

What Is Market Design?

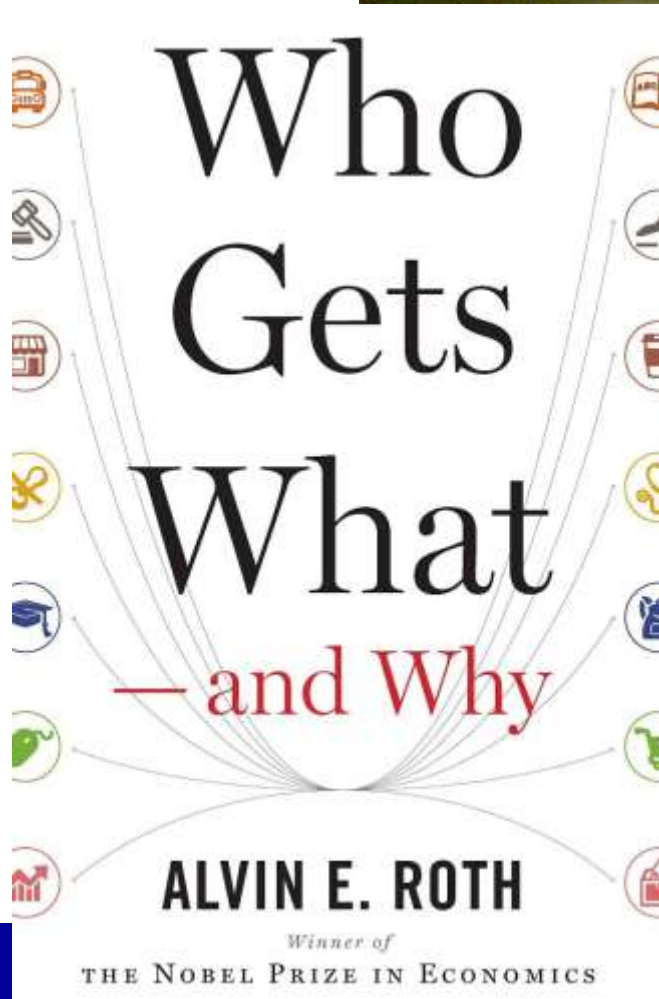
了解市場設計

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Lecture 12, EE-BGT

Market Design: Prizing Winning Idea 2012

- ▶ Both in the Lab and Field
- ▶ Alvin E. Roth (Stanford Univ.)

(Keynote speaker
of 2013 ESA
North American
Meeting at
Santa Cruz, CA)



Market Design is... (市場設計就是)

- ▶ Design institutions to realize **gains from trade** previously unavailable to solve the problem of (lack of) **market failure**.
 - ▶ 設計制度來實現尚未實現的**交易好處**，解決「**市場(不存在導致)失靈**」
- ▶ Traditionally, market failure means:
 - ▶ **Externalities and Public Goods**
- ▶ But these are lack of market failures
 - ▶ **Not failures of the market!**
 - ▶ 傳統上的市場失靈是**殃及他人的外溢效果(外部性)**和**可以共享的財貨(公共財)**，但這些其實是**缺乏**市場所造成的失靈！

Market Design is Everywhere! (已在你我身邊!)

▶ Online Trading Platforms

- ▶ 網拍平台讓原本只能讓社區鄰居參與的跳蚤市場擴大參與

▶ Patents

- ▶ 專利讓知識(可共享的公共財)被發現、發明得到獎勵

▶ Carbon Market

- ▶ 碳排放市場界定排放權歸屬/減少殃及他人的額外效果

▶ Social Norms

- ▶ 社會規範為避免竭澤而漁、共同悲劇(Tragedy of Commons)

▶ Rebuild Taipei First Fruit and Vegetable Wholesale Market (台北第一果菜市場的改建工程也是!)

Examples of Market Design (市場設計的範例)

1. Top-Trading Cycle (Agent-Item Match)

- ▶ 人與物的配對市場使用小圈圈優先交換(TTC)演算法

2. Delayed Acceptance (Agent-Agent Match)

- ▶ 人與人的配對市場使用延遲接受(DA)演算法

3. Auction Design

- ▶ 拍賣設計讓獨佔/獨買者把競爭的力量發揮到極致

4. Screening and Signaling

- ▶ 篩選機制與認證標籤克服市場中的資訊落差(asymmetric information)

▶ Let's see a story regarding Ten Principles of Taiwanese Economics (來看看鄉民經濟學原理第七條)

肝肝相連到天邊(張桂越) (蘋果日報2008/10/24)

- ▶ 我有兩個弟弟，一個2004年死了，一個2008年換肝成功。一個在台灣，一個在美國。...
- ▶ 受限法令 有肝無用
- ▶ 三弟陷入肝昏迷時... 我們全家大小包括媳婦們的肝，統統願意割一片給三弟，這是「合法的」，卻統統不合比對標準，不是血型不合，就是這個那個的，而三弟幾個當兵的兄弟，肝膽相照，個個身強體壯，血型也對，卻不符合中華民國的法律，見死不能救。
- ▶ 我只好鬼鬼祟祟的，聯絡到大陸的換肝捐客...

肝肝相連到天邊(張桂越) (蘋果日報2008/10/24)

- ▶ 故事還沒說完。上個月，接到西雅圖的電話，說大弟已進入開刀房，六小時後換肝。今天，大弟換肝手術成功.....
- ▶ 對兩個弟弟，一個在台灣，一個在美國，一種肝病兩種命運，我不解神的奧秘，
- ▶ 但我知道我們美國家人沒有送一毛錢紅包，沒有求朋友的特權，沒有找什麼參議員，沒有像熱鍋上螞蟻般東奔西跑，沒有用個人的智慧與財力為大弟求得一塊肝，卻順順利利地，在短時間內，可以說是悄悄地換肝成功，

不可思議的背後，大有學問：

肝肝相連到天邊(張桂越)
(蘋果日報2008/10/24)

1. 美國社會對器官捐贈的教育普及

- ▶ 供需失衡 自然要搶：台灣的肝病患者排不到、等不到，因為供需失調，幾千個人等一個肝，當然要搶，十八般武藝勢必出籠，送紅包沒用的話，跳進大陸買賣肝臟的漩渦又是何其自然的事。如果國家有健康的機制，誰願意到大陸冒險？

2. 盡速成立臨時小組，解決危險個案。有些病人命在旦夕，立法審案冗長費時，有些病人是不能等的

3. 建議立法委員或相關衛生單位，能夠盡速**學習與參考** **國外換肝機制，借他山之石，改善國人換肝機制**

7. 許多產業都很神聖，絕對不能商品化。



(財團法人器官捐贈移植登錄中心
2024年4月26日等候/捐贈移植統計)

7. 許多產業都很神聖，絕對不能商品化。



有效等候接受器官
移植病人



本年度接受大愛器官/
組織移植



大愛器官捐贈總人數



大愛器官(組織)捐贈
總例數

(財團法人器官捐贈移植登錄中心
2024年4月26日等候/捐贈移植統計)

等待連線的器官即時統計



肺臟

約 **131** 人 等待中

目前共有約 **11600** 人 正在等候接受器官移植

(財團法人器官捐贈移植登錄中心
OrganDonationWifi 2025年9月23日
等候/捐贈移植統計)

7. 許多產業都很神聖，絕對不能商品化。

▶ 2009年至2017年國內肝、腎臟活體捐贈移植例數

▶ 財團法人器官捐贈移植登錄中心 (2009/1/1 ~ 2017/12/31)

年度	2009	2010	2011	2012	2013	2014	2015	2016	2017	總計
肝臟	266	344	401	431	447	485	505	428	406	3713
腎臟	90	97	84	73	128	129	104	112	112	929

▶ 公共電視—「獨立特派員」心肝那裡找

▶ <https://youtu.be/mkRXHcQMAJo?t=1258>

Post-COVID organ transplant dropped!

2016-2023年國內所有器官受贈移植統計

年度	心臟	肺臟	肝臟	腎臟	胰臟	眼角膜	小腸	總案數
2023	27	9	41	65	1	185	0	326
2022	61	28	98	173	10	518	4	892
2021	57	27	116	211	11	470	0	892
2020	78	23	125	241	18	670	4	1159
2019	86	24	130	243	14	605	3	1105
2018	65	14	96	175	11	530	1	892
2017	82	11	120	217	7	529	2	968
2016	77	11	110	187	20	473	2	880

Is Selling Organs Acceptable? (器官可以買賣嗎?)

- ▶ There is a place you can sell organs legally! Not China!
- ▶ The Guardian posted a touching album of postings on streets around hospitals offering...

(全世界有一個地方可以合法買賣器官，不是中國喔!!)

