1. Introduction

- Basic properties of financial markets
- General remarks on financial market modelling

Outline

- Univariate and multivariate analysis
- Groupings and hierarchical volatility
- Dependence structure analysis and modelling
- De-seasonalisation
- A universal method for univariate and multivariate models and methodologies
- Introduction
WHY STUDYING HIGH-FREQUENCY DATA

- Hypotheses
- More stable environment because of less structural breaks
- Market information may be important
- For understanding the market
- Because they exist

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FROM DAILY AND HIGH FREQUENCY DATA

ANNUALIZED US$/JPY VOLATILITY

- Jan-Feb, 1999
- Period
- High-frequency prices
- USD/JPY
- From daily close at 7pm GMT (circles)
- From daily close at 7am GMT (full)
- Monthly close for USD/JPY volatility
- Top: Annualized
METHOD-LOGICAL REMARKS (CONT.)

ECONOMIC FORECASTING AND HIGH FREQUENCY DATA

LINE BEHAVIOR

1. Observation (quantitative, very) and make predictions of.
2. Verify whether the models represent the empirical facts in
   (finding the empirical facts).
3. Use the empirical facts to formulate adequate models.
   (finding the theoretical facts).
4. Explore the data to discover new fundamental statistical
   science.

Three-step procedure, which has been proved successful in hands

OBSTACLES

ECONOMIC FORECASTING AND HIGH FREQUENCY DATA

Price and markets in general,

- Fundamental basis for understanding market microstructure.
- High frequency data are slowly becoming a faster and
  easier available.
- Development of counter-technology has made data more
  available.

However:

- Little hard work is done for regularly spaced time series.
- Little research has been done and developed.
- High frequency data is costly.
  - Collection, collection, storage, retrieval, manipulation of

APPLICATIONS

ECONOMIC FORECASTING AND HIGH FREQUENCY DATA

- (Over)simplification: Dangers to overlook important features.
  - New, correlations, empirical, distributions, conditional properties.
  - Demanding tests: Modeling daily and weekly seasonalities, etc.

- (Exploratory analysis): assertions as possible candidates the evolutionary process
  - Important development of statistical methods with few
    - New methods for time series needed
    - 300 + today data
    - Quantity of data: 1 year of high frequency data corresponds to

INVESTIGATION OF HIGH FREQUENCY DATA

METHOD-LOGICAL REMARKS ON THE EMPIRICAL
High-frequency data can open the way for studying financial markets at very different time scales. However, when also observed with high significance for intra-day behaviors, reflecting on so-called scaling properties, some empirical properties are similar at different time scales.

**INTERRELATING DIFFERENT TIME SCALES**

### Types of Models

With high-frequency data, it is possible to recognize these different models, focusing on different aspects of the markets.

<table>
<thead>
<tr>
<th>Time Scale</th>
<th>Sample Size</th>
<th>Type of Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 month</td>
<td>15000</td>
<td>Time Series and Financial Models</td>
</tr>
<tr>
<td>1 day</td>
<td>8000</td>
<td>Market Microstructure Models</td>
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<tr>
<td>1 hour</td>
<td>60000</td>
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</tr>
<tr>
<td>10 min</td>
<td>50000</td>
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<tr>
<td>1 min</td>
<td>15 X 10^9</td>
<td></td>
</tr>
</tbody>
</table>

**TYPES OF MODELS**

- **The FX spot market**
- **Spot markets**
- **Types of Instruments**

**BASIC PROPERTIES OF FINANCIAL MARKETS**

<table>
<thead>
<tr>
<th>Event</th>
<th>Size</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 year</td>
<td>700</td>
<td></td>
</tr>
<tr>
<td>1 month</td>
<td>2000</td>
<td></td>
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<tr>
<td>1 week</td>
<td>5000</td>
<td></td>
</tr>
<tr>
<td>1 day</td>
<td>15000</td>
<td></td>
</tr>
<tr>
<td>1 hour</td>
<td>8000</td>
<td></td>
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<tr>
<td>10 min</td>
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<tr>
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<td>15 X 10^9</td>
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</tbody>
</table>

