Implementing Financial Market Quality Measures in Python

Seminar

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Contents

1. Introduction

Financial markets are a generic term for broadly any markets in which securities are traded. This includes stock markets, derivates, bonds, etc. Today, many people encounter financial markets in their everyday lives and with the trend of new cryptocurrencies, new financial markets emerge, and the number of markets increases. Therefore, there is much research about financial markets and researchers want to observe the effects of different events on the quality of a financial market. As there is no inherent measure for this, a whole research branch about capturing the quality of a financial market has formed. Due to the great variety of proposed proxies in the literature, researchers have the choice between many different quality measures among which they observe effects on financial markets. Within this work, I have examined some papers on the use of different quality measures and reasons for the choice, to identify patterns and trends. Furthermore, I screened the papers for references to recognize standard works and role models within this research branch.

The remainder of this work is structured as follows. Section 2 introduces the employed methodology for the structured literature review and the implementation in Python. In Section 3, I summarize different quality measures. Then I analyze the existing body of literature and point out the results. Section 4 includes the implementation in Python. My results will be discussed in section 5 and section 6 concludes my work.

2. Methodology

2.1. Literature Review

My literature research follows the suggestions by Webster and Watson [1]. Using the database *GoogleScholar*, I set up a query to filter the most relevant papers which fit the search term[1] best. By April 2021, this yields an initial set of 119 publications for further review. By analyzing each title and abstract, I can exclude 85 papers that do not explicitly match the scope of the literature review. Reasons for this are that there is often no indication of which quality measures are employed or the papers' topic is not about financial markets at all. That resulted in a total of 34 papers for further review and analysis.

Next, I took a closer look at the first 10 papers to find out more about important works, which are widely cited in this field of research. Thereby I came across the three standard works of Hendershott [2], Hasbrouck [3], and Amihud [4] which proposed different measures for market quality and are therefore often referred to. This gave me a rough overview of the different possibilities to capture market quality.

[1] "stock market*" "market quality measure"

With that basic knowledge on the topic, I created a concept matrix and used different measures of *liquidity*, *market activity*, and *information efficiency* as categories, which will be introduced in Section 3.1. Throughout the entire screening process, I evaluated these categories and added more, if required. Table 2 summarizes all reviewed papers and shows the assignment to the individual categories. After creating the concept matrix as a starting point, I took a closer look at the different quality measures, which I used as categories and summarized them. I compared the formulas, the needed type of information, as well as their advantages and disadvantages. With that as additional knowledge, I took a second look at each paper and searched for reasons why the author uses which measure and tried to summarize this in the concept matrix as well.

2.2. Python Implementation

Using Binance[1] as data source, I accessed the order book data as well as the trade data through the Binance API. With the implementation of different market quality measures, I compared two different financial markets, Ethereum (ETH/USD) and Bitcoin (BTC/USD). The order book and trade data were requested by the API on the 15th of July at 10 am and only provided a snapshot of the data.

3. Literature Review of Financial Market Quality Measures

3.1. Types of Quality Measures

Quality measurement of financial markets has received much attention in research, as it is mandatory to be able to measure the quality of a market, as you want to observe changes due to different interventions or events. Because there is not a single measure of quality, many researchers follow the lead question about how to capture the quality of financial markets, therefore many different methods have emerged. A distinction must be made between 3 different aspects of market quality, as shown in figure 1. These are market efficiency, transaction costs (explicit and implicit), and market activity. There are further criteria like e.g., volatility, which are sometimes treated as independent aspects in literature. For several reasons, I have summarized volatility under market activity. A market is called efficient if it provides the operational infrastructure for trading. If it efficiently allocates bids and asks and if it is information efficient [5]. As the operational infrastructure is in place for all the considered markets, this criterion gets no attention in research. As the pareto-efficient allocation of bid and ask in a market is a dichotomous property, this cannot be compared or quantified and therefore also gets little attention in research. A market is called *information efficient* if prices reflect all existing information and react to new information immediately. The transaction costs can be divided into explicit and implicit

[1] www.Binance.com

transaction costs. Explicit transaction costs are the fees that are actually paid and can therefore be easily quantified. As researchers often want to observe changes in market quality over time and the explicit transaction costs are exogenous and do not change over time, they are not used as quality measures in research. Although they are an important determinant of a market's quality. By far the most attractive field of markets quality research is *implicit transaction costs* (also called *liquidity costs*). Because they are hard to quantify, there are many different approaches to capture them.

