An Economic Framework for Vaccine Prioritization

M. Akbarpour ⓡ (Stanford)
E. Budish ⓡ (UChicago)
P. Dworczak ⓡ (Northwestern)
S. D. Kominers* (Harvard)

June 10, 2022

*Authors' names are in certified random order.

Motivation

Motivation

- What should guide the allocation of scarce resources in a society?

Motivation

- What should guide the allocation of scarce resources in a society?
- Classical economic answer: Prices

Motivation

- What should guide the allocation of scarce resources in a society?
- Classical economic answer: Prices
  (subject to qualifications: externalities, market power etc.)

Motivation

- What should guide the allocation of scarce resources in a society?
- Classical economic answer: Prices
  (subject to qualifications: externalities, market power etc.)
- (Some) Ethicists: Access to essential goods and services should be based on need, not ability to pay; prices should not be used in some contexts (Sandel, Satz, etc.)

Motivation

- What should guide the allocation of scarce resources in a society?
- Classical economic answer: Prices
  (subject to qualifications: externalities, market power etc.)
- (Some) Ethicists: Access to essential goods and services should be based on need, not ability to pay; prices should not be used in some contexts (Sandel, Satz, etc.)
- This debate played out in the context of allocating vaccines during the Covid-19 pandemic.

Motivation

- During the pandemic most countries opted for a pure priority system, without prices.

Motivation

- During the pandemic most countries opted for a pure priority system, without prices.
- NASEM framework (see also Persad et al, 2020): **Priorities** based on four risk-based criteria:

Motivation

- During the pandemic most countries opted for a pure priority system, without prices.
- NASEM framework (see also Persad et al, 2020): **Priorities** based on four risk-based criteria:
  - risk of acquiring infection;

Motivation

- During the pandemic most countries opted for a pure priority system, without prices.
- NASEM framework (see also Persad et al, 2020): **Priorities** based on four risk-based criteria:
  - risk of acquiring infection;
  - risk of severe morbidity and mortality;

Motivation

- During the pandemic most countries opted for a pure priority system, without prices.
- NASEM framework (see also Persad et al, 2020): **Priorities** based on four risk-based criteria:
  - risk of acquiring infection;
  - risk of severe morbidity and mortality;
  - risk of negative social impact;

Motivation

- During the pandemic most countries opted for a pure priority system, without prices.
- NASEM framework (see also Persad et al, 2020): **Priorities** based on four risk-based criteria:
  - risk of acquiring infection;
  - risk of severe morbidity and mortality;
  - risk of negative social impact;
  - risk of transmitting to others.

Motivation

- During the pandemic most countries opted for a pure priority system, without prices.
- NASEM framework (see also Persad et al, 2020): **Priorities** based on four risk-based criteria:
  - risk of acquiring infection;
  - risk of severe morbidity and mortality;
  - risk of negative social impact;
  - risk of transmitting to others.
- Pancs (2020): Position auction for vaccines, adjusted to account for externalities.

Contribution: economic framework for vaccine allocation

- We take a **market-design approach** to the problem.

Contribution: economic framework for vaccine allocation

- We take a **market-design approach** to the problem.
- We derive the optimal allocation mechanism as a function of the designer's objective, available information, and agents' preferences.

Contribution: economic framework for vaccine allocation

- We take a **market-design approach** to the problem.
- We derive the optimal allocation mechanism as a function of the designer's objective, available information, and agents' preferences.
- Relative to the ethicists' approach, we take seriously the problem of private information and incentives.

Contribution: economic framework for vaccine allocation

- We take a **market-design approach** to the problem.
- We derive the optimal allocation mechanism as a function of the designer's objective, available information, and agents' preferences.
- Relative to the ethicists' approach, we take seriously the problem of private information and incentives.
- Relative to a standard economic approach, we account for equity and (to some extent) moral concerns. We also incorporate externalities.

Contribution: economic framework for vaccine allocation

- We take a **market-design approach** to the problem.
- We derive the optimal allocation mechanism as a function of the designer's objective, available information, and agents' preferences.
- Relative to the ethicists' approach, we take seriously the problem of private information and incentives.
- Relative to a standard economic approach, we account for equity and (to some extent) moral concerns. We also incorporate externalities.
- **Dichotomy between priorities vs prices is artificial**; the optimal mechanism combines priorities (derived from observable information) with prices (that screen for unobserved heterogeneity).

Contribution: economic framework for vaccine allocation

- We take a **market-design approach** to the problem.
- We derive the optimal allocation mechanism as a function of the designer's objective, available information, and agents' preferences.
- Relative to the ethicists' approach, we take seriously the problem of private information and incentives.
- Relative to a standard economic approach, we account for equity and (to some extent) moral concerns. We also incorporate externalities.
- **Dichotomy between priorities vs prices is artificial**; the optimal mechanism combines priorities (derived from observable information) with prices (that screen for unobserved heterogeneity).
- We uncover a **novel role of prices**: *(i)* they may help achieve the moral objectives set up by ethicists, and *(ii)* they may be used to screen for externalities.

Related literature

- **Inequality-aware mechanism design:** Weitzman (1977), Che, Gale, and Kim (2012), Condorelli (2013), DKA (2021), ADK (2021).
- **Mechanism design with allocation externalities:** Jehiel et al. (1996), Jehiel and Moldovanu (2001), Ostrizek and Sartori (2021), Kang (2022).
- **Covid-19 vaccine allocation:** NASEM (2020), Persad et al. (2020), Pancs (2020), Emmanuel et al. (2020), Pathak et al. (2021)
- **Vaccine targeting:** Bubar et al. (2021), Vellodi and Weiss (2021a,b), Schmidt et al. (2020), Bibbins-Domingo et al. (2021)

Model

Model

- A designer controls the allocation of vaccines (that become available gradually over time) to a unit mass of agents.

Model

- A designer controls the allocation of vaccines (that become available gradually over time) to a unit mass of agents.
- Prior to receiving a vaccine, each agent takes a binary decision $a \in \{\text{Safe, Risky}\}$.

Model

- A designer controls the allocation of vaccines (that become available gradually over time) to a unit mass of agents.
- Prior to receiving a vaccine, each agent takes a binary decision $a \in \{\text{Safe, Risky}\}$.
- Each agent is characterized by five parameters:

Model

- A designer controls the allocation of vaccines (that become available gradually over time) to a unit mass of agents.
- Prior to receiving a vaccine, each agent takes a binary decision $a \in \{\text{Safe, Risky}\}$.
- Each agent is characterized by five parameters:
  - v: the **private socio-economic benefit** of choosing $a = \text{Risky}$ relative to $a = \text{Safe}$, not including Covid-related risk;

Model

- A designer controls the allocation of vaccines (that become available gradually over time) to a unit mass of agents.
- Prior to receiving a vaccine, each agent takes a binary decision $a \in \{\text{Safe, Risky}\}$.
- Each agent is characterized by five parameters:
  - v: the **private socio-economic benefit** of choosing $a = \text{Risky}$ relative to $a = \text{Safe}$, not including Covid-related risk;
  - h: the **private health benefit** of choosing $a = \text{Safe}$ relative to $a = \text{Risky}$;

Model

- A designer controls the allocation of vaccines (that become available gradually over time) to a unit mass of agents.
- Prior to receiving a vaccine, each agent takes a binary decision $a \in \{\text{Safe, Risky}\}$.
- Each agent is characterized by five parameters:
  - v: the **private socio-economic benefit** of choosing $a = \text{Risky}$ relative to $a = \text{Safe}$, not including Covid-related risk;
  - h: the **private health benefit** of choosing $a = \text{Safe}$ relative to $a = \text{Risky}$;

    The agent chooses $a = \text{Risky}$ if $v > h$ and $a = \text{Safe}$ if $v < h$.

Model

- A designer controls the allocation of vaccines (that become available gradually over time) to a unit mass of agents.
- Prior to receiving a vaccine, each agent takes a binary decision $a \in \{\text{Safe, Risky}\}$.
- Each agent is characterized by five parameters:
  - v: the **private socio-economic benefit** of choosing $a = \text{Risky}$ relative to $a = \text{Safe}$, not including Covid-related risk;
  - h: the **private health benefit** of choosing $a = \text{Safe}$ relative to $a = \text{Risky}$;
  - v_{ex}: the **socio-economic externality** generated by the agent choosing $a = \text{Risky}$ relative to $a = \text{Safe}$, not including Covid-related risk;

Model

- A designer controls the allocation of vaccines (that become available gradually over time) to a unit mass of agents.
- Prior to receiving a vaccine, each agent takes a binary decision $a \in \{\text{Safe, Risky}\}$.
- Each agent is characterized by five parameters:
  - v: the **private socio-economic benefit** of choosing $a = \text{Risky}$ relative to $a = \text{Safe}$, not including Covid-related risk;
  - h: the **private health benefit** of choosing $a = \text{Safe}$ relative to $a = \text{Risky}$;
  - v_{ex}: the **socio-economic externality** generated by the agent choosing $a = \text{Risky}$ relative to $a = \text{Safe}$, not including Covid-related risk;
  - h_{ex}: the **health externality** generated by the agent choosing $a = \text{Safe}$ relative to $a = \text{Risky}$;

Model

- A designer controls the allocation of vaccines (that become available gradually over time) to a unit mass of agents.
- Prior to receiving a vaccine, each agent takes a binary decision $a \in \{\text{Safe, Risky}\}$.
- Each agent is characterized by five parameters:
  - v: the **private socio-economic benefit** of choosing $a = \text{Risky}$ relative to $a = \text{Safe}$, not including Covid-related risk;
  - h: the **private health benefit** of choosing $a = \text{Safe}$ relative to $a = \text{Risky}$;
  - v_{ex}: the **socio-economic externality** generated by the agent choosing $a = \text{Risky}$ relative to $a = \text{Safe}$, not including Covid-related risk;
  - h_{ex}: the **health externality** generated by the agent choosing $a = \text{Safe}$ relative to $a = \text{Risky}$;
  - λ: a **social welfare weight**.

Model

- A designer controls the allocation of vaccines (that become available gradually over time) to a unit mass of agents.
- Prior to receiving a vaccine, each agent takes a binary decision $a \in \{\text{Safe, Risky}\}$.
- Each agent is characterized by five parameters:
  - v: the **private socio-economic benefit** of choosing $a = \text{Risky}$ relative to $a = \text{Safe}$, not including Covid-related risk;
  - h: the **private health benefit** of choosing $a = \text{Safe}$ relative to $a = \text{Risky}$;
  - v_{ex}: the **socio-economic externality** generated by the agent choosing $a = \text{Risky}$ relative to $a = \text{Safe}$, not including Covid-related risk;
  - h_{ex}: the **health externality** generated by the agent choosing $a = \text{Safe}$ relative to $a = \text{Risky}$;
  - λ: a **social welfare weight**.
- The weight λ converts dollar-denominated values into "social-utility units," thus capturing equity and (to some extent) moral concerns.

Model

Information structure:

- Each agent observes (at least) their private benefits v and h.

Model

Information structure:

- Each agent observes (at least) their private benefits v and h.
- The designer does not directly observe which action was taken, and does not observe any of the agents' characteristics (including the welfare weights).

Model

Information structure:

- Each agent observes (at least) their private benefits v and h.
- The designer does not directly observe which action was taken, and does not observe any of the agents' characteristics (including the welfare weights).
- The designer does observe one of finitely many labels $i \in I$ for each agent, and knows the distribution of characteristics.

Model

Information structure:

- Each agent observes (at least) their private benefits v and h.
- The designer does not directly observe which action was taken, and does not observe any of the agents' characteristics (including the welfare weights).
- The designer does observe one of finitely many labels $i \in I$ for each agent, and knows the distribution of characteristics.
- Implicit assumption: The designer is allowed to condition the allocation of vaccines on labels.

Model

Examples:

- **Front-line health worker**: relatively high h, even higher v, very high h_{ex} and v_{ex}, high λ.

Model

Examples:

- **Front-line health worker**: relatively high h, even higher v, very high h_{ex} and v_{ex}, high λ.
- **Ride-share driver**: ranking of h and v may depend on health and wealth, high h_{ex}, low v_{ex}, relatively high λ.

Model

Examples:

- **Front-line health worker**: relatively high h, even higher v, very high h_{ex} and v_{ex}, high λ.
- **Ride-share driver**: ranking of h and v may depend on health and wealth, high h_{ex}, low v_{ex}, relatively high λ.
- **Healthy college student**: low h, high v, high h_{ex}.

Model

Payoffs:

- We model getting vaccinated as receiving both benefits (associated with the Safe and Risky action) at the same time.

Model

Payoffs:

- We model getting vaccinated as receiving both benefits (associated with the Safe and Risky action) at the same time.
- If an **agent is vaccinated at time** t, she enjoys the benefits of vaccination for a fraction $\delta(t)$ of the duration of the pandemic:

$$\delta(t) \underbrace{[v+h]}_{\text{post-vaccination utility}} + (1-\delta(t)) \underbrace{[\max\{v,\, h\}]}_{\text{pre-vaccination utility}} - p$$

Model

Payoffs:

- We model getting vaccinated as receiving both benefits (associated with the Safe and Risky action) at the same time.
- If an **agent is vaccinated at time** t, she enjoys the benefits of vaccination for a fraction $\delta(t)$ of the duration of the pandemic:

$$\delta(t) \underbrace{[v+h]}_{\text{post-vaccination utility}} + (1-\delta(t)) \underbrace{[\max\{v,\, h\}]}_{\text{pre-vaccination utility}} - p$$

- Willingness to pay (WTP) for vaccine: $r = \min\{v,\, h\}$.

Model

Payoffs:

- We model getting vaccinated as receiving both benefits (associated with the Safe and Risky action) at the same time.
- If an **agent is vaccinated at time** t, she enjoys the benefits of vaccination for a fraction $\delta(t)$ of the duration of the pandemic:

$$\delta(t) \underbrace{[v+h]}_{\text{post-vaccination utility}} + (1-\delta(t)) \underbrace{[\max\{v,\, h\}]}_{\text{pre-vaccination utility}} - p$$

- Willingness to pay (WTP) for vaccine: $r = \min\{v,\, h\}$.
- The **designer's payoff** from vaccinating an agent at time t is

$$\delta(t)\left(\mathbf{1}_{\text{Safe}}(\lambda(v-p)+v_{\text{ex}}) + \mathbf{1}_{\text{Risky}}(\lambda(h-p)+h_{\text{ex}})\right) + \alpha p,$$

where $\alpha \geq 0$ is the weight on revenue.

Model

Feasible mechanisms:

- The designer has $A(t)$ vaccines available at time $t \in [0, 1]$.

Model

Feasible mechanisms:

- The designer has $A(t)$ vaccines available at time $t \in [0, 1]$.
- We can define **"quality" of a vaccine** as $q = \delta(t)$, and let F denote the distribution of available quality given A.

Model

Feasible mechanisms:

- The designer has $A(t)$ vaccines available at time $t \in [0, 1]$.
- We can define **"quality" of a vaccine** as $q = \delta(t)$, and let F denote the distribution of available quality given A.
- The designer maximizes the expectation of the objective function over all feasible mechanisms:

Model

Feasible mechanisms:

- The designer has $A(t)$ vaccines available at time $t \in [0, 1]$.
- We can define **"quality" of a vaccine** as $q = \delta(t)$, and let F denote the distribution of available quality given A.
- The designer maximizes the expectation of the objective function over all feasible mechanisms:
  - Each agent reports their private information;

Model

Feasible mechanisms:

- The designer has $A(t)$ vaccines available at time $t \in [0, 1]$.
- We can define **"quality" of a vaccine** as $q = \delta(t)$, and let F denote the distribution of available quality given A.
- The designer maximizes the expectation of the objective function over all feasible mechanisms:
  - Each agent reports their private information;
  - They receive a (potentially random) quality assignment and pay a (non-negative) transfer;

Model

Feasible mechanisms:

- The designer has $A(t)$ vaccines available at time $t \in [0, 1]$.
- We can define **"quality" of a vaccine** as $q = \delta(t)$, and let F denote the distribution of available quality given A.
- The designer maximizes the expectation of the objective function over all feasible mechanisms:
  - Each agent reports their private information;
  - They receive a (potentially random) quality assignment and pay a (non-negative) transfer;
  - Mechanism satisfies IR and IC constraints (on the domain induced by the agent's label).

Model

Feasible mechanisms:

- The designer has $A(t)$ vaccines available at time $t \in [0, 1]$.
- We can define **"quality" of a vaccine** as $q = \delta(t)$, and let F denote the distribution of available quality given A.
- The designer maximizes the expectation of the objective function over all feasible mechanisms:
  - Each agent reports their private information;
  - They receive a (potentially random) quality assignment and pay a (non-negative) transfer;
  - Mechanism satisfies IR and IC constraints (on the domain induced by the agent's label).
  - Vaccines must be allocated as soon as they are available.

Analysis

Analysis

Lemma 1

It is optimal for the designer to condition the allocation of vaccines only on agents' labels i and WTP r.

Analysis

Lemma 1

It is optimal for the designer to condition the allocation of vaccines only on agents' labels i and WTP r.

Let $V_i(r)$ be the expected per-unit-of-quality social benefit from allocating a vaccine to an agent with WTP r in group i in an incentive-compatible mechanism:

Analysis

Lemma 1

It is optimal for the designer to condition the allocation of vaccines only on agents' labels i and WTP r.

Let $V_i(r)$ be the expected per-unit-of-quality social benefit from allocating a vaccine to an agent with WTP r in group i in an incentive-compatible mechanism:

Pareto optimality with perfectly transferable utility and no externalities:

$$V_i(r) = r$$

Analysis

Lemma 1

It is optimal for the designer to condition the allocation of vaccines only on agents' labels i and WTP r.