- ▶ At Iran!! (伊朗)

▶ Kidneys for sale:

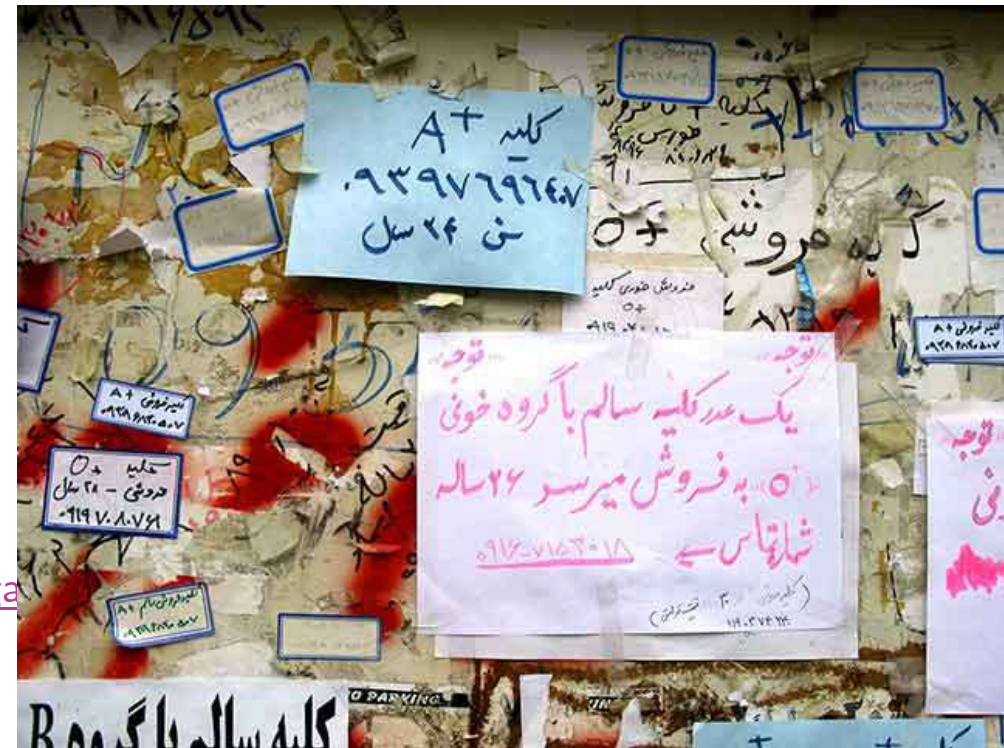
▶ Iran's trade in organs



www.theguardian.com/society/2015/may/10/kidneys-for-sale-organ

Kidney trade in Iran

▶ Wikipedia: en.wikipedia.org/wiki/Kidney_trade_in_Iran



Even If Selling Organs is Not Acceptable

- ▶ Should we ban **all organ exchanges**
 - ▶ including those without monetary transfers?
 - ▶ (即使不能接受器官買賣，難道沒有金錢交易的器官交換也必須禁止嗎?)
- ▶ I want to donate to my wife, but can't
- ▶ You want to donate to your family, but can't either!
 - ▶ 假如我想捐腎給家人、但血型不合，你也一樣想捐，但...
- ▶ Can I donate to your wife **in exchange** for you donating to my wife?
 - ▶ 那可以我捐給你家人、「交換」你捐給我家人嗎？

Even If Selling Organs is Not Allowed...

▶ **Kidney SWAP** (配對交換捐贈)

Paired Donor Exchange Transplantation

- ▶ When a donor and a recipient cannot match (blood type...),
- ▶ they can **exchange** with another pair (of similar problems)

- ▶ 捐贈者和受贈者(血型)不合時可跟有類似問題但正好配合的另一對交換

▶ What about 3-way-exchange?

- ▶ 那「三方捐贈」可以嗎?



Source: UCLA Kidney Exchange Program

SWAPs Allowed? Why Not Chain Reaction?

- ▶ Chain Transplantation/Kidney Chain: (連鎖捐贈)
- ▶ Altruistic donor gives to a recipient, whose relative donates to a 2nd recipient, etc. (如果配對交換捐贈可行，那「連鎖反應」呢？某無私捐贈者捐腎，(無法直接捐贈的)受贈者親屬捐腎給第二位病患，第二位受贈者親屬再繼續捐...)



真正的「肝肝相連到天邊」在加州! (2012/2/18 紐約時報)

- ▶ 60 Lives, 30 Kidneys, All Linked (2012/2/18 NYTimes)

From Start to Finish a donation by a **Good Samaritan, Rick Ruzzamenti,...**

Set in motion a 60-person chain of transplants that ended with a kidney for **Donald C. Terry Jr.**



Design Agent-to-Item Matching Markets

設計「人/物配對市場」

Joseph Tao-yi Wang (王道一)
(坂井豐貴 《如何設計市場機制》 Ch.1)



Agent-Item Matching (設計「人/物配對市場」的例子)

- ▶ 4 dorm rooms assigned to 4 students: (某棟宿舍四個房間、住四位學生)
 - ▶ Room 1 to student 1 (住房間1的學生1) with $4 > 3 > 2 > 1$
 - ▶ Room 2 to student 2 (住房間2的學生1) with $3 > 4 > 2 > 1$
 - ▶ Room 3 to student 3 (住房間3的學生3) with $2 > 4 > 1 > 3$
 - ▶ Room 4 to student 4 (住房間4的學生4) with $3 > 2 > 1 > 4$
 - ▶ Everyone needs only 1 item; cannot buy/sell
 - ▶ Dorm Rooms, Office Space, Kidney (or other organs), etc.
- ▶ What **Properties** do we wish to see? (我們希望結果符合哪些條件?)

Desirable Properties of Market Design (市場設計希望符合哪些條件?)

▶ Dormitory Exchange usually requires:

▶ 通常生自會設計的換宿制度，需要滿足：

1. Non-Repugnance (不起反感、不涉及金錢交易)

2. Individual Rationality (沒有人換到比目前更糟的房間)

3. Pareto Efficiency = No **Pareto Improvement**

▶ Some strictly better-off and nobody worse-off

▶ Pareto效率:沒有另一個分配可以得到**Pareto改善**(=「在不傷害別人的情況下，讓某些人更好」)

▶ Anything else? (還有嗎?)

▶ Shapley and Scarf (1974), "On Cores and Indivisibility," *Journal Mathematical Economics*, 1, 23-37.

Individual Rationality (個體自願參與)

- ▶ 4 dorm rooms assigned to 4 students: (某棟宿舍四個房間、住四位學生)
 - ▶ Room 1 to student 1 (住房間1的學生1) with $4 > 3 > 2 > \boxed{1}$
 - ▶ Room 2 to student 2 (住房間2的學生2) with $3 > 4 > \boxed{2} > 1$
 - ▶ Room 3 to student 3 (住房間3的學生3) with $2 > 4 > 1 > \boxed{3}$
 - ▶ Room 4 to student 4 (住房間4的學生4) with $3 > 2 > 1 > \boxed{4}$
- ▶ How can you get everyone on board?
 - ▶ Nobody worse-off! (如何設計才能讓個體自願參與呢?只要沒有人換到更糟的房間即可!)
- ▶ Just don't give Room 1 to Student 2!
 - ▶ 不要強迫分配「房間1」給「學生2」就行了! 其他學生本來就都在最不喜歡的房間、不會更糟了!

Pareto Efficiency (如何設計能讓結果更有效率呢?)

- ▶ 4 dorm rooms assigned to 4 students: (某棟宿舍四個房間、住四位學生)
 - ▶ Room 1 to student 1 (住房間1的學生1) with $4 > \boxed{3} > 2 > 1$
 - ▶ Room 2 to student 2 (住房間2的學生2) with $3 > \boxed{4} > 2 > 1$
 - ▶ Room 3 to student 3 (住房間3的學生3) with $2 > 4 > \boxed{1} > 3$
 - ▶ Room 4 to student 4 (住房間4的學生4) with $3 > \boxed{2} > 1 > 4$
- 1. Room 3412 to Student 1234 (**Better!**) (房間3412給學生1234比原來好)
 - ▶ Pareto Efficient? Any Pareto Improvement? (但有達成Pareto效率嗎?)
 - ▶ What if assign Student 12 to Room 43?
 - ▶ 有其他分配是更好的Pareto改善嗎? 如果給學生12房間43(而非房間34)呢?

Pareto Efficiency (如何設計能讓結果更有效率呢?)

- ▶ 4 dorm rooms assigned to 4 students: (某棟宿舍四個房間、住四位學生)
 - ▶ Room 1 to student 1 (住房間1的學生1) with $\boxed{4} > \underline{3} > 2 > 1$
 - ▶ Room 2 to student 2 (住房間2的學生2) with $\boxed{3} > \underline{4} > 2 > 1$
 - ▶ Room 3 to student 3 (住房間3的學生3) with $2 > 4 > \boxed{1} > 3$
 - ▶ Room 4 to student 4 (住房間4的學生4) with $3 > \boxed{2} > 1 > 4$
- 1. Room 3412 to Student 1234 (Better!) (分配1: 加底線)
- 2. Room **4312** to Student 1234 (Red) (分配2: 標紅色)
 - ▶ Better than Allocation 1! (房間4312給學生1234比分配1好!)
 - ▶ No Pareto Improvement, so this is Efficient! (已無Pareto改善/最有效率)

Pareto Efficiency (如何設計能讓結果更有效率呢?)

▶ 4 dorm rooms assigned to 4 students: (某棟宿舍四個房間、住四位學生)

▶ Room 1 to student 1 (住房間1的學生1) with $\boxed{4} > 3 > 2 > 1$

▶ Room 2 to student 2 (住房間2的學生2) with $\boxed{3} > 4 > 2 > 1$

▶ Room 3 to student 3 (住房間3的學生3) with $\boxed{2} > 4 > \underline{1} > 3$

▶ Room 4 to student 4 (住房間4的學生4) with $3 > \underline{2} > \boxed{1} > 4$

2. Room **4312** to Student 1234 (**Red**) is PE

▶ What if another allocation is also efficient? (如果有兩種以上分配都符合 Pareto效率怎麼辦?)

3. Room **4321** to Student 1234 (**also PE**)

▶ 分配房間**4321**給學生1234也符合Pareto效率呀! 那要選哪一個?

Will it be Blocked? (看它會不會被小圈圈阻擋?!)

