 0.01964$ ($\sigma = 0.03125$) and the $\langle w \rangle + 1\sigma \approx 0.051$. For this set of data, we use the $\langle w \rangle + 1\sigma$ as a filter to be applied to select the arcs used in network analysis. Thus, we account for the most relevant data to analyze and assess the macroeconomic shocks from a time-series static IO networks perspective.

Fig 2. Histogram of all records of the Brazilian IO matrices from 1995 to 2011. The numbers represent the Leontief's inverse matrix coefficients.



The adopted criterion of using the average weight plus one standard deviation (i.e. $\langle w \rangle + 1\sigma$) of the links as a pruning filter for the arcs is well founded in the literature (e.g. Tsekeris, 2017), and it is also supported by an analysis over time (Fig 3). We see that there is not much fluctuation and it seems reasonable to argue that this is evidence that it is not necessary to use some alternative "varying threshold" approach. As we can see in Fig. 3, the data variability is small from year to year.

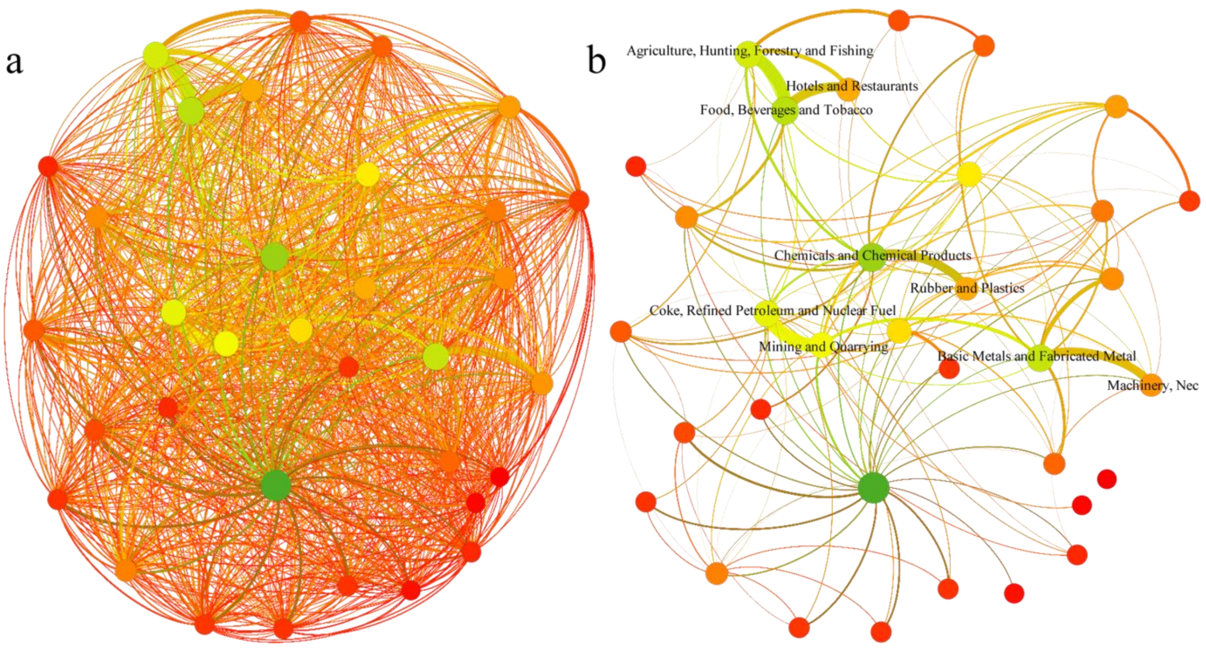
Fig 3. Boxplot of each records of the Brazilian IO matrices from 1995 to 2011, where the dash (—) represents maximum and minimum values of the Leontief's inverse matrix coefficients for each year; the cross (×) represents 99% and 1% percentile of the same data; the little square (☐) represents the mean value.



3.2. Building the aggregate static IO network

In Fig 4, the aggregate static IO network is shown both without (Fig 4a) and with (Fig 4b) the filter $w_{ij} \geq 0.051$. As already said, we consider the average of the all Leontief Inverse matrix's elements for all time windows (17 years). We observe a general pattern related to the connection strength of some sectors of the economy, which we discuss later.

Fig 4. Aggregate static IO networks (a) without filter and (b) with filter $w_{ij} \geq 0.051$. Vertices (i.e. sectors) with higher weighted degree values are painted green, those with lower weighted degree values are painted red, and those with intermediate values are painted with intermediate colors between green and yellow and between yellow and red.

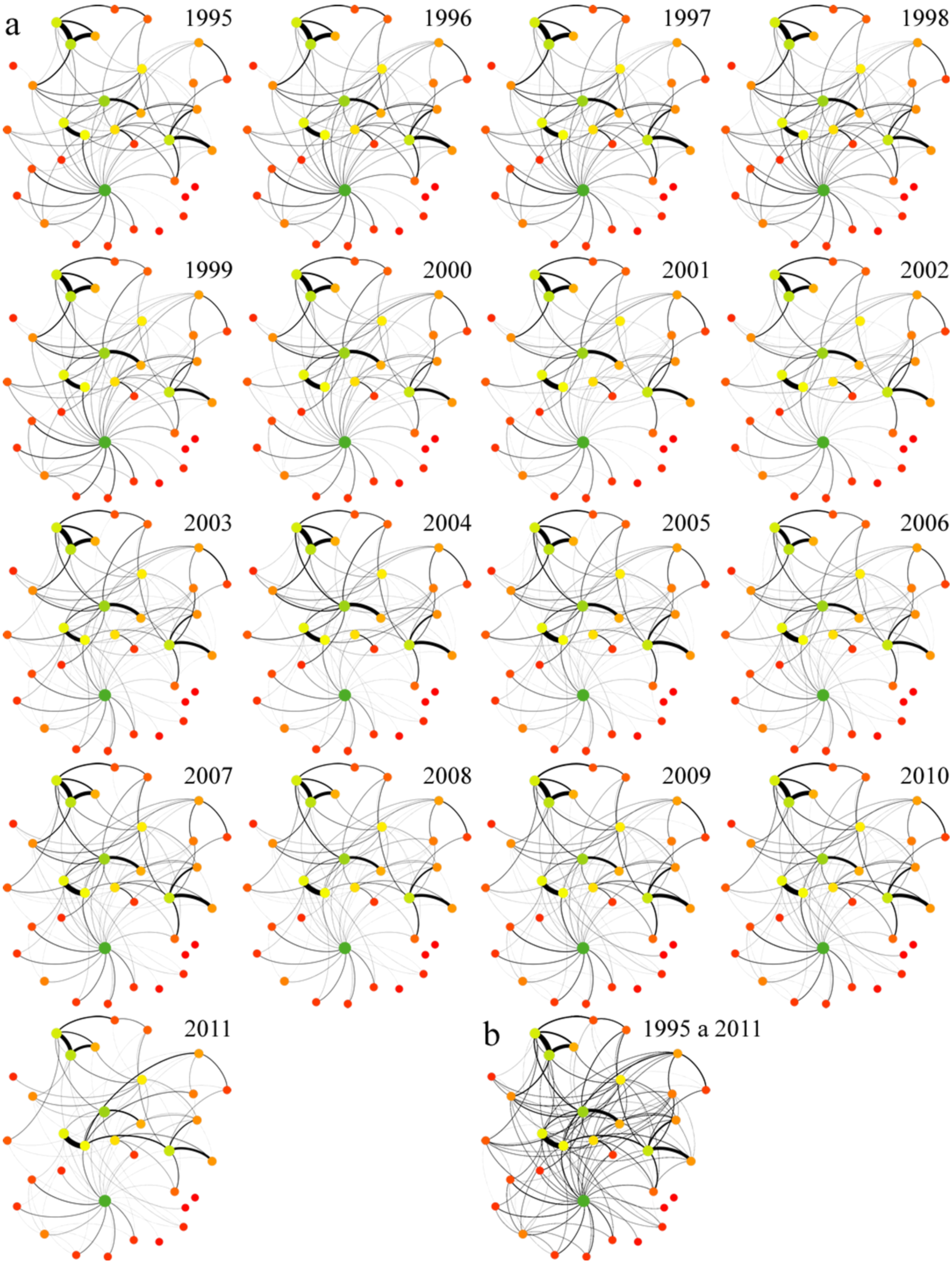


3.3. Building the time-varying IO network

To analyze the dynamics of the IO network, we consider three criteria: (i) the establishment of a filter based on our statistical analysis (previously discussed); (ii) the inclusion of temporal data, to analyze each static IO network separately; and (iii) the analysis of the dynamics of the IO network. We have also carried out topological analysis for each static IO network.

For each instance of time t, we have an $n \times n$ matrix (Fig 5). In Fig 5a, we show the filtered seventeen static IO networks, and in Fig 5b, we present the aggregated filtered static network. In both figures, we have applied the filter $\mathrm{w_{ij}} \geq 0.051$ to select the arcs for use in the network analysis. Temporal data were included during data organization and building the (time-varying) weighted networks, i.e., the second and fourth processes in the proposed method, as explained in Section 3, allowing us to analyze each static IO network separately and to study the time-series static IO networks.

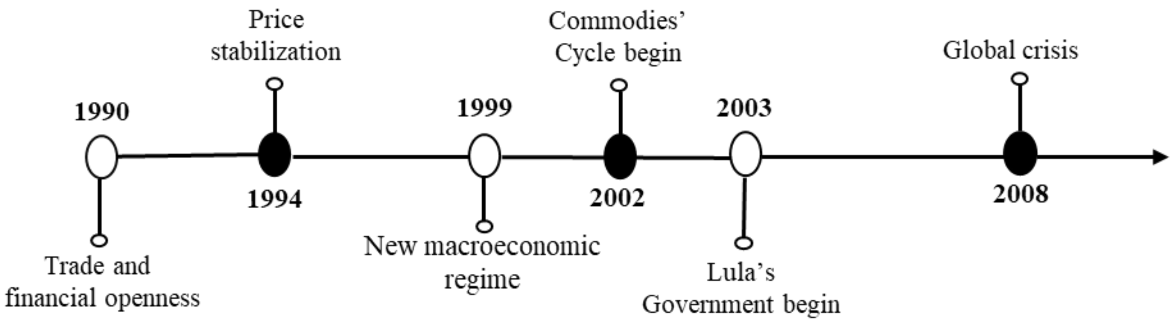
Fig 5. Static IO networks (a) and aggregated static network (b) with $w_{ij} \geq 0.051$. Vertices (i.e. sectors) with higher weighted degree values are painted green, those with lower weighted degree values are painted red, and those with intermediate values are painted with intermediate colors between green and yellow and between yellow and red.