Let $V_i(r)$ be the expected per-unit-of-quality social benefit from allocating a vaccine to an agent with WTP r in group i in an incentive-compatible mechanism:

If $G_i(r)$ is a continuous distribution of WTP conditional on label i:

$$V_i(r) = \frac{1 - G_i(r)}{g_i(r)} + \left(r - \frac{1 - G_i(r)}{g_i(r)} \right)$$

Analysis

Lemma 1

It is optimal for the designer to condition the allocation of vaccines only on agents' labels i and WTP r.

Let $V_i(r)$ be the expected per-unit-of-quality social benefit from allocating a vaccine to an agent with WTP r in group i in an incentive-compatible mechanism:

If $G_i(r)$ is a distribution of WTP with positive density $g_i(r)$ on $[0, \bar{r}_i]$ in group i, then:

$$V_i(r) = \underbrace{\frac{1 - G_i(r)}{g_i(r)}}_{\text{utility}} + \underbrace{\left(r - \frac{1 - G_i(r)}{g_i(r)} \right)}_{\text{revenue}}$$

Analysis

Lemma 1

It is optimal for the designer to condition the allocation of vaccines only on agents' labels i and WTP r.

Let $V_i(r)$ be the expected per-unit-of-quality social benefit from allocating a vaccine to an agent with WTP r in group i in an incentive-compatible mechanism:

With redistributive preferences (ADK):

$$V_i(r) = \Lambda_i(r) \cdot \underbrace{\frac{1 - G_i(r)}{g_i(r)}}_{\text{utility}} + \alpha \cdot \underbrace{\left(r - \frac{1 - G_i(r)}{g_i(r)} \right)}_{\text{revenue}}$$

Analysis

Lemma 1

It is optimal for the designer to condition the allocation of vaccines only on agents' labels i and WTP r.

Let $V_i(r)$ be the expected per-unit-of-quality social benefit from allocating a vaccine to an agent with WTP r in group i in an incentive-compatible mechanism:

With redistributive preferences (ADK):

$$V_i(r) = \Lambda_i(r) \cdot \underbrace{\frac{1 - G_i(r)}{g_i(r)}}_{\text{utility}} + \alpha \cdot \underbrace{\left(r - \frac{1 - G_i(r)}{g_i(r)} \right)}_{\text{revenue}}$$

where $\Lambda_i(r) = \mathbb{E}_{\tilde{r} \sim G_i}[\, \lambda \,|\, \tilde{r} \geq r,\, i]$.

Analysis

Lemma 1

It is optimal for the designer to condition the allocation of vaccines only on agents' labels i and WTP r.

Let $V_i(r)$ be the expected per-unit-of-quality social benefit from allocating a vaccine to an agent with WTP r in group i in an incentive-compatible mechanism:

In our framework:

$$V_i(r) = \Lambda_i(r) \cdot \underbrace{\frac{1 - G_i(r)}{g_i(r)}}_{\text{utility}} + \alpha \cdot \underbrace{\left(r - \frac{1 - G_i(r)}{g_i(r)} \right)}_{\text{revenue}} + \underbrace{\mathbb{E}\left[T_{\text{ex}} | i,\, r\right]}_{\text{externality}}.$$

Analysis

Lemma 1

It is optimal for the designer to condition the allocation of vaccines only on agents' labels i and WTP r.

Let $V_i(r)$ be the expected per-unit-of-quality social benefit from allocating a vaccine to an agent with WTP r in group i in an incentive-compatible mechanism:

In our framework:

$$V_i(r) = \Lambda_i(r) \cdot \underbrace{\frac{1 - G_i(r)}{g_i(r)}}_{\text{utility}} + \alpha \cdot \underbrace{\left(r - \frac{1 - G_i(r)}{g_i(r)} \right)}_{\text{revenue}} + \underbrace{\mathbb{E}\left[T_{\text{ex}} | i,\, r \right]}_{\text{externality}}.$$

where T_{ex} denotes the externality generated by vaccinating the agent.

Analysis

The externality term:

- Assume that v and h are independent of v_{ex} and h_{ex} conditional on i.

Analysis

The externality term:

- Assume that v and h are independent of v_{ex} and h_{ex} conditional on i.
- Then, we have

$$\mathbb{E}[T_{\text{ex}}|i,\, r] = v^i_{\text{ex}} \cdot \mathbb{P}(a = \text{Safe}|i,\, r) + h^i_{\text{ex}} \cdot \mathbb{P}(a = \text{Risky}|i,\, r),$$

where $v^i_{\text{ex}} = \mathbb{E}[v_{\text{ex}}|i]$ and $h^i_{\text{ex}} = \mathbb{E}[h_{\text{ex}}|i]$.

Derivation of Optimal Mechanism

1. Vaccines are allocated "across" groups: F is split into I cdfs $F_i^\star$;

Derivation of Optimal Mechanism

1. Vaccines are allocated "across" groups: F is split into I cdfs $F_i^\star$;
2. Vaccines are allocated "within" groups: For each label i, qualities in $F_i^\star$ are allocated optimally to agents in group i.

Derivation of Optimal Mechanism

1. Vaccines are allocated "across" groups: F is split into I cdfs $F_i^\star$;
2. Vaccines are allocated "within" groups: For each label i, qualities in $F_i^\star$ are allocated optimally to agents in group i.

Derivation of Optimal Mechanism

1. Vaccines are allocated "across" groups: F is split into I cdfs $F_i^\star$;
2. Vaccines are allocated "within" groups: For each label i, qualities in $F_i^\star$ are allocated optimally to agents in group i.

Observation: Only expected quality, $Q_i(r)$, matters for payoffs.

Derivation of Optimal Mechanism

1. Vaccines are allocated "across" groups: F is split into I cdfs $F_i^\star$;
2. Vaccines are allocated "within" groups: For each label i, qualities in $F_i^\star$ are allocated optimally to agents in group i.

Observation: Only expected quality, $Q_i(r)$, matters for payoffs.

Result: Within a group, agents are partitioned into intervals according to WTP, with either the "market" or "non-market" allocation in each interval

Derivation of Optimal Mechanism

1. Vaccines are allocated "across" groups: F is split into I cdfs $F_i^\star$;
2. Vaccines are allocated "within" groups: For each label i, qualities in $F_i^\star$ are allocated optimally to agents in group i.

Observation: Only expected quality, $Q_i(r)$, matters for payoffs.

Result: Within a group, agents are partitioned into intervals according to WTP, with either the "market" or "non-market" allocation in each interval

- **Market allocation**: assortative matching between WTP and quality

$$Q_i(r) = (F_i^\star)^{-1}(G_i(r)),\ \forall r \in [a,\, b];$$

Derivation of Optimal Mechanism

1. Vaccines are allocated "across" groups: F is split into I cdfs $F_i^\star$;
2. Vaccines are allocated "within" groups: For each label i, qualities in $F_i^\star$ are allocated optimally to agents in group i.

Observation: Only expected quality, $Q_i(r)$, matters for payoffs.

Result: Within a group, agents are partitioned into intervals according to WTP, with either the "market" or "non-market" allocation in each interval

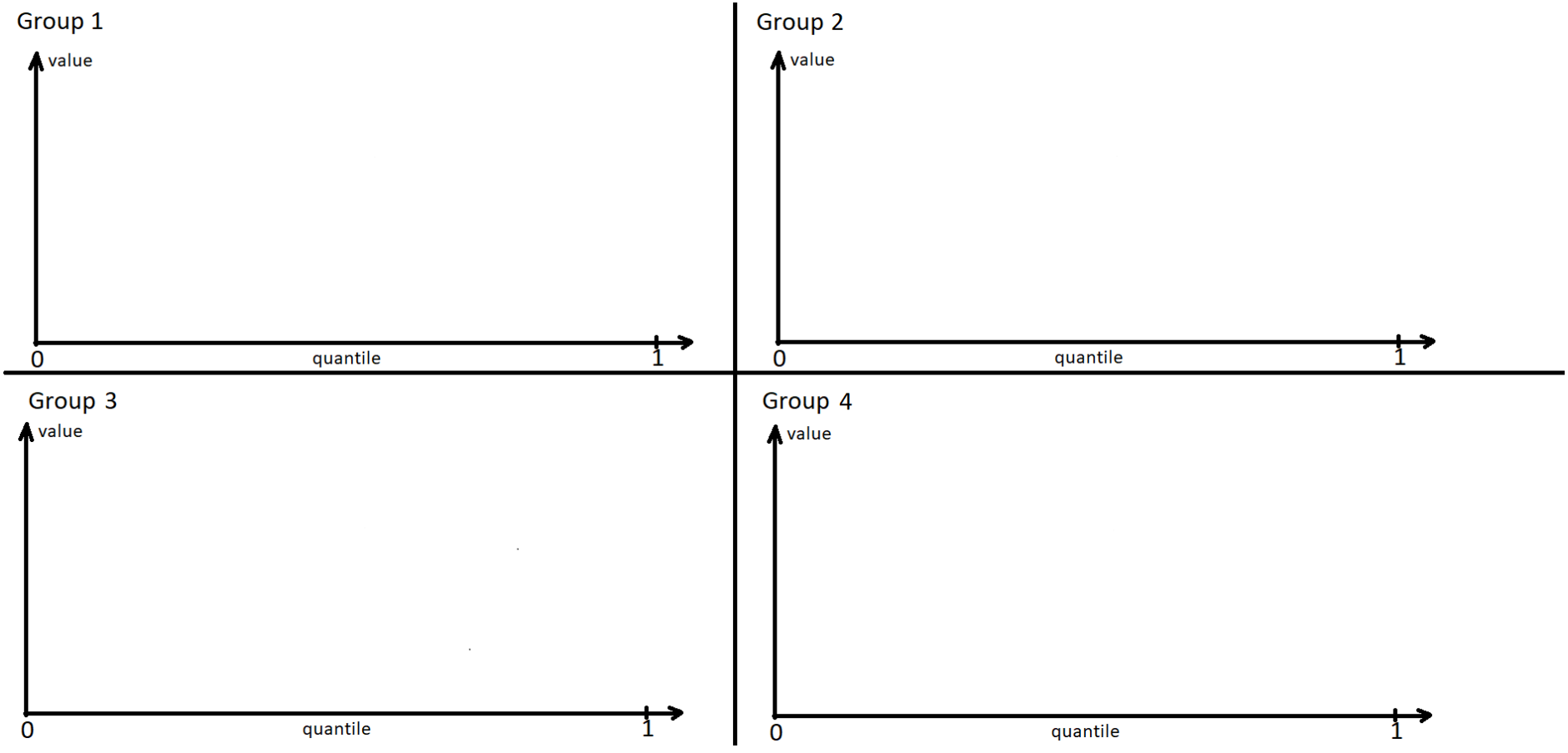
- **Market allocation**: assortative matching between WTP and quality

$$Q_i(r) = (F_i^\star)^{-1}(G_i(r)),\ \forall r \in [a,\, b];$$

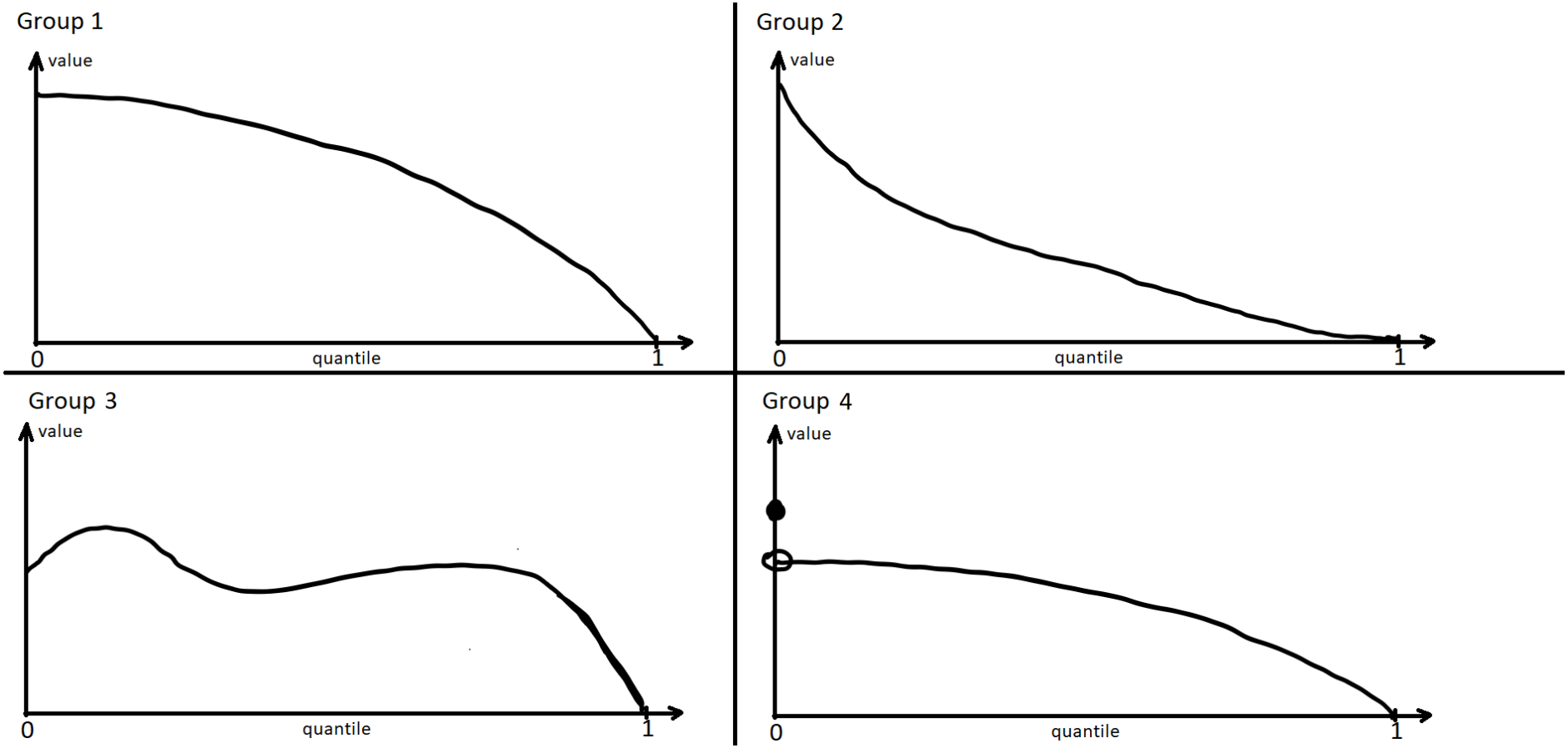
- **Non-market allocation**: random matching between WTP and quality

$$Q_i(r) = \bar{q},\ \forall r \in [a,\, b].$$

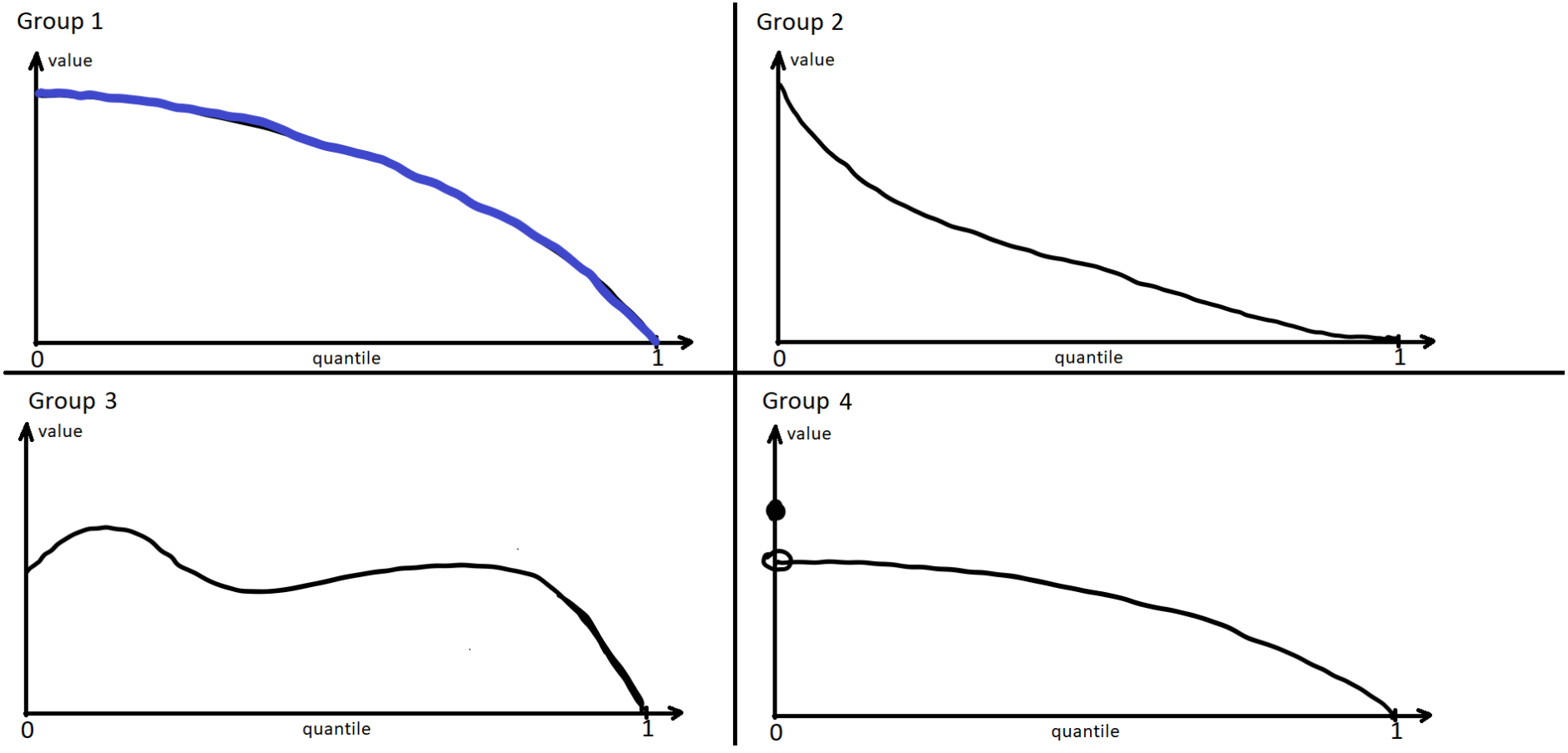
Derivation of Optimal Mechanism: within-group allocation