- ▶ 4 dorm rooms assigned to 4 students:

- ▶ Room 1 to student 1 (住房間1的學生1) with $\boxed{4} > 3 > 2 > 1$

- ▶ Room 2 to student 2 (住房間2的學生2) with $\boxed{3} > 4 > 2 > 1$

- ▶ Room 3 to student 3 (住房間3的學生3) with $\boxed{2} > 4 > \boxed{1} > 3$

- ▶ Room 4 to student 4 (住房間4的學生4) with $3 > \boxed{2} > 1 > 4$

2. Room 4312 to Student 1234 (Red) (分配2: 標紅色)

- ▶ Student 2 and 3 will block Allocation 2:

- ▶ Switching themselves is Pareto Improvement!

- ▶ 學生2和3私下交易會阻擋分配2因為他們互換是Pareto改善($32 > 31$)

Cannot Block Strong Core (強力核可就不會被阻擋!)

▶ 4 dorm rooms assigned to 4 students:

▶ Room 1 to student 1 (住房間1的學生1) with $\boxed{4} > 3 > 2 > 1$

▶ Room 2 to student 2 (住房間2的學生2) with $\boxed{3} > 4 > 2 > 1$

▶ Room 3 to student 3 (住房間3的學生3) with $\boxed{2} > 4 > \boxed{1} > 3$

▶ Room 4 to student 4 (住房間4的學生4) with $3 > \boxed{2} > \boxed{1} > 4$

2. Room 4312 to Student 1234 (Red) (分配2: 標紅色)

▶ Coalition 23 will block Allocation 2 (小圈圈23會阻擋分配2)

▶ Allocation 3 = Strong Core (Can't block)

▶ 分配#3則是「強力核可」不會被擋!! 強力核可(=強力+核/殼!), 有人稱為「強核心」

Desirable Properties of Market Design (市場設計希望符合哪些條件?)

▶ **Non-Repugnance** (市場設計結果希望符合哪些條件? 至少要不起反感、不涉及金錢交易)

1. Individual Rationality (IR) (個體自願參與)

▶ **Youself cannot block** (自己一組不會更好、所以無法阻擋該分配)

2. Pareto Efficiency (PE) (效率)

▶ **Whole cannot block** (所有人一組不會更好、所以無法阻擋該分配)

▶ **Strong Core (SC)**

▶ **No coalition can block** (任何小圈圈都不會更好、所以無法阻擋該分配)

▶ **Satisfies IR+PE automatically** (有強力核可其實就會自動滿足前兩個條件, 因為 IR=「個體自願參與」=「自己當小圈圈」, PE=「Pareto效率」=「所有人圍一大圈」)

Desirable Properties of Market Design (市場設計希望符合哪些條件?)

- ▶ No coalition can block **Strong Core!**
- ▶ It's IR and: (任何小圈圈都無法阻擋強力核可，而且會自願參與)
- ▶ **Strong Core Exists** (強力核可的分配存在)
 - ▶ Shapley and Scarf (1974), "On Cores and Indivisibility," *Journal Mathematical Economics*, 1, 23-37.
- ▶ **Strong Core is Unique** (強力核可的分配**唯一**)
 - ▶ Roth and Postlewaite (1977), "Weak Versus Strong Domination in a Market With Indivisible Goods," *Journal Mathematical Economics*, 4, 131-137.
- ▶ How can we find it? (這麼好的分配要怎麼找出來?)

Form Groups of 4-5 to Discuss! (請4-5人分成一組討論)

7 Dorm Rooms Assigned To 7 Students (7個房間、住7位學生)

- ▶ Rm 1 to student 1: $5 > 6 > 7 > 1 > 2 > 3 > 4$ (住房間1的學生1)
- ▶ Rm 2 to student 2: $3 > 4 > 5 > 6 > 7 > 1 > 2$ (住房間2的學生2)
- ▶ Rm 3 to student 3: $4 > 5 > 2 > 7 > 1 > 3 > 6$ (住房間3的學生3)
- ▶ Rm 4 to student 4: $1 > 2 > 3 > 4 > 5 > 6 > 7$ (住房間4的學生4)
- ▶ Rm 5 to student 5: $4 > 5 > 2 > 3 > 6 > 7 > 1$ (住房間5的學生5)
- ▶ Rm 6 to student 6: $7 > 1 > 2 > 3 > 4 > 5 > 6$ (住房間6的學生6)
- ▶ Rm 7 to student 7: $1 > 7 > 4 > 5 > 6 > 3 > 2$ (住房間7的學生7)
- ▶ Find Strong Core! (請從 $7!=5040$ 種分配、 $2^7=128$ 種小圈圈找出強力核可的分配!)
- ▶ From $7!=5040$ allocations and $2^7=128$ coalitions (7個學生換宿舍)

Is Assigning Top-2 Choices Strong Core? (都上前兩志願是強力核可嗎?)

- ▶ Rm 1 to student 1: 5 > **6** > 7 > 1 > 2 > 3 > 4 (住房間1的學生1)
- ▶ Rm 2 to student 2: **3** > 4 > 5 > 6 > 7 > 1 > 2 (住房間2的學生2)
- ▶ Rm 3 to student 3: **4** > **5** > 2 > 7 > 1 > 3 > 6 (住房間3的學生3)
- ▶ Rm 4 to student 4: 1 > **2** > 3 > 4 > 5 > 6 > 7 (住房間4的學生4)
- ▶ Rm 5 to student 5: **4** > **5** > 2 > 3 > 6 > 7 > 1 (住房間5的學生5)
- ▶ Rm 6 to student 6: **7** > 1 > 2 > 3 > 4 > 5 > 6 (住房間6的學生6)
- ▶ Rm 7 to student 7: **1** > 7 > 4 > 5 > 6 > 3 > 2 (住房間7的學生7)
- ▶ Top-2: Room 6352471 to Student 1-7 (分配房間6352471給學生1-7)
 - ▶ Or switch 54 to 45! Strong Core? (或把54換成45也能讓大家都上前二志願!
但這是強力核可嗎?有小圈圈可以阻擋嗎?)

Assigning Top-2 Choices **Not** Strong Core (都上前兩志願非強力核可)

- ▶ Rm 1 to student 1: $\boxed{5} > \boxed{6} > 7 > 1 > 2 > 3 > 4$ (住房間1的學生1)
- ▶ Rm 2 to student 2: $\boxed{3} > 4 > 5 > 6 > 7 > 1 > 2$ (住房間2的學生2)
- ▶ Rm 3 to student 3: $4 > \boxed{5} > 2 > 7 > 1 > 3 > 6$ (住房間3的學生3)
- ▶ Rm 4 to student 4: $\boxed{1} > \boxed{2} > 3 > 4 > 5 > 6 > 7$ (住房間4的學生4)
- ▶ Rm 5 to student 5: $\boxed{4} > 5 > 2 > 3 > 6 > 7 > 1$ (住房間5的學生5)
- ▶ Rm 6 to student 6: $\boxed{7} > 1 > 2 > 3 > 4 > 5 > 6$ (住房間6的學生6)
- ▶ Rm 7 to student 7: $\boxed{1} > 7 > 4 > 5 > 6 > 3 > 2$ (住房間7的學生7)
- ▶ Top-2: Room 6352471 to Student 1-7 (分配房間6352471給學生1-7)
- ▶ Coalition 145 can block (since all get their favorite!)
(小圈圈145可以阻擋: 他們可都換到第一志願, 產生Pareto改善, 讓學生14更好、學生5沒差)

How to Find Strong Core Allocation? (如何找強力核可的分配?)

- ▶ Room 1 to Student 1: 5 > 6 > 7 > 1 > 2 > 3 > 4 (住房間1的學生1)
- ▶ Room 2 to Student 2: 3 > 4 > 5 > 6 > 7 > 1 > 2 (住房間2的學生2)
- ▶ Room 3 to Student 3: 4 > 5 > 2 > 7 > 1 > 3 > 6 (住房間3的學生3)
- ▶ Room 4 to Student 4: 1 > 2 > 3 > 4 > 5 > 6 > 7 (住房間4的學生4)
- ▶ Room 5 to Student 5: 4 > 5 > 2 > 3 > 6 > 7 > 1 (住房間5的學生5)
- ▶ Room 6 to Student 6: 7 > 1 > 2 > 3 > 4 > 5 > 6 (住房間6的學生6)
- ▶ Room 7 to Student 7: 1 > 7 > 4 > 5 > 6 > 3 > 2 (住房間7的學生7)
- ▶ Top Trading Cycles (用小圈圈優先交換演算法找強力核可)
 - ▶ All point to 1st choice, and bump others out (所有人都指向自己第一志願 把別人擠出去、讓他去擠下一個人出來)
 - ▶ Form Trading Cycle: [1 → 5 → 4 → 1] (形成小圈圈)

How to Find Strong Core Allocation? (如何找強力核可的分配?)

- ▶ Room 2 to Student $2: \boxed{3} > 6 > 7 > 2$ (住房間2的學生2)
- ▶ Room 3 to Student $3: \boxed{2} > 7 > 3 > 6$ (住房間3的學生3)
- ▶ Room 6 to Student 6: $\boxed{7} > 2 > 3 > 6$ (住房間6的學生6)
- ▶ Room 7 to Student $7: \boxed{7} > 6 > 3 > 2$ (住房間7的學生7)
- ▶ Top Trading Cycles Algorithm (小圈圈優先交換演算法)
 - ▶ Cycle $[1 \rightarrow 5 \rightarrow 4 \rightarrow 1]$ trade 1st (第一圈 $[1 \rightarrow 5 \rightarrow 4 \rightarrow 1]$ 就優先交換)
 - ▶ All point to remaining 1st (其餘人都各自指向剩下的房間中自己的第一志願)
 - ▶ Find Trading Cycle $[2 \rightarrow 3 \rightarrow 2]$ and Self Cycle $[7 \rightarrow 7]$
(發現兩人小圈圈, 還有自我小圈圈)
 - ▶ Hence, $[2 \rightarrow 3 \rightarrow 2]$ and $[7 \rightarrow 7]$ trade 2nd (這些小圈圈也先交換)

How to Find Strong Core Allocation? (如何找強力核可的分配?)