4. Results and discussion

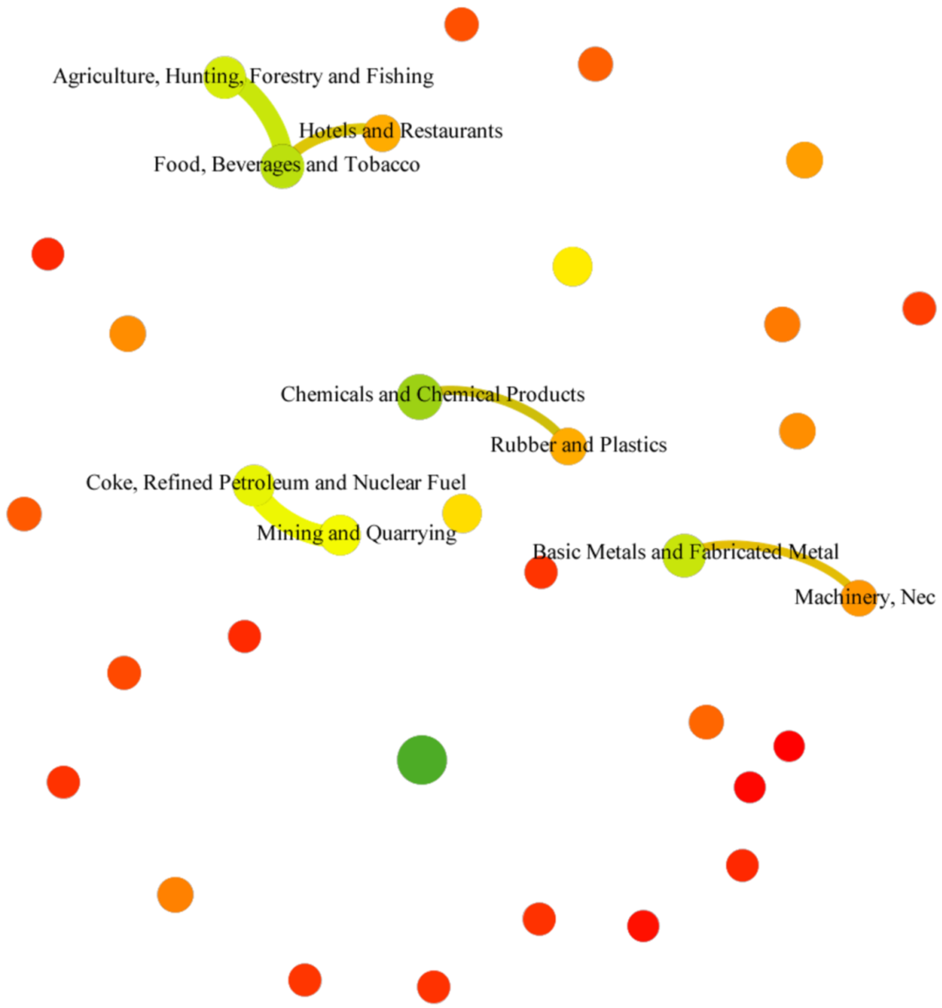
To facilitate our analysis, we present our results from two perspectives: (i) sectoral, through preeminence analysis that allows us to identify poles in the analyzed period, i.e., the sectors that represent the strongest and most important trade relations or linkages in the Brazilian productive structure; and (ii) macroeconomic, identifying the properties of the time-series static IO networks properties. In order to contextualize the analyzed period, firstly we present in Fig 6 the major events of the Brazilian economy which may be reflected in the results uncovered.

Fig 6. Timeline of major events in Brazilian economy



As we proceed, our results are shown to bear on the events listed by Fig 6. The behavior of the network is not homogeneous among the different sectors. Therefore, it is possible to identify of the strongest intersectoral relations of the Brazilian productive structure during the period 1995-2011. Fig 4b reveals the above-average trade ratios considering all the elements of the Leontief inverse matrices ($w_{ij} \geq 0.051$). In addition, Fig 7 shows the strongest trade relationships with above-average values ($0.2015 \leq w_{ij} \leq 0.3362$), considering the average of all the elements of the 17 Leontief inverse matrices. Economically speaking, Fig 7 aggregates the most important trade links during 1995-2011. In visual terms, these relationships are represented by thicker arcs between economic sectors.

Fig 7. Strongest linkages in the static IO aggregate networks (1995-2011). Vertices (i.e. sectors) with higher weighted degree values are painted green, those with lower weighted degree values are painted red, and those with intermediate values are painted with intermediate colors between green and yellow and between yellow and red.



In Fig 7, we clearly observe the formation of three distinct sectorial complexes: (i) food; (ii) petrochemical; and (iii) machinery and metal. The food complex has strong links with the Agriculture, Hunting, Forestry, and Fishing; Food, Beverage, and Tobacco; and Hotel and Restaurant sectors. Although the petrochemical complex shows strong trade relations, they occur between two groups of independent sectors: (i) Mining and Quarrying and Coke, Refined Petroleum, and Nuclear Fuel and (2) Chemicals and Chemical Products and Rubber and Plastics. It is important to emphasize that the first sector aggregates oil extraction activities, whereas the other activities are manufacturing-related. Finally, Fig 7 also reveals a strong trade relationship between Basic Metals and Fabricated Metal and Machinery, “not elsewhere classified” (Nec). Of the three sectorial complexes mentioned above, the largest are Hotels and Restaurants (Group i); Coke, Refined Petroleum, and Nuclear Fuel and Rubber and Plastics (Group ii); and Machinery, Nec (Group iii).

The aggregate IO network represented in Fig 7 (and in Fig 4b), differently from the simple IO analysis, shows the key trade relationships in Brazil in the period 1995-2011. This means these nine sectors, once stimulated from internal or external shocks, could propagate an impact to the whole Brazilian productive structure. It is important to highlight that the most important links (thicker edges) are from commodities sectors, i.e., Agriculture, Hunting, Forestry and Fishing and Mining and Quarrying, which ratifies the well-known Brazilian dependence in sectors of low technological intensity.

In Fig 8, we highlight the behavior of the most important sectors based on the strongest linkages in the static IO aggregate networks, considering the weighted degree, clustering coefficient and minimum path length. We can see in Fig 8 a very different behavior in relation to the sectoral indicators, i.e., weighted degree, clustering coefficient and the minimum path length. The first metric can be interpreted as weighted intersectoral relations, capturing the weight of trade relations between sectors. It is important to highlight that price effect cannot captured in the analysis.

Fig 8. Behavior of the most important sectors with respect to influence over the analysis period (1995-2011) as represented by the average weighted degree, clustering coefficient and minimum path length.

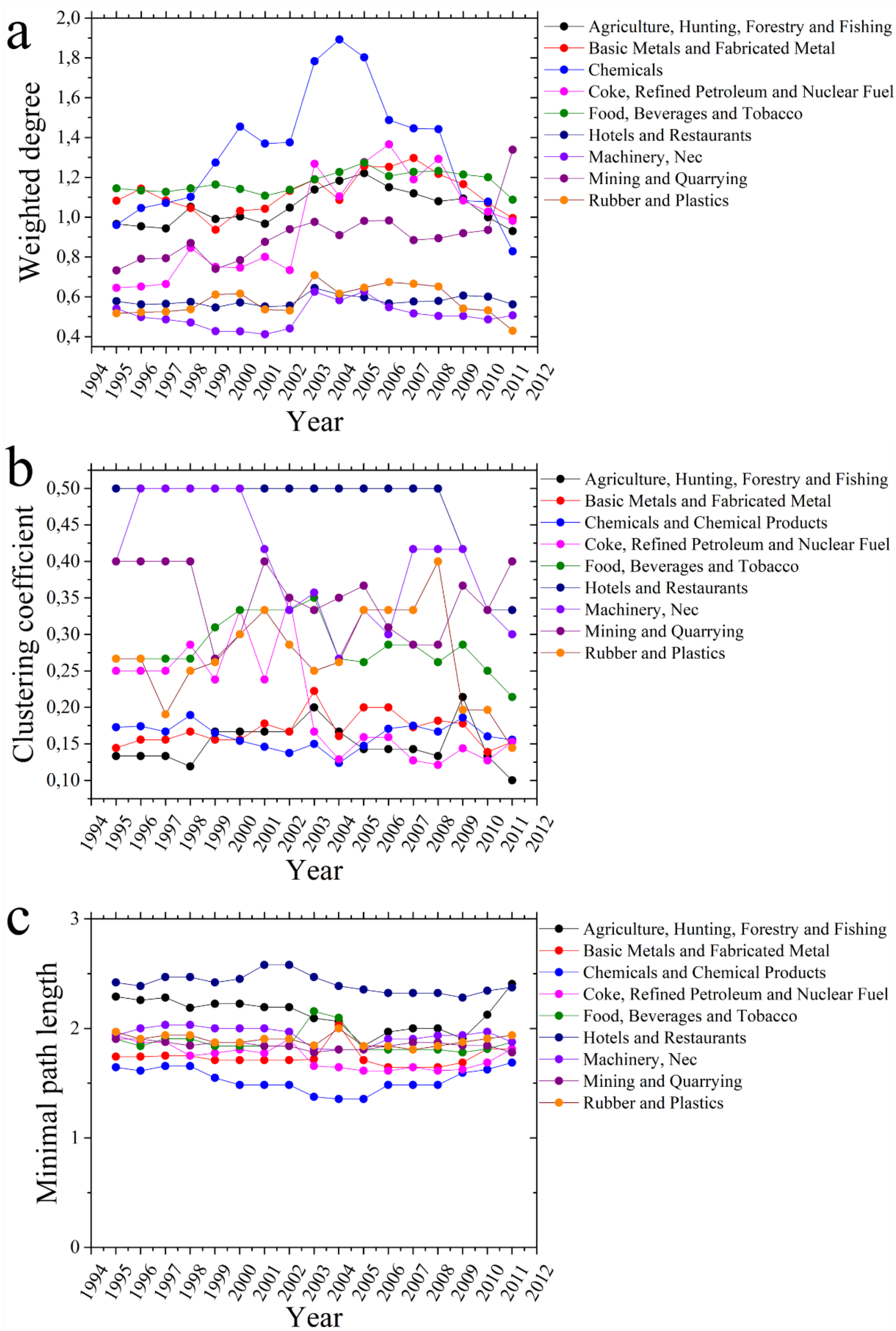


Fig 8a illustrates a completely different dynamic between these nine sectors over time considering the weighted degree. Three groups are defined based on weighted degree: (i) Rubber and Plastic, Machinery, Nec, and Hotels and Restaurants, for which the degree varies between 0 and 0.6 in most periods; (ii) Chemicals and Chemical Products, Agriculture, Hunting, Forestry, and Fishing, Coke, Refined Petroleum, and Nuclear Fuel, Basic Metal and Fabricated Metal, and Food, Beverage, and Tobacco, which have a weighted degree varying on average between 0.7 to 1.2; and (iii) Chemicals and Chemical Products with a weighted degree greater than 1.2 for most of the period.

In Economic terms, the weights of the chemical sector's trade relations (linkages) were the strongest in the Brazilian economy between 1999 and 2008. Moreover, this sector peaked in 2003 and year by year dropped until 2011. Mining and Quarrying, however, is the only sector that has an increase in its weighted degree after the international crisis.

An interesting observation is that the Mining and Quarrying; Food, Beverage, and Tobacco; Coke, Refined Petroleum, and Nuclear Fuel; Chemicals and Chemical Products; and Basic Metals and Fabricated Metal sectors, which showed the highest-weighted degrees, were classified as key sectors in all years. This classification is based on the Hirschman–Rasmussen indices. In general, for an industry to be classified as a key sector, it must simultaneously display backward and forward linkages greater than one (Miller and Blair, 2009). They also had above-average intersectoral supply-and-demand relationships. This result shows that there have not been significant changes in Brazil's economic structure, which justifies using a time-series of static IO tables.

Hotels and Restaurants presents the highest clustering coefficient (0.50) in most of the analyzed period (Fig 8b). On the other hand, Agriculture, Hunting, Forestry, and Fishing, Basic Metals and Fabricated Metal and Chemicals and Chemical Products have the lowest clustering coefficient, varying between 0.10 and 0.20. If the clustering coefficient is zero or too low, locally the sector’s neighbors, at that time period and considering the filter, do not maintain trade relationship between them. If it is one, all neighbors of a given vertex (sector) maintain trade relations with each other. It is important to highlight that in 2008-2009, the clustering coefficient of most sectors, following the same behavior of the weighted degree, decreases. This may be related to the international crisis.

Regarding to the minimal path length (Fig 8c), we can see for all nine sectors that this indicator varies between 1.5 and 2.5. Furthermore, the minimal path length is relatively stable among the sectors. With respect to the average minimum path length, most of the most important sectors did not change over the analyzed period. The only sectors in which this index presents larger changes than the others are 'Agriculture, Hunting, Forestry and Fishing' and 'Food, Beverages and Tobacco'. This means that geodesics are maintained over the period, not influencing the overall efficiency of the network.

Fig 9 shows the behavior of the network properties over time. It is possible to see a change, first during 2002–2003, for variables such as density, weighted average degree and global efficiency. The weighted average degree indicates the influence and prestige of the Brazilian economic sectors. In a directed network, the concepts prestige and influence refer to the quantity of choices received and choices made, respectively. In the input-output networks, prestige is associated with the receipt of inputs and the influence on the supply of inputs. In 2002 and 2005, for instance, we observed increases in the weighted average degree, which means that sectors have become more dependent on each other.

Global efficiency, in turn, can be understood as the speed with which information (i.e. input or output) goes from one Brazilian economic sector to another. This property measures how much the Brazilian economic sectors efficiently supply inputs to other sectors (or “transport information”). In the years of 2002 and 2004, the increase of these indicators may be associated with the commodities cycle, which began in 2002, as shown in Fig 6.