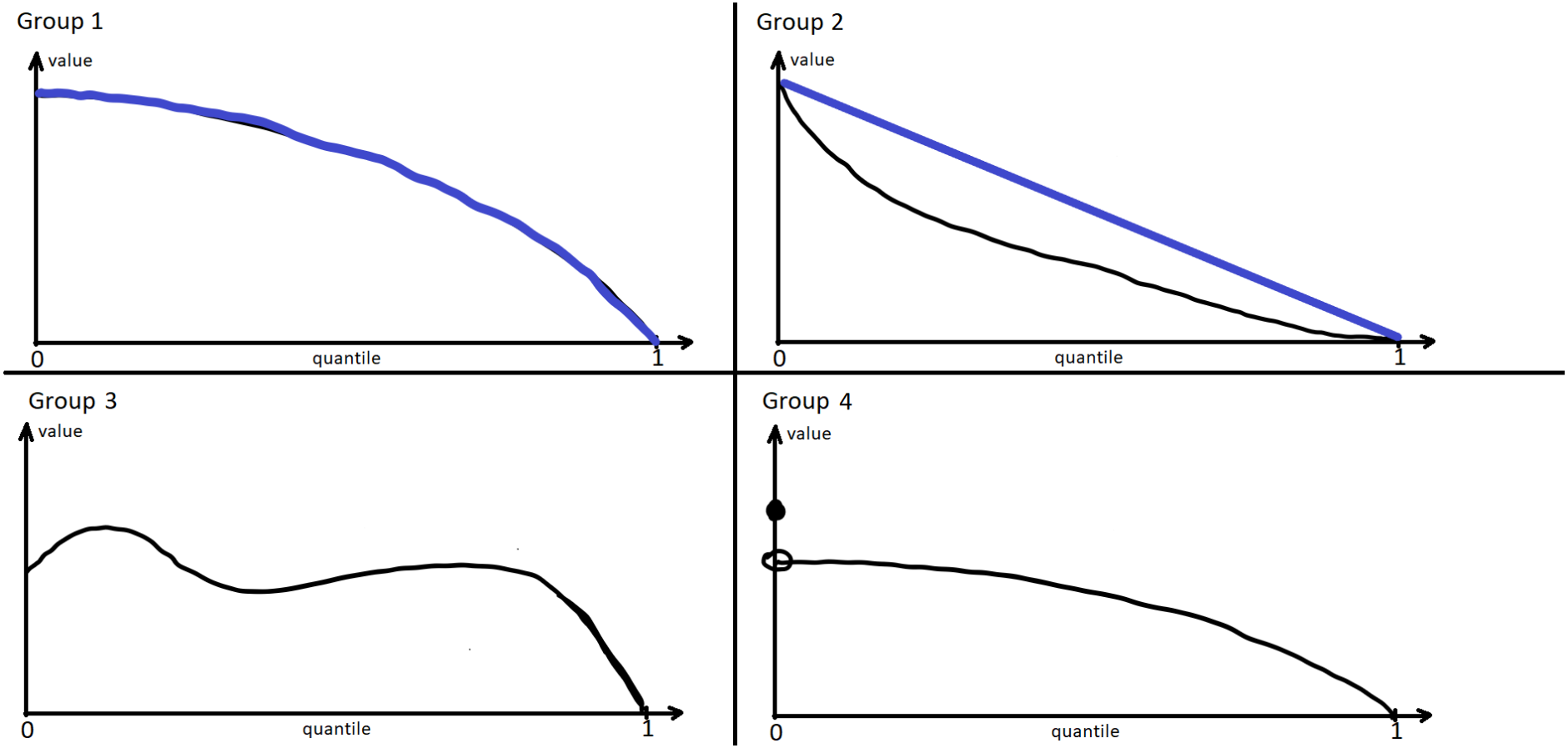
Derivation of Optimal Mechanism: within-group allocation



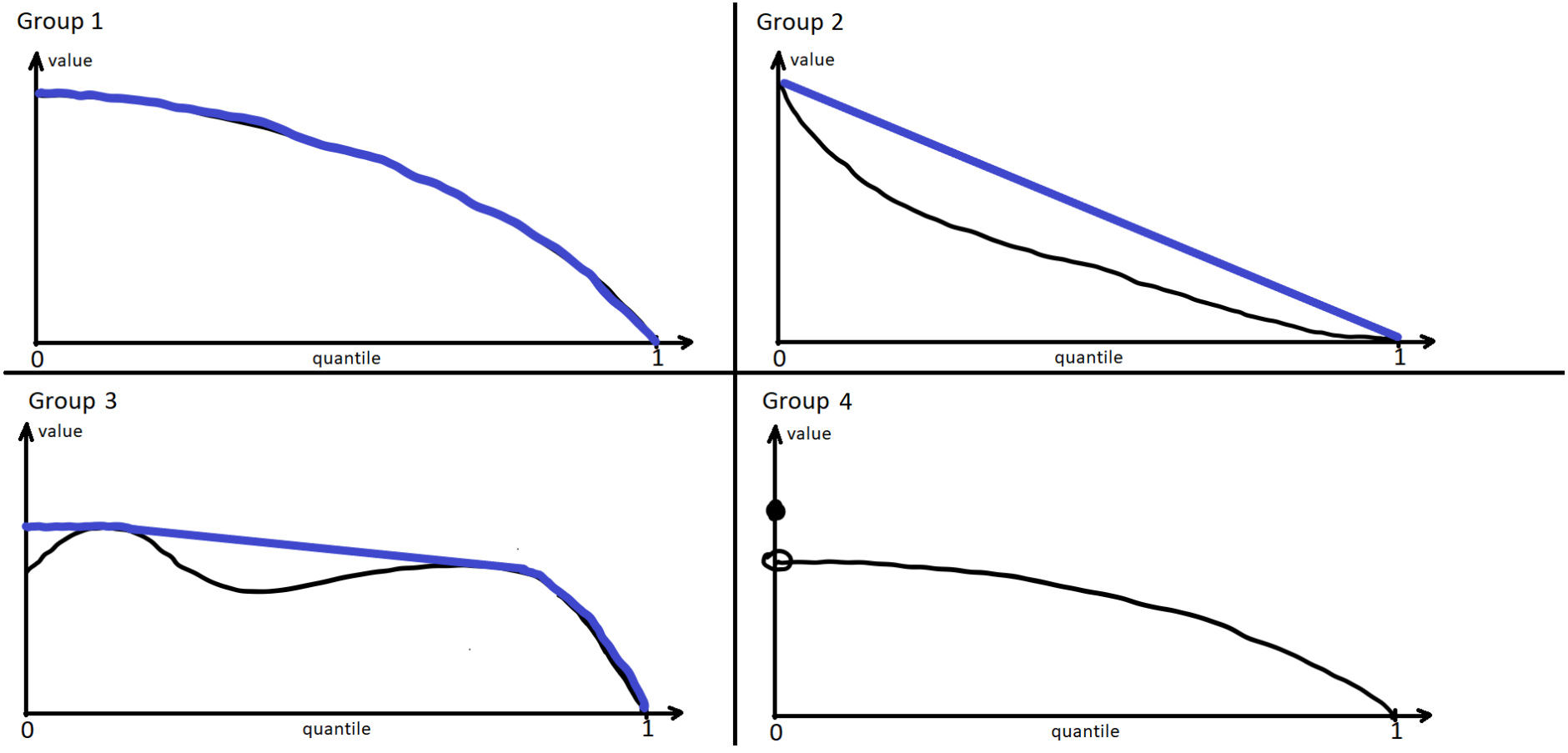
Derivation of Optimal Mechanism: within-group allocation



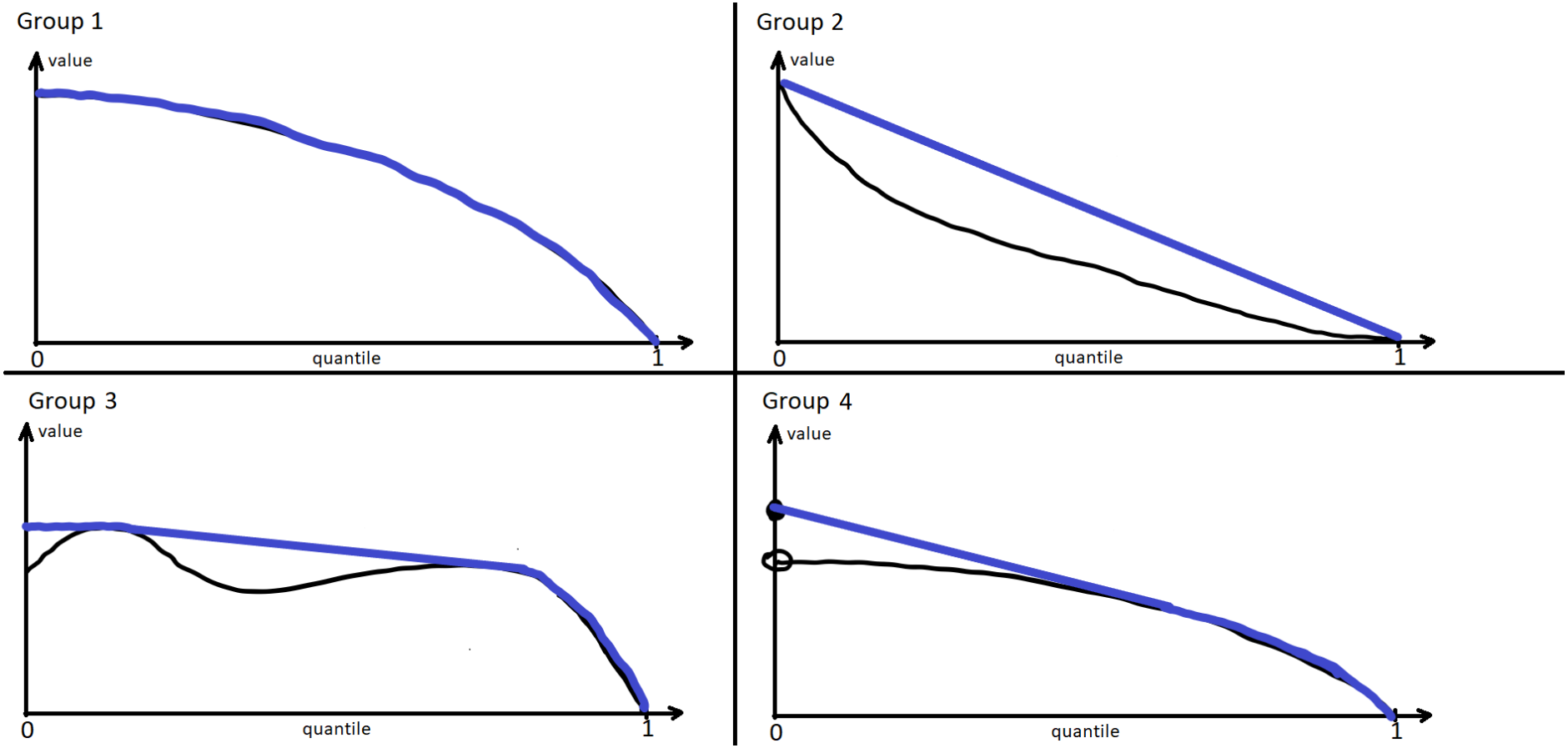
Derivation of Optimal Mechanism: within-group allocation



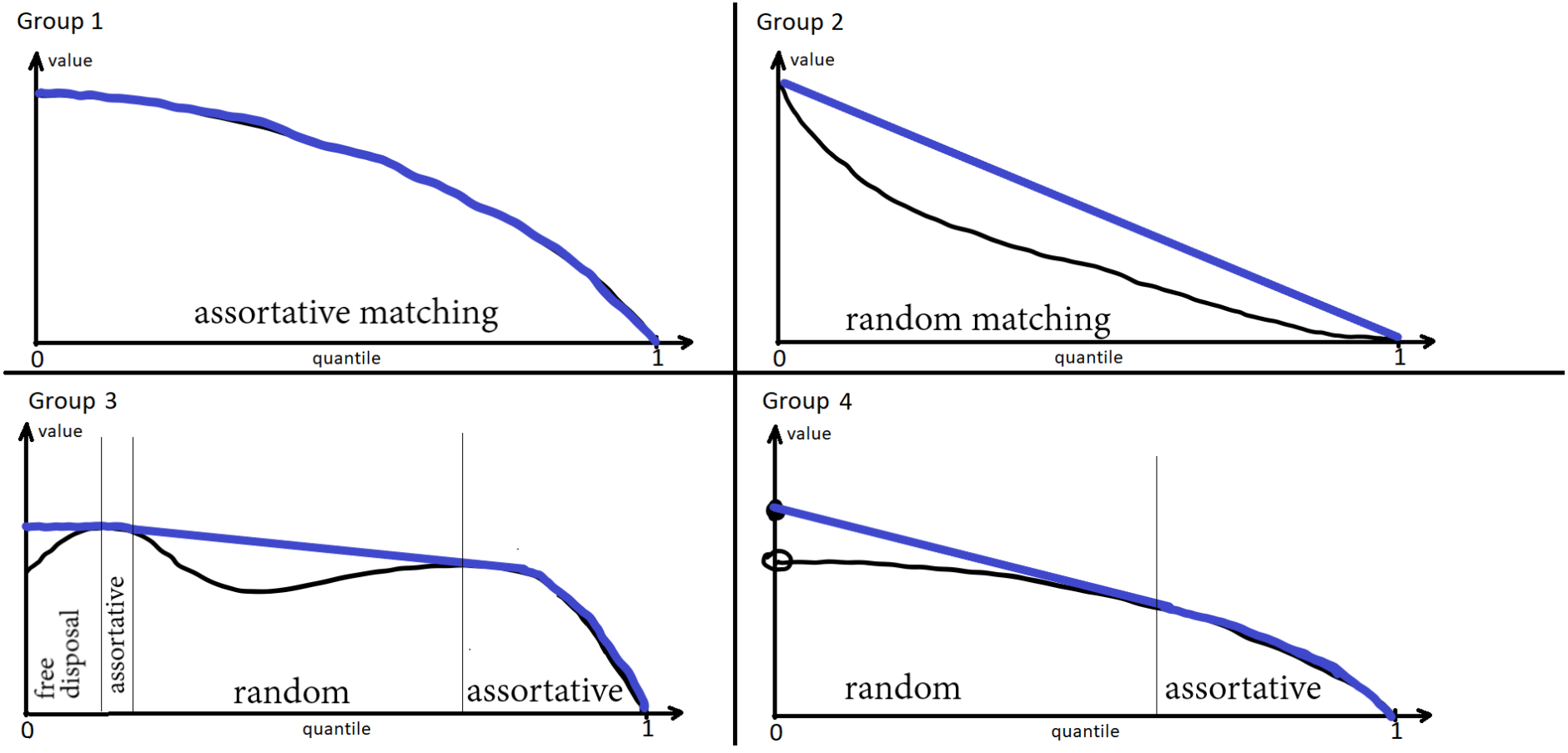
Derivation of Optimal Mechanism: within-group allocation



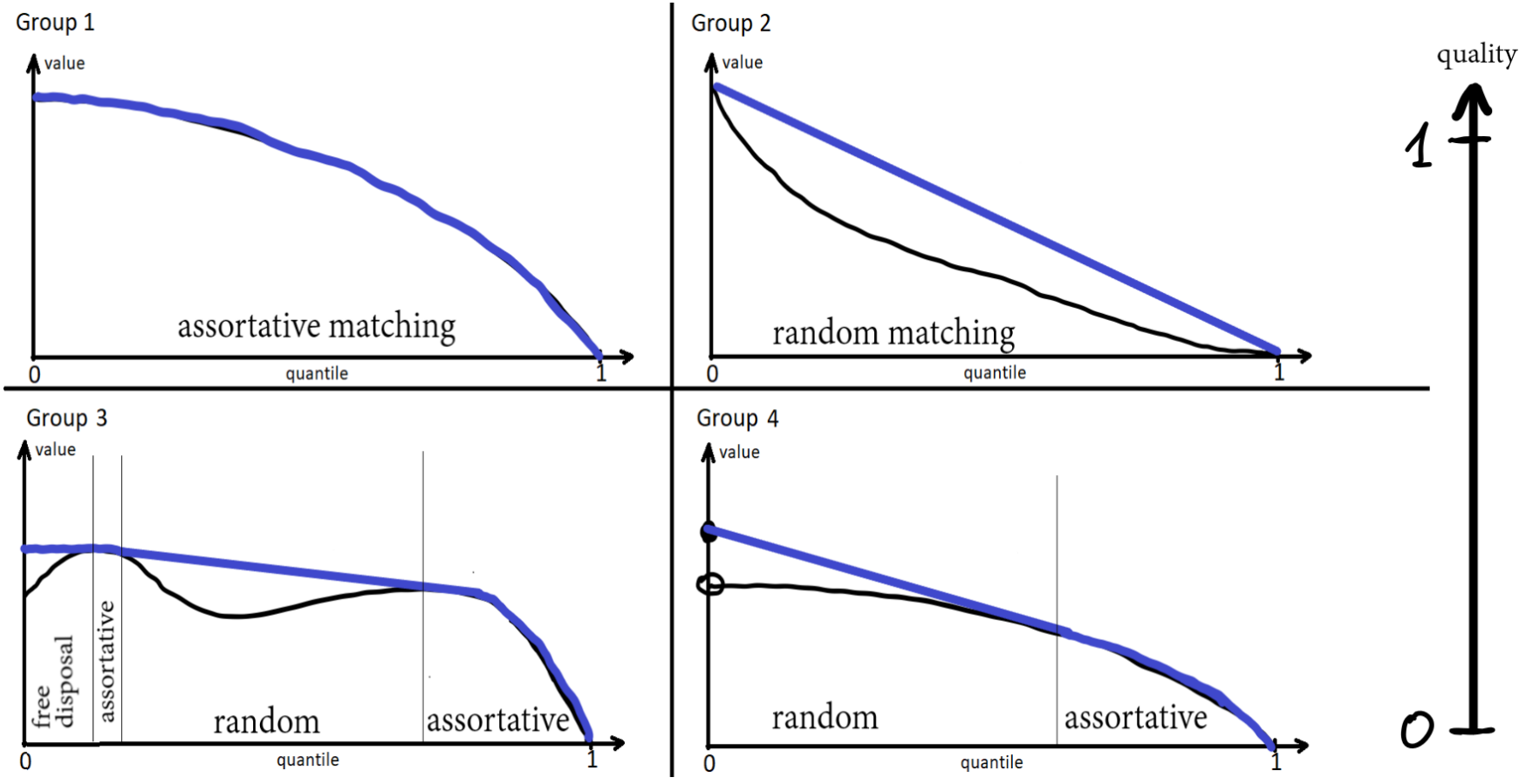
Derivation of Optimal Mechanism: within-group allocation