The analyzed body of literature leverages multiple measures for financial market quality. While reviewing the papers, several core measures have emerged. Distinguishing between the categories *liquidity*, *market activity* and *information efficiency*, I considered 11 different market quality measures. As they formed the columns of the concept matrix, they are briefly explained in the following sections with regard to the formulas, the type of required information as well as advantages and disadvantages.

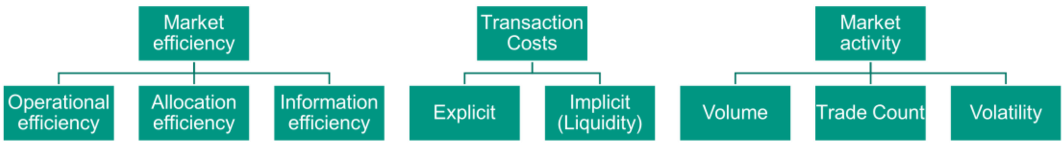

Figure 1: Three different aspects of market quality

3.1.1. Liquidity Measures

Liquidity, as a central element of market quality, can be defined as the ability to quickly trade large size, at low cost [5]. It can be characterized by four different dimensions, namely *immediacy*, *width*, *depth*, and *resiliency* [5].

Immediacy refers to how quickly trades of a given size can be arranged at a given cost. Traders generally use market orders to demand immediate trades [5]. *Width* refers to the cost of doing a trade of a given size. For small trades, traders usually identify width with the bid/ask spread. It also includes brokerage commissions. *Width* is the cost per unit of liquidity. Traders often refer to market width by the term market breadth [5]. *Depth* refers to the size of a trade that can be arranged at a given cost. *Depth* is measured in units available at a given price of liquidity [5]. *Resiliency* refers to how quickly prices revert to former levels after they change in response to large order flow imbalances initiated by uninformed traders [5].

To capture *liquidity* and measure it across these dimensions there are 5 types of measures that are widely used in praxis.

Bid-ask spread

The *bid-ask spread* also referred to as *quoted spread*, is the difference between the lowest ask price and the highest bid price within an order book. According to Harris 2004 [5], it is the price impatient traders pay for *immediacy*. It can be calculated with the following formula:

$$QuotedSpread_{i,t} = \frac{(ask_{i,t} - bid_{i,t})}{2 * mid_{i,t}}$$

Where $ask_{i,t}$ is the lowest price for stock i at time t at which a market participant can buy the asset and $bid_{i,t}$ is the highest price at which an asset can be immediately sold. As the difference between these two gets bigger, the price which the impatient trader must pay for the immediacy of the trade gets bigger. This difference is divided by the midpoint $mid_{i,t}$ multiplied by 2 to put it in relation to the average price of the traded asset. The advantages of this measure are that it is easy to calculate and therefore widely used in the literature [6]. It offers a good and practical proxy for liquidity. Orderbook data is sufficient for the calculation. The main disadvantage is that it tends to overstate investors' expected trading costs when trades frequently take place inside the spread [7]. This gives rise to the use of other liquidity measures such as the effective and realized spread.

Effective Spread

As the signed difference between the trade price and the time-of-trade quotation midpoint, the *effective spread* is an intuitively simple transaction cost estimate [5]. It is calculated the following way:

$$EffectiveSpread_{i,t} = D_{i,t} * \frac{(price_{i,t} - mid_{i,t})}{mid_{i,t}}$$

where $D_{i,t}$ indicates the direction of the trade and is +1 if the buyer initiated and -1 if the seller initiated the trade. The $price_{i,t}$ is the actual price of the stock in the transaction. The effective spread equals the quoted bid/ask spread when all purchases take place at the bid and all sales take place at the offer. When trades take place within the *effective sprea*d that traders pay is smaller than the *quoted spread* [5]. The advantage of the *effective spread* is, that it measures the real trading costs, as it takes the transaction price into account. The disadvantage is that it relies on the direction of the trade $D_{i,t}$ for the calculation and therefore order book data is not sufficient for the computation of this measure, the actual trade data is needed.