- ▶ Room 6 to Student 6: 6 (住房間6的學生6)
- ▶ Top Trading Cycles Algorithm (小圈圈優先交換)
 - ▶ Cycle $[1 \rightarrow 5 \rightarrow 4 \rightarrow 1]$ trade 1st (第一圈先交換)
 - ▶ $[2 \rightarrow 3 \rightarrow 2]$ and $[7 \rightarrow 7]$ trade 2nd (這些也先交換)
 - ▶ All point to remaining 1st (其餘人繼續指剩下房間中自己的第一志願)
 - ▶ Only Self Cycle $[6 \rightarrow 6]$ left (這時只剩下住在房間6的學生6、自己跟自己交換)
- ▶ Algorithm ends if all allocated (所有人都分配完，演算法就終止)
 - ▶ In general, TTC ends in finite time (可證明TTC演算法會在有限時間終止)
 - ▶ Finds the **unique Strong Core** allocation (且找到**唯一**的**強力核可**的分配)

TTC Algorithm Finds Strong Core! (小圈圈優先演算法找到強力核可)

- ▶ Room 1 to Student 1: $\boxed{5} > 6 > 7 > 1 > 2 > 3 > 4$ (住房間1的學生1)
 - ▶ Room 2 to Student 2: $\boxed{3} > 4 > 5 > 6 > 7 > 1 > 2$ (住房間2的學生2)
 - ▶ Room 3 to Student 3: $4 > 5 > \boxed{2} > 7 > 1 > 3 > 6$ (住房間3的學生3)
 - ▶ Room 4 to Student 4: $\boxed{1} > 2 > 3 > 4 > 5 > 6 > 7$ (住房間4的學生4)
 - ▶ Room 5 to Student 5: $\boxed{4} > 5 > 2 > 3 > 6 > 7 > 1$ (住房間5的學生5)
 - ▶ Room 6 to Student 6: $7 > 1 > 2 > 3 > 4 > 5 > \boxed{6}$ (住房間6的學生6)
 - ▶ Room 7 to Student 7: $1 > \boxed{7} > 4 > 5 > 6 > 3 > 2$ (住房間7的學生7)
- ▶ **Strong Core:** Assign Room **5321467** to student 1-7 (強力核可)
1. $[1 \rightarrow 5 \rightarrow 4 \rightarrow 1]$ trade 1st (小圈圈 $[1 \rightarrow 5 \rightarrow 4 \rightarrow 1]$ 優先交換) 的分配是把房間 5321467 給學生1-7)
 2. $[2 \rightarrow 3 \rightarrow 2], [7 \rightarrow 7]$ trade 2nd / $[6 \rightarrow 6]$ last (這些再交換)

Form Groups of 4-5 to Discuss! (請4-5人分成一組討論)

Find Strong Core in 6-on-6 Market! (找找看6對6強力核可的分配)

- ▶ Room 1 to Student 1: 3 > 6 > 1 > 2 > 4 > 5 (住房間1的學生1)
- ▶ Room 2 to Student 2: 1 > 6 > 2 > 3 > 4 > 5 (住房間2的學生2)
- ▶ Room 3 to Student 3: 2 > 6 > 5 > 1 > 3 > 4 (住房間3的學生3)
- ▶ Room 4 to Student 4: 3 > 1 > 6 > 2 > 5 > 4 (住房間4的學生4)
- ▶ Room 5 to Student 5: 4 > 1 > 2 > 6 > 3 > 5 (住房間5的學生5)
- ▶ Room 6 to Student 6: 4 > 1 > 2 > 3 > 5 > 6 (住房間6的學生6)
- ▶ Top Trading Cycles (小圈圈優先交換演算法)
 - ▶ All point to 1st choice (所有人都指向自己的第一志願)
 - ▶ Find Trading Cycle [1 → 3 → 2 → 1] (發現小圈圈[1 → 3 → 2 → 1])
 - ▶ Cycle [1 → 3 → 2 → 1] trade 1st (這一圈就先交換)

Find Strong Core in 6-on-6 Market! (找找看6對6強力核可的分配)

- ▶ Room 4 to Student 4: 6 > 5 > 4 (住房間4的學生4)
- ▶ Room 5 to Student 5: 4 > 6 > 5 (住房間5的學生5)
- ▶ Room 6 to Student 6: 4 > 5 > 6 (住房間6的學生6)
- ▶ Top Trading Cycles (小圈圈優先交換演算法)
 - ▶ Cycle [1 → 3 → 2 → 1] trade 1st (第一圈先交換)
 - ▶ All point to remaining 1st (其餘人都指向剩下的房間中自己的第一志願)
 - ▶ Find Trading Cycle [4 → 6 → 4] trade 2nd (發現兩人小圈圈也先交換)
 - ▶ All point to remaining 1st (其餘人繼續指剩下的房間中自己的第一志願)
 - ▶ Only Self Cycle [5 → 5] left (這時候只剩下住房間5的學生5、自己跟自己交換)

Find Strong Core in 6-on-6 Market! (找找看6對6強力核可的分配)

- ▶ Room 1 to Student 1: $\boxed{3} > 6 > 1 > 2 > 4 > 5$ (住房間1的學生1)
- ▶ Room 2 to Student 2: $\boxed{1} > 6 > 2 > 3 > 4 > 5$ (住房間2的學生2)
- ▶ Room 3 to Student 3: $\boxed{2} > 6 > 5 > 1 > 3 > 4$ (住房間3的學生3)
- ▶ Room 4 to Student 4: $3 > 1 > \boxed{6} > 2 > 5 > 4$ (住房間4的學生4)
- ▶ Room 5 to Student 5: $4 > 1 > 2 > 6 > 3 > \boxed{5}$ (住房間5的學生5)
- ▶ Room 6 to Student 6: $\boxed{4} > 1 > 2 > 3 > 5 > 6$ (住房間6的學生6)
- ▶ TTC assigns Room **312654** to Student 1-6
 - ▶ 小圈圈優先演算法把房間**312654**給學生1-6
 - 1. $[1 \rightarrow 3 \rightarrow 2 \rightarrow 1]$ trade 1st (小圈圈 $[1 \rightarrow 3 \rightarrow 2]$ 優先交換)
 - 2. $[4 \rightarrow 6 \rightarrow 4]$ trade 2nd / $[5 \rightarrow 5]$ last (小圈圈 $[4 \rightarrow 6]$ 也優先交換/5跟自己換)

Why is Strong Core Rule Better? (強力核可制度有甚麼優點?)

- ▶ TTC is a **Strong Core Rule** (TTC是強力核可制度)
 - ▶ It cannot be blocked and is: (除了不會被小圈圈阻擋還是)
- ▶ **Strategy-Proof (SP)** (對策免疫，因為謊報偏好只會更糟!)
 - ▶ Honesty is the Best Policy (Lying is worse!)
- ▶ Can you see TTC is **strategy-proof**? (看出來嗎?)
- ▶ If not, we may need to remind subjects

"This rule is strategy-proof, so it is best for you to report truthfully!"
(需要提醒: 本規則對策免疫，所以誠實為上策!!)
- ▶ Other rules **strategy-proof**? (還有哪些規則也滿足對策免疫?)

Only Strong Core Rule Satisfies All Three: (只有強力核可制度符合)

1. **Strategy-Proof (SP)** (對策免疫，因為謊報偏好只會更糟!)
 - ▶ Honesty is the Best Policy (lying is worse!)
2. **Individual Rationality (IR)** (個體自願參與)
 - ▶ **Youself cannot block** (自己一組不會更好、無法阻擋該分配)
3. **Pareto Efficiency (PE)** (效率)
 - ▶ **Whole cannot block** (所有人一組不會更好、無法阻擋該分配)
- ▶ **Non-TTC Rules Can Only Satisfy 2 out of 3!**
 - ▶ 馬金朋證明只有強力核可制度TTC同時符合三個條件，其他只能三選二!
 - ▶ Jinpeng Ma (1994), "Strategy-proofness and the strict core in a market with indivisibilities," *International Journal of Game Theory*, 23(1), 75-83.

Room 5-7 Vacated for New Student 5-7 (畢業空出房間給新生)

- ▶ Room 1 to Student 1: $5 > 6 > 7 > 1 > 2 > 3 > 4$ (住房間1的學生1)
- ▶ Room 2 to Student 2: $3 > 4 > 5 > 6 > 7 > 1 > 2$ (住房間2的學生2)
- ▶ Room 3 to Student 3: $4 > 5 > 2 > 7 > 1 > 3 > 6$ (住房間3的學生3)
- ▶ Room 4 to Student 4: $1 > 2 > 3 > 4 > 5 > 6 > 7$ (住房間4的學生4)
- ▶ Room 5 empty/New5: $4 > 5 > 2 > 3 > 6 > 7 > 1$ (房間5空給新生5)
- ▶ Room 6 empty/New6: $7 > 1 > 2 > 3 > 4 > 5 > 6$ (房間6空給新生6)
- ▶ Room 7 empty/New7: $1 > 7 > 4 > 5 > 6 > 3 > 2$ (房間7空給新生7)
- ▶ New Student 567 not assigned (新生567還沒分配到房間，不能直接用TTC)
- ▶ Can randomly assign New Student 5-7 to Room 5-7
- ▶ Then use TTC (可隨機分配空房間5-7給新生5-7，再跟舊生一起用TTC演算法分配)

If Only Assign Priority to New Students (只給新生優先排序呢?)