**TIME SCALES AND SAMPLE SIZES**
Exchange-traded markets:

- Data readily available from data provider or directly from exchanges
- Data available from data provider or directly from exchanges
- Data available from exchange

OTC markets:

- Data availability not real-time
- No volume data available
- Prices subject to negotiation, no transaction prices
- Prices not subject to negotiation, no transaction prices
- Data are collected and provided by data providers

AVAILABILITY OF DATA

TYPES OF INSTRUMENTS

Spot Markets

- Futures
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FOREIGN EXCHANGE MARKETS: BASIC FACTS

- FX traders serve as the model for study of other high-frequency markets.
- New facts often found first in FX spot data.

Therefore:

- Not restricted to just traders of the business.
- Data available in high frequency over long sampling periods.
- Market active round-the-clock during weekends and holidays.
- Large liquidity.

Symmetry because both exchanged assets are currencies.

- 100% of volume attributed to interbank interdealer market.

<table>
<thead>
<tr>
<th>Year</th>
<th>USD Billion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>832</td>
</tr>
<tr>
<td>1999</td>
<td>829</td>
</tr>
<tr>
<td>1998</td>
<td>827</td>
</tr>
</tbody>
</table>

Daily turnover (spot and forwards):

- The largest financial market.

FOREIGN EXCHANGE MARKETS: VOLUME

Complexity of the FX Market

- Heterogeneous Market Hypotheses
  - Risk premiums:
  - Time horizons
  - Institutional constraints
  - Geopolitical locations
  - Objectives
- Reason: Interaction of market participants with different
- Homogeneity of market agents disappears.

Number of trades of entire FX market can: 27.5000 ticks/day

<table>
<thead>
<tr>
<th>Currency</th>
<th>April 1992 - Dec 1993</th>
<th>Apr 98</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEM/JPY</td>
<td>1.3 400</td>
<td>1.3 400</td>
</tr>
<tr>
<td>USD/JPY</td>
<td>1.1 38</td>
<td>1.1 36</td>
</tr>
<tr>
<td>EUR/JPY</td>
<td>0.5 562</td>
<td>0.5 580</td>
</tr>
<tr>
<td>JPY/USD</td>
<td>5.0 210</td>
<td>5.0 200</td>
</tr>
<tr>
<td>EUR/GBP</td>
<td>3.3 275</td>
<td>3.5 300</td>
</tr>
<tr>
<td>GBP/USD</td>
<td>5.3 210</td>
<td>5.0 200</td>
</tr>
<tr>
<td>USD/CHF</td>
<td>2.7 295</td>
<td>2.7 295</td>
</tr>
<tr>
<td>CHF/USD</td>
<td>2.7 295</td>
<td>2.7 295</td>
</tr>
</tbody>
</table>

Rate Period #Ticks Daily

EUR/USD | Jan 1987-Jun 2001 | 1.0 400 | 1.0 400 | 1.0 400 |
GBP/USD | Jan 1987-Jun 2001 | 1.0 400 |
USD/JPY | Jan 1987-Jun 2001 | 1.0 400 |
EUR/JPY | Jan 1987-Jun 2001 | 1.0 400 |
GBP/JPY | Jan 1987-Jun 2001 | 1.0 400 |
USD/CHF | Jan 1987-Jun 2001 | 1.0 400 |
CHF/USD | Jan 1987-Jun 2001 | 1.0 400 |
EUR/GBP | Jan 1987-Jun 2001 | 1.0 400 |
GBP/EUR | Jan 1987-Jun 2001 | 1.0 400 |
FOREIGN EXCHANGE MARKETS: TRADING

- Smaller but growing group of FX derivatives
  - FX spot market also used for FX forward market
  - Populatation was 50:50 in 1992 and 40:60 in 1998

Two dominating parts:
- FX forward market
- FX spot market

FOREIGN EXCHANGE MARKETS: STRUCTURE

FOREIGN EXCHANGE MARKETS: ACTORS

Central banks
- Hedgy funds
- Institutional investors
- Unauthorized corporations
- Type of actors:

- Theorny direct or long-term indirect transactions
- Short-term foreign exchange and bond investment
- Central banks
- Hedgy funds
- Institutional investors
- Unauthorized corporations
- Type of actors:

FOREIGN EXCHANGE MARKETS: ACTIVITY

- Activity pattern composed of three continental components:
  - Global market
- No business hour limitations; trading is practically continuous

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MULTIPLE CONTRIBUTORS II
FOREIGN EXCHANGE MARKETS

II. BASIC VARIABLES AND METHODS

If direct quotes exist, there is a no-arbitrage condition:

\[
\frac{p_{USD/CAD}}{p_{USD/CAD}'} = \frac{p_{JPY/CAD}}{p_{JPY/CAD}'}
\]

and

\[
\frac{p_{USD/CAD}''}{p_{USD/CAD}'} = \frac{p_{JPY/CAD}''}{p_{JPY/CAD}'}
\]

computed, e.g:, for JPY/CAD:

- \(EUR/CHF, EUR/JPY, GBP/JPY, GBP/CHF\)
- Quotations exist only for some important cross rates such as
- FX rates between currencies other than USD

FOREIGN EXCHANGE MARKETS: CROSS RATES

Contributions
- Queues lag behind the real market. The delay differs for different
- Some contributions try to manipulate the market by abusive
- Price dependent on actions of market maker
- There are many market makers with different prices
- Every instruction that publishes quotes is a market maker

MULTIPLE CONTRIBUTORS I
FOREIGN EXCHANGE MARKETS
For FX spot rate a tick contains: bid price, ask price, or open
Possible quantities: price, interest rate, level, quote...
Quantity in the information part depends on the instrument
Always contains date and time ("time stamp")
Tick: a number on a tick tape
Basic unit of information: An individual observation

Advantages:

\[ x_{USD/eur}^{(t)} = \frac{x_{EUR/USD}^{(t)}}{x_{USD/EUR}^{(t)}} \]

In FX, rates and its inverses are related by
- mean not on its absolute level
- logarithmic prices depend only on the relative price move

where \( t \) is the time stamp
\[ \frac{\sigma_p(x_{USD/eur}^{(t)})}{\sigma_p(x_{EUR/USD}^{(t)})} = \frac{\sigma_p(x_{USD/EUR}^{(t)})}{\sigma_p(x_{EUR/USD}^{(t)})} \]

Logarithmic middle price

Most important variable under study:

Prices
Two methods of interpolation are of particular interest:

- **Linear interpolation:**
  \[ f(x) = \frac{f(x) - f(x_0)}{x_1 - x_0} x + f(x_0) \]

- **Previous tick interpolation:**
  \[ f(x) = f(x_0) \]

Two ways to transform irregular time series into a regular:

- one is by interpolation
  \[ x_i = x_0 + i \Delta t \]
- the regularized time series: \( f_i = f(x_i) \)

Consider irregular time series: \( x_i \) and \( f_i \).

**INTERPOLATION**

Cases:

- With high frequency data, the difference is small in most realistic properties.
- Therefore, linear interpolation sometimes has better properties.
- However, artificial jumps may occur when large data gaps occur.
- Therefore, for real-time applications, previous tick interpolation preserves causality.

**INTERPOLATION (cont.)**

**FX PRICES FOR USD/JPY AND USD/DEM**
Daily Returns of USD/JPY Spot Rates

Effects of Interpolation

Volatility: Overview

Volatility ratio •
Dependence on time scale •
Scaling and unification •
Definition •
Different types •
Importance •
Volatility: Definition

\[ \sum_{t=1}^{\tau} \left| \frac{r_t}{u} \right| \]

Regularly spaced intervals as 1 is the size of the total sample and \( \tau \) is the return interval (time horizon of return).

