Modeling of the investors behavior

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The general context

- The evolution of financial markets is a function of the individual decisions:
  - Multiple **financial actors** with multiple **behaviors**.
  - Huge amount of **information**
  - Various **decisions**

  **Very difficult to predict**

- For this purpose, we need to apprehend the actors behavior:

  **Work on case studies**
Objectives

- Understand the behavior of financial actors
- Model the behavior of investors
- Predict the behavior of investors

  \[ \text{Simulate decisions (help)} \]

  \[ \text{Simulate the evolution of the market} \]
Outline

- The Swissquote case study
  - Data
  - Model
  - Sample enumeration

- The Lombard-Odier case study
  - Data
  - Modeling framework

- Conclusions and perspectives
The Swissquote case study

**SWISSQUOTE**: Swissquote Bank SA, the largest Swiss online broker
- Headquarter in Gland (VD), one office in Zürich, 300 employees
- Trading online on several markets

- Necessity to understand the behavior of markets
- Will for advising clients in their trading choices

→ Study the trading behavior
The trading interface

Stock Request > NESTLE N (NESN) / Val: 003886335
Status: Open

<table>
<thead>
<tr>
<th>Stock Exchange</th>
<th>Currency</th>
<th>Last</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWX Europe</td>
<td>CHF</td>
<td>44.04</td>
<td>-0.02 (-0.0%)</td>
</tr>
<tr>
<td>Bid size</td>
<td>Bid</td>
<td>Ask</td>
<td>Ask size</td>
</tr>
<tr>
<td>10'262</td>
<td>44.04</td>
<td>44.06</td>
<td>5'248</td>
</tr>
</tbody>
</table>

Real time prices

BUY  SELL
Number of Shares: 1000
Stock Symbol or Valoren: NESN
Trade Type:
Trigger: 44.02 CHF
Limit Price: 44.02 CHF
Termination: One Week

Basic trading mask
Data: variables

- Trading data: SWISSQUOTE
  - Swiss market
  - Period 2007-12-28 → 2008-09-29
    - 193 open days
  - 42,494 clients
    - 565,996 observations
  - 10 variables

- Market information: public indices
  - 6 variables
**Data: variables**

- **Trading data:**
  - Date (year-month-day)
  - Id (number)
  - Investment (stocks, bonds, derivatives)
  - Action (buy, or sell)
  - Gender
  - Type of client (retail, asset manager, company)
  - Age (years)

- **Market information:**
  - SPI: Swiss performance index
  - SBI: Swiss bonds index
  - VSMI: indirect volatility of Swiss market index
  - Volatility SPI
  - Volatility SBI
  - Volatility VSMI
Data: choice

- **Investment:**
  - *Stock*: ownership in a corporation (assets and earnings).
  - *Bond*: debt investment in which an individual loans money to an entity that borrows the fund for a defined period at an interest rate.
  - *Derivative*: financial contract whose price is derived from an underlying asset

- **Action:**
  - *Buy*
  - *Sell*
Data: public indices (attributes)

- SPI: Swiss performance index

\[
I_s = \frac{\sum_{i=1}^{M} p_{i,s} * x_{i,t} * f_{i,t} * r_s}{D_t}
\]

- $t$: current day
- $s$: current time on day $t$
- $I_s$: current index level at time $s$
- $D_t$: divisor on day $t$
- $M$: number of issues in index $\sim 220$
- $p_{i,s}$: last-paid price of security $i$
- $x_{i,t}$: number of shares of security $i$ on day $t$
- $f_{i,t}$: free float for security $i$ on day $t$
- $r_s$: current CHF exchange rate at time $s$

characterizing the price of stocks
**Data:** public indices (attributes)

- SBI: Swiss bonds index

\[
P_{R_s} = \frac{\sum_{i=1}^{N} P_{i,s} \cdot X_{i,t}}{D_t}
\]

**Definitions:**

- \( t \): Current day
- \( s \): Current time on day \( t \)
- \( P_{R_s} \): Current index level
- \( D_t \): Divisor on day \( t \)
- \( N \): Number of issues in the index
- \( P_{i,s} \): Valid price of bond \( i \) at time \( s \) as \%
- \( X_{i,t} \): Nominal amount of the bond \( i \) issue on day \( t \)

characterizing the price of bonds
Data: public indices (attributes)