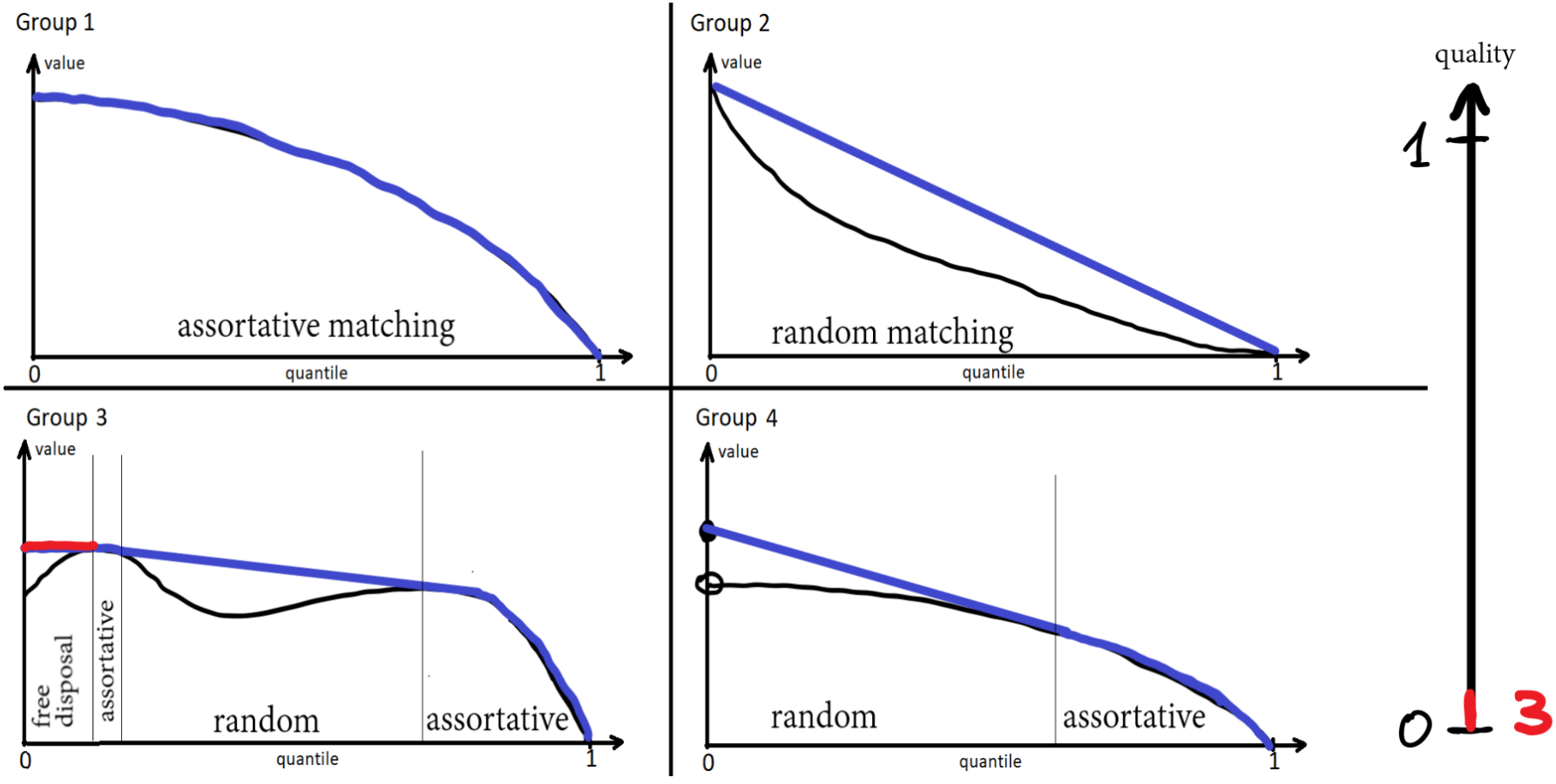
Derivation of Optimal Mechanism: within-group allocation



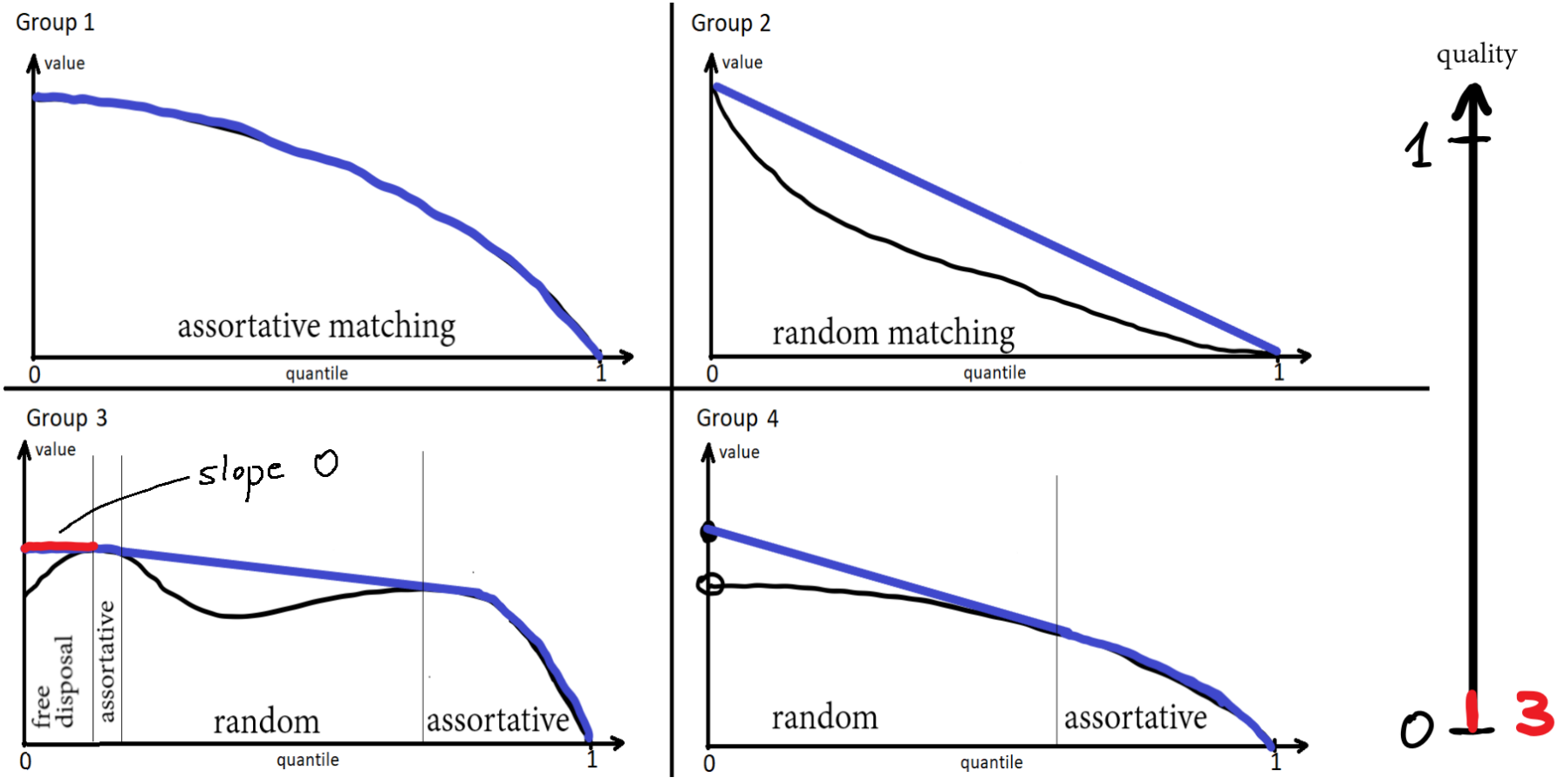
Derivation of Optimal Mechanism: across-group allocation



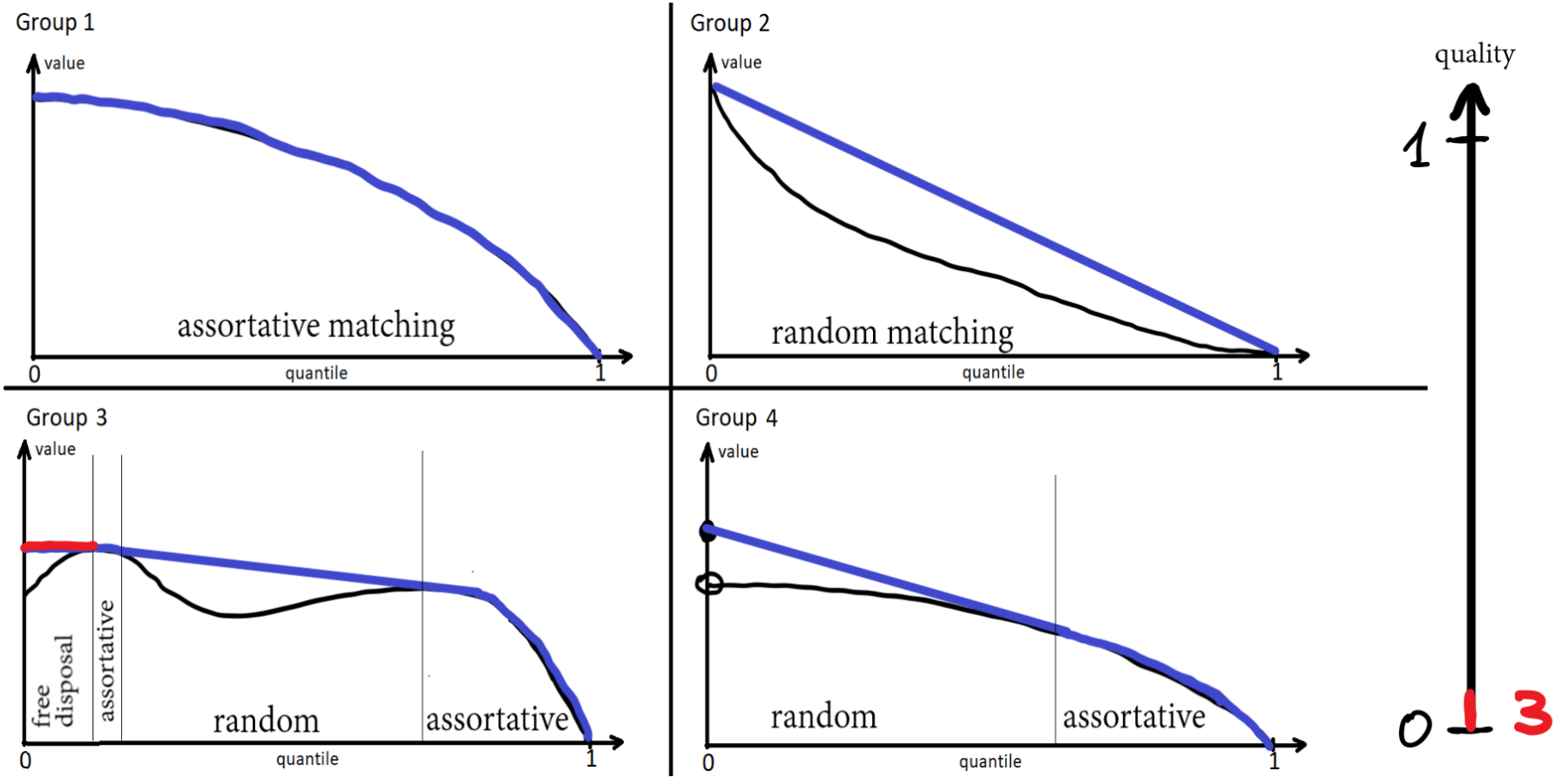
Derivation of Optimal Mechanism: across-group allocation



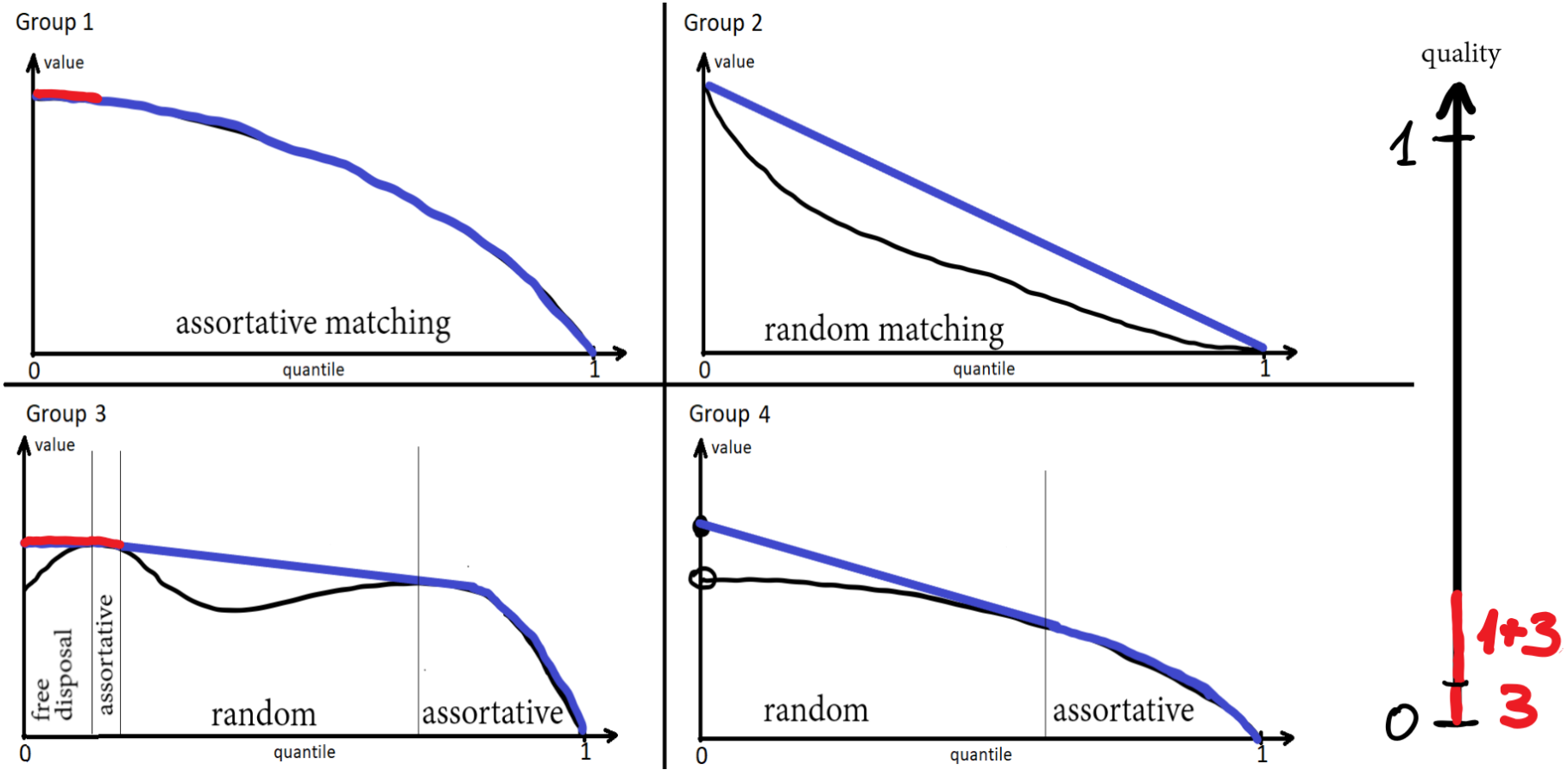
Derivation of Optimal Mechanism: across-group allocation



