- Formulate problems as LPs.
- Equivalence theorem
- Minimum cost trading to achieve target sector exposures.

Midterm 25 points × 4.

- Least squares
- Multi-obj / constrained LS.
- Linear optimization modeling.
- Linear optimization geometry. (equivalence theorem)

no coding / no simplex

you are allowed to use all course materials (lecture slides, precept, homework, books)

no internet no communications

no precept next week!

Q1 Formulate problems as LPs

(a) $A \in \mathbb{R}^{m\times n}$ $b \in \mathbb{R}^m$ find the vector $x \in \mathbb{R}^n$ that minimizes.

$$\sum_{i=1}^{m} \max\{0, a_i^T x + b_i\}. \quad (1)$$

$$c_i = \max\{0, a_i^T x + b_i\}.$$

$$\Updownarrow$$

$$\begin{cases} c_i \geq 0 \\ c_i \geq a_i^T x + b_i \end{cases}$$

minimize $\mathbb{1}^T \cdot c.$ $\quad c = \begin{pmatrix} c_1 \\ \vdots \\ c_m \end{pmatrix}$

$$\underset{(c,x)}{\text{minimize}} \quad (\mathbb{1}^T, 0)\begin{pmatrix} c \\ x \end{pmatrix} \qquad \mathbb{1}^T c \qquad ②$$

$$\text{s.t.} \quad \begin{cases} c_i \geq 0 \\ c_i - a_i^T x \geq b_i \end{cases} \qquad \triangle$$

Let x_1 minimize ①

(c^*, x_2) minimize ②

By definition of ①. $\forall x$

$$\sum \max\{0, a_i^T x_1 + b\} \leq \sum \max\{0, a_i^T x_2 + b\}$$

$$\leq \sum \max\{0, a_i^T x + b\}.$$

for any c satisfies $\begin{cases} c_i \geq 0 \\ c_i - a_i^T x_1 \geq b_i \end{cases}$

x_1

(c, x_1) is a feasible solution of ②

(c^*, x_2)

$$\Rightarrow \mathbb{1}^T c \geq \mathbb{1}^T c^*$$

$$(\mathbb{1}^T, 0)\begin{pmatrix} c \\ x_1 \end{pmatrix} \geq (\mathbb{1}^T, 0)\begin{pmatrix} c^* \\ x_2 \end{pmatrix}$$

$$\underset{(c,x)}{\text{minimize}} \quad (\mathbb{1}^T, 0)\begin{pmatrix} c \\ x \end{pmatrix}$$

$$\frac{(c^*, x_2)}{(c, x_1)}$$

②

$$\text{s.t.} \quad \begin{cases} c_i \geq 0 \\ c_i - a_i^T x \geq b_i \end{cases}$$

$$c_i \geq \max\{0, a_i^T x + b_i\}.$$

$$\Rightarrow \quad \mathbb{1}^T c = \sum \max\{0, a_i^T x_1 + b\}.$$

$$\mathbb{1}^T c^* = \sum \max\{0, a_i^T x_2 + b\}.$$

$$\sum \max\{0, a_i^T x_1 + b\} \geq \sum \max\{0, a_i^T x_2 + b\}$$

$$\Rightarrow \sum \max\{0, a_i^T x_1 + b\}$$

$$= \sum \max\{0, a_i^T x_2 + b\}.$$

Lec2 equivalence theorem.

$P = \{x \mid Ax \le b\}$.

① Show that every vertex is an extreme point.

vertex: if $\exists c$ such that x is the unique optimum of

$$\begin{aligned} \text{minimize} \quad & c^T y \\ \text{s.t.} \quad & y \in P. \end{aligned}$$

extreme point: x not on a straight line between any other points in the set.

$\underline{x = \lambda y + (1-\lambda) z}$

vertex $\Rightarrow$ extreme point.

(proof by contradiction)

Assume x is vertex, but not extreme point.

$\exists\, y, z \neq x \quad y, z \in P \quad x = \lambda y + (1-\lambda) z$

vertex $\exists\, c$. such that $c^T x < c^T w \quad \forall\, w \in P$

$\min\ c^T x$

s.t. $x \in P$

$c^T y,\ c^T z > c^T x$

$\Rightarrow \quad c^T x = \lambda c^T y + (1-\lambda) c^T z > c^T x$

Contradiction!