- VSMI: indirect measure of the volatility of the Swiss market index

\[ I_s = \frac{\sum_{i=1}^{M} p_{i,s} x_{i,s,t} f_{i,t} r_s}{D_t} \]

- SMI: Swiss market index

- Volatility: \( V_t = (1 - \lambda) \sum_{t=1}^{T} \lambda^{t-1} |R_t| \)

\[ R_t = \log\left(\frac{I_t}{I_{t-1}}\right) \]

\[ \lambda = 0.94 \]

characterizing the price of derivatives
Data: volatility of public indices

- Volatility:
  - Short time variations of indices
  - Weighted average of the log-return \( R_t = \log\left( \frac{I_t}{I_{t-1}} \right) \)
  - Exponential weights \( \lambda = 0.94 \)

\[
V_t = (1 - \lambda) \sum_{t=1}^{T} \lambda^{t-1} |R_t|
\]

- New attributes:
  - Volatility of SPI
  - Volatility of SBI
  - Volatility of VSMI
Model: specification of the generic model

- Choice set:
  \[ i \in \{B - \text{stocks, } B - \text{bonds, } B - \text{derivatives, } S - \text{stocks, } S - \text{bonds, } S - \text{derivatives}\} \]

- Utilities:
  \[ u_{in} = v_{in} + \epsilon_{in} \]

- Deterministic parts of utilities:
  - Constants
  - Indices
  - Variations of indices
  - Volatilities
  - Variations of volatilities
Model: specification of the generic model

- Error terms:

\[ \epsilon_{in} \sim EV(0, 1) \]

- Logit model

- Several nested structures have been tested but none appeared to be significant
Model: Estimation results (generic model)

- Estimation using BIOGEME
- General estimation results:

<table>
<thead>
<tr>
<th>Nb of observations</th>
<th>565996</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb of parameters</td>
<td>23</td>
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<tr>
<td>Null log-likelihood</td>
<td>-1014128.693</td>
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<td>Cte log-likelihood</td>
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<tr>
<td>Final log-likelihood</td>
<td>-799882.931</td>
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<tr>
<td>$\bar{\rho}^2$</td>
<td>0.211</td>
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</table>
Model: Estimation results (generic model)

- Parameters values:

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Std err</th>
<th>t-test</th>
<th>p-value</th>
<th>Robust Std err</th>
<th>Robust t-test</th>
<th>p-value</th>
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<tbody>
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<td>ASC_bonds_BUY</td>
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<td>0.067</td>
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<td>0.93</td>
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<td>0.03</td>
<td>0.237</td>
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<td>beta_VOL-BUY_SELL_stocks</td>
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<td>0.298</td>
<td>2.57</td>
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<td>beta_VOL-DER_BUY_stocks</td>
<td>0.548</td>
<td>0.323</td>
<td>1.70</td>
<td>0.09</td>
<td>0.326</td>
<td>1.68</td>
<td>0.09</td>
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<tr>
<td>beta_VOL_BUY_Bonds</td>
<td>0.513</td>
<td>0.323</td>
<td>1.59</td>
<td>0.11</td>
<td>0.321</td>
<td>1.60</td>
<td>0.11</td>
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<tr>
<td>beta_VOL_BUY_stocks</td>
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<td>0.01</td>
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<td>beta_VOL_SELL_Bonds</td>
<td>-1.59</td>
<td>0.503</td>
<td>-3.14</td>
<td>0.00</td>
<td>0.518</td>
<td>-3.07</td>
<td>0.00</td>
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<td>beta_VOL_SELL_derivatives</td>
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<td>0.0604</td>
<td>-9.94</td>
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<td>beta_VOL_SELL_stocks</td>
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<td>-3.97</td>
<td>0.00</td>
<td>0.0376</td>
<td>-3.95</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Model: Socio-economic segmentations

<table>
<thead>
<tr>
<th></th>
<th>Generic</th>
<th>Type of client</th>
<th>Age</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb of parameters</td>
<td>23</td>
<td>49</td>
<td>53</td>
<td>149</td>
</tr>
<tr>
<td>Final log-likelihood</td>
<td>$-799882.931$</td>
<td>$-798108.743$</td>
<td>$-797987.357$</td>
<td>$-795974.41$</td>
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<tr>
<td>$\bar{\rho}^2$</td>
<td>0.211</td>
<td>0.213</td>
<td>0.213</td>
<td>0.215</td>
</tr>
</tbody>
</table>
Prediction: choice probabilities

