

Chapter 4: Equilibrium and Efficiency

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Equilibrium

Competitive Equilibrium

- n assets, possibly including a risk-free asset, with values \tilde{x}_i .
- Investors $h = 1, \dots, H$ have endowments of shares $\bar{\theta}_h \in \mathbb{R}^n$ at date 0.
- Choose portfolios $\theta_h \in \mathbb{R}^n$ subject to budget constraint

$$p' \theta_h \leq p' \bar{\theta}_h$$

- Maximize expected utility of date-1 wealth $\tilde{w}_h := \sum_{i=1}^n \theta_{hi} \tilde{x}_i$.
- Equilibrium is $(p, \theta_1^*, \dots, \theta_H^*)$ such that θ_h^* is optimal for each investor h given p , and markets clear:

$$\sum_{h=1}^H \theta_h^* = \sum_{h=1}^H \bar{\theta}_h.$$

- Existence? Optimality? Equilibrium risk premia?

Arrow-Debreu Model

- k states.
- Assets are Arrow securities: pay 1 in single state and 0 otherwise.
- Denote price vector by $q \in \mathbb{R}^k$.
- Portfolio θ determines date-1 wealth as $w_j = \theta_j$ for $j = 1, \dots, k$. In other words, the wealth vector $w \in \mathbb{R}^k$ is the portfolio.
- Existence: standard result
- Optimality: standard welfare theorems

- When is a competitive equilibrium in a securities market equivalent to an equilibrium in an Arrow-Debreu model?
- Answer: if the securities market is complete.
- Asset prices $p = (p_1, \dots, p_n)$ and state prices (q_1, \dots, q_k) correspond as $Xq = p$.
- So, equilibria in complete markets are Pareto optimal.

Efficiency

Pareto Optimum

- Let \tilde{w}_m denote end-of-period market wealth.
- An allocation is $\tilde{w}_1, \dots, \tilde{w}_H$ such that $\sum_h \tilde{w}_h = \tilde{w}_m$.
- A Pareto optimum is an allocation such that any other allocation that makes at least one person better off also makes at least one person worse off.
- A Pareto optimum solves a social planner's problem: for some weights $\lambda_1, \dots, \lambda_H$,

$$\max \sum_{h=1}^H \lambda_h E[u_h(\tilde{w}_h)] \quad \text{subject to} \quad \sum_{h=1}^H \tilde{w}_h = \tilde{w}_m.$$

Social Planner's Problem

- The resource constraint is a separate constraint for each state. And, expected utility is additive across states.
- So, we can solve the maximization problem state-by-state.
- What does this mean? Consider the problem $\max a + b$ subject to $a \leq 3$ and $b \leq 5$. We can solve this as separate problems: $\max a$ s.t. $a \leq 3$ and $\max b$ s.t. $b \leq 5$.
- In each state of the world ω , the social planner solves

$$\max \sum_{h=1}^H \lambda_h u_h(\tilde{w}_h(\omega)) \quad \text{subject to} \quad \sum_{h=1}^H \tilde{w}_h(\omega) = \tilde{w}_m(\omega).$$

- Let $\tilde{\eta}(\omega)$ denote the Lagrange multiplier in state ω .
- Then, for all h ,

$$\lambda_h u'_h(\tilde{w}_h(\omega)) = \tilde{\eta}(\omega).$$

Sharing Rules

- At a Pareto optimum, there is equality of MRS's: for all individuals h and ℓ and states i and j ,

$$\frac{u'_h(\tilde{w}_h(\omega_i))}{u'_h(\tilde{w}_h(\omega_j))} = \frac{u'_\ell(\tilde{w}_\ell(\omega_i))}{u'_\ell(\tilde{w}_\ell(\omega_j))}$$

- If market wealth is higher in state i than in state j , then at any Pareto optimum (assuming strict risk aversion) all investors have higher wealth in state i than in state j :

$$\begin{aligned}\tilde{w}_h(\omega_i) > \tilde{w}_h(\omega_j) &\Rightarrow \frac{u'_h(\tilde{w}_h(\omega_i))}{u'_h(\tilde{w}_h(\omega_j))} < 1 \\ &\Rightarrow \frac{u'_\ell(\tilde{w}_\ell(\omega_i))}{u'_\ell(\tilde{w}_\ell(\omega_j))} < 1 \\ &\Rightarrow \tilde{w}_\ell(\omega_i) > \tilde{w}_\ell(\omega_j).\end{aligned}$$

- This implies each investor's wealth is a function of market wealth. The function is called a sharing rule.