Realized Spread

The *realized spread* is the difference between the prices at which dealers actually buy and sell. *Realized spreads* are usually smaller than *quoted spreads* because dealers occasionally trade at better prices than they quote and because they often adjust their bid and ask prices between trades [5]. It can be calculated the following way:

$$RealizedSpread_{i,t} = D_{i,t}\frac{(price_{i,t} - mid_{i,t+x})}{mid_{i,t}}$$

Where $mid_{i,t+x}$ is the midpoint at the later time period $t + x$. The disadvantage here is that it is not possible to know the $mid_{i,t+x}$ at the time t, thus a proxy is needed. There are some time spans which are typically used but however the choice of x is arbitrarily. Again, order book data is not sufficient and trade data is needed.

Depth

As the *depth* refers to the size of a trade that can be arranged at a given cost [5], it can be measured the following way:

$$Depth(X) = \frac{Vol.Bid_{i,t} + Vol.Ask_{i,t}}{2}$$

Where $Vol.Bid_{i,t}$ and $Vol.Ask_{i,t}$ are the total volumes of bids and ask of the stock i at time t. This measure only needs orderbook data. Since it only provides a snapshot, it is often calculated in intervals (e.g., 15 minutes) and then the mean over the last 24 hours is taken.

Illiquidity

Another measure, frequently used, is the *Amihud illiquidity*. It was introduced in Amihud 2002 [4]. The author claims, that *liquidity* is an elusive concept, which is not observed directly, but rather has several aspects that cannot be captured in a single measure. Thus, Amihud introduced the *Amihud illiquidity measure*, that gives the daily *price impact* of the order flow [8]. It can be calculated the following way:

$$ILLIQ_{i,y} = \frac{1}{D_{i,y}}\sum_{i=1}^{D_{i,y}}\frac{|R_{i,y,d}|}{VOL_{i,y,d}}$$

Where $D_{i,y}$ is the number of days for which data are available for stock I in year y, $VOL_{i,y,d}$ is the *trading volume* in euros (currency) for stock i the day d of year y and $R_{i,y,d}$ is the return of stock i the day of year y. So, in cases that great price changes with small *trading volume* exist, this ratio increases, which means that the *illiquidity* of the stock increases [8]. Again, there is trade data required for the computation.

3.1.2. Market Activity Measures

Next to the *liquidity* aspect of a market, the *market activity* is also an important factor, determining the quality of a market and should therefore be measured. Just as the *bid-ask spread* as a measure for liquidity, the ways to measure *market activity* are very intuitive. In the following, the most common measures for *market activity* will be briefly explained. All of them need trade data for calculation.

Trade Count

This market quality measure captures the number of trades per day and is therefore a measure of *trading intensity*.

Volume

The *volume* of a market is the size of the total trade volume within the market. It can be observed over different periods of time, although it is most common to observe it over 24 hours. Sometimes the *daily volume* is also called *turnover*.

Average Trade Size

The *average trade size* as a market activity measure combines both, the *trade count*, and the *volume* as it divides the *trading volume* by the *number of trades*.

Volatility

As we want to measure market activity and the quality of a market, it is mandatory to look at the *volatility* of a market. The literature offers a vast number of measurements and possibilities for modelling *volatility* [9]. Therefore, I have summarized all of them under the term '*volatility'*. In order not to go beyond the scope of this seminar, I have not looked at the exact calculation of all of them. Most of the screened papers use the *intraday volatility* as measure.

3.1.3. Market Information Measures

A market is called *information efficient* if prices reflect all existing information and react to new information immediately. The two following measures have emerged as the most common ways to capture the *information efficiency* aspect of a market.

Price Impact

The *price impact* can be calculated as the difference of the *effective* and *realized spread*. It captures the changes in price due to a trade. As a measure of the *information efficiency* of a market, it reflects the market's assessment of the information content of a trade.

Hasbrouck measure

In his widely cited paper [3], the author Joel Hasbrouck, proposes a new approach to capture market quality. In his approach the author decomposes the transaction prices into a random-walk component and a stationary component.

$$p_t = m_t + s_t$$

The first component m_t is the efficient price, defined as the final value of the security conditional on all public information available at time t. The second component s_t is the deviation between this efficient price and the actual transaction price and is termed the pricing error. The author proposes the standard deviation of the pricing error σ_s as a summary measure of market quality, as it captures intuitively how close the efficient price tracks the actual transaction price [3].