- Constant model:
Prediction: choice probabilities

- Generic model:
Prediction: choice probabilities

- Combined model (socio-economic):
Conclusion

- Noisy data: 565 996 observations for 193 levels of attributes
- Public indices are proxy of the real attributes

→ Refine the data

- Logit model
- Linear specification of utilities
- Socio-economic segmentation

→ Refine the model
The Lombard Odier case study

- Private bank in Geneva, which invests in some firms in different fields.

  For a given firm, each day, some collaborators (investors) have the choice to wait for investing, buy or sell a quantity of stocks.

- Necessity to understand the behavior of markets

- Will of having a tool for decision helping

  Model the behavior of investors
The modeled process

Firm 1
Buy $Q_{B,1,n}(t-2)$
Wait
Wait
Wait
Wait

Firm 2
Wait
Wait
Sell $Q_{S,2,n}(t)$
Sell $Q_{S,2,n}(t+1)$
Wait
...
...
...
...
...
...

Firm F
Sell $Q_{S,F,n}(t-2)$
Wait
Wait
Buy $Q_{B,F,n}(t+1)$
Wait
...
...
...
...
...
...

Budget (t-2)  Budget (t-1)  Budget (t)  Budget (t+1)  Budget (t+2)
The modeled process

Daily decision variables:
- **Buy** or **Sell** if an action is performed
- **Number of days until the next action**, if an action is performed
Data: the variables

- Information about the investors choices:
  → choice (buy, sell, wait) / quantity of stocks / budget

- Information about the investors:
  → socio-economic characteristics

- Information about the firms:
  → quality / value / technic / historic (price)

- Information about the market:
  → VIX / S&P500 / MSCI
Model: definitions

- The **observed** variables
- The **latent** variables
- The causal effect between a and b
- The constraint on b imposed by a
- The causal effect between the past variable a and the current variable b
- The constraint on the current variable b imposed by the past variable a
# Model: the variables

<table>
<thead>
<tr>
<th>The explanatory variables</th>
<th>The latent variables</th>
<th>The dependent variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socio-economic characteristics</td>
<td>Risk aversion (t)</td>
<td>Quantity (t)</td>
</tr>
<tr>
<td>S&amp;P500 index (t)</td>
<td>Risk utility (t)</td>
<td>Waiting duration (t)</td>
</tr>
<tr>
<td>VIX index (t)</td>
<td>Firm attractiveness (t)</td>
<td>Choice (t)</td>
</tr>
<tr>
<td>MSCI index (t)</td>
<td>Choice utility (t)</td>
<td></td>
</tr>
</tbody>
</table>
Model: the risk measure and the firm attractiveness

- The objective **measure of risk**: \( R(t|\beta_R) = \sum_{k=1}^{3} \beta_{R,k} W_{t,k} \)
- The objective **attractiveness of the firm**: \( A_f(t|\beta_A) = \sum_{k=1}^{5} \beta_{A,k} V_{t,k} \)
Model: the risk utility

- The perception of risk: 
  \[ u_{R,n}(t|\beta_{UR}) = ASC_R + \sum_{k=1}^{K_Z} \beta_{Z,k}Z_{n,k} + (1 - \alpha_{UR}) \sum_{k=1}^{t} \alpha_{UR}^{t-k}R(k|\beta_R) + \epsilon_{R,n} \]

- 2 latent classes: "Risky", "not Risky"

Binary choice model
Model: the waiting duration

- The **number of days between 2 consecutive actions** (buy / sell):
Model: the waiting duration

- Poisson regression model:

\[ P_D(D_{f,n}(t) = T|\beta_\lambda, \beta_A, \beta_{UR}) = \frac{\exp(-\lambda_{f,n}(t|\beta_\lambda, \beta_A, \beta_{UR}))\lambda_{f,n}(t|\beta_\lambda, \beta_A, \beta_{UR})^T}{T!} \]

