Optimal Liquidation Strategies for Portfolios under Stress Conditions.

A. F. Macias, C. Sagastizábal, J. P. Zubelli

IMPA

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Summary

Problem Set Up
  Portfolio Liquidation
  Motivation
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  Methodology
  Examples

Conclusions
Problem Set Up
Portfolio Liquidation/Close out strategy

Question
How to liquidate a large portfolio under possibly stress conditions?

Figure: Typical day in old markets
Problem Set Up
Portfolio Liquidation/Close out strategy

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Motivation

Clearing Houses and Exchanges

- It is fundamental for clearing houses to define close-out strategies to suitably liquidate securities in a given portfolio.
- Often such liquidation procedures occur during market stress events.
- The bigger the portfolio the harder it is to find suitable buyers.
- Large transactions can negatively impact the market and produce further losses.

This problem is also relevant for hedge funds and large investors.
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- Impact on the market
- Liquidity: NOT ENOUGH TO HAVE THE ASSETS M-t-M!
- Effectiveness
- Scenario generation
- Computational Complexity
- Time constraints
- Risk factors

Remark:

- Looking for static strategies.
- Typical Application: Margin call calculation.
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Non-comprehensive Bibliographical Review
Some Related Works

- Optimal control of execution costs [Bertsimas and Lo(1998)]
- Liquidation of portfolio with the aim of minimizing a combination of volatility risk and transaction costs arising from permanent and temporary market impact. [Almgren and Chriss(2000)]
- Modelling liquidity effects in discrete time: Rogers and Çetin’s Model (2005)
- Butenko, Golodnikov and Uryasev’s Model (2005)
- Çetin, Soner and Touzi’s Model (2010)
- Close-Out Risk Evaluation [Avellaneda and Cont(2013)]
Problem Set Up
The Model

- Initial Portfolio \((\Pi_1, \cdots, \Pi_i, \cdots, \Pi_{Na})\)
- Considered over a period with \(T_m\) time steps, indexed by \(t\).
- Uncertainty depends on risk factors \(j = 1, \cdots, RF\),
- Each risk factor evolves following scenarios \(m = 1, \cdots, N_s(j)\).

Decision variables \(q^t_i\) for \(i = 1 : Na \& t = 1 : T_m\)

\(q^t_i\) is the *proportion* of the exposition \(\Pi_i\), to be liquidated at time \(t\).

Denote by \(q^t := (q^t_1, q^t_2, \cdots, q^t_{Na})\)

the vector gathering such proportions, for all the assets/contracts in
the portfolio at time \(t\).

To each proportion \(q^t\) corresponds a *liquidation strategy* at time \(t\),
denoted by \(Q^t_\Pi:\)

\[ Q^t_\Pi := (\Pi_1 q^t_1, \Pi_2 q^t_2, \cdots, \Pi_{Na} q^t_{Na}) \]

where \(\Pi_i\) stands for the exposition of the \(i\)-th contract.
Since

$$\sum_{t=1}^{T_m} Q_t^{i} = \Pi_i,$$

for each \(i = 1 : \text{Na}\)

$$\sum_{t=1}^{T_m} q_t^{i} = 1$$

(1)

Note

some contracts have a “window of opportunity”, which makes them active only in some subinterval of time.

Such constraints are also linear, and couple decision variables along time steps for an individual contract. Thus

$$ (q_1^i, \ldots, q_t^i, \ldots, q_{T_m}^i) \in Q_i, i = 1 : \text{Na}, $$

for some closed polyhedron \(Q_i\), that also contains box constraints of the form

$$ 0 \leq q_t^i \leq 1. $$
Loss definition

At each time $t$
The liquidation strategy $q^t$ induces a random loss, and we want the optimization problem to hedge against the uncertainty in such loss.

Uncertainty

Represented by a set of scenarios, describing the evolution of the $j = 1 : \mathbb{N}_r$ risk factors along the considered $t = 1 : \mathbb{T}_m$ time steps. To each risk factor corresponds a number of scenarios $\mathbb{N}_s(j)$, corresponding to various historical or extreme situations. (in principle equiprobable)
The random loss depends on how the portfolio varies with the $j - th$ risk factors, for $j = 1 : Nr$. Such variation is a vector with $i = 1 : Na$ components, denoted by

$$\Delta_{i}^{t}(j, m), \quad (2)$$

Note

This variation prices the loss resulting from each contract, knowing its exposition, $\Pi_{i}$. At any time $t$, the portfolio loss induced by the $m - th$ scenario of the $j - th$ risk factor has the expression