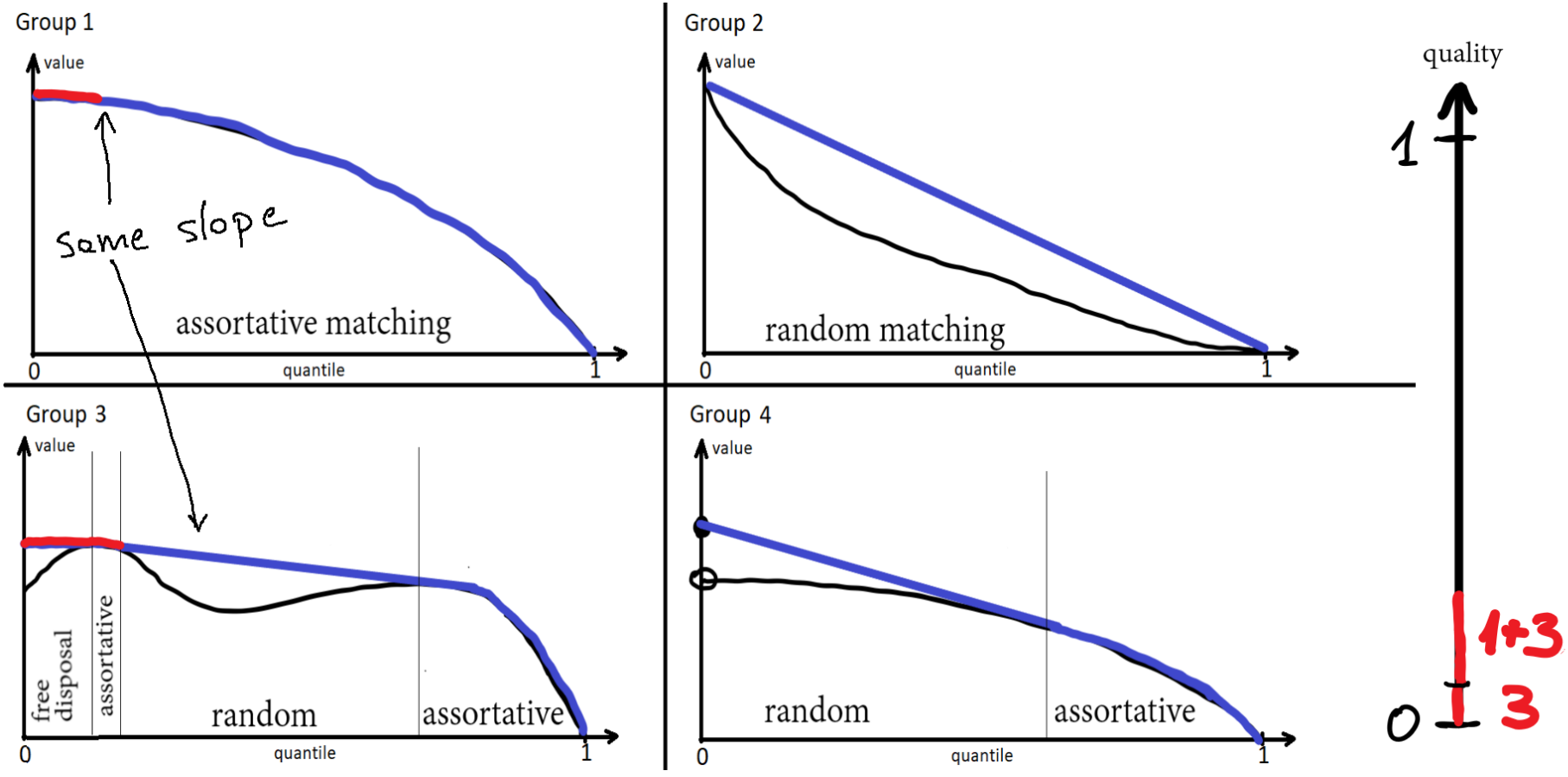
Derivation of Optimal Mechanism: across-group allocation



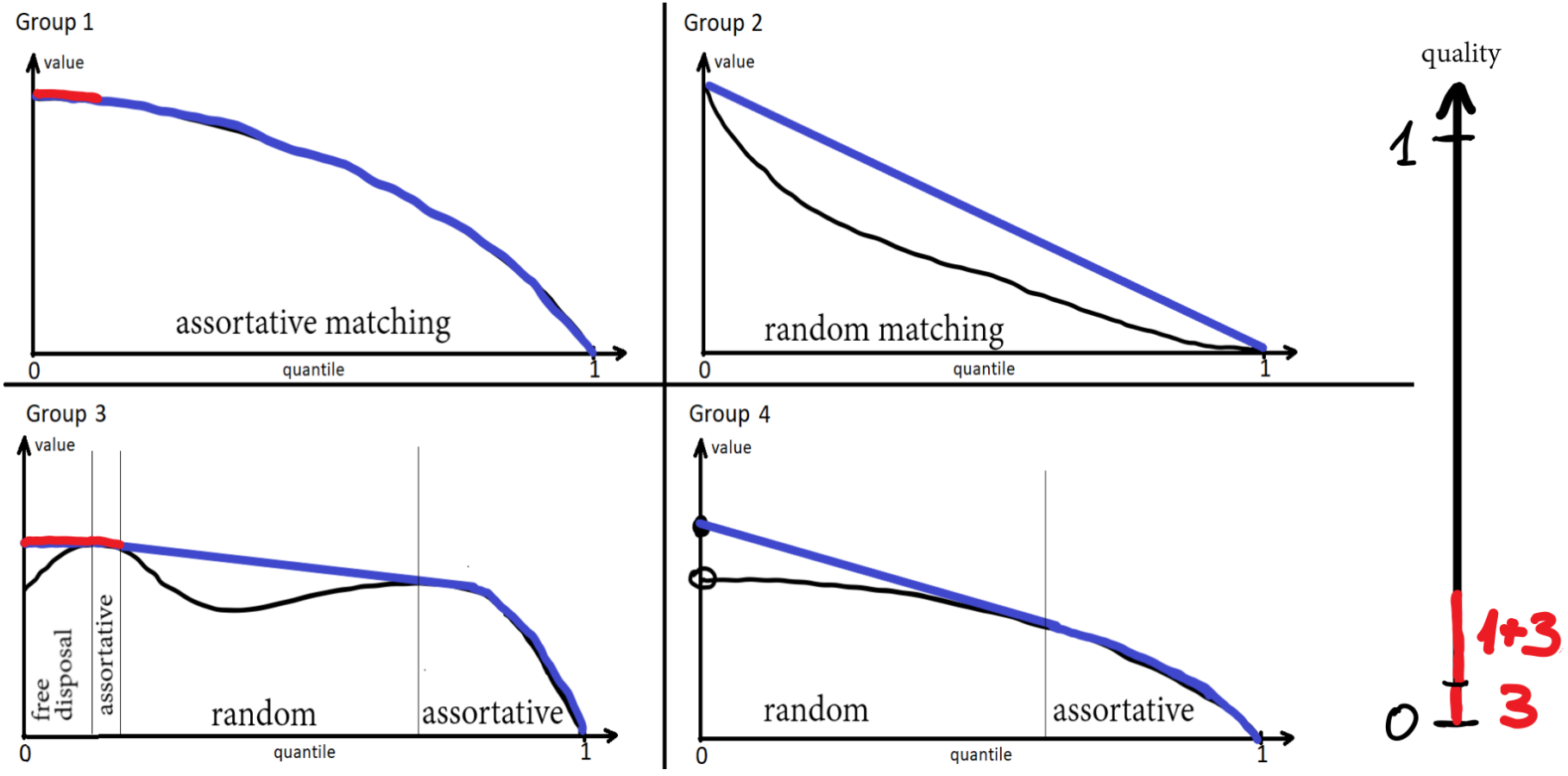
Derivation of Optimal Mechanism: across-group allocation



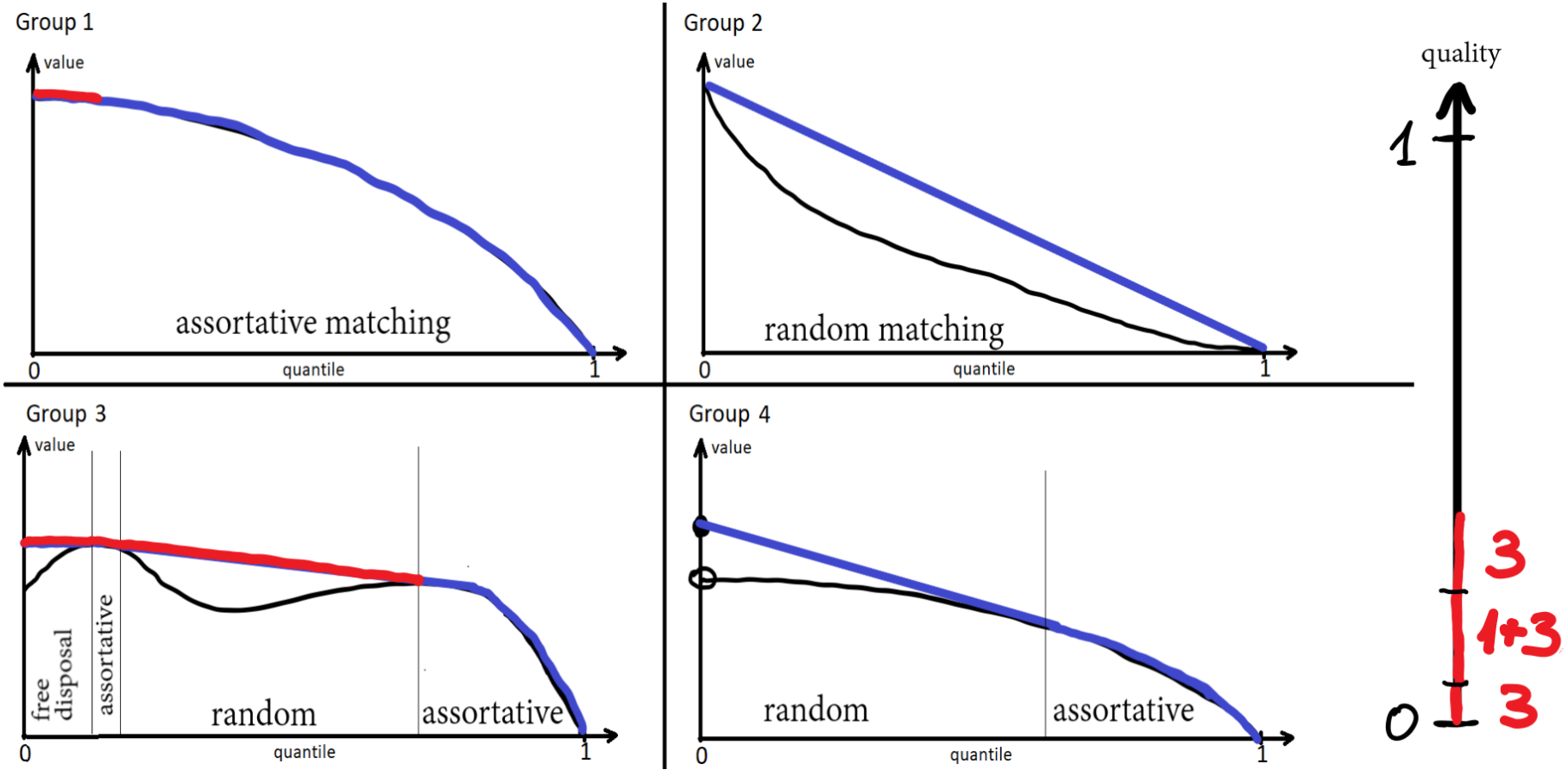
Derivation of Optimal Mechanism: across-group allocation



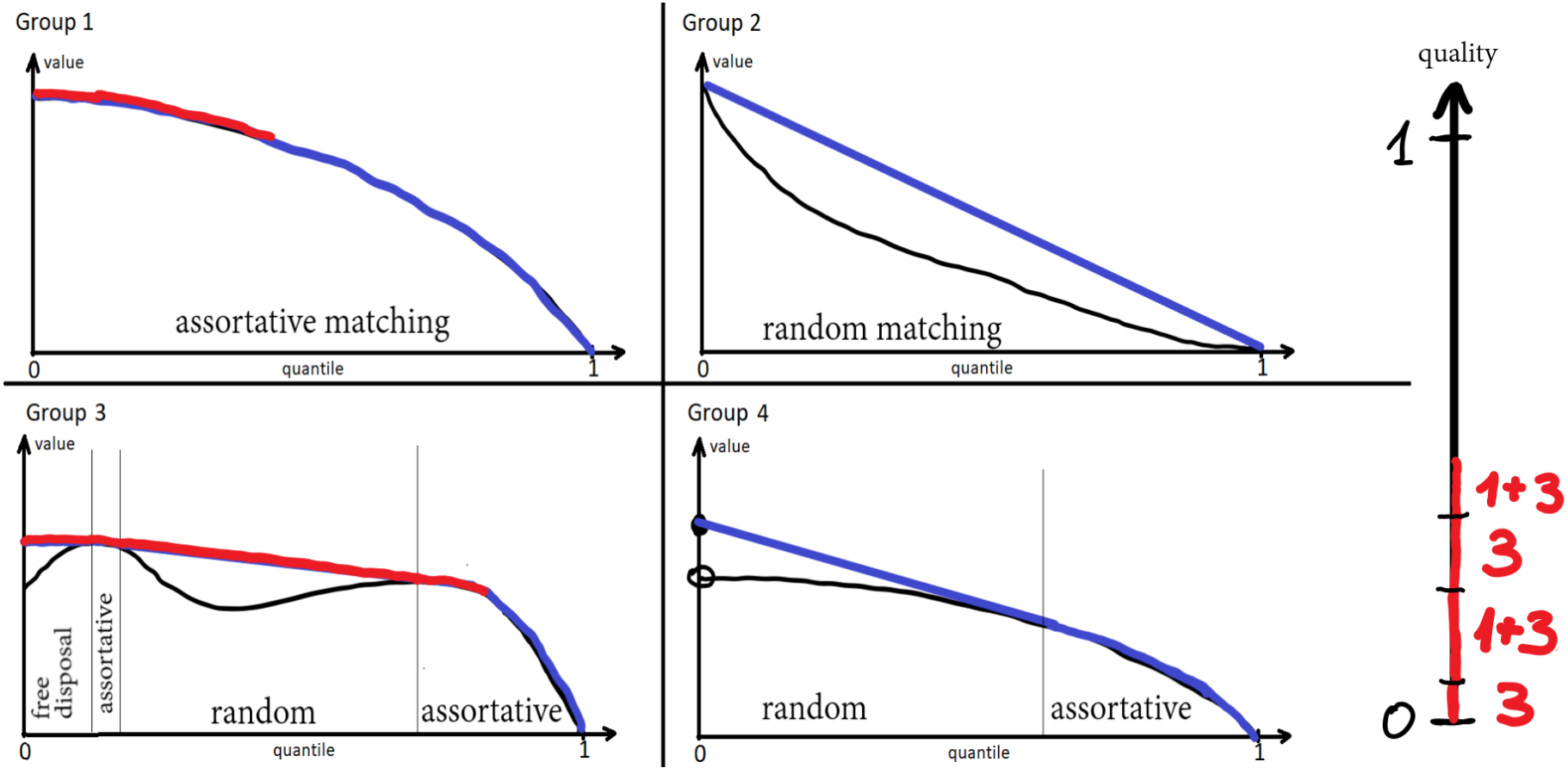
Derivation of Optimal Mechanism: across-group allocation



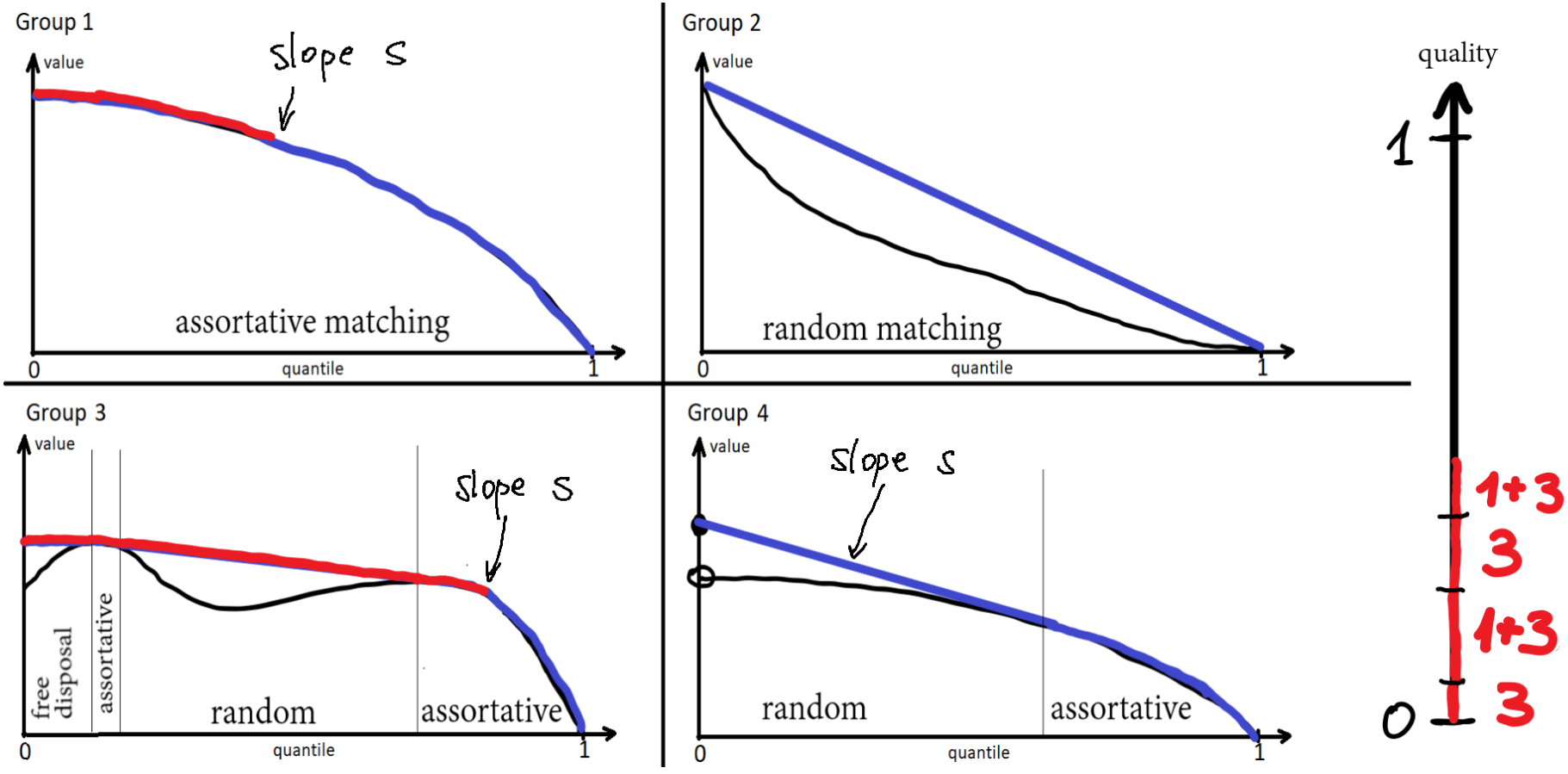
Derivation of Optimal Mechanism: across-group allocation