- ▶ Room 1 to Student 1: $5 > 6 > 7 > 1 > 2 > 3 > 4$ (住房間1的學生1)
- ▶ Room 2 to Student 2: $3 > 4 > 5 > 6 > 7 > 1 > 2$ (住房間2的學生2)
- ▶ Room 3 to Student 3: $4 > 5 > 2 > 7 > 1 > 3 > 6$ (住房間3的學生3)
- ▶ Room 4 to Student 4: $1 > 2 > 3 > 4 > 5 > 6 > 7$ (住房間4的學生4)
- ▶ Room 5 empty/New5: $4 > 5 > 2 > 3 > 6 > 7 > 1$ (房間5空給新生5)
- ▶ Room 6 empty/New6: $7 > 1 > 2 > 3 > 4 > 5 > 6$ (房間6空給新生6)
- ▶ Room 7 empty/New7: $1 > 7 > 4 > 5 > 6 > 3 > 2$ (房間7空給新生7)
- ▶ Assign 1st to tenant, then by priority (房間優先給現住戶，不然就給最優先的人)
 - ▶ Priority 1-3 to New Student 5-7 (新生5-7排序為1-3)
 - ▶ Priority 4-7 for Student 1-4 (舊生1-4排序為4-7)

(小圈圈與連鎖反應優先交換)

Top Trading Cycles and Chains (TTCC)

1 ← Room 1 to Student 1: 5 > 6 > 7 > 1 > 2 > 3 > 4 (住房間1的學生1)

2 ← Room 2 to Student 2: 3 > 4 > 5 > 6 > 7 > 1 > 2 (住房間2的學生2)

3 ← Room 3 to Student 3: 4 > 5 > 2 > 7 > 1 > 3 > 6 (住房間3的學生3)

4 ← Room 4 to Student 4: 1 > 2 > 3 > 4 > 5 > 6 > 7 (住房間4的學生4)

5 ← Room 5 empty/New 5: 4 > 5 > 2 > 3 > 6 > 7 > 1 (房間5空給新生5)

5 ← Room 6 empty/New 6: 7 > 1 > 2 > 3 > 4 > 5 > 6 (房間6空給新生6)

5 ← Room 7 empty/New 7: 1 > 7 > 4 > 5 > 6 > 3 > 2 (房間7空給新生7)

► Student point to 1st; Room to priority (學生指向自己的第一志願, 房間指向最優先)

► Tenant/Top Priority (Student 5) (現住戶/排序第一新生5)

► Find Cycle [1 → 5 → 5 → 4 → 4 → 1 → 1] (發現小圈圈)

(小圈圈與連鎖反應優先交換)

Top Trading Cycles and Chains (TTCC)

2 ← Room 2 to Student 2: 3 > 6 > 7 > 2 (住房間2的學生2)
3 ← Room 3 to Student 3: 2 > 7 > 3 > 6 (住房間3的學生3)
6 ← Room 6 empty/New 6: 7 > 2 > 3 > 6 (房間6空給新生6)
6 ← Room 7 empty/New 7: 7 > 6 > 3 > 2 (房間7空給新76)

- ▶ Top Trading Cycles and Chains (小圈圈與連鎖反應優先交換演算法)
 - ▶ $[1 \rightarrow 5 \rightarrow 5 \rightarrow 4 \rightarrow 4 \rightarrow 1 \rightarrow 1]$ trade 1st (第一圈優先交換)
 - ▶ Students point to remaining 1st (剩下學生指向剩下房間中的第一志願)
 - ▶ Rooms point to remaining priority (剩下房間指向剩下學生中的第一優先)
 - ▶ Cycle $[2 \rightarrow 3 \rightarrow 3 \rightarrow 2 \rightarrow 2]$ & $[6 \rightarrow 7 \rightarrow 6]$ (發現兩個小圈圈)
 - ▶ Only New Student 7/Room 6 left $[7 \rightarrow 6 \rightarrow 7]$ (只剩學生7和房間6)

(小圈圈與連鎖反應優先交換)

Top Trading Cycles and Chains (TTCC)

- ▶ Room 1 to Student 1: $\boxed{5} > 6 > 7 > 1 > 2 > 3 > 4$ (住房間1的學生1)
- ▶ Room 2 to Student 2: $\boxed{3} > 4 > 5 > 6 > 7 > 1 > 2$ (住房間2的學生2)
- ▶ Room 3 to Student 3: $4 > 5 > \boxed{2} > 7 > 1 > 3 > 6$ (住房間3的學生3)
- ▶ Room 4 to Student 4: $\boxed{1} > 2 > 3 > 4 > 5 > 6 > 7$ (住房間4的學生4)
- ▶ Room 5 empty/New5: $\boxed{4} > 5 > 2 > 3 > 6 > 7 > 1$ (房間5空給新生5)
- ▶ Room 6 empty/New6: $\boxed{7} > 1 > 2 > 3 > 4 > 5 > 6$ (房間6空給新生6)
- ▶ Room 7 empty/New7: $1 > 7 > 4 > 5 > \boxed{6} > 3 > 2$ (房間7空給新生7)
- ▶ TTCC assigns Rm **5321476** to Stud. 1-7 (房間5321476給學生1-7)
 - ▶ $[1 \rightarrow 5 \rightarrow 5 \rightarrow 4 \rightarrow 4 \rightarrow 1 \rightarrow 1]$ trade 1st (小圈圈/連鎖反應優先交換)
 - ▶ $[2 \rightarrow 3 \rightarrow 3 \rightarrow 2 \rightarrow 2], [6 \rightarrow 7 \rightarrow 6], [7 \rightarrow 6 \rightarrow 7]$ (其他再交換)

Roth Designs Kidney Exchange with TTCC

- ▶ Student 1 in Room 1 $\rightarrow$ Patient 1 with Donor 1,
- ▶ ... (住房間 i 的學生 $i \rightarrow$ 有親友願意捐腎 i 的病患 i)
- ▶ Student n in Room $n \rightarrow$ Patient n with Donor n ,
- ▶ Empty Room ($n+1$) $\rightarrow$ Deceased Donor
- ▶ $N(n+1) \rightarrow$ waitlist Patient ($n+1$) without Donor
 - ▶ 空房間($n+1$) $\rightarrow$ 屍腎 / 新生($n+1$) $\rightarrow$ 等候名單上(無捐腎親友)病患($n+1$)
- ▶ Since Deceased Donors are rare, empty rooms waitlisted (由於屍腎太少，空房間只是等候名單)
 - ▶ Adjusts real-time as deceased donors appear 1-by-1 (實務上屍腎是一個個臨時出現的，演算法必須即時調整)

(如果臨時多了(只有學生4最喜歡的)空房間0呢?)

What If Room 0 Pops Up (Only Student 4 Likes It)

- ▶ Room 1 to Student 1: $\boxed{5} > 6 > 7 > 1 > 2 > 3 > 4 > 0$ (住房間1的學生1)
- ▶ Room 2 to Student 2: $\boxed{3} > 4 > 5 > 6 > 7 > 1 > 2 > 0$ (住房間2的學生2)
- ▶ Room 3 to Student 3: $4 > 5 > \boxed{2} > 7 > 1 > 3 > 6 > 0$ (住房間3的學生3)
- ▶ Room 4 to Student 4: $\boxed{0} > \boxed{1} > 2 > 3 > 4 > 5 > 6 > 7$ (住房間4的學生4)
- ▶ Room 5 empty/New5: $\boxed{4} > 5 > 2 > 3 > 6 > 7 > 1 > 0$ (房間5空給新生5)
- ▶ Room 6 empty/New6: $\boxed{7} > 1 > 2 > 3 > 4 > 5 > \boxed{6} > 0$ (房間6空給新生6)
- ▶ Room 7 empty/New7: $\boxed{1} > \boxed{7} > 4 > 5 > 6 > 3 > 2 > 0$ (房間7空給新生7)
- ▶ **Strong Core** was: Room 5321467 to Student 1-7
- ▶ But now has Pareto Improvement $[4 \rightarrow 0, 1 \rightarrow 7, 7 \rightarrow 1]$
(原本強力核可分配出現Pareto改善: 學生4換到空房間0/讓出房間1給學生7/讓出房間7給學生6)

Roth Designs Kidney Exchange with TTCC

- ▶ Kidney swap is a Pareto Improvement (交換捐贈是Pareto改善)
 - ▶ Nobody better-off even if kidney swap banned (禁止交換捐贈無人獲益)
- ▶ Kidney chains give priority to those who can continue the chain reaction (連鎖捐贈則把機會讓給能起連鎖反應的人，而非等候名單上的人)
 - ▶ Not Pareto Improvement (Waitlist deferred) (因此不是Pareto改善)
 - ▶ Unless Altruistic Donor donates **only if** chain reaction occurs
 - ▶ Or, if chain reaction ends at the first person on the waitlist
 - ▶ 除非無償捐贈者**只有**激起連鎖反應才願意捐，或連鎖反應的終點回到等候名單上的第一個人

活體腎移植 配對系統7月上線 (聯合報2018/1/29，記者修瑞瑩/台南報導)