$$Y_{m}^{t}(j, q^{t}) = \sum_{i=1}^{Na} q_{i}^{t} \Delta_{i}^{t}(j, m).$$
Remark

This is a scalar random variable, with mean

$$\overline{Y}(j, q^t) = \frac{1}{\text{Ns}(j)} \sum_{m=1}^{\text{Ns}(j)} Y_m(j, q^t)$$

$$= \sum_{i=1}^{\text{Na}} q_i^t \left( \frac{1}{\text{Ns}(j)} \sum_{m=1}^{\text{Ns}(j)} \Delta_i(j, m) \right).$$

Consider the column vector of all prices $\Delta^t(j, m)$, with components $\Delta_i^t(j, m)$, for $i = 1 : \text{Na}$. The loss can be written as

$$Y_m^t(j, q^t) = \Delta^t(j, m)^\top q^t,$$

a linear combination of the decision variable at time $t$. 
Remark

Letting

$$
\bar{\Delta}_i^t(j) = \frac{1}{N_s(j)} \sum_{m=1}^{N_s(j)} \Delta_i^t(j, m)
$$

denote the average price of the $i$-th asset at time $t$, under the $m$ scenario of the risk factor $j$, the mean loss has the alternative expression

$$
\bar{Y}_m^t(j, q^t) = \bar{\Delta}^t \top q^t,
$$

where the column vector $\bar{\Delta}^t$ has $Na$ components, with the average individual prices.
Assumptions at the optimization phase of the model:

1. Risk factors are independent of each other.
2. The temporal dependence of uncertainty is addressed by the simulation phase.

The optimization problem

Consider objective

$$\sum_{j=1}^{Nr} \sum_{t=1}^{Tm} \left( (1 - \kappa) \mathbb{E}[Y_{m}^{t}(j, q^{t})] + \kappa \rho[Y_{m}^{t}(j, q^{t})] \right),$$

for a parameter $\kappa \in [0, 1]$ (risk aversion).
In particular

When the risk measure is the variance,

\[ \rho[\Delta^t(j,m)^\top q^t] = \frac{1}{N_s(j) - 1} \sum_{m=1}^{N_s(j)} (\Delta^t(j,m)^\top q^t - \bar{Y}^t(j,q^t))^2 \]

the objective function becomes

\[ (1 - \kappa) \sum_{j=1}^{N_r} \sum_{t=1}^{T_m} \Delta^t \top q^t + \sum_{j=1}^{N_r} \frac{\kappa}{N_s(j) - 1} \sum_{t=1}^{T_m} \sum_{m=1}^{N_s(j)} (Y_m^t(j,q^t) - \bar{Y}^t(j,q^t))^2. \]

(3)

Obs

Plenty of choices: E.G., the variance in (3), or the Expected shortfall.
Our Contribution

Theoretical

Show that from the optimization point of view the problem is equivalent to solving reduced quadratic program of the form

$$\min_{V} \frac{1}{2} \sum_{t \in T} \left( V_t^\top H_{VV} V_t + (g_v^t + f_v^t)^\top V_t \right)$$

subject to

$$0 \leq V_i^t \leq 1 \text{ for all } i \in \text{Act}^t \text{ and } t \in T$$

$$\sum_{T \ni t \geq t_1(i)} V_i^t = 1 \text{ for all } i = 1, \ldots, Na$$

where we defined $T := \left\{ t \in \{1, \ldots, Tm\} : \text{Act}^t \neq \emptyset \right\}$. (4)

with $Tm \times Na$ variables. Here, the set of active contracts at time $t$ is denoted by $\text{Act}^t$.

The new quadratic program has a reduced dimensionality, equal to with $\sum_{t \in T} |\text{Act}|^t$ variables.
Our Contribution

Practical

1. Implemented the minimization algorithm associated to the model.
2. Compared to other strategies (in particular to that of [Avellaned and Cont(2013)])
3. Confirmed its good (time) performance and its robustness in a number of practical examples.
Case Study

Methodology

Compare Liquidation Portfolios

- Specially chosen assets with hedging properties
- Impose liquidity constraints
- Generate a large number of scenarios
- Consider the linear programming approach of Avellaneda and Cont as a benchmark.