Example

- Suppose there are two risk-averse investors and two possible states of the world, with \tilde{w}_m being the same in both states, say, $\tilde{w}_m = 6$, and with the two states being equally likely.
- Can the allocation

$$\tilde{w}_1 = \begin{cases} 2 & \text{in state 1} \\ 4 & \text{in state 2} \end{cases}$$

$$\tilde{w}_2 = \begin{cases} 4 & \text{in state 1} \\ 2 & \text{in state 2} \end{cases}$$

be Pareto optimal?

LRT Utility

Sharing Rules with Linear Risk Tolerance

- Assume $\tau_h(w) = A_h + Bw$ with same cautiousness parameter $B \geq 0$ for all individuals. Note $B > 0$ implies DARA. Then, either
 - Everyone has CARA utility: $-e^{-\alpha_h w}$, or
 - Everyone has shifted log utility: $\log(w - \zeta_h)$, or
 - Everyone has shifted power utility with $\rho > 0$:

$$\frac{1}{1 - \rho} (w - \zeta_h)^{1 - \rho}$$

- In this case, Pareto optimal sharing rules are affine: $\tilde{w}_h = a_h + b_h \tilde{w}_m$.

- Pareto optimal sharing rules with LRT utility and same cautiousness parameter are affine ($\tilde{w}_h = a_h + b_h \tilde{w}_m$) with
 - $\sum_{h=1}^H a_h = 0$, and
 - $\sum_{h=1}^H b_h = 1$.
- With CARA utility, $b_h = \tau_h / \sum_{j=1}^H \tau_j$.
- With shifted log ($\rho = 1$) or shifted power,

$$b_h = \frac{\lambda_h^{1/\rho}}{\sum_{j=1}^H \lambda_j^{1/\rho}}$$

where the λ 's are the weights in the social planning problem.

Proof for CARA Utility

- Social planner's problem is (in each state of the world)

$$\max \sum_{h=1}^H \lambda_h e^{-\alpha_h w_h} \quad \text{subject to} \quad \sum_{h=1}^H w_h = w$$

where w denotes the value of \tilde{w}_m in the given state.

- FOC is: $(\forall h) \lambda_h \alpha_h e^{-\alpha_h w_h} = \eta$ where η is the Lagrange multiplier (in the given state). Set $\tau = \sum_h \tau_h$. We have

$$w_h = -\tau_h \log \eta + \tau_h \log(\lambda_h \alpha_h)$$

$$\Rightarrow w = -\tau \log \eta + \sum_{\ell=1}^H \tau_{\ell} \log(\lambda_{\ell} \alpha_{\ell})$$

$$\Rightarrow -\log \eta = \frac{1}{\tau} w - \frac{1}{\tau} \sum_{\ell=1}^H \tau_{\ell} \log(\lambda_{\ell} \alpha_{\ell})$$

$$\Rightarrow w_h = \frac{\tau_h}{\tau} w - \frac{\tau_h}{\tau} \sum_{\ell=1}^H \tau_{\ell} \log(\lambda_{\ell} \alpha_{\ell}) + \tau_h \log(\lambda_h \alpha_h)$$

Competitive Equilibria with LRT Utility

- Assume there is a risk-free asset. Assume all investors have linear risk tolerance $\tau_h(w) = A_h + Bw$ with the same cautiousness parameter B . Assume there are no \tilde{y}_h 's.
- The set of equilibrium prices does not depend on the distribution of wealth across investors.
 - Called Gorman aggregation
 - Due to wealth expansion paths being parallel (Chapter 2)
- Any Pareto optimal allocation can be implemented in the securities market.
 - Due to affine sharing rules, we only need the risk-free asset and market portfolio
 - Example of two-fund separation (Chapter 2)
- Any competitive equilibrium is Pareto optimal.