The average clustering coefficient behavior indicates that, from a general point of view, the increases occurred (2004-2008) are related to the influence that the Brazilian economic sectors exert on each other (local neighborhoods) from each sector analyzed in terms of supplied inputs. The average minimum paths *(L)* indicate how close the Brazilian economic sectors are. The decrease in *L* and the increase in density suggest an “approximation” among the sectors, which could be related to the emergence of strategic arcs (important economic relationship). In other words, sectors can interact with each other without the need for many intermediaries, i.e., the Brazilian economy became more conducive to diffusion processes since its sectors became more connected.

In 2004, there was a reduction in density, weighted average degree and global efficiency. To explain this drop is important to mention that President Lula's government began in 2003 (Fig 6). His political position provoked a general distrust on the ability of the new government to honor the pre-established commitments such as the payment of external debt. Giambiagi and Villela (2005) argue that to contain speculation in the financial markets, President Lula took some economic adjustment measures, especially the increase of the interest rate and the reduction of public spending. These measures adopted in 2003 possibly impacted sectoral relations in the following years, especially in 2004. This discouragement of trade relations between sectors contributed to the reduction of network connectivity as reflected in the indicators analyzed.

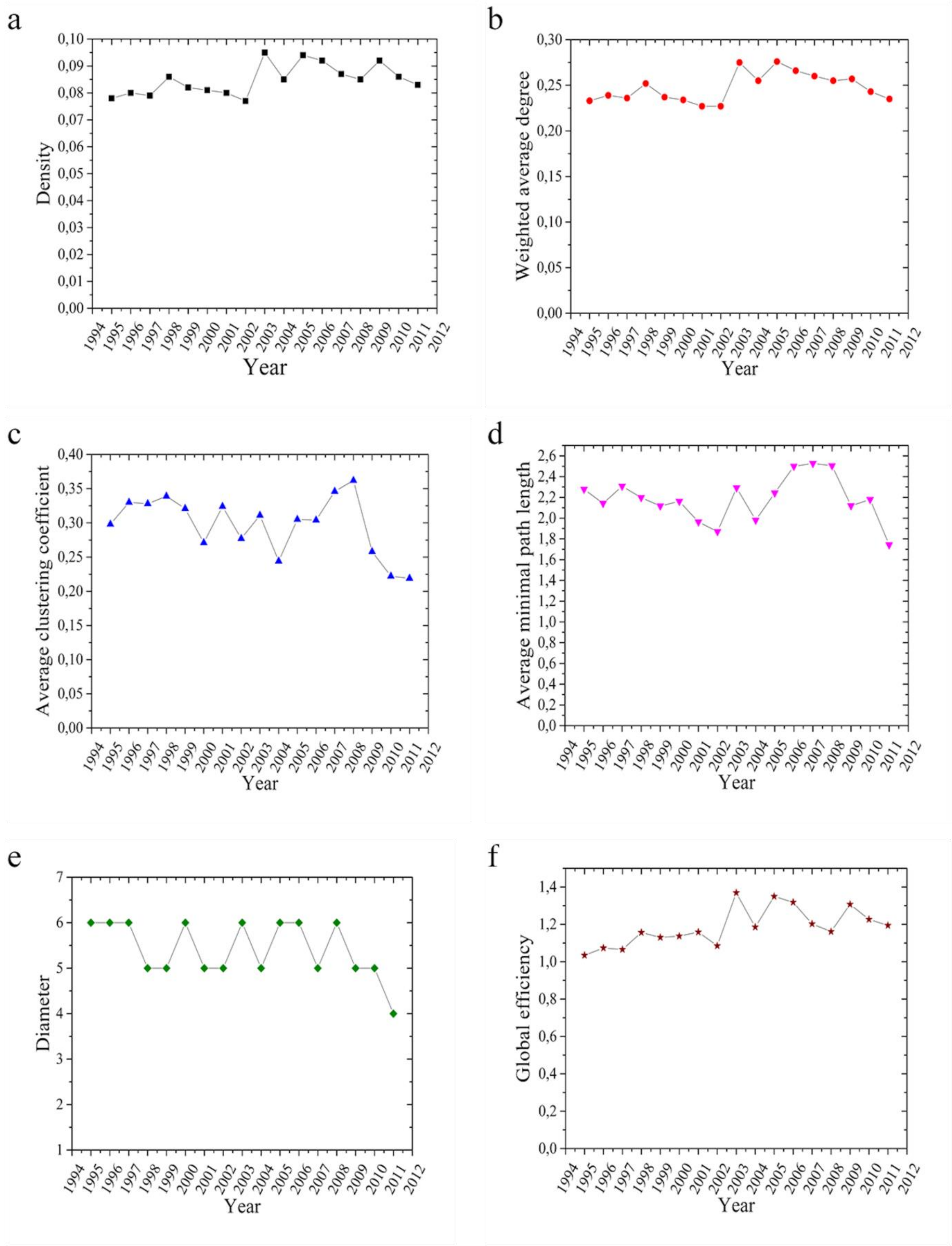
In 2009, there was also a reduction in average degree, diameter, and local efficiency. With respect to local and global efficiencies, we observe a network tendency to a small-world topology. This means that the network tends to be sparse and connected, having a high agglomeration coefficient and a reduced average minimum path (Watts and Strogatz, 1998). In addition, the input-output network tends to be more efficient in transporting information (inputs). We can assume that in 2003–2009, for reasons we discuss below that average degree, diameter, and average minimum path length as the static and aggregate IO networks are more interconnected.

Possible influences on networks properties for the period between 2003 and 2009 include the macroeconomic policies adopted during Fernando Henrique Cardoso's second term, such as adopting a floating exchange rate, inflation targets and primary surplus target, which became known as the new macroeconomic regime installed in 1999 (see Fig 6). They would have contributed to an increase in the network interconnection. This pattern is visible from the density behavior since the number of vertices is fixed at 34, the density in each time window indicates the importance of Brazilian economic sectors as suppliers or demanders of inputs (Fig 9a). These policy mechanisms may have positively impacted intersectoral trade relations, due to the greater degree of trade liberalization in the Brazilian economy that began in the 1990s. In addition, those mechanisms provided greater macroeconomic stability during the period analyzed and increased incentives for several sectors (Fig 9b).

Those changes in network properties (Fig 9) may also be associated with what was known in the Brazilian economy as the "commodity cycle." This cycle, delimited between 2002 and 2009, was characterized by the continuous rise in commodity prices in the international market. Since Brazil has historically been an agro-exporting country, this rise in prices was followed by an upturn in the economy, as reflected in the increase in trade relations between several network sectors, based on the rise in average levels (Fig 9b). It is worth noticing that, according to Cepal (2014), commodity-producing activities usually have productive enclaves and multiplier effects on other sectors are reduced. That is, the positive effects on the Brazilian economy could have been much larger if the external shock influenced more interconnected sectors, as is the case, for example, with industrial activities.

The increase in demand from the Chinese market was one of the main causes of the commodity cycle. For these reasons, between 2005 and 2011, commodity exports contributed to a real growth of 0.7% to the Brazilian Gross Domestic Product (Sessa et al., 2017). The economic effects of these exports in the Brazilian economy involve important micro and macroeconomic aspects, such as changes in relative prices and an exchange rate depreciation. Considering the spatial heterogeneity of Brazilian development (one of the five regions, Southeast, accounted for 53.2% of Brazilian GDP in 2016), the expansion and retraction of commodity exports altered the general structure of relative prices within the economy.

Fig 9. Analysis of IO networks properties of the Brazilian productive structure.



After 2009, on the other hand, we observe a drop in all network properties analyzed (Fig 9). The greatest reduction was in relation to the average cluster coefficient, global efficiency, and local efficiency (Figs 9c and 9f). A likely explanation for this behavior is the 2008 global economic crisis. According to Borghi (2017), this crisis “severely affected Brazil’s growing economy at the end of 2008 and especially in the following year.” Industrial production and GDP in several countries declined rapidly in the last quarter of 2008, which may have negatively influenced relations between various sectors of the Brazilian economy. In that year, the Brazilian economy registered a decrease of 0.13% in GDP. Moreover, Borghi (2017) argues that the Brazilian industrial sector was the most affected sector and because it accounts for the most links in the economy, this could explain the results observed after 2009.

5. Conclusions

To evaluate the Brazilian productive structure between 1995 and 2011, we have developed an integrated network IO model using annual IO matrices composed of 34 economic sectors. The main contribution of this method is its ability to capture the structural endogenous or exogenous effects on the productive structure of a given country or set of countries. Such effects are measured in an integrated manner given the connectivity of economic agents via trade relations. In fact, the analysis of IO network using TGV is one of the main strengths of this work because enables the assessment of productive structures over time.

Interpretations based on the networks’ properties, although qualitative, are supported by quantitative values. Measures of network properties during the analyzed period are sensitive to variations in political and economic changes, for instance, the new macroeconomic regime in 1999 and the strengthening of Lula's social policies in the early 2000s.

We found two main distinct macroeconomic effects on the Brazilian economy during the two periods: (i) possible positive impacts of the macroeconomic policies of Fernando Henrique

Cardoso’s second term as president and growing commodity prices in the increase in network connectivity between 2002 and 2003; and (ii) the negative influence of the 2008 crisis, shown as a decrease in network connectivity. Thus, we conjecture that, in the first period, the macroeconomic policies initiated in the late 1990s associated with the beginning of the commodities cycle had a positive influence on the dynamics of the country's intersectoral relations. On the other hand, in 2009, the fall in the intensity of these relations may be associated with the deleterious effects of the global crisis.

The sector results revealed three groups whose trade relations increased throughout the period analyzed: food, petrochemical and metals, and machinery. The Coke, Refined Petroleum, and Nuclear Fuel sector, in particular, has experienced intensified trade relations since 2003, which can be explained by the greater targeting of investments in this area, a policy conducted by the Lula Government, particularly for the Petrobras company.

However, it is worth remarking that part of these results could be due to price effects as our tables are in current prices. Between 2003 and 2011, for instance, the average inflation rate in Brazil was 5.9%, measured by the official index (IPCA).

In terms of policy directions, these results can be used to support macroeconomic policies, since when there is an exogenous shock the government could stimulate the intersectoral relations in the country through macroeconomic measures, such as appreciate (depreciate) the exchange rate and/or increase (reduce) interest rates.

Like any model, the main limitation of the present method is its reductionist characteristics. During construction, information was lost; however, this loss was minimized using window-to-window temporal analysis. In addition, topological analysis of the network is affected by the small number of sectors (vertices) considered and, consequently, the emergence of some network properties (e.g., degree distribution) may stay unnoticed.

Even with these limitations, the use of TVG properly captures the possible effects of economic shocks on Brazilian intersectoral relations. Given the relevance of the results obtained, we suggest research focused on IO and network analyses should be taken forward. In this sense, we recommend that future studies apply the methodology developed in this work to relevant economic and environmental issues, for example, trade relations between emerging countries, greenhouse gas emissions (GHG), or water use. It would be of interest to find what are the main communities or sectoral clusters in terms of GHG global emissions and the degree of relationship between them. For this purpose, many others IO databases are available, such as OECD-ICIO, EORA and EXIOBASE.

Furthermore, we can also correlate the network metrics with external economics variable (e.g. GDP or labour productivity) in order to make econometric models where the network variables are part of the regression.

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Capítulo Oito

Considerações finais

Após vinte anos do seu surgimento, a Econofísica está presente em diversas áreas da economia, tendo utilizado vários métodos, modelos e teorias para estudar sistemas complexos na tentativa de resolução de alguns problemas econômicos, entre eles as redes complexas. Nesse intervalo de tempo, aconteceu a maior crise econômica desse século, a crise dos *subprime*, ocorrida em 2008, provocando instabilidade em diversas economias com a diminuição do PIB (Produto Interno Bruto) e um aumento do desemprego. Dentro desse contexto econômico, esta pesquisa analisou os efeitos da crise dos *subprime* nas redes financeiras e intersetoriais, com o objetivo de identificar padrões que pudessem ser associados a choques exógenos em duas áreas diferentes, as finanças e a macroeconomia.

Para isso, foram desenvolvidos três modelos teóricos. O primeiro em finanças, envolvendo redes multiscala ou a junção da teoria de redes com o cálculo das correlações entre os retornos das ações utilizando o coeficiente de correlação cruzada ρ_{DCCA}. O segundo modelo envolveu economia brasileira com a aplicação dos *Time Varying Graphs* (TVG) e o modelo Insumo-Produto. O terceiro modelo utilizado foi o método de Motif com a finalidade de relacionar as variações nas propriedades das redes com movimentações abruptas nos mercados financeiros europeus. Em síntese, essa tese contribuiu com a construção de três modelos, dois aplicados às finanças e outro aplicado à economia brasileira.