3.2. Choice of Measures

As there is a big variety of market quality measures, every paper employs a different combination of measures. As seen before, every quality measure has its advantages and disadvantages. While reviewing the papers and analyzing the motives for the choice of the used measures, I found out that it is important for the authors to be comparable to other papers. Thus, they often want to employ measures that are widely used in literature and are proposed by standard works like the references discussed in section 3.3. [6]

Another determinant factor of the choice is the type of information that is needed to calculate the measures. For example, if the purpose of the study is to observe effects on a market's quality over very long time periods and the microstructure data of the market is not available, this makes the usage of finer liquidity measures impossible and justifies the choice of more coarse measures, like for example the Amihud illiquidity measure [4], [10]. Sometimes there are slightly modified versions of the common market quality measures used to serve the paper's purpose best. For example, if the author wants to observe the effects of fragmentation on a market's quality, which can only be measured at a weekly frequency [9]. Therefore, the authors construct their market quality measures as the weekly median of the daily measures. Other papers for example use standardized versions of the measures to make them more comparable [11]. Some authors are addressing the disadvantage of the simple bid-ask spread measure, that it tends to overestimate the implicit transaction costs, and therefore justify their choice of using more sophisticated measures like the realized or effective spread[12]. 6 authors claim that they choose one of the employed quality measures because it is intuitive [13][14][15]. There is no paper which only uses a single measure for market quality, there is always a combination of multiple measures used. A reason for this could be the multi-dimensionality of market quality and the impossibility of capturing all information within a single quality measure.

3.3. Referenced Literature

While reviewing the papers, three authors stand out, as they are widely cited by others. They have in common, that their papers suggest new types of quality measures, or they employ combinations of measures, which are used by later works within the same research branch.

The author, who is most often cited by the other reviewed papers, is Joel Hasbrouck. In his papers Hasbrouck 1991 [16] and Hasbrouck 1993 [3] he addresses the question of how to measure the information content of markets. Hasbrouck 1993 [3] proposes a new approach to measure market quality. The core concept of this paper is the idea of a transaction price decomposition, like previously described.

Another paper suggesting a combination of different quality measures is Hendershott 2011[2]. In this paper the author follows the lead question "*does algorithmic trading improve liquidity?"* and employs different liquidity measures, containing the bid-ask spread, the effective spread and the realized spread. As many of the reviewed papers are about the effects of different forms of algorithmic trading on market quality, many of them refer to the work of Hendershott. It forms a role model for later works, as it proposes a combination of different measures to capture market quality within this field of research.

The third paper, frequently referred to, is Amihud 2002 [4]. In this paper, the author introduces the *Amihud illiquidity measure*. The *illiquidity measure* employed here, called ILLIQ, is the daily ratio of absolute stock return to its dollar volume, averaged over some period. Finer and better measures of *illiquidity* proposed by others require a lot of microstructure data which is not available in many stock markets. And, even when available, the data does often not cover long periods of time. As this being the main advantage of the *Amihud illiquidity measure,* it is often used when long time periods are observed.

3.4. Further Results

As shown in the concept matrix, almost every author employs a different mixture of employed measures. Although only a part of the authors justified their choice of quality measures, there are still trends and patterns recognizable. As the authors are primarily free in their choice, it is understandable that they prefer to use measures, which fit the paper's purpose best. What can be extracted from the concept matrix is, that measures of liquidity are roughly as frequent as measures of market activity. This is comprehensible, as they together cover two big aspects of market quality and as *information efficiency* is often harder to capture.

Among the different liquidity measures, it is striking that the *bid-ask spread* is used more frequently than the other spread measures. A reason for that could be the advantages of this measure, namely that it is a simple and intuitive way to measure *liquidity costs*. But because of its disadvantages, that it tends to overestimate the *liquidity costs*, the *realized* and *effective spread* are often additionally employed. It is rare, that authors only use the more sophisticated measures like the *realized* and *effective spread* without including the bid-*ask spread*. Therefore, it is used by over 85% of the reviewed papers.