- Average of the parameters over risk:

\[
\lambda_{f,n}(t|\beta_\lambda, \beta_A, \beta_{UR}) = \lambda_{R,f,n}(t|\beta_{UR}, \beta_A)P_{R,n}(t|\beta_{UR}) + \lambda_{N_{OR},f,n}(t|\beta_{N_{OR}}, \beta_A)P_{N_{OR},n}(t|\beta_{UR})
\]

- Generic specification of the parameters specific to risk:

\[
\lambda_{r,f,n}(t|\beta_{\lambda_r}, \beta_A) = \exp(ASC_{\lambda_r} + \beta_{\lambda_r,B} \frac{1}{B(t)} + (1 - \alpha_{\lambda_r}) \sum_{k=1}^{t} \alpha_{\lambda_r}^{t-k} A_f(k|\beta_A))
\]
Model: the choice of action

- The **choice** between ```buy``` or ```sell``` given that there is an action:
**Model: the choice of action**

- Discrete choice model with 2 latent classes:
  
  **Utilities:**
  
  \[
  u_{B,r,t}(t|\beta_{C,r}, \beta_A) = ASC_{B,r} + (1 - \alpha_{B,r}) \sum_{k=1}^{t} \alpha_{B,r} \cdot A_{B}(k|\beta_A),
  \]
  
  \[
  \quad + \beta_{B,r,B} \cdot \frac{1}{B(t)} + \epsilon_{B,r}
  \]
  
  \[
  u_{B,r,t}(t|\beta_{C,r}, \beta_A) = \epsilon_{S,r},
  \]

- Probabilities:

  \[
  p_{B,n,t}(t|Action, \beta_{C,r}, \beta_A, \beta_{U_R}) = p_{B,R,t}(t|Action, \beta_{C,r}, \beta_A)p_{R,n}(t|\beta_{U_R})
  \]
  
  \[
  \quad + p_{B,NoR,t}(t|Action, \beta_{C,NoR}, \beta_A)(1 - p_{R,n}(t|\beta_{U_R})),
  \]

  \[
  p_{S,n,t}(t|Action, \beta_{C,r}, \beta_A, \beta_{U_R}) = p_{S,R,t}(t|Action, \beta_{C,r}, \beta_A)p_{R,n}(t|\beta_{U_R})
  \]
  
  \[
  \quad + p_{S,NoR,t}(t|Action, \beta_{C,NoR}, \beta_A)(1 - p_{R,n}(t|\beta_{U_R})),
  \]
Model: the choice of action

- The alternative buy is available if:
  \[ B(t) > 0 \]

- The alternative sell is available if:
  \[
  Q_{f,n}(t - 1|\beta_{Q_B}, \beta_{Q_S}, \beta_{u_C}, \beta_{A}) > 0
  \]
  \[
  Q_{f,n}(t - 1|\beta_{Q_B}, \beta_{Q_S}, \beta_{u_C}, \beta_{A}) = \sum_{k=1}^{t-1} Q_{B,f,n}(k|\beta_{Q_B}, \beta_{u_C}, \beta_{A})
  \]
  \[
  - \sum_{k=1}^{t-1} Q_{S,f,n}(k|\beta_{Q_S}, \beta_{u_C}, \beta_{A})
  \]
Model: the quantity of stocks

- The involved **quantity of stocks** when an action is performed:
Model: the quantity of stocks

- Average over risk of 2 linear regressions:

\[
Q_{i,f,n}(t|\beta_{Q_i},\beta_{U_C},\beta_A) = Q_{i,R,f}(t|\beta_{Q_i,R},\beta_{U_C,R},\beta_A)P_{R,n}(t|\beta_{U_R}) + Q_{i,NOR,f}(t|\beta_{Q_i,NOR},\beta_{U_C,NOR},\beta_A)P_{NOR,n}(t|\beta_{U_R})
\]

- Generic specification over risk:

\[
Q_{i,r,f}(t|\beta_{Q_i,r},\beta_{U_C,r},\beta_A) = ASC_{Q_i,r} + \beta_{Q_i,r,Q} \sum_{k=1}^{t-1} Q_{i,r,f}(k|\beta_{Q_i,r},\beta_{U_C,r},\beta_A) + \beta_{Q_i,r,B}U_{B,r,f}(t|\beta_{U_C,r},\beta_A) + \epsilon_{Q,r,f,i},
\]