Nas finanças, a aplicação dos grafos variantes no tempo e das redes multiscala possibilitaram relacionar as propriedades de redes temporais e atemporais com a instabilidade econômica ocorrida. Na economia brasileira, foram identificados padrões na topologia das redes que identificam os efeitos das crises financeiras. Dessa forma, a pesquisa doutoral levou em consideração redes dinâmicas em duas áreas fundamentais da economia, os mercados financeiros e a economia brasileira, com o objetivo de reconhecer padrões no comportamento das redes que possam identificar os efeitos das crises nas relações financeiras e intersetoriais.

Em relação aos mercados financeiros, a observação da dinâmica da conectividade das bolsas de valores pode contribuir com a predição ou até mesmo na identificação de crises financeiras. Isso é mensurado por meio das seguintes propriedades das redes: coeficiente de aglomeração, densidade e as centralidades de grau ponderado e *Page-Rank*.

No primeiro ensaio *Econophysics: Past and Present* é feito uma revisão da disciplina econofísica abordando os aspectos históricos, principais áreas e aplicações. Em relação aos aspectos históricos é mostrado desde a relação inicial da física com a economia feito por Adam Smith, no século XVIII, até os dias atuais. Depois são mostradas as principais áreas ou modelos utilizados na econofísica com o intuito de fazer uma breve introdução da temática para pesquisadores interessados na disciplina. No final, foi mostrado o seu uso por alguns grandes economistas da atualidade e até ganhadores do prêmio Nobel, por exemplo, Joseph Stiglitz e Esther Duflo com a intenção de contextualizar a econofísica na resolução de problemas econômicos.

No segundo ensaio *Multiscale Network for 20 stock Markets using DCCA* foi constatado que, com a crise de 2008, além das propriedades das redes alterarem, houve mudanças nos grupos de países conectados. Como resultado foi encontrado uma alta conectividade dos países da Zona do Euro indicando um maior risco financeiro nessa região. Isso foi evidenciado, principalmente, nos países da Europa Central como: França, Inglaterra, Alemanha e Itália uma elevada conectividade nesses países demonstrando que eles são mais susceptíveis a crises financeiras.

Ademais, outro fato encontrado é que, após a crise de 2008, surgirão duas grandes comunidades, uma formada pelas bolsas de valores dos países da Ásia e outra formada pelos países da Europa e da América. Isso evidencia a elevação da integração financeira, mostrando que os mercados se tornarão mais interligados.

No terceiro ensaio *Network Dynamic and Stability on Eurozone* foi encontrada uma relação entre a crise de 2008 e o aumento da conectividade das bolsas de valores, a partir da análise do comportamento das propriedades das redes. As propriedades relacionadas a conectividade no artigo: coeficiente de aglomeração, densidade, eficiência global e eficiência local apresentaram um comportamento crescente de 1988 até 2008, entretanto, após a crise dos subprime, elas passam a ter um comportamento decrescente. Esse aumento da conectividade da rede antes da crise financeira dos *subprime*, indica que os mercados estavam mais interconectados, estando mais vulneráveis a grandes flutuações, já que o efeito contágio tende a ser maior quanto maior for a conectividade da rede de acordo com (ACEMOGLU *et al.*, 2012; MINOIU; REYES, 2013; TABAK *et al.*, 2014b).

Outra contribuição do ensaio *Network Dynamic and Stability on Eurozone* foi a identificação do papel de hub na rede de bolsas de valores de países que estão relacionados diretamente a Crise do Euro, por exemplo, Grécia, Itália, Portugal, Irlanda e Espanha. O papel de hub vinha acontecendo antes da crise europeia acontecer. A participação na rede financeira europeia como hub dessas bolsas de valores pode sugerir que índices financeiros relacionados diretamente à crise já vinham influenciando os outros num momento anterior a ela.

Em síntese, esses dois ensaios demonstram a capacidade da Teoria de Redes (TR) de identificar padrões que correspondem às instabilidades financeiras, podendo a TR ser utilizada para captar padrões nos mercados financeiros que indicam momento de incertezas como crises. Outro aspecto, é que esses dois ensaios demonstram a centralidade das economias europeias nos mercados financeiros mundiais. Esse padrão identifica que um choque negativo nas bolsas de valores desses países (França, Alemanha, Inglaterra e Itália) pode afetar toda a rede financeira mundial, devido à sua centralidade. Essa informação é útil para fundos de investimento, fundos hedge e bancos que monitoram os riscos no mercado financeiro mundial.

No que diz respeito à economia brasileira, no quarto ensaio, foi encontrado uma relação entre as propriedades da rede calculados a partir da Matriz Insumo-Produto brasileira, entre 1994 e 2011 e os choques exógenos. Entre 2003 e 2008, período do *Boom das Commodities* a rede aumentou sua conectividade, isso pode ser explicado pelo o fato de que com o aumento das exportações brasileiras durante o período, os setores relacionados as *Commodities* aumentaram suas receitas, aumentando as relações comerciais com os demais setores. Contudo, após a crise de 2008, ocorreu um fenômeno contrário, provocando uma diminuição nas relações comerciais brasileiras, fato que foi mensurado pelas propriedades das redes.

A relação entre a conectividade de uma rede setorial com choques exógenos pode auxiliar a compreender a dinâmica das relações intersetoriais num determinado país de acordo com diversos acontecimentos econômicos (preço das *das Commodities*, crises financeiras, etc.). Esses eventos são recorrentes na economia e afetam as relações comerciais entre os diversos setores, podendo causar desequilíbrios na geração de emprego e renda. Dessa forma, a análise via redes das relações intersetoriais na economia, pode contribuir com a discussão sobre como as relações comerciais nacionais se comportam durante choques econômicos, podendo auxiliar na tomada de decisões econômicas.

Portanto, essa tese contribui com a economia demonstrando que o mesmo efeito, a crise de 2008, pode ser identificado com o auxílio de grafos variantes no tempo em duas áreas distintas da economia. Sendo esse um padrão que se repete nos índices financeiros ou nas relações comerciais brasileiras. A capacidade da TR de identificação do comportamento de crises financeiras na economia, pode auxiliar bancos, fundos de investimento, gestores públicos em políticas macro prudenciais e nas tomadas de decisão para a contenção do risco seja ele nas finanças ou nas cadeias de valores nacionais.

Além desses, foram produzidos outros ensaios durante a tese relacionados à energia, ao meio ambiente e à econofísica. Em todos eles foram utilizados os elementos de sistemas complexos, direta ou indiretamente, para a resolução dos problemas relacionados aos choques do petróleo, ao desmatamento na Amazônia e à econofísica de modo geral. Em relação aos choques do petróleo e o desmatamento da Amazônia é preciso ressaltar que são fenômenos complexos, visto que uma leve alteração nas condições iniciais pode alterar totalmente a trajetória do sistema, além de estarem relacionados a outros sistemas como: político, econômico, financeiro e à saúde. Com isso, foi utilizado na compreensão desses fenômenos elementos de sistemas complexos para a abordagem desses problemas como: o coeficiente de correlação cruzada ρ_{DCCA} e a TR.

Em relação aos choques do petróleo, os efeitos deles na economia podem provocar inflação, redução do PIB, desemprego e até crises econômicas, como as ocorridas no anos de 1973 e 1979. Além disso, o setor relacionado ao petróleo possui uma posição de destaque nas relações comerciais brasileiras, como foi demonstrado no quarto ensaio dessa tese. Como o setor petrolífero possui várias relações comerciais com diversos setores econômicos no Brasil, é natural que qualquer variação nos preços do petróleo provoque flutuações nos seus derivados e de outros produtos relacionados como: plásticos, borrachas, produtos petroquímicos, etc. Por isso, as flutuações nos preços do petróleo, têm um papel de relevância para a compreensão das variações nos mercados, em especial, o brasileiro. Assim, foram produzidos quatro artigos que analisam essas relações com o objetivo de identificar a influência do preço do petróleo nos mercados financeiros nacional, europeu e mundial.

No que tange a questão ambiental, em especial a Amazônia, faz-se necessário apontar seu papel de destaque na biodiversidade mundial, pois ela é responsável, por ¼ das espécies nativas, e 1/3 da biodiversidade de todo o planeta. Além de ser importante também para as mudanças climáticas globais e para o ciclo das chuvas (DIELE-VIEGAS; ROCHA, 2020). Contudo, recentemente, a floresta vem sofrendo ataques de garimpeiros, madeireiros, fazendeiros e grileiros, com a anuência do governo que desmantelou a legislação ambiental e reduziu o orçamento de órgãos de fiscalização da floresta. Por isso, num outro apêndice dessa tese foram produzidos quatro artigos que analisam a relação da política, pecuária e do garimpo ilegal com o desmatamento da Amazônia e suas possíveis consequências econômicos e ambientais.

Com o recente aumento do desmatamento da floresta, além dos possíveis impactos ambientais já mencionados existem os possíveis impactos econômicos, pois alguns países como: Holanda, Bélgica e França já ameaçam não ratificar o acordo comercial entre a União Europeia e o Mercosul, devido à elevação do desmatamento na Amazônia, esse acordo agregaria o Produto Interno Bruto Brasileiro. Em Junho de 2020, um grupo de 34 investidores com um capital de 5 trilhões de doláres anunciaram que se o Brasil não revisasse a sua política ambiental o país estaria fora da rota de investimentos. Dessa forma, os ensaios pretendem mostrar a importância da floresta sob a óptica ambiental e econômica. Por fim, no apêndice D, foram produzidos ensaios com a temática da econofísica. Eles analisam a relação entre o *Big Data* e a econofísica, as buscas pelo termo Donald Trump, o mercado de criptomoedas e a economia regional. O objetivo foi demonstrar a abrangência da econofísica na resolução de diversos problemas econômicos. Esses problemas envolvem desde a ciência dos dados até a análise das relações comerciais regionais.

Como trabalhos futuros, pretende-se continuar a desenvolver modelos na área de finanças. A ideia é usar o ρ_{DCCA} com janela deslizante no tempo com teoria de redes. Nesse caso, o resultado seria uma *multiscale dinamic networks*, uma rede que além de analisar várias escalas de tempo, seria dinâmica, essa proposta possibilitaria a identificação do comportamento das propriedades das redes para diversas escalas e variantes no tempo. Em relação ao uso de Insumo-Produto e redes, espera-se a utilização de redes com várias camadas para a análise regional, possibilitando a aplicação em diversas situações econômicas ou ambientais.

Apêndice A

Produções acadêmicas durante o doutorado

Além dos trabalhos expostos que formaram o corpo da tese, durante o doutorado foram produzidos outros artigos que envolvem econofísica e as áreas de energia, meio ambiente e econofísica com diversos colaboradores. O objetivo desses trabalhos foi solucionar problemas que surgiram durante a escrita desta tese de doutorado, problemas esses relacionados à econofísica, à energia e à área ambiental, que constituem três áreas essenciais para a humanidade. Essa experiência, além de enriquecer a tese, contribuiu para a formação de uma rede de colaboração, melhorando substancialmente esta pesquisa. Isso contribuiu para que a tese possuísse um caráter interdisciplinar, dado a experiência com outras áreas do conhecimento e a verificação da importância dos elementos dos sistemas complexos na atualidade.

Todos os trabalhos possuem uma influência dos sistemas complexos, pois analisam sistemas que possuem muitos elementos, se interagem de forma não-linear e estão sujeitos a mudanças abruptas. Alguns trabalhos possuem aplicação direta de elementos dos sistemas complexos, outros apenas utilizam alguns conceitos. Contudo, todos analisam sistemas que são complexos, como: o movimento do preço do petróleo, a Amazônia, a dinâmica do preço do Bitcoin e o comércio inter-regional no Brasil.

Para facilitar a exposição, os trabalhos foram divididos em três grandes áreas de análise: Energia (influência do preço do petróleo nas bolsas de valores mundiais), Meio Ambiente (política ambiental na Amazônia) e Econofísica (dinâmica dos preços de ativos financeiros e inter-relações comerciais). Ademais, apresentaremos somente a primeira página de cada artigo ou a página da informação sobre sua citação ou publicação.