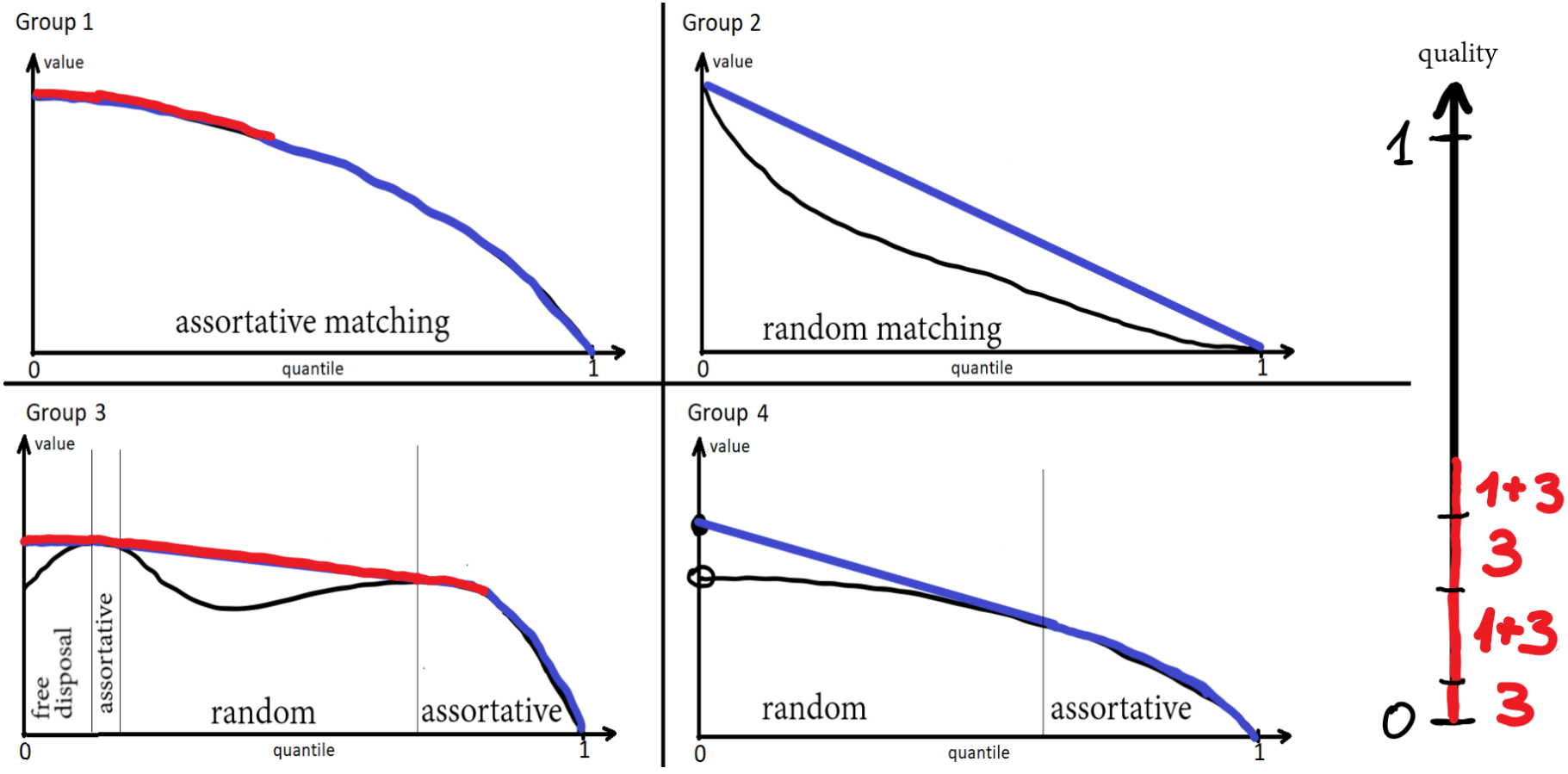
Derivation of Optimal Mechanism: across-group allocation



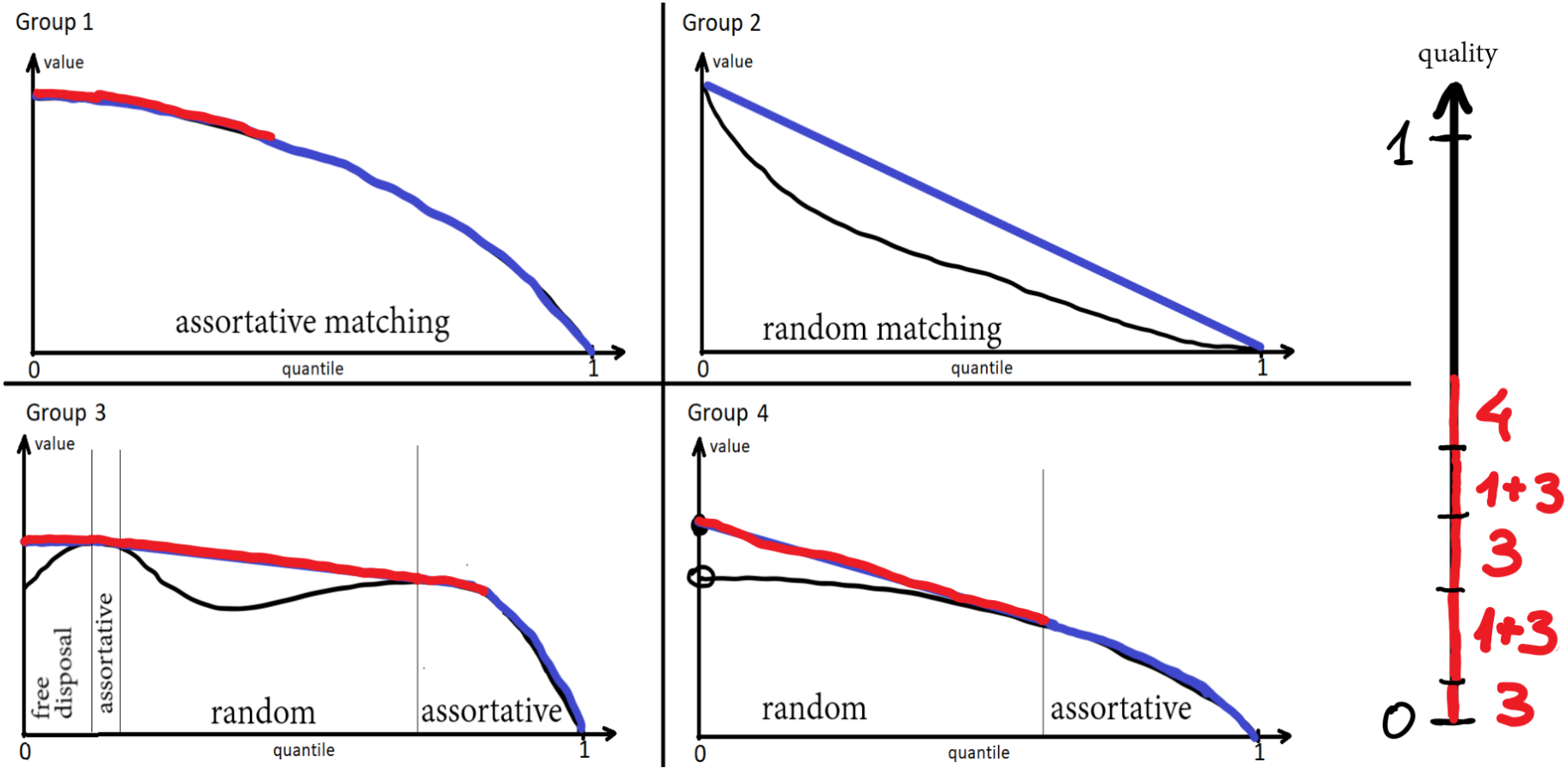
Derivation of Optimal Mechanism: across-group allocation



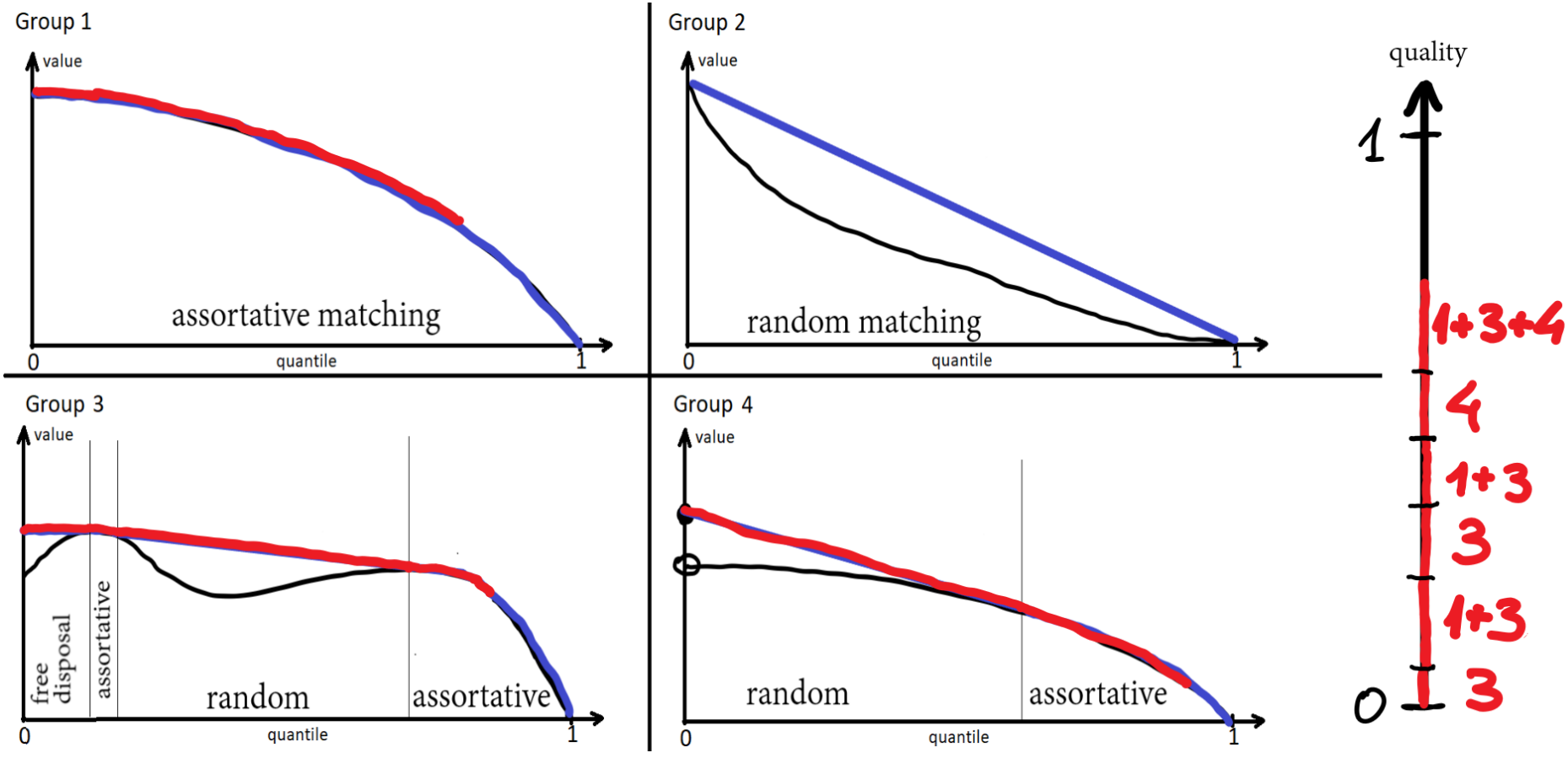
Derivation of Optimal Mechanism: across-group allocation



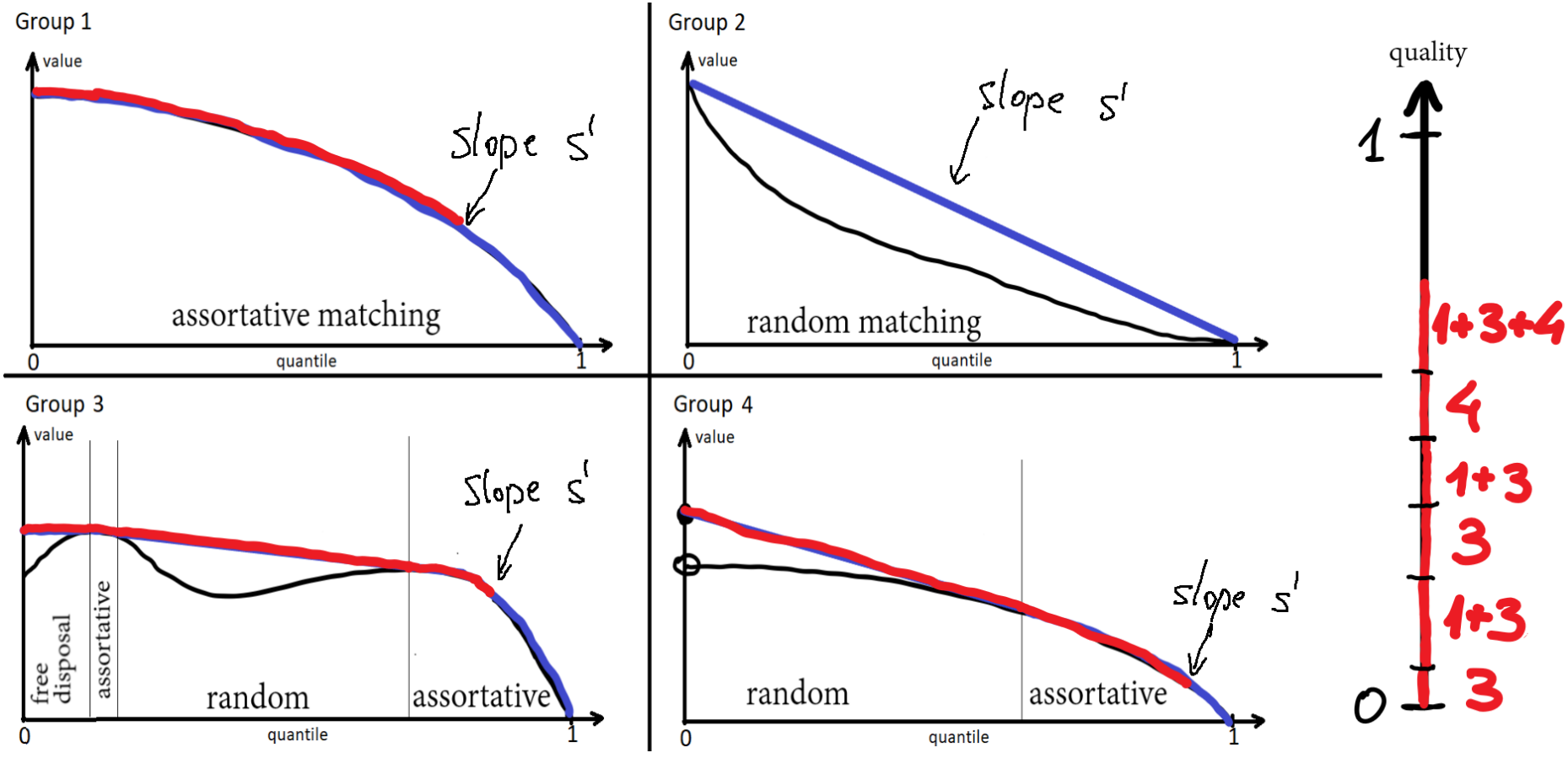
Derivation of Optimal Mechanism: across-group allocation