$P = \{ x \mid Ax \leq b \}$

x

$x \to$ basic

② extreme point $\Rightarrow$ feasible solution

$\{a_1, a_2, a_3, a_4\}$.

- $\{ a_i \mid i \in I(x) \}$ has n linear independent vectors.

$I(x) = \{ i \in \{1, \cdots, m\} \mid a_i^T x = b_i \}$.

$I(x) = \{1, 2, 3, 4\}$

(proof by contradiction)

Assume x is extreme point but not basic feasible solution.

Then $\{a_i \mid i \in I(x)\}$ does not span $\mathbb{R}^n$ $\Rightarrow$ $\exists\, d \in \mathbb{R}^n$ $a_i^T d = 0$ $i \in I(x)$

$x = \lambda y + (1-\lambda) z$

Let $y = x + \varepsilon d$ $z = x - \varepsilon d$.

for any i

$a_i^T y \le b_i$

$a_i^T z \le b_i$

$\forall i \in I(x)$ $a_i^T x = b_i \Rightarrow \begin{cases} a_i^T y = b_i \\ a_i^T z = b_i \end{cases}$

$a_i^T y = a_i^T (x + \varepsilon d) = b_i$

$\forall i \notin I(x)$ $a_i^T x < b_i$. ε small enough

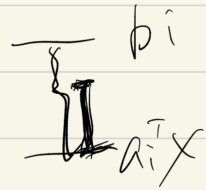
$\Rightarrow a_i^T y < b_i$ $a_i^T z < b_i$

$x = 0.5 y + 0.5 z$. and $y, z \in P$.

$\Rightarrow$ x not extreme point

contradiction!

$a_i^T y = a_i^T x + \epsilon a_i^T d$



Q3. $h^{curr} \to$ n-vector (portfolio) with entries giving the dollar value invested in the n assets.

total value $= \mathbb{1}^T h^{curr}$

we seek a new portfolio h.

s.t. $\mathbb{1}^T h = \mathbb{1}^T h^{curr}$

same total ~~vector~~ value.

m - industry sectors.

(Tech / bio).

s m-vector denotes the sector exposures (dollar value) to the m sectors. $s = Sh$.

S is $m \times n$ matrix

stock

$$\begin{cases} S_{ij} = 1 & \text{asset } j \text{ in sector } i \\ S_{ij} = 0 & \text{asset } j \text{ not in sector } i. \end{cases}$$

The new portfolio must have a given sector exposure s^{des}.

$$s^{des} = Sh$$

Among all portfolios that have the same value as our current portfolio and achieve the desire exposures we wish to minimize the trading cost.

$$\sum_{i=1}^{n} k_i (h_i - h_i^{curr})^2.$$

$k_i > 0.$

Explain how to find h.
give KKT equations.

$$h^{curr} = (v_1, v_2, \ldots, v_n) \cdot n.$$

$$h = (h_1, h_2, \ldots, h_n)\ n$$

$$\boxed{\begin{aligned} &\text{constrains:} \quad Sh = s^{des} \\ &\qquad\qquad\qquad \mathbb{1}^T h = \mathbb{1}^T h^{curr} \\ &\text{minimize} \quad \sum_{i=1}^{n} k_i (h_i - h_i^{curr})^2 \end{aligned}}$$

Let $K = \begin{pmatrix} k_1 & & \\ & \ddots & \\ & & k_n \end{pmatrix}$

$$\mathbb{1}^T h^{curr} = V$$

$$\underset{h}{\text{minimize}} \; \| Kh - Kh^{curr} \|_2$$

$$\begin{bmatrix} S \\ \mathbb{1}^T \end{bmatrix} h = \begin{bmatrix} s^{des} \\ v \end{bmatrix}$$

KKT equation:

$$\min \|Ax - b\|^2 \quad \text{s.t. } Cx = d.$$

$$A = K, \quad b = Kh^{curr}$$

$$C = \begin{bmatrix} S \\ \mathbb{1}^T \end{bmatrix} \quad d = \begin{bmatrix} s^{des} \\ v \end{bmatrix}$$

$$\begin{bmatrix} 2A^TA & C^T \\ C & 0 \end{bmatrix} \begin{bmatrix} x^* \\ z \end{bmatrix} = \begin{bmatrix} 2A^Tb \\ d \end{bmatrix}$$