- ▶ ...美國知名女藝人席琳娜因為紅斑性狼瘡病症損及腎臟，由閨蜜捐腎移植，重啓演藝事業，
- ▶ 財團法人器官捐贈移植登錄中心董事長、健保署長李伯璋表示，國內目前活體腎臟捐贈，為避免有買賣行為，只限於配偶及五親等家屬，沒辦法像美國連閨蜜也能捐贈，但線上配對，等於突破只有親人才能捐贈的限制。
- ▶ 李伯璋表示，器官捐贈中心繼推動器官捐贈者家人可優先獲得他人器官捐贈，再推動活體腎臟線上配對，相關計畫報衛福部審查後，7月上路。

活體腎移植 配對系統7月上線 (聯合報2018/1/29，記者修瑞瑩/台南報導)

- ▶ **線上配對**是指需要移植的患者與願意捐贈的親人，能與其他病患及親人一起配對，相互捐贈，
- ▶ 例如A、B、C3名患者都在等待換腎，親人也願意捐贈，與患者配對不合，經過線上配對後，可能A的親人捐腎給B，B的親人捐贈給C，C的親人再捐贈給A。
- ▶ 移植醫師表示，部分醫師認為新制效果有限，但以美國實施多年經驗來看，確實可提高配對成功機率。過去親人間如果配對不成，例如血型不合...能與其他患者親人配對成功，是另一條出路。

非親屬活體交換捐腎 新制上路 (中央社2019/2/14)

- ▶ ...衛福部公告新制，開放非親屬活體腎臟捐贈。有意捐腎的家屬若跟病人無法配對，可與其他擬換腎家庭交叉比對，「一腎換一腎」，今天上路。
- ▶ 依規定，活體捐贈器官限於5等親內親屬、配偶，但人體器官移植條例在民國104年修法時，特別對腎臟移植另有考量，「等待移植者在找到合適捐贈者時，得進行2組以上的器官互相配對、交換及捐贈，並做移植手術」。
- ▶ 衛生福利部醫事司公告活體腎臟交換捐贈移植手術管理辦法，明訂非親屬間器官互相配對、捐贈的程序，

非親屬活體交換捐腎 新制上路 (中央社2019/2/14)

- ▶ ...避免有倫理爭議或有非法買賣器官的疑慮，讓有意願捐腎家屬可跟其他家庭共同配對、交換，增加成功機會。
- ▶ 醫事司長石崇良受訪表示：有些病人的5等親內家屬願意捐腎，但都無法配對成功，過去只能放棄；但新制上路後，這些病人可在原醫院經過第一次醫院倫理委員會審查後，上器捐中心平台登錄、進行交叉配對。
- ▶ ...如果兩兩順利比對成功，還要再經移植開刀醫院倫理委員會確認及衛福部審查後，就可約定同日開刀時間，避免衍生反悔爭議。.....病人在手術前皆可書面撤回同意.....

非親屬活體交換捐腎 新制上路 (中央社2019/2/14)

- ▶ 器捐中心執行長江仰仁受訪表示：目前各大醫院共識是同時最多可進行4台刀，意即接受2對病人和家屬互捐...
- ▶ 新光醫院腎臟科主治醫師呂至剛受訪指出：如果民衆有意採「一腎換一腎」方式移植，...術前一定要妥善了解捐贈者的腎臟狀況，並了解術後風險，必須終身吃抗排斥藥物，且也可能發生機率較低的嚴重排斥狀況。
- ▶ 如果術後狀況不佳，「也不能怪別人」，移植的狀況很難事前預防，且自身必須努力控制慢性病、調整生活保養腎臟...

(2019-12-30聯合報/記者陳雨鑫、鄧桂芬、李樹人報導)

你家腎臟沒我家大：「一腎換一腎」卡在這個人性陰暗面

(2019-12-30聯合報/記者陳雨鑫、鄧桂芬、李樹人報導)

- ▶ 有些人結婚，講究門當戶對，但器官捐贈也需如此斤斤計較嗎？
- ▶ 衛福部今年二月發布「活體腎臟交換捐贈移植手術管理辦法」，開放非親屬家庭可相互交換捐贈腎臟，截至目前，僅三組家庭成功申請，但配對後卻因為血型不同而告吹。
- ▶ 新制上路十個多月非親屬活體捐腎案例掛零，台大腎臟移植名醫蔡孟昆一語道破，大部分病家自私、小心眼，總認為自家捐贈的腎臟較優，別人家的較差，怎可能「一腎換一腎」。

你家腎臟沒我家大：「一腎換一腎」卡在這個人性陰暗面

- ▶ 台灣每年約七千多病患等待腎臟移植，位居移植等候器官首位，但因器捐風氣不盛，大愛腎臟移植比率偏低，平均每100位等待腎臟移植的患者中，僅3人有機會等腎臟完成移植。
- ▶ 為此，衛福部於今年年初開放非親屬等待腎臟家庭可一腎換一腎，即使在親屬間未能配對成功，透過其他患者家庭交換機會，增加活體腎臟移植機率，無須赴國外冒險移植。只不過，新制上路後，迄今移植個案仍掛零，衛福部醫事司長石崇良坦言，推動「非親屬家庭一腎換一腎」，確實困難重重……

你家腎臟沒我家大：「一腎換一腎」卡在這個人性陰暗面

- ▶ 台大醫院外科主治醫師蔡孟昆則點出了窒礙難行的關鍵，
 - ▶ 原因有三，申請程序繁瑣、減敏治療效果佳，以及人心自私。
- 1. 首先，申請非親屬活體捐腎移植，須經過倫理委員會三次審查，光是第一關等候程序，就刷掉許多有意願的患者及家屬；
- 2. 醫療進步，親屬間即使血型不同，透過術前減敏治療，還是有機會換腎，不少患者不願意移植一顆陌生人的好腎，寧願花大錢，自費接受減敏治療。

你家腎臟沒我家大：「一腎換一腎」卡在這個人性陰暗面

3. 至於第三點則是人性自私，蔡孟昆說，即使雙方家屬配對成功，但許多病家卻斤斤計較，批評「你家腎臟比較小、功能相對差」，反觀我家腎臟較大顆、且捐贈者年紀較輕等，對於即將移植的腎臟並不滿意，
- ▶ 許多醫師擔心術後衍生糾紛，而不敢執行。
 - ▶ 對此，北榮一般外科教授級特約醫師龍藉泉也有同感，
 - ▶ 該措施在美國實施後，成效顯著，美國人對於有其他家庭成員願意捐腎，萬分感恩，感謝上帝恩寵，開心都來不及。但新制在台灣上路後，遠不如預期……

你家腎臟沒我家大：「一腎換一腎」卡在這個人性陰暗面

- ▶ ...臨床上看到太多台灣人自私的一面，常對著別人家的腎臟秤斤論兩，認為還是自家的好，擔心這樣交換，可能會吃虧。龍藉泉說，「想在台灣順暢推行一腎換一腎，還有一段很長的路要走。」.....
- ▶ 台大醫院兼任主治醫師李伯皇指出，十年前，國內曾討論全面開放非親屬腎臟移植，但擔心淪為器官買賣，一直不敢開放。
- ▶ 但目前器官移植已出現瓶頸，建議政府評估可行性與管控方式，原地踏步，無助於等候移植的患者。

你家腎臟沒我家大：「一腎換一腎」卡在這個人性陰暗面

- ▶ 另一個值得注意的是，器官移植趨勢是肝臟整體移植率逐年下降，
 - ▶ 根據器捐登錄中心統計去年至今本月中旬，去年肝臟大愛移植人數96人，今年則增至124人，但活體捐贈則從494人降至370人，整體移植數從590人降至494人。
- ▶ 陳肇隆表示，很可能是肝病型態的改變。
 - ▶ 他舉例，C肝新藥上市後，臨床證明有98%的病毒清除率，且有效改善肝功能，2017年納入健保後，讓需多原本需要換肝者不必換肝。

你家腎臟沒我家大：「一腎換一腎」卡在這個人性陰暗面

- ▶ 三軍總醫院外科部一般外科主任陳登偉也認為，應與健保給付C肝新藥有關。
- ▶ 陳登偉說，等候肝移植患者多是C肝或B肝患者，民國73年政府推動B肝疫苗接種，大幅降低B肝引起的肝病變，
- ▶ 近這兩年來，健保給付C肝新藥，今年更是全面健保給付，本來需要換肝的患者用藥之後，病情穩定，無需等候肝移植。
- ▶ 令人擔憂的是，台灣肥胖人口眾多，未來因脂肪性肝炎引起肝硬化的患者勢必愈來愈多，將成為肝臟移植的主要族群。

8488人等待腎臟器捐,“一腎換一腎”媒合掛零 (2023/8/20聯合新聞網)

- ▶ ...衛福部四年前，為拓展等候人數最多的「腎臟」來源，開放腎臟可採非親屬捐贈，兩個都在等待腎臟移植的家庭，可透過媒合「一腎換一腎」，**至今有六組登記，但媒合率掛零。**
- ▶ 專家批評，大愛捐贈(屍體捐贈)的來源都不足，更何況非親屬捐贈條件更加嚴苛，掛蛋是可預期結果，若不積極拓展器官來源，恐會有更多人赴陸移植。
- ▶ 國人器官捐贈意願受到疫情衝擊嚴重下滑，2019年器捐人數有375人，2020年來到歷史新高402人，

8488人等待腎臟器捐,“一腎換一腎”媒合掛零 (2023/8/20聯合新聞網)