Volatility: Importance

Types of Volatility

- Implied volatility
- Model volatility
- Computed from historical data
For high-frequency FX data:

- For high-frequency FX data, spot returns are approximated by $r_t = r_{t-1} + \Delta r_t$.
- If volatility is present, $\sigma^2$ should be replaced by $\sigma^2 + \Delta r_t^2$.
- Therefore, $d$ should be smaller than the usual index $a$.

\[ \text{Volatility: Choice of Parameter} \]

- Larger values of $d$ give more weight to the tails.

\[ \text{Volatility: Scaling and Annualization} \]

- For FX spot prices of major currencies about 10%.
- Predictions often use annualized volatility in percent.

\[ \frac{\sigma^2 \text{year}}{\text{volatility}} \]

- Annualized volatility is the most popular choice for a frequency of 1 year.

\[ \frac{\sigma^2 \text{year}}{\text{volatility}} \]

- For convenience, one may want volatility in scaled form:
  \[ \text{10 min time series} \]
  \[ \text{Ratio of volatility for 10 min to annual volatility} \]

\[ \frac{\sigma^2 \text{year}}{\text{volatility}} \]
Volatility: Dependence on Time Scale

Volatility: Choice of Parameter $\Delta t$
Inventory costs

Transaction costs

Risk of price quotation mismatch

Bid-ask spread effects:

- Difference \( p(b) - p(a) \) is called bid-ask spread

In bid-ask price: \( p(a) < p(b) \)

BID-ASK SPREAD

If \( \mu \) is mean reverting, \( \lambda > 0.5 \).

If \( \mu \) is trend following, \( \lambda < 0.5 \).

For random walk of logarithmic prices, \( \lambda = 0.5 \).

\( \lambda \) depends on dynamics of the time series:

\[
\frac{d}{dt} \left( \frac{d \mu}{d t} \right) + \frac{d \mu}{d t} = \lambda \nabla \theta_1
\]

Volatility ratio with different time resolutions:

Volatility ratio for USD/CHF spot rates

USD/CHF volatility ratio with \( \Delta t = 5 \) min, \( \Delta t = 30 \) min, and \( \Delta t = 28 \) min.
IRREGULAR TIME SERIES OPERATORS

ILLUSTRATED FACTS

TICK FREQUENCY
III. stylized facts

- Seasonality and exogenous impact
- Scaling laws and volatility autocorrelation
- Distributional properties of returns
- Price formation (market microstructure effects)

Sequences:

Volatility of a Gaussian Random Walk

Clustered volatility of a financial time series

- Short-term triangular arbitrage
- Discreteness of quoted spreads
- Negative (or over) autocorrelation of returns

1.03% average does not represent the sample 0.00:00.00 0.00:00.31.23
Sample period: simulation over 7 years random walk (multivariate) as driven by a Gaussian random walk (volatility) absolute return weekly absolute return
their objectives
- Quotes of maker makers are skew to depending on
- Autocorrelation reflects different on prices of trades
  
  Reason:
  - This is a sign of the price formation process.
  - Correlation disappears after about 5 minutes.
  - Autocorrelation
  - All highest frequencies return display negative
  
  SHORT RANGE CORRELATIONS OF RETURNS

short range correlations after about 5 minutes.

autocorrelation

All highest frequencies return display negative

SHORT RANGE CORRELATIONS OF RETURNS

Discreteness of Quotes Spread

smoothly distributed over all possible values.

Traded spreads computed from transaction data are

Over the year maximum shifted from 5 bps to 5 bps.

Peaks at 5 and 10 basis points.

Quotes spread have discrete values. There are major

SHORT RANGE CORRELATIONS OF RETURNS

Auto- correlations of USD/DEM 1 min. returns (sample: 1987-1998)
Univariate Returns

SF: Distributional Properties of

\[ \sum \frac{P(x)}{(x-x)^{\infty}} = \gamma \]

Kurtosis: \( K = \frac{P(\infty)}{(\infty-x)^{\infty}} \)

Skewness: \( \frac{P(\infty)}{(\infty-x)^{\infty}} \)

Variance: \( \frac{P(\infty)}{(\infty-x)^{\infty}} \)

Mean: \( \frac{P(\infty)}{(\infty-x)^{\infty}} \)

Basic Statistical Properties

Histogram of Bid-Ask Spread

January 1993

This gives rise to very short term triangular arbitrage.

Reversals in the major rates are reflected in the cross rates.

The reason is that it takes some time before trend power over the cross rates.

On the very short term, the major rates have predictive power.