Also noticeable during the creation of the concept matrix was, that some measures like the average trade size are very little used, compared to others (Only 20% of papers used the *average trade size*). Reasons for this could be, that some other market activity measures are simply more intuitive and therefore more common. So, it is more obvious to measure the market activity by the trading volume, than by the average trade size, because it gives more information about the total activity in the market and is often more interesting than knowing the size of an average trade in the market.

4. Implementation in Python

4.1. Simulation of quality measures in Python

Before implementing the quality measures of the two observed markets (ETH/USD and BTC/USD) I was assuming that the Bitcoin market is more liquid and active than the Ethereum market, as Bitcoin is more famous and common among the cryptocurrencies than Ethereum.

With the order book data of the two observed markets (ETH/USD and BTC/USD) all required information for the calculation of the quoted spread was available. The API provided an order book with 100 asks and 100 bids at the specific time the request was made, and I was able to calculate the *quoted spread* for both markets.

With adding the trade data of the two markets to the available data, the calculations of *effective* and *realized spreads* get possible, as the trade direction and the prices of the actual trades are now available. With the previous calculation of the midpoint, I computed the *effective spreads* of 500 trades and stored them in a list. For the calculation of the realized spreads, it was necessary to request the order book data again and calculate a new midpoint 15 minutes after the first midpoint was calculated. This time period is chosen arbitrarily, but 5/10/15 minutes have been established as standard in the literature. Using the old and the new midpoint, I computed the realized spreads of 500 trades and stored them in a second list.

To compare the 3 different spread measures, I computed the mean of the two lists and put all 3 spreads into a dataframe [B]. Then I calculated the price impact as the difference of *effective* and *realized spread*. Because the own calculated volume would only present a snapshot and because of the *24h-volume* being displayed, I extracted this information and added it to the dataframe.

As shown in the chart below, the Ethereum market has lower spread measures than the Bitcoin market. As higher spreads coincide with lower *liquidity*, this confirms the assumptions, made before. A higher *market activity* of the Bitcoin market can also be recognized by the higher *24h-Volume*. Because of the higher *liquidity* and *volume*, it is comprehensible, that the Bitcoin market has a lower *price impact* than the Ethereum market.

	Market	Quoted Spread	Effective Spread	Realized Spread	Price Impact	Volume
0	ETH/USD	3.704248e-05	1.970465	1.969614	0.000851	1.300638e+09
1	BTC/USD	1.530539e-07	0.000077	-0.000140	0.000217	1.372541e+09

Table 1: Market quality measures for Ethereum and Bitcoin implemented in Python

5. Discussion

Although the field of the dimensions and the measurement of market quality received lots of attention in the last decades, there is still a vivid discussion going on in market microstructure research. There are many theoretical concepts and ideas of measuring market quality but there is still not the single best measure for liquidity. Still, some measures are used more frequently.

5.1. Limitations

There are two main limitations of this work. The first one is, that due to the numerous different measures of market quality that are known, it is necessary to limit the categories under consideration. Like already mentioned, almost every author employs his own unique set of measures to capture market quality. If one would want to add every suggested measure, even if it is only used in one paper, the concept matrix would have more than 30 columns and this would not match the scope of the work. Therefore, it is mandatory to group and summarize the used measures. Sometimes this is easily justifiable, as the measures are only slightly modified (e.g., standardized, mean over the daily measures is taken). But in some cases, it is not so self-evident to group the measures by sense. Furthermore, a considerable amount of available literature barely meets academic standards in terms of transparent documentation of applied methods and results. Only a few authors go further into the reasons for their choice of measures, which limits the presented analysis. More than half of the reviewed papers (56%) do not even contain information about why they choose which measure and the few of them which do, often do not go into much detail. Therefore, it is hard to extract information and to gain a sense of motivations behind the choice of the dimensions across which market quality was measured. Although there were still some informative papers, which allowed a further analysis, I think this is a main limitation of the work.