Apêndice B

Choques do Petróleo

Um dos ativos mais importante da economia é o petróleo, pois serve de insumos para diversos outros bens (GLP, produtos asfálticos, nafta petroquímica, querosene, polímeros asfálticos, solventes, óleos lubrificantes, óleo diesel e combustível para aviação) e é uma das principais fontes de energia do mundo. Além disso, a indústria do petróleo tem um papel essencial para a economia brasileira, gerando milhares de emprego e renda, principalmente nos estados de São Paulo, Rio de Janeiro e Bahia. Por esses motivos, o estudo da dinâmica do preço do petróleo é importante para entender as flutuações econômicas, principalmente no mercado financeiro.

No mercado financeiro, o petróleo já ocasionou algumas crises, como as do preço do petróleo ocorrida em 1973, quando a OPEP (Organização dos Países Exportadores de Petróleo) resolveu aumentar o preço do barril de petróleo em quatro vezes. Outros choques conhecidos do petróleo aconteceram em 1979, na segunda crise do petróleo, em 1991, durante a guerra do Golfo, em 2008, durante a crise dos *subprime* e, recentemente, durante a crise provocada pela pandemia da Covid-19. Esses choques abalaram negativamente os mercados financeiros, afetando o balanço e as receitas das empresas e grande parte dos setores da economia.

Nessas circunstâncias, foram feitos quatro trabalhos sobre energia, sendo três trabalhos sobre a influência do preço do petróleo nos ativos financeiros e um sobre a correlação cruzada entre as margens da venda do etanol e da gasolina no Brasil. Nos três artigos que estudam a influência do preço do petróleo com os ativos financeiros tem-se, o primeiro ensaio trata do preço do petróleo e sua correlação cruzada com vinte bolsas de valores mundiais durante a crise de 2008 (FERREIRA *et al.*, 2019).

O segundo que é trata sobre a evolução da dependência dos setores financeiros europeus do preço do petróleo durante as décadas de 1990, 2000 e 2010 (FERREIRA; PEREIRA; PEREIRA, 2020a). E o terceiro, que identifica o impacto do choque do petróleo, ocorrida durante a crise dos *subprime*, nos índices financeiros das empresas brasileiras (FERREIRA; PEREIRA; SILVA, 2020). E por último, será mostrado a capa de um artigo que analisa a correlação cruzada entre os valores das margens das revendas de gasolina e etanol nos estados brasileiros (MURARI *et al.*, 2019). A seguir serão expostos os artigos:

Physica A 517 (2019) 86–96

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Detrended correlation coefficients between oil and stock markets: The effect of the 2008 crisis

Paulo Ferreira [a,b,c,*], Éder Johson de Area Leão Pereira [d], Marcus Fernandes da Silva [e], Hernane Borges Pereira [f]

[a] VALORIZA – Research Center for Endogenous Resource Valorization, Portalegre, Portugal
[b] CEFAGE-UE, IIFA, Universidade de Évora, Portugal
[c] Instituto Politécnico de Portalegre, Portugal
[d] Instituto Federal do Maranhão, Brazil
[e] Instituto Federal da Bahia, Brazil
[f] Senai-Cimateca/Universidade Estadual do Estado da Bahia, Brazil

HIGHLIGHTS

- We analyse the relationship between oil prices and 20 different stock markets.
- We use the $\Delta\rho_{\mathrm{DCCA}}$ to analyse the long-range correlation before and after the 2008 crisis.
- Results show that stock markets are now more exposed to oil price fluctuation.

ARTICLE INFO

Article history:
Received 8 August 2018
Received in revised form 7 October 2018
Available online 9 November 2018

Keywords:
Correlation coefficient
Detrended cross-correlation analysis
Oil prices
Stock markets

ABSTRACT

The relationship between oil prices and stock markets is commonly studied, in order to understand how financial markets are influenced by this important real asset. The evidence of any kind of interdependence is important, because investors could have additional information about the evolution of those kinds of assets. In this paper, we analyse the detrended cross-correlation coefficient between oil price and 20 different stock markets. We split our sample, in order to analyse the behaviour of that correlation before and after the 2008 crisis, allowing us to use the $\Delta\rho_{\mathrm{DCCA}}$, searching for a possible increase in the connection between both variables. Based on the existing literature, which used simulated and real time series to define the critical values for $\Delta\rho_{\mathrm{DCCA}}$, we study the statistical significance of this variable Our results show some evidence that before the crisis the correlations were low, but increased after the crisis, which could be understood as an increase in the relationship between oil and stock markets. This is an interesting result because it shows that stock markets are now more exposed to oil price fluctuation than before the crisis.

1. Introduction

Since the 1970s, the behaviour of oil prices has been a constant concern for society. Until then, the price of oil was not a problem for developed markets, but in 1973, the Organization of Petroleum Exporting Countries (OPEC) introduced an

* Corresponding author at: Instituto Politécnico de Portalegre, Portugal.
E-mail addresses: pferreira@ipportalegre.pt (P. Ferreira), eder.johnson@ifma.edu.br (É.J.d.A.L. Pereira), marcusfis@hotmail.com (M.F.d. Silva), hernanebbpereira@gmail.com (H.B. Pereira).

https://doi.org/10.1016/j.physa.2018.11.021
0378-4371/

sustainability

MDPI

Article

The Exposure of European Union Productive Sectors to Oil Price Changes

Paulo Ferreira [1,2,3,*], Éder J. A. L. Pereira [4,5] and Hernane B. B. Pereira [4]

1 VALORIZA—Research Center for Endogenous Resource Valorization, 7300-555 Portalegre, Portugal
2 Instituto Politécnico de Portalegre, 7300-110 Portalegre, Portugal
3 CEFAGE-UE, IIFA, Universidade de Évora, Largo dos Colegiais 2, 7000 Évora, Portugal
4 Programa de Modelagem Computacional, SENAI Cimatec, Salvador, BA 41650-010, Brazil; eder.johnson@ifma.edu.br (É.J.A.L.P.); hernane@fieb.org.br (H.B.B.P.)
5 Instituto Federal do Maranhão, São Luís 65075-441, Brazil
* Correspondence: pferreira@ipportalegre.pt; Tel.: +351-268-628-528

Received: 19 January 2020; Accepted: 19 February 2020; Published: 21 February 2020

Abstract: Oil is one of the most important products in the world, being used for fuel production but also as an input in several industries. After the oil shocks of the 1970s, which caused great turbulence, the interest in the analysis of this particular product grew. The analysis of the comovements between oil and other assets became a hot topic. In this study, we propose an analysis of how oil price correlates with several industry indexes. The detrended cross-correlation analysis coefficient (ρDCCA) is used, with data from 1992 to 2019, and we analyze not only the correlation between oil and several Euro Stoxx indexes during the whole sample, but also how that correlation evolved for the different decades (1990s, 2000s and 2010s). Naturally, oil and gas are the sectors that correlate the most with crude oil, with correlation coefficients reaching levels higher than 0.6 in some cases. However, the results also indicate that all sectors are now more exposed to oil price variations than in the past, with the financial sector as one of the sectors with the greatest increase in correlation.

Keywords: correlation coefficient; detrended cross-correlation analysis; exposure oil price; sectors

1. Introduction

Oil is one of the main inputs of the economy, not only because it is used for fuel production, but also because it serves as an input in several sectors. Moreover, crude oil and petroleum products account for about one third of energy consumption in the European Union (EU), with two thirds of the final demand for oil (330 million tons per year—MTPy) being from the transport sector and about 20% from industrial sectors [1].

During the 1970s, oil shocks caused great turbulence in the world economy and contributed to a period of stagflation in the economy. Another important event involving oil occurred during the early 1990s, with the Gulf War, followed by the Asian and Russian crises, which ended with a fall in oil prices. However, between 2003 and 2008, with the commodity boom, mainly due to the entry of major players such as China and India, the price of a barrel of oil increased. The subprime crisis, which triggered the bankruptcy of the Lehman Brothers on September 15th 2008, also had some effect on oil prices [2,3]. In summary, in the last 30 years several events have influenced the price of a barrel of oil positively or negatively (see [4–10], among many others).

An analysis of the comovements between assets is important for several agents belonging to financial markets, since information about how a given asset correlates with other asset(s) could be relevant for investors, portfolio managers, firm managers and supervising authorities, among others [11]. One of the most studied assets, regarding its correlation with others, is oil, due to its

Physica A xxx (xxxx) xxx

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

The relationship between oil prices and the Brazilian stock market

Paulo Ferreira [a,b,c,*], Éder Pereira [d,e], Marcus Silva [f]

[a] *VALORIZA - Research Center for EndogenousResourceValorization, Portalegre, Portugal*
[b] *Instituto Politécnico de Portalegre, Portalegre, Portugal*
[c] *CEFAGE-UE, IIFA, Universidade de Évora, Largo dos Colegiais 2, 7000 Évora, Portugal*
[d] *Programa de Modelagem Computacional, SENAI Cimatec, Av. Orlando Gomes 1845, 41.650-010, Salvador, BA, Brazil*
[e] *Instituto Federal do Maranhão, Brazil*
[f] *Instituto Federal da Bahia, Brazil*

A R T I C L E I N F O

Article history:
Received 25 June 2019
Received in revised form 5 November 2019
Available online xxxx

Keywords:
Brazilian stock market
Correlation coefficient
Detrended cross-correlation analysis
Oil price

A B S T R A C T

Crude oil remains a very important product not only because of its regular use, but also because it is a very important financial asset, influencing the economy as a whole. In this paper, we assess how WTI oil price shocks are related with the Brazilian economy as a whole, but also with each of the listed companies in Ibovespa, searching for the relationships with different economic activities. Based on the Detrended Cross-Correlation Analysis correlation coefficient, which allows us to analyse the impacts for different time scales, we conclude unsurprisingly that the most affected sectors are those most related with the use of oil. However, another important result is the significant correlation between oil price shocks and the returns of the financial sector, showing this particular sector's exposure to oil, i.e., this is one of the sectors most correlated with oil returns. This is relevant not only for investors but also for authorities, because possible future oil shocks could have a high impact on the Brazilian financial sector

1. Introduction and related literature

Oil is considered a strategic resource and is extremely relevant to a particular country or region, since its derivatives such as gasoline and diesel are used by most forms of transport, besides other uses in industry in products such as paraffin, asphaltic products, petrochemical naphtha, kerosene, polymers, solvents, fuel oils, lubricating oils among others. For many decades, oil was one of the major drivers of the international economy, reaching almost 50% of the world's primary energy consumption in the early 1970s. Although this share has been declining over time, accounting for about 43% of consumption, it should remain significant for decades.

Several studies identify different amounts of oil as responsible for all the electricity generated in the world, ranging from 7.5% to about 10% (see [1] and [2,3]), which is still a relevant amount. During World War II, about 90% of Brazil's oil was imported from the United States, showing Brazil's heavy dependence on North American oil [4]. An important milestone for the national oil industry was the founding of Petrobras (PetróleoBrasileiro S.A.) in 1953, which is a mixed-economy corporation in the conception of Decree-Law No. 200, dated 25th February, 1967.

In 1973, Brazil imported 78% of the oil consumed in the country. Reducing that dependence was a matter of survival for the country, which led the government to encourage Petrobras to increase its national oil production and develop

* Corresponding author at: CEFAGE-UE, IIFA, Universidade de Évora, Largo dos Colegiais 2, 7000 Évora, Portugal.
E-mail addresses: pferreira@ipportalegre.pt (P. Ferreira), eder.johnson@ifma.edu.br (É. Pereira), marcus.fisico@gmail.com (M. Silva).

https://doi.org/10.1016/j.physa.2019.123745 *sustainability*

MDPI

Article

Comparative Analysis between Hydrous Ethanol and Gasoline C Pricing in Brazilian Retail Market

Thiago B. Murari [1,*], Aloisio S. Nascimento Filho [1], Eder J.A.L. Pereira [1,2], Paulo Ferreira [3,4,5], Sergio Pitombo [1], Hernane B.B. Pereira [1,6], Alex A.B. Santos [1] and Marcelo A. Moret [1,6]

1 Faculdade de Tecnologia, Centro Universitário SENAI CIMATEC, Salvador, BA 41650-010, Brazil
2 Instituto Federal do Maranhão—IFMA, Bacabal, MA 65700-000, Brazil
3 VALORIZA—Research Center for Endogenous Resource Valorization, 7300 Portalegre, Portugal
4 Instituto Politécnico de Portalegre, 7300 Portalegre, Portugal
5 CEFAGE-UE, IIFA, Universidade de Evora, 7000 Evora, Portugal
6 Senai CIMATEC, Universidade do Estado da Bahia—UNEB, Salvador, BA 41150-000, Brazil
* Correspondence: thiagomurari@hotmail.com

Received: 31 July 2019; Accepted: 28 August 2019; Published: 29 August 2019

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Abstract: The global energy landscape is rapidly changing, including the transition to a low carbon economy and the use of liquid biofuel. The production of liquid biofuel has emerged as an alternative to the use of fossil fuels for purposes of energy conservation, carbon emission mitigation and agricultural development. In this article we study the co-movements between hydrous ethanol and gasoline C in the Brazilian retail market. A multi-scale cross correlation analysis was applied to the Average Retail Margin time series of hydrous ethanol for fifteen relevant retail markets in Brazil to analyze the competitiveness of hydrous ethanol towards gasoline C. The empirical results showed a remarkable different behavior between hydrous ethanol and gasoline C, for any time scale, regardless of geographical distance or regional differences.