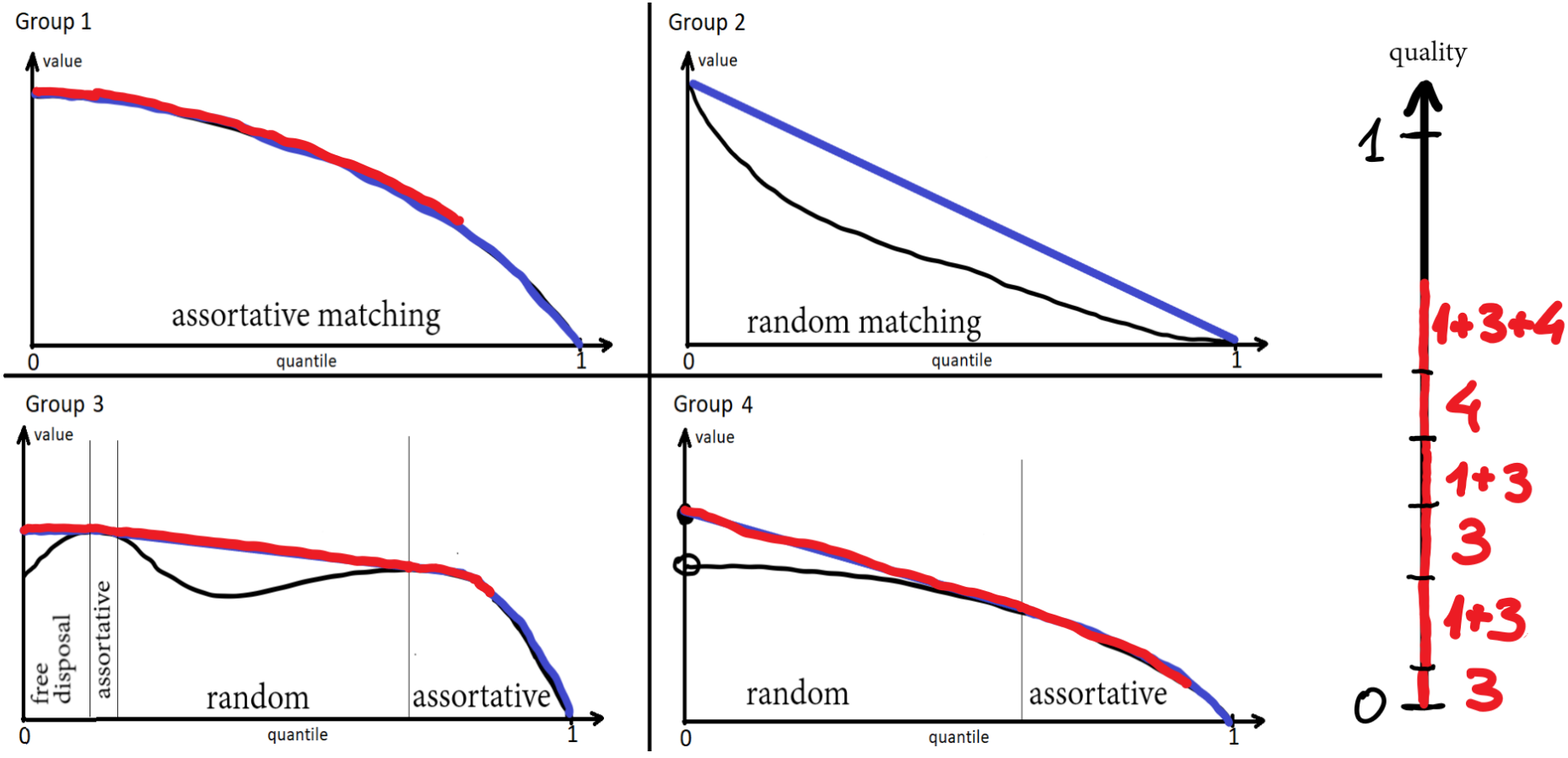
Derivation of Optimal Mechanism: across-group allocation



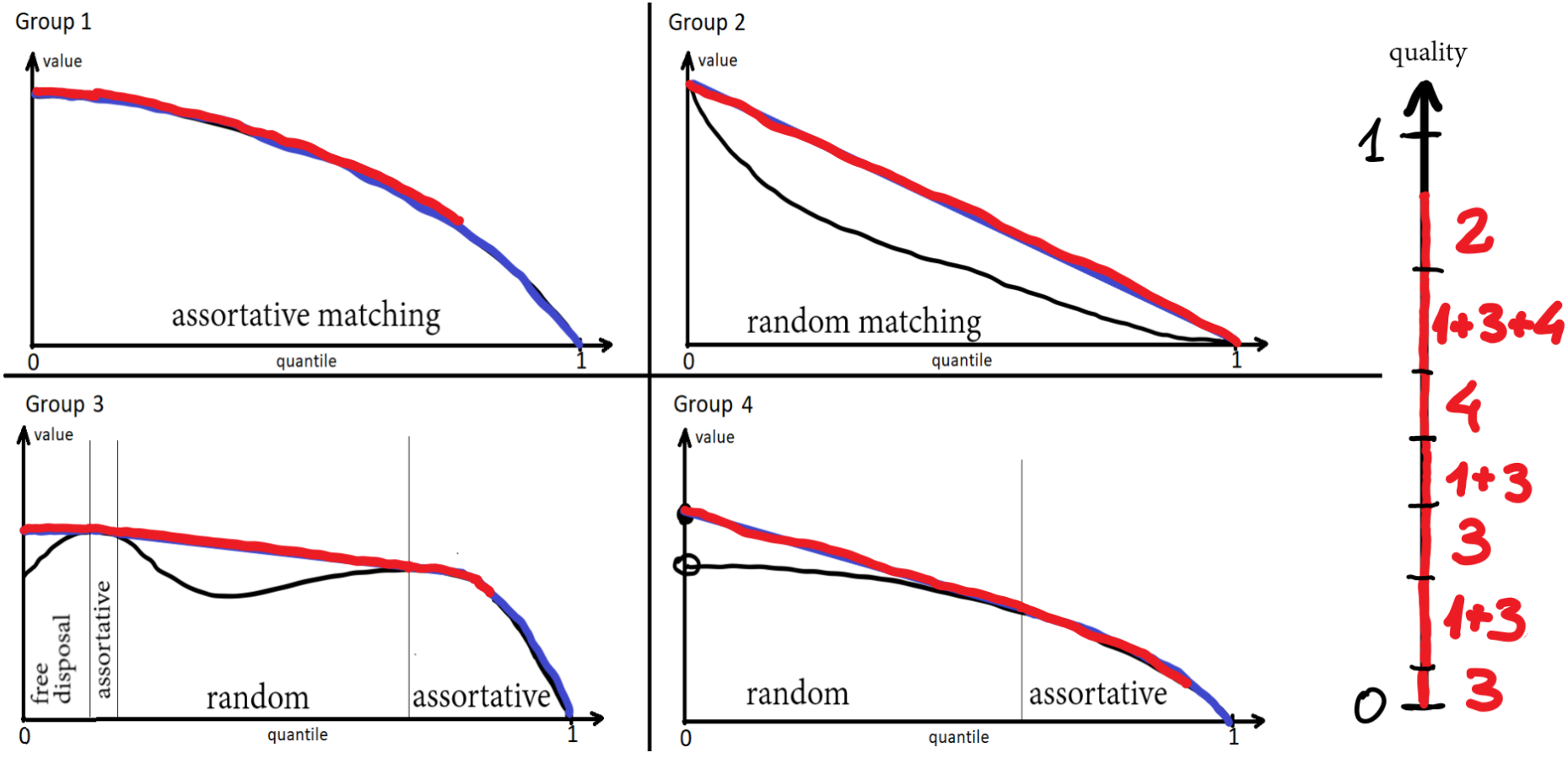
Derivation of Optimal Mechanism: across-group allocation



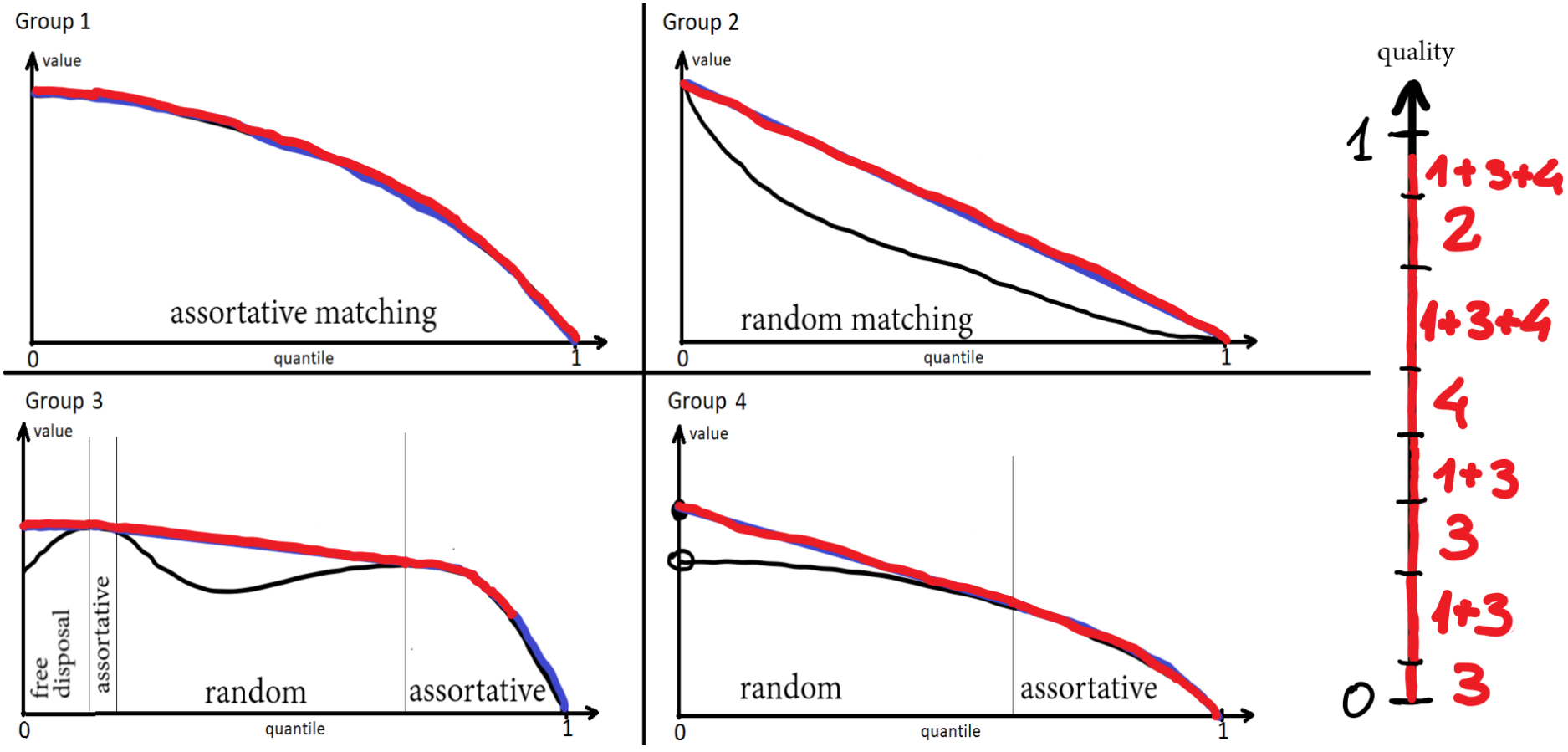
Derivation of Optimal Mechanism: across-group allocation



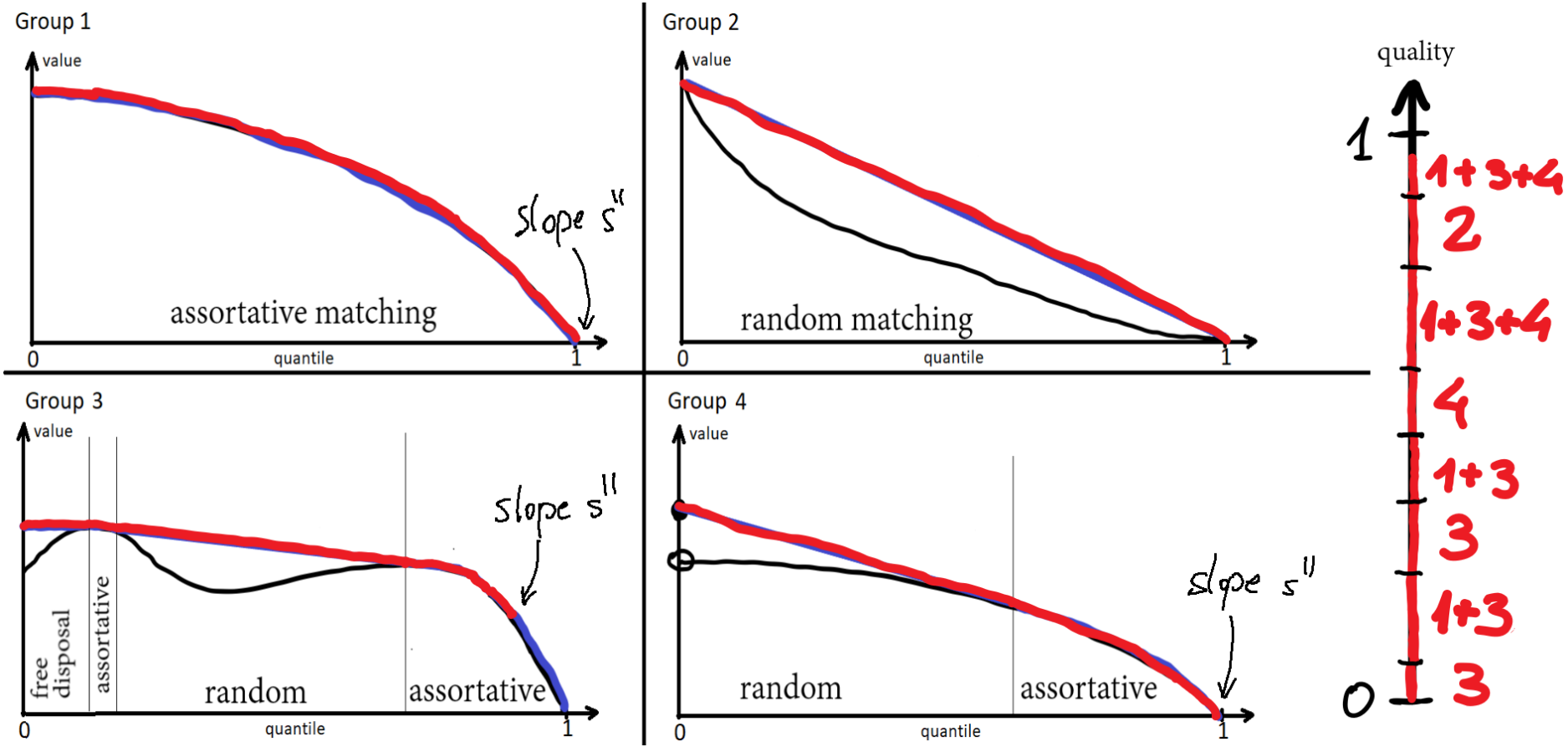
Derivation of Optimal Mechanism: across-group allocation



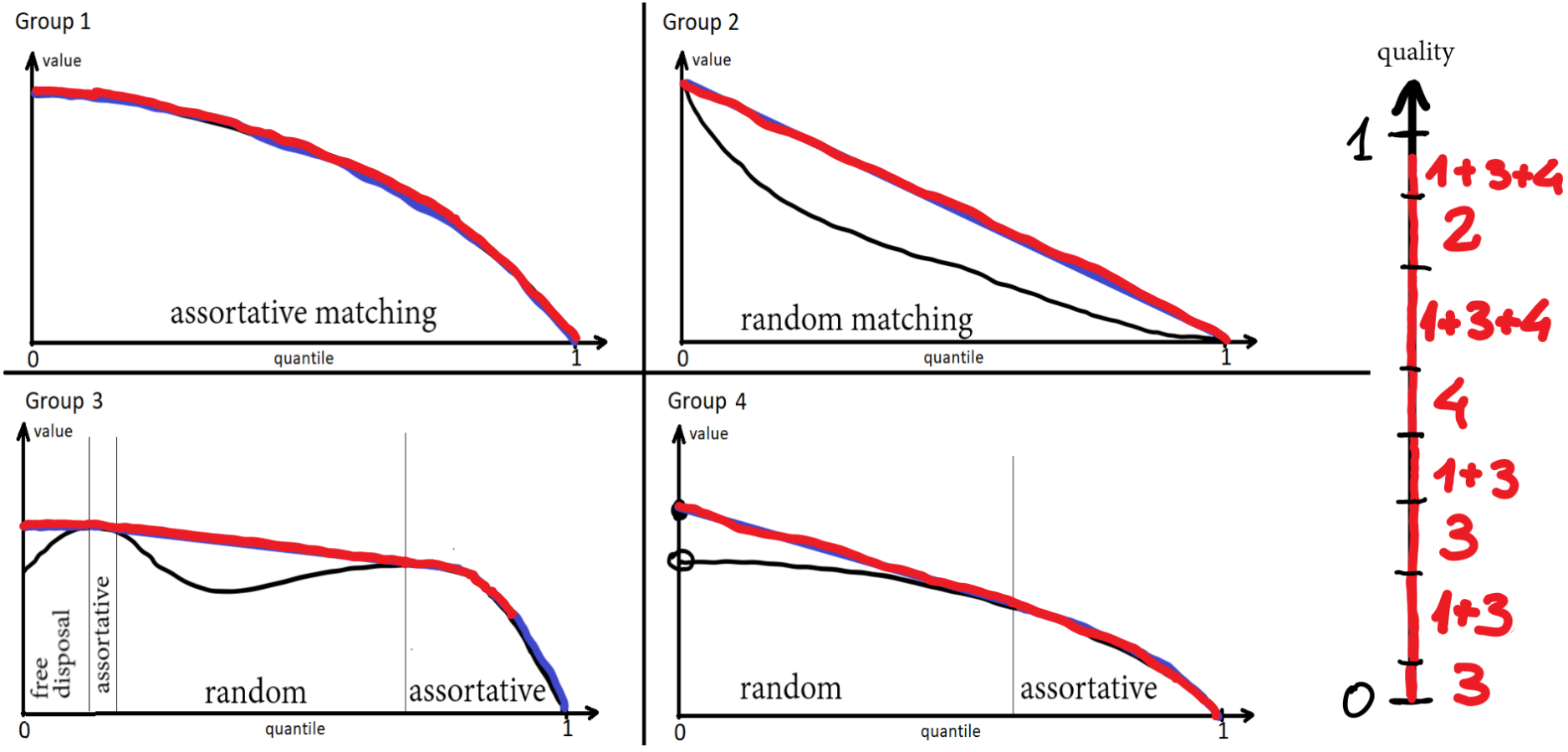
Derivation of Optimal Mechanism: across-group allocation