- Constraints:

\[
\sum_{f=1}^{F} Q_{B,f}(t|\beta_{Q_B},\beta_{U_C},\beta_A) \leq B(t),
\]

\[
Q_{S,f,n}(t|\beta_{Q_S},\beta_{U_C},\beta_A) \leq Q_{f,n}(t-1|\beta_{Q_B},\beta_{Q_S},\beta_{U_C},\beta_A)
\]
Model: the likelihood function

- The joint likelihood function:

$$L(\beta) = \prod_{t=1}^{T} \prod_{f=1}^{F} \prod_{n=1}^{N} (L_C(f, t, n|\beta_C) L_D(f, t, n|\beta_D) L_Q(f, t, n|\beta_Q))^{Y_{action,t,f,n}}$$

- The joint likelihood of the 3 sub-models:

  - Choice model:
    $$L_C(f, t, n|\beta_{D,C}) = P_{B,f,n}(t|action, \beta_{D,C})^{Y_{B,t,f,n}} P_{S,f,n}(t|action, \beta_{D,C})^{Y_{S,t,f,n}}$$

  - The Duration model:
    $$L_D(f, t, n|\beta_D) = P_{D}(D_{f,n}(t) = T_{f,n,t}|\beta_\lambda, \beta_A, \beta_{U_R})$$

  - Quantity model:
    $$L_Q(f, t, n|\beta_Q) = f_{Q_B}(Q_{B,f,n}(t|\beta_{Q_B,\beta_{U_C},\beta_{A}})^{Y_{B,t,f,n}} f_{Q_S}(Q_{S,f,n}(t|\beta_{Q_S,\beta_{U_C},\beta_{A}})^{Y_{S,t,f,n}}$$
Conclusions and perspectives

- **Conclusions:**
  - Data analysis
  - Classical discrete choice approach
  - Difficulties analysis
  - Theoretical framework

- **Perspectives:**
  - Estimate the theoretical model using the Lombard Odier data
  - Validate the prediction power of the model on the estimation data
  - Apply the model on the Swissquote data
Thanks for your attention
Prediction

- The probability to buy or sell stocks:

\[
P_{i,n}(t|\beta_D,C) = P_{i,n,f}(t|\text{Action, }\beta_D,C)P_{\text{action}}(t|\beta_D,C)
\]

\[
= P_{i,n,f}(t|\text{Action, }\beta_D,C) \sum_{k=1}^{t-1} P_{\text{action}}(k|\beta_D,C)P_D(D_{f,n}(t-k))
\]
Model: specification of the generic model

- Deterministic parts of utilities:

\[
\begin{align*}
V_{B\text{-}stocks} &= \beta_\text{SPI,BSPI} + \beta_\delta_\text{SPI,BSPI} + \beta_\text{VOLSPI,BSPI} + \beta_\delta_\text{VOLSPI,BSPI} \\
V_{B\text{-}bonds} &= \text{ASC}_{\text{bonds,B}} + \beta_\text{SBI,BSBI} + \beta_\text{VOLSBI,BSBI} + \beta_\delta_\text{VOLSBI,BSBI} \\
V_{B\text{-}derivatives} &= \text{ASC}_{\text{derivatives,B}} + \beta_\text{VSMI,BVSMI} + \beta_\delta_\text{VSMI,BVSMI} + \beta_\delta_\text{VOLVSMI,BVOLVSMI} \\
V_{S\text{-}stocks} &= \text{ASC}_{\text{stocks,S}} + \beta_\delta_\text{SPI,SVSPI} + \beta_\text{VOLSPI,SVSPI} + \beta_\delta_\text{VOLSPI,SVSPI} \\
V_{S\text{-}bonds} &= \text{ASC}_{\text{bonds,S}} + \beta_\text{VOLSBI,SVOLSBI} + \beta_\text{VOLSBI,SVOLSBI} \\
V_{B\text{-}derivatives} &= \text{ASC}_{\text{derivatives,S}} + \beta_\text{VSMI,SVSMI} + \beta_\delta_\text{VSMI,SVSMI}
\end{align*}
\]
Model: introduction

- The objective is to have an overview of the dependencies between variables:
  - Understand the data
  - Understand the investors behavior
  - Specify a model