Keywords: ethanol; fuel retail market; DCCA cross-correlation coefficient

1. Introduction

There is a consensus in the scientific community that human activity is related to global warming [1]. The burning of fossil fuels could have severe consequences, for the planet's environmental balance. Nowadays, the challenges facing by the oil industry is to compete with clean energy sources, which are increasingly present in the world energy matrix. In the last decades discussions about the depletion of natural resources have intensified nations around the world, including the adoption of sustainable energy source, such as renewable energies [2,3].

Although the global community will continue to use fossil fuels during the transition to a low carbon economy, the global energy landscape is changing quickly as predicted by the International Energy Agency [2]. Projections indicate that by 2030 the world's car fleet will double to 2 billion, most of them still fueled by fossil fuels [4], but the increase of electric cars coupled with fuel efficiency gains should not lead to increased oil consumption for passenger cars. However the demand for oil will continue to grow for trucks, aviation and petrochemicals [2,3].

Bioeconomy may be defined as an economy where materials, chemicals and energy are derived from renewable biological resources [5]. The bioeconomy can adress issues regarding industrial restructuring, energy security and health. Switch from fossil-fuel to bio-fuel, for example, is important from a climate change outlook [6,7].

According to Goldemberg [8], the main example of rapid growth in the use of renewable in developing countries is the sugarcane ethanol program in Brazil. Ethanol is a renewable, domestically

Apêndice C

Politica Ambiental no Brasil

> Maior problema econômico do Brasil é o ambiental.
>
> (Candido Bracher, presidente do Itaú, 24 de Junho de 2020)

Desde o conceito de desenvolvimento sustentável que o considera como a conservação da natureza para uso das gerações posteriores, várias ações têm sido tomadas. Essas ações visam melhorar a relação do homem com o meio ambiente, entre elas estão a realização da Rio 92, e a Rio+2012. Nesse contexto, a Amazônia é de fundamental importância para as mudanças climáticas globais (FEARNSIDE, 2016), para o ciclo das chuvas no Brasil com o fenômeno dos "Rios Voadores", por representar mais da metade das florestas tropicais do mundo e abrigar cerca de um quarto das espécies de animais e plantas do planeta (DIELE-VIEGAS; ROCHA, 2020).

Para reduzir o desmatamento na Amazônia, em 2004, foi lançado o Plano de Ação para a Prevenção e Controle do Desmatamento na Amazônia Legal (PAPCDAm) no Brasil, com o qual o governo assumiu o compromisso de controlar o desmatamento e reduzi-lo ao valor mínimo até o ano de 2020 (FEARNSIDE, 2016). Contudo, desde 2016, o desmatamento na Amazônia vem crescendo, motivando uma preocupação mundial e gerando diversos estudos sobre as causas e consequências dessa situação.

Dito isso, durante a tese de doutorado foram desenvolvidos alguns artigos com a finalidade de avaliar os efeitos das políticas econômicas e ambientais ou a falta delas. Em comum, esses artigos analisam as relações inter-setoriais do agronegócio no Brasil e sua relação com as emissões de carbono e o desmatamento na Amazônia, falta de política ambiental em governos recentes e a nova "corrida do ouro"na Amazônia brasileira. (RIBEIRO; LEÃO; FREITAS, 2018; PEREIRA *et al.*, 2019a; PEREIRA *et al.*, 2020; DIELE-VIEGAS; PEREIRA; ROCHA, 2020).

Greenhouse Gases Emissions and Economic Performance of Livestock, an Environmental Input-Output Analysis[1]

Luiz Carlos de Santana Ribeiro[2], Eder Johnson de Area Leão[3] and Lúcio Flávio da Silva Freitas[4]

Abstract: In the last three decades, the developing countries have sharply increased its contribution to global warming. From 2005 to 2012, Brazil has reduced its total emissions in 12% due to deforestation control. In the same period, the total GHG emissions excluding land-use change and forestry have increased 18% (WRI, 2014), while *per capita* GPD has raised 17%. The Brazilian climate policy must go beyond the deforestation control to avoid an unsustainable pattern of development. Since the mitigation effort bears heavily on primary activities, one must ask: how important are those sectors for Brazilian economy? And how their emissions are connected to other sectors along the productive chain? Specifically, this paper aims to calculate the GHG emissions multipliers of the Brazilian economy in 2009 and associate these results with the employment and income multipliers, particularly of the Agriculture sector. The 'field of influence' method (SONIS and HEWINGS, 1992) is applied to calculate the intersectorial relations in terms of input linkages and GHG emissions.

Key-words: input-output, GHG emissions, agriculture, Brazilian economy.

Resumo: *Nas últimas três décadas, os países em desenvolvimento aumentaram significativamente a sua contribuição para o aquecimento global. O Brasil, entre 2005 e 2010, reduziu suas emissões totais em 12%, devido ao controle do desmatamento. No mesmo período, as emissões totais de GEE, excluindo mudanças no uso da terra e florestas, aumentaram 18% (WRI, 2014), enquanto o PIB per capita aumentou 17%. A política climática brasileira deve ir além do controle do desmatamento para evitar um padrão insustentável de desenvolvimento. As principais medidas para o controle das emissões são aplicadas às atividades primárias, assim, cabe perguntar: qual a importância dessas atividades para a economia brasileira? E como as suas emissões estão ligadas às emissões de outras atividades ao longo da*

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1. Data de submissão: 12 de junho de 2016. Data de aceite: 11 de setembro de 2017.

2. Universidade Federal de Sergipe. São Cristóvão-SE, Brasil. E-mail: ribeiro.luiz84@gmail.com

3. Instituto Federal de Educação do Maranhão. Bacabal-MA, Brasil. E-mail: ederjohnson1@hotmail.com. O autor agradece ao suporte financeiro da Fundação de Amparo e Pesquisa do Estado da Bahia – Fapesb.

4. Universidade Municipal de São Caetano do Sul. São Caetano do Sul-SP, Brasil. E-mail: lucioffreitas@yahoo.com.br

Environmental Science and Policy 100 (2019) 8–12

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Short communication

Policy in Brazil (2016–2019) threaten conservation of the Amazon rainforest

Eder Johnson de Area Leão Pereira[a,b,*], Paulo Jorge Silveira Ferreira[c,d], Luiz Carlos de Santana Ribeiro[e], Terciane Sabadini Carvalho[f], Hernane Borges de Barros Pereira[a]

[a] Programa de Modelagem Computacional, SENAI Cimatec, Salvador, Av. Orlando Gomes, 1845 – Piatã, Salvador – Ba, 41650 Prédio CIMATEC 3, 3° Andar, Brazil
[b] Instituto Federal do Maranhão – Campus Bacabal, Avenida Governador João Alberto, s/n, Areal, Bacabal/MA, CEP 65700-000. Brazil
[c] VALORIZA – Reserch Center for Endogneous Resource Valorization, Portalegre, Portugal
[d] Instituto Politécnico de Portalegre, CEFAGE-EU, IIFA, Universidade de Évora, Portugal
[e] Universidade Federal de Sergipe, Sergipe, Campus São Cristóvão, Av. Marechal Rondon, s/n, Jardim Rosa Elze, São Cristóvão/SE, CEP 49100-000, Brazil
[f] Departamento de Economia, Universidade Federal do Paraná - PPGDE/UFPR, Endereço: Avenida Prefeito Lothário Meissner, 632 - Jardim Botânico, Curitiba, PR, CEP: 80210-170, Brazil

ARTICLE INFO

Keywords:
Amazon
Brazil
Economic
Politic
Environmental risk

ABSTRACT

This article aims to analyze the influence of recent Brazilian political change demonstrating like the measures taken by former President Meichel Temer and those promised in presidential campaign by the current president Jair Bolsonaro threaten on the conservation of the Amazonian forest, both in the short and long term. In order to do so, it will be discussed the adoption of political instruments, which reduce investment in the Ministry of the Environment during a period of twenty years, making it difficult to supervise and monitor the entire Amazon forest. As a result, a debate will be presented in the current situation of the forest and the possibility of reconciling agricultural production with environmental preservation.

1. Introduction

Conservation of the Amazon rainforest is essential for the planet because it contains more than half of the world's rainforests and a quarter of all fauna, and it is essential for controlling climate change (Malhi et al., 2008). Despite the drop in deforestation between 2004 and 2012 as a result of federal control (Freitas et al., 2016; Souza et al., 2016), there was an unprecedented increase in 2015 and 2016. At the same time, Brazil is experiencing the greatest economic crisis in its recent history and a serious political crisis.

The approved of the Constitutional Amendment Proposal PEC 241, which has frozen the Ministry of the Environment MMA budget for a period of 20 years, threatens the functioning, in both the short and long term, of national institutes that directly control the Amazon, such as the Brazilian Institute of Environment and Renewable Natural Resources IBAMA and the Chico Mendes Institute for Biodiversity Conservation ICMBio. Moreover, other political and economic measures, such as PEC 65 and the increase in the exchange rate, threaten the lack of control of deforestation.

Another factor that may threaten the sustainability of the forest is the election of candidate Jair Bolsonaro in November 2018, as he has promised several measures that affect the conservation of the Amazon rainforest and has left, from the first day he took over as president of the republic, in January 2019, environmental issues aside from the debate in his government. For these reasons, this article proposes to show some measures that were taken in the Michel Temer government that could undermine the sustainability of the forest and argue that should the Bolsonaro government maintain its position, when it was a candidate for president of the republic, the Amazon could be affected and at the end some solutions will be proposed to reconcile economic recovery with preservation. Fig. 1 describes the methodology used in the paper. We started the work identifying the problem under analysis and making a literature review consistent with that problem. After that, we collected data about the Amazon rainforest and for different Brazilian presidents. We made a critical analysis and draw the final conclusions.

2. Amazon rainforest

The Amazon contains more than half of the world's rainforests and is home to about a quarter of the planet's animal and plant species. It is of vital importance because the global consequences of deforestation and burning affect biodiversity, the water cycle, and CO_2 and greenhouse gas emissions (Houghton, 2005). Deforestation in the Amazon

* Corresponding author.
E-mail addresses: eder.johnson@ifma.edu.br (E.J. de Area Leão Pereira), pferreira@ipportalegre.pt (P.J. Silveira Ferreira), ribeiro.luiz84@ufs.br (L.C. de Santana Ribeiro), terciane.carvalho@ufpr.br (T. Sabadini Carvalho), hernane@fieb.org.br (H.B. de Barros Pereira).

https://doi.org/10.1016/j.envsci.2019.06.001
Received 13 April 2019; Received in revised form 31 May 2019; Accepted 1 June 2019
1462-9011/

Land Use Policy 92 (2020) 104491

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Brazilian policy and agribusiness damage the Amazon rainforest

Eder Johnson de Area Leão Pereira[a,d,*], Luiz Carlos de Santana Ribeiro[b], Lúcio Flávio da Silva Freitas[c], Hernane Borges de Barros Pereira[d]

[a] *Instituto Federal de Educação do Maranhão, Av. João Alberto 1840, Bacabal, MA, 65700-000, Brazil*
[b] *Universidade Federal de Sergipe, São Cristóvão, SE, Brazil*
[c] *Universidade Municipal de São Caetano do Sul, São Caetano do Sul, SP, Brazil*
[d] *Programa de Modelagem Computacional, SENAI Cimatec, Av. Orlando Gomes 1845, 41.650-010, Salvador, BA, Brazil*

ARTICLE INFO

Keywords:
Policy
Bolsonaro
Amazon
Agribusiness
GHG emissions

ABSTRACT

Since his inauguration on January 1, 2019, Jair Bolsonaro, a declared right-wing candidate nicknamed "Tropical Trump," has introduced measures to reduce environmental restrictions on livestock farming, the main greenhouse gas (GHG) producing sector in Brazil that is responsible for most of the deforestation in the country. This dangerous relationship between politics and livestock farming in Brazil is detrimental to environmental conservation. Politicians are introducing measures that facilitate the expansion of this type of farming, which in turn provides inputs for the food industry, i.e. agribusiness, which in turn finances politics, thus producing a dangerous cycle in forest conservation.

