



# Time series analysis of the developed financial markets' integration using visibility graphs



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## HIGHLIGHTS

- A time series of markets' segmentation is studied via visibility graphs.
- Visibility graphs provide means to quantitatively analyze time series.
- Important historical incidents coincide with variations in graphical node degree.
- The frequencies of historical incidents are disclosed through neighborhood span.
- Large "cycles" and significant noise are linked to large and small communities.

## ARTICLE INFO

### Article history:

Received 2 January 2014

Received in revised form 16 May 2014

Available online 23 May 2014

### Keywords:

Market integration  
Market segmentation  
Visibility graphs  
Time series  
Complex networks

## ABSTRACT

A time series representing the developed financial markets' segmentation from 1973 to 2012 is studied. The time series reveals an obvious market integration trend. To further uncover the features of this time series, we divide it into seven windows and generate seven visibility graphs. The measuring capabilities of the visibility graphs provide means to quantitatively analyze the original time series. It is found that the important historical incidents that influenced market integration coincide with variations in the measured graphical node degree. Through the measure of neighborhood span, the frequencies of the historical incidents are disclosed. Moreover, it is also found that large "cycles" and significant noise in the time series are linked to large and small communities in the generated visibility graphs. For large cycles, how historical incidents significantly affected market integration is distinguished by density and compactness of the corresponding communities.

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## 1. Introduction

In a financial market where investors can trade assets freely, an asset's price depends only on the so-called "invisible hand", i.e. its supply and demand. The prices of all the assets reach an equilibrium under which the assets and the investors' capital are optimally allocated. Economic growth then benefits from this optimal allocation of the capital. However, the real world financial market is far from a free market. It is segmented into a number of small markets due to, for example, geographical or political reasons. To promote social welfare, many countries make efforts to fully integrate their domestic markets with the world market. Since 1980s, developed countries and emerging markets have gradually removed their various capital controls. In 1999, the Eurozone was established to integrate financial markets across the European Union.

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In the past few decades, financial market integration has been witnessed around the world [1–4] and social welfare has been improved via optimal allocation of the capital [5,6]. If markets are fully integrated, then the law of one price will hold, which means that the prices of the same asset in different markets are the same. Otherwise, investors could gain through arbitrage—buying assets from the markets with the lowest prices and selling assets to the markets with the highest prices. Hence, price differentials provide a measure of market segmentation [3]. In this paper, we construct a measure of the developed financial markets' segmentation based on price discrepancy between various developed markets and the world market.

For time series analysis, a new framework of transforming a time series into a network has recently been proposed and popularized by many authors. Given a time series, a network is built by encoding some characteristics of the time series into the network's nodes and edges. Then, the time series and its underlying system can be investigated by applying the measures of complex network structure to the generated network. Under this general framework, several methods have been introduced—such as cycle networks [7], correlation networks [8], recurrence networks [9–11], transition networks [12], visibility graphs [13,14], and many others. Among these methods, visibility graphs have a straight-forward geometric interpretation of the original time series, and are therefore suitable for quantitative analysis of the time series of market segmentation.

The time series of the developed financial markets' segmentation from 1973 to 2012 is constructed from Datastream Global Equity Indices, and studied. From the market segmentation time series, the trend of market integration is easily found as well as a number of fluctuations. To quantitatively analyze these fluctuations, the time series is divided into seven ten-year windows and then transformed into seven visibility graphs. From these visibility graphs, important incidents that influenced the market integration, for example the 2008 financial crisis, are found by examining the graphical node degree. Through the measure of neighborhood span, variance in amplitude distribution in each time window is revealed, and the frequencies of historical incidents are disclosed. Moreover, large cycles and significant noise in the time series are found by detecting large and small communities in the generated visibility graphs. For large cycles, the time series' geometric features are distinguished by density and compactness of the corresponding communities, and thus we are able to determine those historical incidents that took place and how significantly they affected the market integration.

Furthermore, this paper provides a novel exemplary application of the method of visibility graphs—an approach not previously taken with the visibility graphs. The measures and analysis presented here will have potential applications in the study of other time series and other physical systems.

The remainder of this paper is organized as follows. Sections 2 and 3 describe the time series data and the visibility graphs method, respectively. Section 4 presents the analysis of market segmentation time series by investigating the generated visibility graphs. Section 5 concludes the paper with some discussion and remarks.

## 2. Time series of the developed financial markets' segmentation

We construct the time series of the developed financial market segmentation using daily industry sectors' indices provided by Datastream Global Equity Indices.<sup>1</sup> In this indices database, stocks are allocated to industrial sectors and industry sector indices are then calculated from stocks.<sup>2</sup> We choose industry sector indices for the world and 22 developed markets<sup>3</sup> from 1973 to 2012.<sup>4</sup> The measure of market segmentation we use is analogous to the price discrepancy of a portfolio made up of industry sectors, which is proposed in Ref. [3]. For each market  $i$ , the measure of its market segmentation at time  $t$  is defined as

$$SEG_{i,t} = \sum_j MV_{i,j,t} |EY_{i,j,t} - EY_{w,j,t}|,$$

where  $EY_{i,j,t}$  denotes earnings yield of industry  $j$  in market  $i$  at time  $t$ ,  $EY_{w,j,t}$  denotes the world's earnings yield of industry  $j$  at time  $t$  and  $MV_{i,j,t}$  is the weight of industry  $j$  in market  $i$  at time  $t$ . The earnings yield difference between market  $i$  and

<sup>1</sup> The data of Datastream Global Equity Indices was collected through Thomson Reuters Datastream Professional on 18 October 2013. "Thomson Reuters Datastream Professional is a powerful tool that integrates economic research and strategy with cross asset analysis to seamlessly bring together top down and bottom up in one single, integrated application" (from <https://forms.thomsonreuters.com/datastream/> on 9 December 2013). It provides a large range of global financial data covering equities, stock market indices, currencies, company fundamentals, fixed income securities and key economic indicators for many countries and markets.

<sup>2</sup> The classification of industrial sectors follows the Industry Classification Benchmark (ICB) jointly created by FTSE and Dow Jones. The indices data used covers 37 industrial sectors, namely, Oil and Gas Producers, Oil Equipment and Services, Chemicals, Forestry and Paper, Industrial Metals and Mining, Mining, Construction and Materials, Aerospace and Defense, General Industrials, Electronic and Electric Equipment, Industrial Engineering, Industrial Transportation, Support Services, Automobiles and Parts, Beverages, Food Producers, Household Goods and Home Construction, Leisure Goods, Personal Goods, Tobacco, Healthcare Equipment and Services, Pharmaceuticals and Biotechnology, Food and Drug Retailers, General Retailers, Media, Travel and Leisure, Fixed Line Telecommunications, Mobile Telecommunications, Electricity, Gas Water and Multiutilities, Banks, Nonlife Insurance, Life Insurance, Real Estate, Equity Investment Instruments, Software and Computer Services, and Technology Hardware and Equipment.

<sup>3</sup> The 22 developed markets are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Hong Kong, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Singapore, Spain, Sweden, Switzerland, United Kingdom, and United States.

<sup>4</sup> Not all the developed markets' data are available from 1973. See the red (piecewise constant) line in Fig. 1 for the number of markets involved.

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