- ▶ 隨後碰上本土疫情，器捐人數不斷下滑，今年到七月底為止，有233人捐出器官。
- ▶ 等待器官移植的人龍也因此攀升。據衛福部統計，2019年等待人數為9,985人，2020年突破一萬大關，來到10,080人，今年等待人數則達11,091人。
- ▶ 腎臟一直是器官等候最大宗，目前有8,488人正在等待腎臟。
- ▶ 四年前，衛福部開放腎臟的非親屬器官捐贈，為避免出現買賣疑慮，規定需與其他等待換腎家庭配對，等於是「一腎換一腎」，只是上路至今無任何成功配對的案例。

8488人等待腎臟器捐,“一腎換一腎”媒合掛零 (2023/8/20聯合新聞網)

- ▶ 器捐病主中心副執行長劉嘉琪說，制度上路至今有六組患者登錄配對，礙於「血型」最終沒有配對成功，且登錄配對若沒有每半年更新，檢驗資料將失效，須重新登錄，以致現在無任何等候名單。
- ▶ 林口長庚醫院器官移植中心副主任江仰仁說，實施非親屬腎臟交換，需要醫院及捐贈者、受贈者家庭「高度的信任」，
- ▶ 兩組家庭的器官捐贈，需四台刀，醫院得跨院合作，且這四台刀的任一病人都不能反悔，也增推動難度。

8488人等待腎臟器捐,“一腎換一腎”媒合掛零 (2023/8/20聯合新聞網)

- ▶ 「與其推動非親屬腎臟捐贈，不如想一想怎麼增加大愛捐贈的來源」，北醫大公共衛生學院講座教授李伯璋說，
- ▶ 大愛捐贈是器官移植最大宗來源，但一直卡在「死要全屍」的思維。
- ▶ 西班牙的「指定同意制」（默許制）大幅增加器官來源，
- ▶ 江仰仁表示，台灣可參考無默許制的美國，醫療團隊在病人腦死時與家屬說明器捐運作，若家屬無意願器捐，則安排撤呼吸器，否則不少在加護病房病人形同死亡，卻依舊使用呼吸器、點滴等維生設備。

8488人等待腎臟器捐,“一腎換一腎”媒合掛零 (2023/8/20聯合新聞網)

- ▶ 一位不願具名的移植界大老指出，高齡化社會等候器官的人數會愈來愈多，屆時患者為了求生，得自行想辦法，赴美、赴陸找移植器官，反而增加更多風險。
- ▶ 衛福部醫事司司長劉越萍指出，非親屬間的腎臟捐贈上路雖然尚無成功案例，但只能加強宣導，例如透過兒童繪本傳遞遺愛分享觀念等，期待社會觀念漸漸改變，強行推動只會帶來更多倫理問題。

Institution Design Anticipating Human Reaction

- ▶ 考慮「上有政策/下有對策」來設計制度 (這也是「成功改變的三個必要條件」)
- ▶ To Push for Reform, You Need: (要推動改革, 你需要)
 1. Understand **Logic of Current System** (How it Works)
 - ▶ 瞭解現況的邏輯: 知道為甚麼現在是這樣的光景
 2. **Wisdom from God** (on How to **Fine Tune** the System)
 - ▶ 有從上帝而來的智慧: 知道突破點在哪裡、知道如何微調現有制度讓大家更好
 3. **Convince Key Person** (to Make the Change)
 - ▶ 說服有能力改變的人來改變: 這是比較容易的, 因為前兩者根本是互斥的!
- ▶ Note: 1 & 2 are mutually exclusive!

Market Design @ Taiwan

市場設計：台灣國中會考

Joseph Tao-yi Wang (王道一)



志願難填 教團：學生陷賽局困境

(2014/6/9國語日報)國教行動聯盟昨天痛批，升學制度儼然變成**賭博式賽局**，學生想進理想學校，竟得**猜測別人的志願怎麼填**，陷入「**賽局理論**」困境。國教行動聯盟理事長王立昇表

- ▶ 示，志願序納入超額比序計分，填錯會被扣分，加上第一次免試分發後，基北區約有六千個學生可能放棄錄取考特招，所以**預測別人填哪些志願、會不會放棄一免**，成了填寫志願的重要因素。
- ▶ 「賽局理論」是**研究遊戲中個體預測對方和己方行為，所產生的影響，並分析最佳策略**。現在的十二年國教，已經讓學生面臨一樣的困擾。

填志願謀對謀 國教盟驚爆：學生想輕生 (2014/6/7蘋果日報)

國中會考成績上周四公布後，家長學生茫然不知如何選填志願。

國教行動聯盟今上午公開呼籲教育部，今年取消志願序計分或採3-7個志願為群組，差一個群組扣1分，以免學生陷入選填志願的**博弈賽局**中，填志願淪為**謀對謀**。



填志願謀對謀 國教盟驚爆：學生想輕生 (2014/6/7蘋果日報)

聯盟理事長王立昇表示，...教育部**應公布更多資訊**並**延長志願表繳交時間**，讓學生有更充足資訊能錄取最理想的學校。

他進一步表示，學生為了上好學校，同學間已**互相猜忌**，**打探彼此第一志願是什麼**做為自己選填志願的參考，**陷入博弈賽局**中，解決方法只有取消志願序計分，或擴大為群組計分，降低傷害。



制度變數多 教團憂入學如賽局 (2014/6/8中央社)

- ▶ (中央社記者許秩維) 國教行動聯盟今天說，國教入學制度變數多，恐陷**賽局理論**，孩子得**預測他人如何填志願**，聯盟籲取消志願序計分。
- ▶ 國教行動聯盟舉行記者會，憂心**國教入學制度陷入賽局理論的困境**，讓學生和家長寢食難安。
- ▶ 國教行動聯盟理事長王立昇表示，目前國教入學制度面臨幾個問題，如志願序計分，由於**不知別人如何填志願，要進入自己理想的學校就可能有很多變數**，導致陷入賽局理論的困境，學生家長難以填志願。

Taiwan High School Choice

- ▶ **History School Choice in Taiwan**
 - ▶ Old: Sequential Dictator using Exam Score
 - ▶ New System in 2014
- ▶ **Exam-exempt School Choice** based on:
 - ▶ # of ABC from **Joint Exam (會考)**
 - ▶ Self-reported School Choice Rankings
 - ▶ Chinese composition: Grade 1-6
 - ▶ A++, A+, A, A-, etc.
 - ▶ Other factors (that all get the same score)

Taiwan School Choice: a Simplified Model

- ▶ How can we analyze this?
 - ▶ Simplify to obtain a tractable model/example
- ▶ What are **key elements** of the situation?
- ▶ What are the **key results** to reproduce?
- ▶ **Next:** Run lab experiments to
 1. **Test** the model
 2. **Try alternative** institutions
 3. **Teach** parents/policy makers

Form Groups of 3 to Discuss and Report!

Taiwan School Choice: a Simplified Model

- ▶ 3 schools: A, B, C
- ▶ 3 students: 1 and 2 are type a , 3 is type c
 - ▶ Student Payoffs: $u(A) = h, u(B) = 1, u(C) = 0$
 - ▶ School Payoffs: $v(a) = 1, v(c) = 0$
- ▶ Actions: Self-report School Choice Rankings
$$S = \{ABC, BAC, ACB, CAB, CBA, BCA\}$$
- ▶ Assign 1st choice (tie-break: type then random)
 - ▶ Remaining students go to remaining schools

Form Groups of 3 to Discuss and Report!

Taiwan School Choice: a Simplified Model

- ▶ Would all students truthfully report ABC ?
 - ▶ If others truthfully report ABC , truthful reporting is not BR!
- ▶ What is this game's Nash Equilibrium?
 - ▶ Is the equilibrium outcome efficient?
- ▶ Does this model capture key elements of situation?
- ▶ Does the outcome reproduce key results of interest?
 - ▶ How can this example inspire you to design your experiment?

Taiwan School Choice: a Simplified Model

- ▶ Would all students truthfully report ABC ?
 - ▶ If others truthfully report ABC , truthful reporting is not BR!
- ▶ This is **manipulable** (=not strategy-proof)
- ▶ **Outcome:** Student 1, 2 go to schools A , B (randomly); student 3 goes to school C
 - ▶ Schools ABC get students of type aac
- ▶ **But:** Student 3 can gain by **misreporting!**

$$U_3(\underline{BAC}) = u(B) = 1 > u(C) = 0 = U_3(ABC)$$

Taiwan School Choice: a Simplified Model

- ▶ What is this game's **Nash Equilibrium**?
 1. Student 3 reports BAC
 2. Student 1 and 2 report ABC with prob. p ,
report BAC with prob. $(1-p)$
- ▶ **Outcome:**
- ▶ p^2 : School ABC get students aca
 - ▶ When both Student 1 & 2 report ABC ...
- ▶ $1-p^2$: School ABC get students aac

Taiwan School Choice: a Simplified Model

3 reports BAC ; 1,2 report ABC/BAC w/ $(p, 1-p)$

► For Student 1 (and 2) to mix, need: $1 + p = h$

$$\begin{aligned} U_1(ABC) &= p \left(\frac{1}{2} \cdot \underline{\underline{u(A)}} + \frac{1}{2} \cdot \underline{\underline{u(C)}} \right) + (1-p) \cdot \underline{\underline{u(A)}} \\ &= p \left(\frac{1}{2} \cdot \underline{\underline{h}} + \frac{1}{2} \cdot \underline{\underline{0}} \right) + (1-p) \cdot \underline{\underline{h}} = \left(1 - \frac{p}{2} \right) h \end{aligned}$$

$$\begin{aligned} U_1(BAC) &= p \cdot \underline{\underline{u(B)}} + (1-p) \left(\frac{1}{2} \cdot \underline{\underline{u(B)}} + \frac{1}{2} \cdot \underline{\underline{u(A)}} \right) \\ &= p \cdot \underline{\underline{1}} + (1-p) \left(\frac{1}{2} \cdot \underline{\underline{1}} + \frac{1}{2} \cdot \underline{\underline{h}} \right) = \frac{1+p}{2} + \frac{1-p}{2} \cdot h \end{aligned}$$

Taiwan School Choice: a Simplified Model

► Why is this a **Nash Equilibrium**?