1. Introduction

Bolsonaro assumed the Brazilian presidency and, in exchange for political support, mainly of the ruralist group (deputies and senators who are linked to Brazilian agribusiness), he has introduced several measures that encourage the expansion of agriculture and livestock. Among these is a drastic reduction in funds for forest inspection and control agencies (Brasil, 2019a), freer use of agrochemicals and pesticides, a third of which contains at least one substance that is forbidden in the European Union (Brasil, 2019b; Bombardi, 2019; Gortazár, 2019), the loosening of environmental licenses, and the unsuccessful attempt to transfer the demarcation of indigenous lands to the Ministry of Agriculture.

The Amazon has a key role in mitigating global climate change because, if the deforestation situation remains, the temperature in the Amazon can rise up to $6-8$ °Celsius above the 1996–2005 average from June to August until 2100. This will not only cause the death of the forest but also harm human life in many ways (Hegerl et al., 2006; Fearnside, 2006). The deforestation of the Amazon contributes significantly to intensifying the greenhouse effect both by releasing carbon from forest biomass and by releasing carbon from the soil, concentrating more than half of the rainforests and a quarter of all plant and animal species on the planet. In fact, land use change and forest are the main source of Brazilian emissions (see Appendix 1). Forest conservation is therefore essential for planet conservation (Fearnside, 2006; Huntingford et al., 2004).

In addition, there is the phenomenon of flying rivers, which are water vapor transport systems from the Amazon rainforest to the Brazilian central and southern regions. These are water vapors that are transported through the atmosphere and originate from the tropical Atlantic Ocean, being processed by the Amazon rainforest and transported to these regions. They play a fundamental role in the Brazilian water system (Marengo, 2006).

Even though Brazilian Greenhouse Gas (GHG) emissions are lower in comparison to Chinese, European or USA emissions (see Appendix 2 to top-20 global polluters), there are many good reasons to conserve the Amazon. These include decreasing agriculture and economic productivity, water availability for human use, river navigation or energy generation, and also increasing the incidence of respiratory diseases (Davidson et al., 2012)[1] .

If deforestation continues to rise, reaching about 40 % of the total forest area and causing global temperatures to rise by 4 °Celsius, much of the central, eastern, and southern Amazon will surely become a savannah. This phenomenon is known as the tipping point (Nobre and

* Corresponding author at: Instituto Federal de Educação do Maranhão, Av. João Alberto 1840, Bacabal, MA, 65700-000, Brazil
E-mail addresses: eder.johnson@ifma.edu.br (E.J. de Area Leão Pereira), ribeiro.luiz84@ufs.br (L.C. de Santana Ribeiro), lucioffreitas@yahoo.com.br (L.F. da Silva Freitas), hbbpereira@gmail.com (H.B. de Barros Pereira).

[1] Despite the argument of carbon colonialism (see Bumpus and Liverman, 2011), the conservation of Amazon is still important for ecological and socioeconomic reasons. An alternative sustainable development path for the Amazon region is presented in Nobre (2018).

https://doi.org/10.1016/j.landusepol.2020.104491
Received 7 August 2019; Received in revised form 14 January 2020; Accepted 22 January 2020

Forest Policy and Economics 119 (2020) 102270

Contents lists available at ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

The new Brazilian gold rush: Is Amazonia at risk?

Luisa Maria Diele-Viegas[a,*], Eder Johnson de Area Leão Pereira[b,c], Carlos Frederico Duarte Rocha[d]

[a] *Department of Biology, University of Maryland, College Park, MD 20742, USA*
[b] *Instituto Federal do Maranhão, Campus Bacabal, Maranhão, Brazil*
[c] *Programa de Modelagem Computacional, SENAI Cimatec, Av. Orlando Gomes, 1845 Salvador, BA, Brazil*
[d] *Departamento de Ecologia, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*

ARTICLE INFO

Keywords:
Mining activity
Amazonia
Indigenous lands
Brazil
Green bonds

ABSTRACT

The Brazilian parliament has emitted intentions on releasing mining within Amazonian indigenous lands since President Jair Bolsonaro took office in January 2019, disregarding the potential impacts of such activities on human livelihood and environmental conservation. The rapid and cluttered development of mining in the Brazilian Amazonia is historically related to local economic collapse, besides representing a global environmental risk. Here we bring a historical perspective of human activities in the Brazilian Amazonia, focusing on mining activities to discuss how it can threaten Amazonia's integrity, leading to negative consequences to biodiversity, human populations, and the world climate system. We also highlight the role of indigenous lands on buffering the impacts of human-induced environmental threats, which depends on government actions toward sustainable policies rather than inadequate environmental regulation aiming short term profits. Finally, we suggest the sustainable use of forest resources through the emission of green bonds, which may represent the best alternative to avoid the Amazonia depletion while allowing Brazilian economic growth.

1. Introduction

Amazonia is the largest tropical forest on the planet, hosting a quarter of the world's terrestrial species and accounting for 15% of global terrestrial photosynthesis, being its ecosystem services of global importance (Dirzo and Raven, 2003). It plays a central role in regulating the rainfall cycle in South America through the processing and transport of water vapor from the Atlantic Ocean, phenomena known as flying rivers (Marengo, 2006). Besides, it is also essential to global carbon budget by stocking nearly half of the tropical forest carbon, being its maintenance paramount to mitigate the effects of climate change (Yang et al., 2018). Thus, any threat to this biome represents a global environmental risk (Houghton et al., 2000).

Despite its global importance, Amazonia's integrity has been threatened by economic activities since South America colonization. Shifting cultivation is used as the dominant land-use activity in the forest for centuries, even though it is no longer considered a sustainable practice (Villa et al., 2020). Agricultural and pasture expansion is the forest's main threat in the last years (Swann et al., 2015), with the conversion of forest to pasture and farmland being responsible for the emission of 0.7 to 1.6 gigatons of carbon to the atmosphere per year between 1996 and 2005 (Pereira et al., 2019). Here we bring a historical perspective of human activities in Brazilian Amazonia, focusing on mining activities to discuss how it can threaten Amazonia's integrity, leading to negative consequences to biodiversity, human populations, and the world climate system.

In 2004, the Brazilian government has pledged to decrease deforestation by introducing several reforms in land and forest governance (West et al., 2019). Consequently, between 2005 and 2012, the country reduced 54% of its greenhouse gas emissions, mostly by reducing 78% of the deforestation (Rochedo et al., 2018). However, in recent years, this commitment was compromised, and Amazonia deforestation started to increase again (Pereira et al., 2019), reaching 10,129 km2 of forest lost in 2019, the highest annual rate since 2008 (INPE, 2020).

Future predictions also indicate a strong effect of climate change on the biome, which may lead to a decrease in precipitation and increase of the duration and intensity of droughts, especially in southern Amazonia, where climate change interactions with land-use change are stronger (Feeley and Rehm, 2012; Malhi and Wright, 2004). A long-term decreasing trend of carbon accumulation in Amazonia is predicted due to increased tree turnover and mortality rates (Brienen et al., 2015; Yang et al., 2018). Moreover, increased dryness may result in large-

* Corresponding author.
E-mail addresses: luisa.mviegas@gmail.com (L.M. Diele-Viegas), eder.johnson@ifma.edu.br (E.J.d.A.L. Pereira), cfdrocha@gmail.com (C.F.D. Rocha).

https://doi.org/10.1016/j.forpol.2020.102270
Received 4 June 2020; Received in revised form 21 July 2020; Accepted 23 July 2020
1389-9341/

Apêndice D

Econofísica

Durante o doutorado foram produzidos ainda outros ensaios envolvendo a aplicação de sistemas complexos em diversas áreas da economia. O objetivo foi resolver problemas que foram aparecendo durante esse período em diversas áreas como: mercado de criptomoedas, economia regional e mercado de ações. Inicialmente, será apresentado um trabalho que propõe uma explicação da crise da Covid-19 à luz da econofísica e do Big Data (FERREIRA; PEREIRA; PEREIRA, 2020b). Em seguida, um paper que relaciona às buscas pelo termo Donald Trump as variações em diversas bolsas de valores (PEREIRA *et al.*, 2018).

Na linha dos trabalhos envolvendo *bitcoin*, serão apresentados dois, o primeiro analisando a possibilidade do efeito contágio no mercado de criptomoedas (FERREIRA; PEREIRA, 2019) e o segundo identificando a eficiência de mercado usando os métodos *DCCA* e *DMCA* (FERREIRA; KRISTOUFEK; PEREIRA, 2020). Depois, um trabalho que analisa as relações comerciais inter- regionais entre os diversos setores da economia brasileira, encontrando quais são os setores mais centrais e quais os grupos formados.

Diante do exposto, os sistemas complexos podem ser importantes ferramentas de uso na tomada de decisões econômicas relacionadas a mercados financeiros, regionais ou auxiliar na compreensão das relações entre buscas no *Google Trends* e movimentações nas bolsas de valores. Segue os artigos:

Journal of
Risk and Financial Management

Review

From big data to Econophysics and its use to explain complex phenomena

Paulo Ferreira [1,2,3,*], Éder Pereira[4,5] and Hernane Pereira[4,6]

[1] VALORIZA - Research Center for Endogenous Resource Valorization, Portalegre, Portugal
[2] Instituto Politécnico de Portalegre, Portalegre, Portugal
[3] CEFAGE-UE, IIFA, Universidade de Évora, Largo dos Colegiais 2, 7000 Évora, Portugal
[4] Programa de Modelagem Computacional, SENAI Cimatec, Av. Orlando Gomes 1845, 41.650-010, Salvador, BA, Brazil
[5] Instituto Federal do Maranhão, Brazil
[6] Universidade do Estado da Bahia, Salvador, BA, Brazil

* Correspondence: pferreira@ipportalegre.pt

Received: date; Accepted: date; Published: date

Abstract: Big data has become a very frequent research topic, due to the increase in data availability. In this introductory paper, we make the linkage between the use of big data and Econophysics, a research field which uses a large amount of data and deals with complex systems. Different approaches such as power laws and complex networks are discussed, as possible frameworks to analyse complex phenomenon, could be studied using Econophysics and resorting to big data.

Keywords: Big data; Complexity; Networks; Stock Markets; Power laws.

1. Introduction

Big data has become a very popular expression in recent years, related to the advance of technology which allows, on the one hand, the recovery of a great amount of data, and on the other hand, the analysis of that data, benefiting from the increasing computational capacity of devices. Big data has been used in several research areas such as business intelligence (Chen et al. 2012; Sun et al. 2018), marketing (Verhoef et al. 2015; Wright et al. 2019), economics (Glaeser et al. 2016; Sobolevsky et al. 2017), health (Pramanik et al. 2017; Rose et al. 2019), and psychology (Matz and Netzer 2017; Adjerid and Kelley 2018), among many other areas and studies which could be mentioned.

Another area where big data is being applied is finance. In this particular case, the existence of large amounts of data allows a very broad type of analysis, from general indices to single specific assets. In particular, the use of big data allows the analysis of complex problems and has attracted the attention of physicists in recent decades. In fact, big data and complexity are intimately related to the emergence of a new research area called Econophysics.

In this paper, which is a brief introductory approach to the special issue "The Use of Big Data in Finance", we start by presenting a general view of big data and its advantages in finance (Section 2), building the bridge to Econophysics (Section 3) and some of its possible approaches, in particular power laws and networks (Sections 4, 5 and 6) and conclude the paper, including some suggestions for future research (Section 7).