Compare:

1. Expected value of the chosen strategy (mark-to-market)
2. Total variance of the strategy
3. Execution time
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- Compare:
  1. Expected value of the chosen strategy (mark-to-market)
  2. Total variance of the strategy
  3. Execution time
Recall Put-Call parity: “Asset” - “Call” + “Put” = riskless investment
Test Portfolio # 1
Liquidation Strategy

Figure: Left liquidation strategy of [Avellaneda and Cont(2013)]. Right liquidation strategy minimizing the variance.
Test Portfolio # 1

Liquidation Strategy

<table>
<thead>
<tr>
<th>MODEL</th>
<th>MEAN MtM</th>
<th>STD MtM</th>
<th>J</th>
<th>Op TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>0.1966</td>
<td>7.2921</td>
<td>282.6999</td>
<td>14.9968</td>
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<td>Mean-Variance</td>
<td>-0.5897</td>
<td>15.3603</td>
<td>228.8453</td>
<td>0.0478</td>
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</table>
Test Portfolio # 2

Portfolio Description

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<thead>
<tr>
<th></th>
<th>CONTRACT</th>
<th>MOUNT</th>
<th>MAX MT P/ DAY</th>
<th>MATURITY</th>
<th>MIN TIME TO LIQ</th>
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<tbody>
<tr>
<td>1</td>
<td>Forward</td>
<td>2000</td>
<td>500</td>
<td>63</td>
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</tr>
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<td>2</td>
<td>Option Call</td>
<td>2000</td>
<td>500</td>
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<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Option Put</td>
<td>-2000</td>
<td>500</td>
<td>63</td>
<td>2</td>
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<tr>
<td>4</td>
<td>Option Call</td>
<td>-2000</td>
<td>2000</td>
<td>252</td>
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</tr>
<tr>
<td>5</td>
<td>Option Put</td>
<td>2000</td>
<td>2000</td>
<td>252</td>
<td>15</td>
</tr>
</tbody>
</table>

**Figure**: Case Study 2
Figure: Left liquidation strategy of [Avellaneda and Cont (2013)]. Right liquidation strategy minimizing the variance.
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<table>
<thead>
<tr>
<th>MODEL</th>
<th>MEAN MtM</th>
<th>STD MtM</th>
<th>J</th>
<th>Op TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>25.3647</td>
<td>13.1000</td>
<td>173.3637</td>
<td>81.3731</td>
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<tr>
<td>Mean-Variance</td>
<td>23.1192</td>
<td>15.2453</td>
<td>124.4010</td>
<td>0.0768</td>
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</table>
## Test Portfolio # 3

### Portfolio Description

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<th>CONTRACT</th>
<th>MOUNT</th>
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<th>MIN TIME TO LIQ</th>
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<tbody>
<tr>
<td>1 Forward</td>
<td>2000</td>
<td>500</td>
<td>63</td>
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</tr>
<tr>
<td>2 Option Call</td>
<td>2000</td>
<td>500</td>
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</tr>
<tr>
<td>3 Option Put</td>
<td>-2000</td>
<td>500</td>
<td>63</td>
<td>2</td>
</tr>
<tr>
<td>4 Option Call</td>
<td>2000</td>
<td>500</td>
<td>250</td>
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</tr>
<tr>
<td>5 Option Put</td>
<td>-2000</td>
<td>500</td>
<td>250</td>
<td>2</td>
</tr>
<tr>
<td>6 Option Call</td>
<td>-2000</td>
<td>2000</td>
<td>252</td>
<td>15</td>
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<tr>
<td>7 Option Put</td>
<td>2000</td>
<td>2000</td>
<td>252</td>
<td>15</td>
</tr>
</tbody>
</table>

**Figure:** Case Study 3
Figure: Left liquidation strategy of [Avellaned and Cont(2013)]. Right liquidation strategy minimizing the variance.
## Test Portfolio # 3

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<table>
<thead>
<tr>
<th>MODEL</th>
<th>MEAN MtM</th>
<th>STD MtM</th>
<th>J</th>
<th>Op TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Linear</td>
<td>40.4271</td>
<td>26.6668</td>
<td>172.1046</td>
<td>57.9215</td>
</tr>
<tr>
<td>2 Mean-Variance</td>
<td>33.6846</td>
<td>29.4838</td>
<td>84.5314</td>
<td>0.3177</td>
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</tbody>
</table>
## Test Portfolio # 4