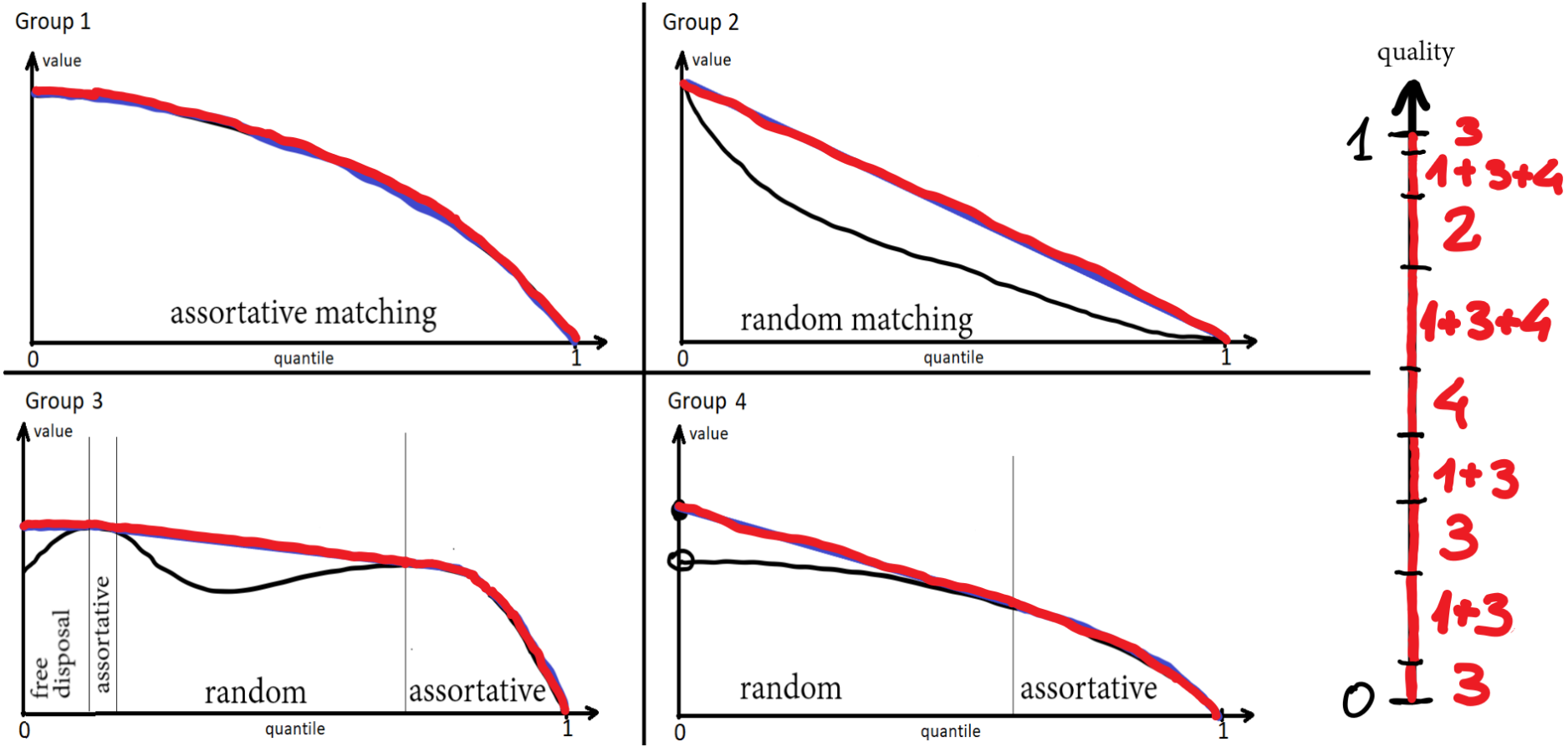
Derivation of Optimal Mechanism: across-group allocation



Derivation of Optimal Mechanism: across-group allocation



Derivation of Optimal Mechanism: across-group allocation



Economic Implications

Economic Implications

What's the optimal mechanism when prices cannot be used?

Economic Implications

Result 1

Suppose that prices cannot be used, so that allocation within each group i is fully random. Then, it is optimal to vaccinate groups **sequentially** *in the order of decreasing*

$$\overline{V}_i = \mathbb{E}[V_i(r) | \, i].$$

Economic Implications

Result 1

Suppose that prices cannot be used, so that allocation within each group i is fully random. Then, it is optimal to vaccinate groups **sequentially** *in the order of decreasing*

$$\overline{V}_i = \mathbb{E}[V_i(r)|\, i].$$

$$\overline{V}_i = \mathbb{E}[\lambda \cdot r|\, i] + h^i_{\mathsf{ex}} \cdot \mathbb{P}(a = \mathsf{Risky}|\, i) + v^i_{\mathsf{ex}} \cdot \mathbb{P}(a = \mathsf{Safe}|\, i)$$

Economic Implications

Result 1

Suppose that prices cannot be used, so that allocation within each group i is fully random. Then, it is optimal to vaccinate groups **sequentially** *in the order of decreasing*

$$\overline{V}_i = \mathbb{E}[V_i(r)|\, i].$$

$$\overline{V}_i = \mathbb{E}[\lambda \cdot r|\, i] + h^i_{\text{ex}} \cdot \mathbb{P}(a = \text{Risky}|\, i) + v^i_{\text{ex}} \cdot \mathbb{P}(a = \text{Safe}|\, i)$$

Example: (Recall that $r = \min\{v, h\}$)

Economic Implications

Result 1

Suppose that prices cannot be used, so that allocation within each group i is fully random. Then, it is optimal to vaccinate groups **sequentially** *in the order of decreasing*

$$\overline{V}_i = \mathbb{E}[V_i(r)|\, i].$$

$$\overline{V}_i = \mathbb{E}[\lambda \cdot r|\, i] + h^i_{\text{ex}} \cdot \mathbb{P}(a = \text{Risky}|\, i) + v^i_{\text{ex}} \cdot \mathbb{P}(a = \text{Safe}|\, i)$$

Example: (Recall that $r = \min\{v, h\}$)

College students: $\overline{V}_i \approx h^i_{\text{ex}}$;

Economic Implications

Result 1

Suppose that prices cannot be used, so that allocation within each group i is fully random. Then, it is optimal to vaccinate groups **sequentially** *in the order of decreasing*

$$\overline{V}_i = \mathbb{E}[V_i(r)|\, i].$$

$$\overline{V}_i = \mathbb{E}[\lambda \cdot r|\, i] + h^i_{\mathsf{ex}} \cdot \mathbb{P}(a = \mathsf{Risky}|\, i) + v^i_{\mathsf{ex}} \cdot \mathbb{P}(a = \mathsf{Safe}|\, i)$$

Example: (Recall that $r = \min\{v, h\}$)

College students: $\overline{V}_i \approx h^i_{\mathsf{ex}}$;

High-risk populations: $\overline{V}_j \approx \mathbb{E}[\lambda \cdot r|\, j] + v^j_{\mathsf{ex}}$.

Economic Implications

What if we can use prices?

Economic Implications

Result 2

It is optimal to use (within group i)

- *market allocation, when $V_i(r)$ is increasing;*
- *free allocation, when $V_i(r)$ is decreasing.*

Economic Implications

Result 2

It is optimal to use (within group i)

- *market allocation, when $V_i(r)$ is increasing;*
- *free allocation, when $V_i(r)$ is decreasing.*

$$V_i(r) = \underbrace{\Lambda_i(r) \cdot \frac{1 - G_i(r)}{g_i(r)}}_{\text{weighted utility}} + \alpha \underbrace{\left(r - \frac{1 - G_i(r)}{g_i(r)} \right)}_{\text{revenue}} +$$

$$\underbrace{v^i_{\text{ex}} \cdot \mathbb{P}(a = \text{Safe} | i,\, r) + h^i_{\text{ex}} \cdot \mathbb{P}(a = \text{Risky} | i,\, r)}_{\text{externality}}$$

Economic Implications

Result 2

It is optimal to use (within group i)

- *market allocation, when $V_i(r)$ is increasing;*
- *free allocation, when $V_i(r)$ is decreasing.*

$$\underbrace{v^i_{\text{ex}} \cdot \mathbb{P}(a = \text{Safe}|i,\, r) + h^i_{\text{ex}} \cdot \mathbb{P}(a = \text{Risky}|i,\, r)}_{\text{externality}}$$

Economic Implications

Result 2

It is optimal to use (within group i)

- *market allocation, when $V_i(r)$ is increasing;*
- *free allocation, when $V_i(r)$ is decreasing.*

$$\underbrace{v^i_{\text{ex}} + (h^i_{\text{ex}} - v^i_{\text{ex}}) \cdot \mathbb{P}(a = \text{Risky}|i,\, r)}_{\text{externality}}$$

Ride-share driver: If WTP r is positively correlated with wealth,

Economic Implications

Result 2

It is optimal to use (within group i)

- *market allocation, when $V_i(r)$ is increasing;*
- *free allocation, when $V_i(r)$ is decreasing.*

$$\underbrace{v^i_{\text{ex}} + (h^i_{\text{ex}} - v^i_{\text{ex}}) \cdot \mathbb{P}(a = \text{Risky}|i,\, r)}_{\text{externality}}$$

Ride-share driver: If WTP r is positively correlated with wealth, and wealth is positively correlated with not driving,

Economic Implications

Result 2

It is optimal to use (within group i)

- *market allocation, when $V_i(r)$ is increasing;*
- *free allocation, when $V_i(r)$ is decreasing.*

$$\underbrace{v^i_{\text{ex}} + (h^i_{\text{ex}} - v^i_{\text{ex}}) \cdot \mathbb{P}(a = \text{Risky}|i,\, r)}_{\text{externality}}$$

Ride-share driver: If WTP r is positively correlated with wealth,
and wealth is positively correlated with not driving,
$\implies$ $\mathbb{P}(a = \text{Risky}|i,\, r)$ could be **decreasing** in r.

Economic Implications

Result 2

It is optimal to use (within group i)

- *market allocation, when $V_i(r)$ is increasing;*
- *free allocation, when $V_i(r)$ is decreasing.*

$$\underbrace{v^i_{\text{ex}} + (h^i_{\text{ex}} - v^i_{\text{ex}}) \cdot \mathbb{P}(a = \text{Risky}|i,\, r)}_{\text{externality}}$$

Office worker: WTP might be higher if in-person work is encouraged,

Economic Implications

Result 2

It is optimal to use (within group i)

- *market allocation, when $V_i(r)$ is increasing;*
- *free allocation, when $V_i(r)$ is decreasing.*

$$\underbrace{v^i_{\text{ex}} + (h^i_{\text{ex}} - v^i_{\text{ex}}) \cdot \mathbb{P}(a = \text{Risky} | i,\, r)}_{\text{externality}}$$

Office worker: WTP might be higher if in-person work is encouraged,

$$\implies \text{WTP is positively correlated with } a = \text{Risky}$$

Economic Implications

Result 2

It is optimal to use (within group i)

- *market allocation, when $V_i(r)$ is increasing;*
- *free allocation, when $V_i(r)$ is decreasing.*

$$\underbrace{v^i_{\text{ex}} + (h^i_{\text{ex}} - v^i_{\text{ex}}) \cdot \mathbb{P}(a = \text{Risky} | i,\, r)}_{\text{externality}}$$

Office worker: WTP might be higher if in-person work is encouraged,

$\implies$ WTP is positively correlated with $a = \text{Risky}$

$\implies$ $\mathbb{P}(a = \text{Risky} | i,\, r)$ could be **increasing** in r.

Economic Implications

Can we justify giving "absolute priority" to some group?

Economic Implications

Result 3

Suppose that $A(0) \geq \mu_i$ (mass of agents in group i). Then, it is optimal for all agents in group i to receive a vaccine **immediately and for free** *if*

$$\min_x \mathbb{E}[V_i(r) | \, r \leq x] \geq \max_{j \neq i,\, x} \mathbb{E}[V_j(r) | \, r \geq x].$$

Moreover, this condition is necessary when $A(0) = \mu_i$.

Economic Implications

Result 3

Suppose that $A(0) \geq \mu_i$ (mass of agents in group i). Then, it is optimal for all agents in group i to receive a vaccine **immediately and for free** *if*

$$\min_x \mathbb{E}[V_i(r) | \, r \leq x] \geq \max_{j \neq i,\, x} \mathbb{E}[V_j(r) | \, r \geq x].$$

Moreover, this condition is necessary when $A(0) = \mu_i$.

Interpretation: The minimal marginal value of vaccinating an agent with label i is higher than the highest marginal value the designer could obtain from any other agent.

Economic Implications

Result 3

Suppose that $A(0) \geq \mu_i$ (mass of agents in group i). Then, it is optimal for all agents in group i to receive a vaccine **immediately and for free** *if*

$$\min_x \mathbb{E}[V_i(r) | \, r \leq x] \geq \max_{j \neq i,\, x} \mathbb{E}[V_j(r) | \, r \geq x].$$

Moreover, this condition is necessary when $A(0) = \mu_i$.

Interpretation: The minimal marginal value of vaccinating an agent with label i is higher than the highest marginal value the designer could obtain from any other agent.

Condition likely to hold for **front-line health workers**:
very high externality + high welfare weights

Economic Implications

Result 3

Suppose that $A(0) \geq \mu_i$ (mass of agents in group i). Then, it is optimal for all agents in group i to receive a vaccine **immediately and for free** *if*

$$\min_x \mathbb{E}[V_i(r) | \, r \leq x] \geq \max_{j \neq i, \, x} \mathbb{E}[V_j(r) | \, r \geq x].$$

Moreover, this condition is necessary when $A(0) = \mu_i$.

Interpretation: The minimal marginal value of vaccinating an agent with label i is higher than the highest marginal value the designer could obtain from any other agent.

Condition likely to hold for **front-line health workers**:
very high externality + high welfare weights
(but only if the weight on revenue is relatively low)

Economic Implications

What if the weight on revenue is relatively high?

Economic Implications

Result 4

Suppose that it is optimal to use a **market allocation** *within group* j *and a* **free allocation** *within group* i*. If*

$$V_j(\bar{r}_j) > \overline{V}_i > V_j(\underline{r}_j),$$

then it is optimal to start vaccinating agents in group j *first, then to vaccinate all agents in group* i*, and then the remaining agents in group* j*.*

Economic Implications

Result 4

Suppose that it is optimal to use a **market allocation** *within group* j *and a* **free allocation** *within group* i*. If*

$$V_j(\bar{r}_j) > \overline{V}_i > V_j(\underline{r}_j),$$

then it is optimal to start vaccinating agents in group j *first, then to vaccinate all agents in group* i*, and then the remaining agents in group* j*.*

Example: If the weight on revenue α is high, we should vaccinate "millionaires" first.

Economic Implications

Result 4

Suppose that it is optimal to use a **market allocation** *within group* j *and a* **free allocation** *within group* i*. If*

$$V_j(\bar{r}_j) > \overline{V}_i > V_j(\underline{r}_j),$$

then it is optimal to start vaccinating agents in group j *first, then to vaccinate all agents in group* i*, and then the remaining agents in group* j*.*

Example: If the weight on revenue α is high, we should vaccinate "millionaires" first.

The price $p^\star$ charged in the initial stage can be approximated as

$$V_j(p^\star) = \overline{V}_i \implies p^\star \approx \frac{\mathbb{E}[\lambda r \,|\, i] + \mathbb{E}[T_{\mathsf{ex}} \,|\, i]}{\alpha}.$$

Discussion

Discussion

- **Pure health objective**:

$$\delta(t)\mathbf{1}_{\mathsf{Risky}}(\lambda h + h_{\mathsf{ex}}).$$

Paradoxically leads to lower priority for people with high h.

Discussion

- **Pure health objective**:

$$\delta(t)\mathbf{1}_{\mathsf{Risky}}(\lambda h + h_{\mathsf{ex}}).$$

  Paradoxically leads to lower priority for people with high h.

- **Vaccine hesitancy** (negative h): could justify negative prices.

Discussion

- **Pure health objective**:

$$\delta(t)\mathbf{1}_{\mathsf{Risky}}(\lambda h + h_{\mathsf{ex}}).$$

  Paradoxically leads to lower priority for people with high h.

- **Vaccine hesitancy** (negative h): could justify negative prices.
- **Elastic supply** of vaccines: captured by higher α.

Discussion

- **Pure health objective**:

$$\delta(t)\mathbf{1}_{\mathsf{Risky}}(\lambda h + h_{\mathsf{ex}}).$$

  Paradoxically leads to lower priority for people with high h.

- **Vaccine hesitancy** (negative h): could justify negative prices.
- **Elastic supply** of vaccines: captured by higher α.
- **Across-country allocation**: captured by labels.

Discussion

- **Pure health objective**:

$$\delta(t)\mathbf{1}_{\mathsf{Risky}}(\lambda h + h_{\mathsf{ex}}).$$

  Paradoxically leads to lower priority for people with high h.

- **Vaccine hesitancy** (negative h): could justify negative prices.
- **Elastic supply** of vaccines: captured by higher α.
- **Across-country allocation**: captured by labels.
- **Queuing** as a mechanism: captured by setting $\alpha = 0$.

Discussion

- **Pure health objective**:

$$\delta(t)\mathbf{1}_{\text{Risky}}(\lambda h + h_{\text{ex}}).$$

  Paradoxically leads to lower priority for people with high h.

- **Vaccine hesitancy** (negative h): could justify negative prices.
- **Elastic supply** of vaccines: captured by higher α.
- **Across-country allocation**: captured by labels.
- **Queuing** as a mechanism: captured by setting $\alpha = 0$.
- **Decentralized implementation**: market mechanism + label-specific coupons.

Summary

The most important equation...

$$V_i(r) = \underbrace{\Lambda_i(r) \cdot \frac{1 - G_i(r)}{g_i(r)}}_{\text{weighted utility}} + \alpha \underbrace{\left(r - \frac{1 - G_i(r)}{g_i(r)} \right)}_{\text{revenue}} + \underbrace{\mathbb{E}\left[T_{\mathsf{ex}} | i,\, r\right]}_{\text{externality}}.$$