2. The use of big data in economics and finance

The use of big data allows the analysis of (very) large datasets, reaching conclusions for some processes which could involve complex analysis. With the growth of web access in recent decades,

Physica A 512 (2018) 241–247

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Trump's Effect on stock markets: A multiscale approach

Eder Johnson de Area Leão Pereira [a,b], Marcus Fernandes da Silva [c], I.C. da Cunha Lima [a], H.B.B. Pereira [a,d,*]

[a] Programa de Modelagem Computacional, SENAI Cimatec, Av. Orlando Gomes 1845, 41.650-010, Salvador, BA, Brazil
[b] Instituto Federal do Maranhão, Brazil
[c] Instituto Federal da Bahia, Brazil
[d] Universidade do Estado da Bahia, Rua Silveira Martins, 2555, 41.150-000, Salvador, BA, Brazil

HIGHLIGHTS

- We examine the Trump's Effect on stock markets based on a multiscalar approach.
- The term Donald Trump has some significant values on the volatilities and returns.
- The proposed analysis contributes to understanding financial risks.

ARTICLE INFO

Article history:
Received 11 July 2017
Received in revised form 25 June 2018
Available online 7 August 2018

Keywords:
Econophysics
Financial markets
Volatilities and returns
Trump's Effect
Detrended cross-correlation coefficient

ABSTRACT

In this paper we demonstrate the "Trump Effect" based on the cross-correlations between the occurrence of the term "Donald Trump" in *Google Trends* and the volatilities and returns of indices corresponding to several stock exchanges around the world. For that, we associate the ρ_{DCCA} coefficient with its significance test. We observe that the occurrence of the term "Donald Trump" has an effect of moderate and weak intensities with positive and significant correlation on the volatilities of the Mexican, Japanese, Australian and Brazilian stock exchanges. Regarding returns, the occurrence of the term "Donald Trump" has a positive effect of weak and moderate intensities with positive and significant correlation on the North American stock exchange and a negative and significant effect of weak intensity on the Mexican stock exchanges. The results show that news related to the current North American president are correlated with fluctuations in the financial markets.

1. Introduction

The use of complex systems in financial markets has revolutionized financial modeling [1–7], with a diversity of instruments and applications that are enabling a fresh look at financial markets. Econophysics has contributed to our understanding of the dynamics of stock exchanges, considering several phenomena from the last 20 years (e.g., the *subprime* and the European crises). Recently, an event has drawn the attention of financial markets: the candidacy and election of Donald Trump as president of the United States (US).

The election of the current US president was one of the most important events of the year 2016, as he presides over the world's leading economy, with the US having both an economic and political influence over a range of countries. Since being announced as a candidate for the presidency of the US in June 2015, searches for the term "Donald Trump", as indicated

* Corresponding author at: Programa de Modelagem Computacional, SENAI Cimatec, Av. Orlando Gomes 1845, 41.650-010, Salvador, BA, Brazil.
E-mail addresses: eder.johnson@ifma.edu.br (E.J. de Area Leão Pereira), marcus.fisico@gmail.com (M.F. da Silva), ivandacunhalima@gmail.com (I.C. da Cunha Lima), hbbpereira@gmail.com (H.B.B. Pereira).

https://doi.org/10.1016/j.physa.2018.08.069
0378-4371/

Journal of
Risk and Financial Management

Communication

Contagion Effect in Cryptocurrency Market

Paulo Ferreira [1,2,3,*] **and Éder Pereira** [4,5]

[1] VALORIZA—Research Center for Endogenous Resource Valorization, 7300 Portalegre, Portugal
[2] Instituto Politécnico de Portalegre, 7300 Portalegre, Portugal
[3] CEFAGE-UE, IIFA, Universidade de Évora, Largo dos Colegiais 2, 7000 Évora, Portugal
[4] Programa de Modelagem Computacional, SENAI Cimatec, Av. Orlando Gomes 1845, 41650-010 Salvador, BA, Brazil
[5] Instituto Federal do Maranhão, 65075-441 São Luís-MA, Brazil
* Correspondence: pferreira@ipportalegre.pt; Tel.: +351-268-628-528

Received: 11 June 2019; Accepted: 8 July 2019; Published: 10 July 2019

Abstract: The rapid development of cryptocurrencies has drawn attention to this particular market, with investors trying to understand its behaviour and researchers trying to explain it. The evolution of cryptocurrencies' prices showed a kind of bubble and a crash at the end of 2017. Based on this event, and on the fact that Bitcoin is the most recognized cryptocurrency, we propose to evaluate the contagion effect between Bitcoin and other major cryptocurrencies. Using the Detrended Cross-Correlation Analysis correlation coefficient ($\Delta\rho$DCCA) and comparing the period after and before the crash, we found evidence of a contagion effect, with this particular market being more integrated now than in the past—something that should be taken into account by current and potential investors.

Keywords: cryptocurrency; contagion effect; detrended cross-correlation analysis; Bitcoin

1. Introduction

Cryptocurrencies are digital currencies which can be used for direct retail purchases but also as financial assets in general. They are characterized by some features that make them different from other assets, namely the facts that they are not subject to any centralized institutional authority and that they do not have physical representation. Another important feature, which makes this kind of currency somewhat controversial, is the fact that they are not associated with any tangible assets (Corbet et al. 2019).

Since the creation of Bitcoin in 2009, which was the first cryptocurrency, this particular market has increased its value exponentially, reaching about 260 billion USD of capitalization in May 2019. Bitcoin itself was responsible for about 55% of that capitalization, being by far the most important cryptocurrency. This evolution makes cryptocurrencies very interesting for investors, as well as for researchers, with a growing body of literature on several issues (Urquhart 2018; Corbet et al. 2019). These studies include topics more linked with financial issues like efficiency or the relationship with other assets (which is addressed in the next section), in addition to analysis issues like regulation or even linkages with possibly illicit activities (see, respectively, the works of Chaffee (2018) and Campbell-Verduyn (2018) as examples on each of those topics).

Despite the evolution of cryptocurrencies' prices, during 2017 this market experienced a kind of bubble, with prices reaching maximum levels on 15 December 2017, followed by a sharp decrease. With such an episode, and considering Bitcoin as the most relevant cryptocurrency, we can evaluate the possibility of a contagion effect in this market. According to Forbes and Rigobon (2002), there is a certain pre-existing integration between assets and, after a given episode of instability, this relationship is intensified, i.e., correlations between those assets increase.

Physica A xxx (xxxx) xxx

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

DCCA and DMCA correlations of cryptocurrency markets

Paulo Ferreira [a,b,c,*], Ladislav Kristoufek [d,e], Eder Johnson de Area Leão Pereira [f,g]

[a] *VALORIZA - Research Center for Endogenous Resource Valorization, Portalegre, Portugal*
[b] *Instituto Politécnico de Portalegre, Portalegre, Portugal*
[c] *CEFAGE-UE, IIFA, Universidade de Évora, Largo dos Colegiais 2, 7000 Évora, Portugal*
[d] *Institute of Economic Studies, Faculty of Social Sciences, Charles University, Prague, Czech Republic*
[e] *The Czech Academy of Sciences, Institute of Information Theory and Automation, Prague, Czech Republic*
[f] *Programa de Modelagem Computacional, SENAI Cimatec, Av. Orlando Gomes 1845, 41.650-010, Salvador, BA, Brazil*
[g] *Instituto Federal do Maranhão, Brazil*

ARTICLE INFO

Article history:
Received 10 June 2019
Received in revised form 3 November 2019
Available online xxxx

Keywords:
Cryptocurrency
Bitcoin
Correlations
Detrended cross-correlation analysis
Detrending moving-average cross-correlation analysis
Efficiency

ABSTRACT

We examine the serial correlation structure of six liquid cryptocurrencies with a long data record – Bitcoin, DASH, Stellar, Litecoin, Monero, and Ripple – with a use of the detrended cross-correlation (DCCA) and detrending moving-average cross-correlation (DMCA) correlation coefficients. We find that these cryptocurrencies behave differently from the stock markets which are much closer to the random walk (efficient) dynamics. We further discuss issues connected to strong statements about cryptocurrency markets practical inefficiency.

1. Introduction

Cryptocurrencies correspond to digital currencies based on the blockchain technology and cryptography for validation of new transactions either via specialized exchange, over the counter, or direct retail purchases. Thus, unlike the vast majority of other available financial assets, they have no association with any centralized institutional authority, have no physical representation, and are infinitely divisible. Additionally, and again unlike traditional financial assets, the intrinsic value of encrypted currencies has been controversial since the beginnings as it cannot be derived from any tangible assets [1]. Often, the whole cryptocurrencies market is interchanged with Bitcoin which is the most popular one and also the original one introduced in the whitepaper under (most likely) a pseudonym of Satoshi Nakamoto and launched in 2009 with the first and now legendary Bitcoin purchase of a pizza for 10,000 BTC in May 2010. Since then, the worldwide capitalization of the cryptocurrencies market has been increasing and reaching a total of 260 billion USD as of May 2019, with Bitcoin itself with a capitalization of almost 150 billion USD, equivalent to approximately 55% of the entire value of cryptocurrencies market. In 2016, about 62.5 million transactions were carried out of 109 million accounts. In contrast to traditional currencies, Bitcoin transactions are not dependent on central banks, but rather on a decentralized computer network to validate transactions and increase the money supply [1].

The evolution and development of cryptocurrencies called the attention of researchers. A quick search using the word "cryptocurrencies" in Google Scholar shows the exponential increasing trend of documents, year by year, starting with a total of 15 works in 2009 to about 7650 works in 2018. If we use Bitcoin, the most known cryptocurrency, the trend is similar, starting with 363 works in 2009 and 16,800 in 2018 (both results are present in Fig. 1).

* Corresponding author at: CEFAGE-UE, IIFA, Universidade de Évora, Largo dos Colegiais 2, 7000 Évora, Portugal.
E-mail address: pferreira@ipportalegre.pt (P. Ferreira).

https://doi.org/10.1016/j.physa.2019.123803

AN INTER-REGIONAL NETWORK PERSPECTIVE TO EVALUATE THE BRAZILIAN ECONOMY

Luiz Carlos de Santana Ribeiro - NUPEC/UFS
Eder Johnson de Area Leão Pereira - SENAI/CIMATEC
Fernando Salgueiro Perobelli - PPGE/UFJF
Hernane Borges de Barros Pereira - SENAI/CIMATEC

Abstract: This paper aims to deepen the discussion about the productive interdependence among the Brazilian states through an input-output network in order to identify emergent patterns or properties within the Brazilian states. We use an inter-regional IO matrix, base year 2011, for the 27 Brazilian states and 68 sectors. The main results show that the out-degree of most important sectors was greater than the in-degree, which reveals, for this group of sectors, a greater relative importance on the supply side of the economy. The modularity analysis suggests that some states are isolated in the Brazilian productive structure. Thus, the use of seven indicators gave us a kaleidoscopic vision of the Brazilian internal trade performance and enables us to deal with points like complementarity, hierarchy and integration in spatial terms. We can affirm that this diagnosis plays an important role for the development process as it disaggregates the interdependence in different aspects.
Keywords: Brazilian economy; regional development; network; input-output.

Resumo: Este artigo objetiva aprofundar a discussão sobre interdependência produtiva entre os estados brasileiros por meio de uma rede de insumo-produto no sentido de identificar padrões emergentes ou propriedades inerentes aos estados. Utilizamos uma matriz inter-regional de insumo-produto, ano base 2011, para os 27 estados brasileiros e 68 setores. Os principais resultados mostram que o grau de saída da maioria dos setores mais importantes foi maior do que o grau de entrada, o que revela, para este grupo de setores, uma maior importância relativa pelo lado da oferta da economia. A análise de modularidade sugere que alguns estados estão isolados na estrutura produtiva brasileira. Portanto, o uso de sete indicadores nos deu uma visão caleidoscópica do desempenho do comércio interno brasileiro e nos permitiu lidar com questões de complementariedade, hierarquia e integração em termos espaciais. Podemos afirmar que este diagnóstico desempenha um importante papel no processo de desenvolvimento na medida em que desagrega a interdependência em diferentes aspectos.
Palavras-chave: Economia brasileira; desenvolvimento regional; rede; insumo-produto.

JEL: C67; R15; R58.
Área 10 - Economia Regional e Urbana

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Ensaios em Econofísica e Teoria de Redes

Eder Johnson de Area Leão Pereira

Salvador, Outubro de 2020.