### Portfolio Description

<table>
<thead>
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<th>CONTRACT</th>
<th>MOUNT</th>
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<th>MATURITY</th>
<th>MIN TIME TO LIQ</th>
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<tbody>
<tr>
<td>1 Forward</td>
<td>4000</td>
<td>500</td>
<td>63</td>
<td>2</td>
</tr>
<tr>
<td>2 Option Call</td>
<td>-2000</td>
<td>2000</td>
<td>252</td>
<td>15</td>
</tr>
<tr>
<td>3 Option Put</td>
<td>2000</td>
<td>2000</td>
<td>252</td>
<td>15</td>
</tr>
</tbody>
</table>

**Figure:** Case Study 4
Figure: Left liquidation strategy of [Avellaned and Cont(2013)]. Right liquidation strategy minimizing the variance.
Test Portfolio # 4

Liquidation Strategy

<table>
<thead>
<tr>
<th>MODEL</th>
<th>MEAN MtM</th>
<th>STD MtM</th>
<th>J</th>
<th>Op TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>0.7574</td>
<td>14.3673</td>
<td>307.0883</td>
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<tr>
<td>Mean-Variance</td>
<td>0.9434</td>
<td>17.7923</td>
<td>260.6839</td>
<td>0.0033</td>
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Test Portfolio # 5

Portfolio Description

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<tr>
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</tr>
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</table>

Figure: Case Study 5
**Figure:** Left liquidation strategy of [Avellaneda and Cont(2013)]. Right liquidation strategy minimizing the variance.
Test Portfolio # 5

Liquidation Strategy

<table>
<thead>
<tr>
<th>MODEL</th>
<th>MEAN MtM</th>
<th>STD MtM</th>
<th>J</th>
<th>Op TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Linear</td>
<td>-1.4960e+03</td>
<td>7.7969</td>
<td>171.6489</td>
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<tr>
<td>2 Mean-Variance</td>
<td>-1.4955e+03</td>
<td>9.0898</td>
<td>162.4430</td>
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## Test Portfolio # 6

### Portfolio Description

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<tr>
<th>CONTRACT</th>
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<tr>
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<td>2</td>
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<tr>
<td>3 Option Put</td>
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<td>500</td>
<td>63</td>
<td>2</td>
</tr>
<tr>
<td>4 Option Call</td>
<td>-2000</td>
<td>2000</td>
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<td>15</td>
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<tr>
<td>5 Option Put</td>
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<td>252</td>
<td>15</td>
</tr>
</tbody>
</table>

**Figure:** Case Study 6
Test Portfolio # 6
Liquidation Strategy

Figure: Left liquidation strategy of [Avellaned and Cont(2013)]. Right liquidation strategy minimizing the variance.
Test Portfolio # 6
Liquidation Strategy

<table>
<thead>
<tr>
<th>MODEL</th>
<th>MEAN MtM</th>
<th>STD MtM</th>
<th>J</th>
<th>Op TIME</th>
</tr>
</thead>
<tbody>
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Test Portfolio # 7

Portfolio Description

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<th>CONTRACT</th>
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<th>MATURITY</th>
<th>MIN TIME TO LIQ</th>
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<tbody>
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<tr>
<td>2 Option Call</td>
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<td>3 Option Put</td>
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</table>

**Figure:** Case Study 7
Test Portfolio # 7

Liquidation Strategy

Figure: Left liquidation strategy of [Avellaneda and Cont(2013)]. Right liquidation strategy minimizing the variance.
Test Portfolio # 7

Liquidation Strategy

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<th>MEAN MtM</th>
<th>STD MtM</th>
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<th>Op TIME</th>
</tr>
</thead>
<tbody>
<tr>
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<td>707.7095</td>
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<td>108.3392</td>
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<td>2 Mean-Variance</td>
<td>707.9378</td>
<td>18.3293</td>
<td>-54.1079</td>
<td>0.2368</td>
</tr>
</tbody>
</table>
Performance Comparison (note the scales!)

Figure: Left Model of [Avellaned and Cont(2013)] × Right Quadratic Minimization
Conclusions

- We have proposed a (static) liquidation strategy for portfolios under stress with liquidity constraints.
- This methodology minimizes a weighted sum of the variance and the expected values of losses.
- It takes advantage of a variable reduction present in the problem that substantially decreased the computational effort.
- We have implemented and compared our results with the results of the strategy proposed in [Avellaneda and Cont(2013)].
- Our preliminary results indicate that we can obtain a substantial speed up of the problem solution and minimization strategies with comparable average results (in the class of studied scenarios).
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- This methodology minimizes a weighted sum of the variance and the expected values of losses.
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