5.2. Future Research

I want to encourage future researchers in the field of markets microstructure to report and justify their choice of market quality measures in a structured way to provide more transparency and to make it easier for standards to establish. As market quality is multi-dimensional and as the application fields of the quality measures are different, it is not possible to capture all information within a single quality measure. Therefore, it is comprehensible that until now no universally applicable standard measure or combination of measures has been established. Although it could be helpful if a guideline for choosing market quality measures was proposed. This guideline could provide an overview of different market quality measures and their primary fields of application, as well as advantages and disadvantages.

6. Conclusion

The measurement of financial market quality has received a big amount of attention within the last decades. As many researchers would like to observe the effects of different events on the quality of a financial market, it is mandatory to measure the quality in a quantitative manner. I reviewed the existing body of literature of this research branch based on the guidelines of Webster and Watson [1] and summarized the collected information about the year, the used quality measures, the reasons of choice, and referenced literature within a concept matrix (Table 2). Because of the multi-dimensionality of market quality (Liquidity, activity, efficiency), it is not possible to capture all information about the quality of a financial market within a single measure. This is the reason why all of the reviewed papers used a combination of different quality measures. Still, it is recognized that some quality measures are more popular than others. Reasons for that are differences in the complexity of the calculation and in the required data. Within the reviewed literature, there is a lack of transparency, limiting options to comprehend and compare the choice of employed quality measures.

Because of these issues, I propose the establishment of a guideline, which can give an overview of possible quality measures and helps with the correct choice for the individual research branch. Moreover, it would be helpful for future research if more authors would briefly mention their choice of measures in a structured way and give reasons for it.

7. Declaration about the thesis

Ich versichere hiermit wahrheitsgemäß, die Arbeit selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt, die wörtlich oder inhaltlich übernommenen Stellen als solche kenntlich gemacht und die Satzung des Karlsruher Instituts für Technologie (KIT) zur Sicherung guter wissenschaftlicher Praxis in der jeweils gültigen Fassung beachtet zu haben.

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Karlsruhe, den 15.07. 2021 ____________________________

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Appendix

Source	Year	Type of Quality Measure											Reasons	References		
		Liquidity					Market Activity				Information		I: Intuitive D: Data Availability W: Widely Used			
		Bid-ask spread	Realized Spread	Effective Spread	Depth	Amihud Illiquidity	Trade Count	Volume	Average Trade Size	Volatility	Hasbrouck measure	Price Impact		Hasbrouck (1991,1993)	Hendershott (2011)	Amihud (2002)
[4]	2003						×	×	×		×		D	×		
[6]	2011		×	×						×			W	×	×	
[13]	2012	×		×	×		×		×	×		×		×	×	
[17]	2017	×	×	×	×		×	×	×	×				×	×	
[18]	2017	×		×	×					×			I		×	
[19]	2012	×		×	×		×	×		×			W	×	×	
[20]	2011	×		×							×			×		
[21]	2020	×		×		×		×					W			×
[22]	2010	×		×	×					×						
[11]	2016	×	×	×	×			×		×			I		×	
[12]	2015	×	×	×	×		×	×	×	×	×	×		×	×	
[14]	2012	×		×	×		×	×	×				I	×		
[15]	2017	×	×	×	×			×		×			I		×	
[23]	2018	×				×				×			D			×
[24]	2020	×						×								
[25]	2019	×	×	×		×		×		×			W	×	×	×
[26]	2014	×		×		×	×	×		×	×	×	W	×		×
[9]	2015	×						×		×						
[10]	2014						×	×		×						
[27]	2013	×				×		×		×			W,D		×	×
[28]	2013	×		×	×			×		×	×			×	×	
[29]	2013				×		×			×						
[30]	2020	×	×					×		×						
[31]	2011	×	×	×	×		×	×	×						×	
[32]	1998	×			×					×			W,I			
[33]	2015	×			×	×	×	×		×		×		×	×	×
[34]	2015	×						×		×				×	×	
[35]	2018	×	×	×				×				×		×	×	
[36]	2020	×		×						×		×		×		
[37]	2002	×		×	×			×		×					×	
[38]	2011	×		×		×		×		×		×				×
[39]	2006	×						×		×						
[40]	2021	×			×	×		×		×		×		×		×
[32]	2002	×		×	×		×	×	×	×				×		×
Σ = 34		30	9	21	17	8	12	25	7	27	5	8	I:5, D:2, W:7	17	16	9

Table 2: Literature overview as concept matrix

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