► Student 1 and 2 report ABC with probability $p = h - 1$

► **For Student 3**, we need $p \geq 0.55496$

$$\begin{aligned} f(p) &= U_3(BAC) - U_3(ABC) \geq 0 \\ &= p^2 \cdot 1 - (1 - p)^2 \cdot h \\ &= p^2 - (1 - p)^2 \cdot (1 + p) = p^2 - (1 - p) \cdot (1 - p^2) \end{aligned}$$

► Since $f'(p) = 2p + (1 - p^2) + 2p(1 - p) > 0$

$f(p)$ increasing and $f(p) \geq 0$ requires $\Rightarrow 1 + p = h \geq 1.55496$

Conclusion (for the Example) 結論

- ▶ **Nash Equilibrium** of this 3-student game:
 1. Student 3 untruthfully reports BAC
 2. Student 1 and 2 mix between truthful and untruthful reports ABC and BCA with probability $(p, 1-p)$
- ▶ **Outcome:**
- ▶ p^2 : School ABC get students aca
 - ▶ When both Student 1 and 2 report ABC ...
- ▶ $1-p^2$: School ABC get students aac

Possible Extensions:

1. Is Cardinal Utility Required?

► Ordinal preferences is fine if exists p so that

$$\left(\frac{p}{2}\right) \cdot C + \left(1 - \frac{p}{2}\right) \cdot A \sim \left(\frac{1+p}{2}\right) \cdot B + \left(\frac{1-p}{2}\right) \cdot A$$

2. If students have different preferences?

► Different Risk Attitudes?

3. If there are more students/schools?

4. If schools can also act strategically?

5. What is a Good Alternative Mechanism?

A Simple Theory of Matching (Roth-Sotomayor, Ch.2)

- ▶ Gale and Shapley (1962); Roth and Sotomayor (1990)
- ▶ Finite Set of **Students** S and **Schools** C
- ▶ 1-1 Matching, Strict (Ordinal) Preferences:
 - ▶ $c \succ_s \tilde{c}$: Student s prefers School c to $\tilde{c}$
 - ▶ $s \succ_c \tilde{s}$: School c prefers Student s to $\tilde{s}$
 - ▶ $i \succ_j \emptyset$: i is **acceptable** to j
- ▶ A **matching** is $\mu : S \cup C \rightarrow S \cup C \cup \{\emptyset\}$
$$\mu(s) = c \in C \cup \{\emptyset\} \iff \mu(c) = s \in S \cup \{\emptyset\}$$

A Simple Theory of Matching (Roth-Sotomayor, Ch.2)

- ▶ Matching μ blocked by individual $i: \emptyset \succ_i \mu(i)$
- ▶ Matching μ blocked by pair s, c if
 - ▶ $c \succ_s \mu(s)$ and $s \succ_c \mu(c)$
- ▶ Matching is stable if blocked by neither
 - ▶ Core = Set of all stable matchings
 - ▶ A stable matching is Pareto efficient
- ▶ Theorem (Gale-Shapley, Roth-Sotomayor Theorem 2.8)
 - ▶ Stable matching exists in 1-1 matching market

Deferred Acceptance (DA) Algorithm

- ▶ **Step 1**: Students apply to their **first choices**
 - ▶ Schools tentatively hold most preferred student and **reject all others**
- ▶ **Step t** (2 and above): Students rejected in Step $t-1$ apply to **next highest** choice
 - ▶ Schools tentatively hold most preferred student (new or held) and **reject all others**
- ▶ **Stop** when no more new applications
 - ▶ Happens in finite time!

DA Algorithm in Taiwan School Choice Model

- ▶ 3 schools: A, B, C ; 3 students: a, b, c
 - ▶ Student Payoffs: $u(A) = h, u(B) = 1, u(C) = 0$
 - ▶ School Payoffs: $v(a) = 1, v(b) = 0.999, v(c) = 0$
- ▶ Step 1: All students apply to school A
 - ▶ School A holds student a and rejects b, c
- ▶ Step 2: Students b, c apply to school B
 - ▶ School B holds student b and rejects c
- ▶ Step 3: Student c applies to school C
 - ▶ School C holds student c and terminates DA!

Deferred Acceptance (DA) Algorithm

- ▶ **Proof** of Theorem (Gale-Shapley)
- ▶ DA gives matching where no student/school applies to/holds unacceptable schools/students
- ▶ Matching μ not blocked by **any** individual!
 - ▶ If $c \succ_s \mu(s) \neq c$, s rejected by c before in DA
 - ▶ But in DA, c rejects only if sees better choice
 - ▶ Hence, $\mu(c) \succ_c s$
- ▶ Matching μ not blocked by **any** pair!
 - ▶ Resulting Matching μ of DA is stable. QED

DA Algorithm in Taiwan School Choice Model

- ▶ What does **stable** mean in the field?!
- ▶ Roth (1984):
 - ▶ Stable ones successfully used
 - ▶ Continue to use (unstable ones abandoned)
- ▶ Few complaints in Taiwan?!
- ▶ A **student-proposing** DA algorithm yields:
- ▶ **Student-optimal** stable matching
 - ▶ (superior to all other stable matching)
- ▶ Proof of Theorem? See Roth-Sotomayor Theorem 2.12

Deferred Acceptance Algorithm: Marriage Matching

- ▶ **Male-optimal** stable matching
 - ▶ (superior to all other stable matching)

= **Female-pessimal**

- ▶ (inferior to all other stable matching)
- ▶ In contrast, **female-proposing** DA leads to
 - ▶ **Female-optimal/male-pessimal** stable matching
- ▶ Proposing power less crucial in school choice
 - ▶ Since Student/School Preferences More Aligned?

Rural Hospital Theorem (Roth-Sotomayor Th'm 2.22)

- ▶ The **same** set of students/schools are left unmatched in **all stable** matching
- ▶ This means:
 - ▶ A loser is a loser in any stable matching
(魯蛇到哪裡都是魯蛇)
 - ▶ Cannot expect any stable-matching mechanism to solve rural hospital problem (偏遠地區醫療)
- ▶ Proof?

Proof of Rural Hospital Theorem

- ▶ Student-optimal stable matching $\bar{\mu}$
- ▶ Alternative stable matching μ
- ▶ $\bar{\mu}$ is **student-optimal**:
 - ▶ Students matched in μ also matched in $\bar{\mu}$
$$\#\{\mu(s) \neq \emptyset\} \leq \#\{\bar{\mu}(s) \neq \emptyset\}$$
- ▶ $\bar{\mu}$ is **school-pessimal**:
 - ▶ Schools matched in $\bar{\mu}$ also matched μ
$$\#(\bar{\mu}(s) \neq \emptyset) \leq \#(\mu(s) \neq \emptyset)$$

Proof of Rural Hospital Theorem

$$\underline{m = \#(\mu(s) \neq \emptyset)} \leq \underline{\#(\bar{\mu}(s) \neq \emptyset) = n}$$

$$\underline{n = \#(\bar{\mu}(s) \neq \emptyset)} \leq \underline{\#(\mu(s) \neq \emptyset) = m}$$

- ▶ $\#$ of matches are the same in any match

$$m = \#(\mu(s) \neq \emptyset) = \#(\bar{\mu}(s) \neq \emptyset) = n$$

- ▶ **Same** set of students/schools matched in both student-optimal stable matching and alternative stable matching

$\bar{\mu}, \mu$

Truthful Reporting vs. Strategy-Proofness

- ▶ Main problem of new system in Taiwan:
 - ▶ People want to misrepresent their preferences
- ▶ **Mechanism:** Rule that yields a **matching** from (reported) **preferences**
- ▶ Mechanism is **strategy-proof** if reporting true preferences is a **dominant strategy** for everyone
 - ▶ New system in Taiwan is not strategy-proof
 - ▶ Is DA strategy-proof?

Truthful Reporting vs. Strategy-Proofness

- ▶ In fact, **no stable mechanism** is strategy-proof! (Roth-Sotomayor Theorem 4.4)
 - ▶ But, Dubins and Freedman 1981, Roth 1982:
- ▶ **Theorem (Roth-Sotomayor Theorem 4.7):** Student-proposing DA strategy-proof **for students**.
- ▶ Why DA (and Taiwan old system) is **good**:
 1. **Stable**
 2. **Student-preferred in all stable matching**
 3. **Strategy-proof for students**

Further Extensions

1. Strategy-proof $\rightarrow$ **Manipulable** (Degree instead of Y/N)
2. 1-1 $\rightarrow$ **Many-to-one**
 - ▶ Schools can accept up to q_c students (quota)
 - ▶ Existence of stable many-to-one matching market
 - ▶ X-proposing DA $\rightarrow$ X-optimal stable matching
 - ▶ Rural Hospital Theorem (fill same # of students)
 - ▶ Student-proposing DA strategy-proof for students
 - ▶ No stable mechanism strategy-proof for schools
3. Problem for **Married Couples**?!