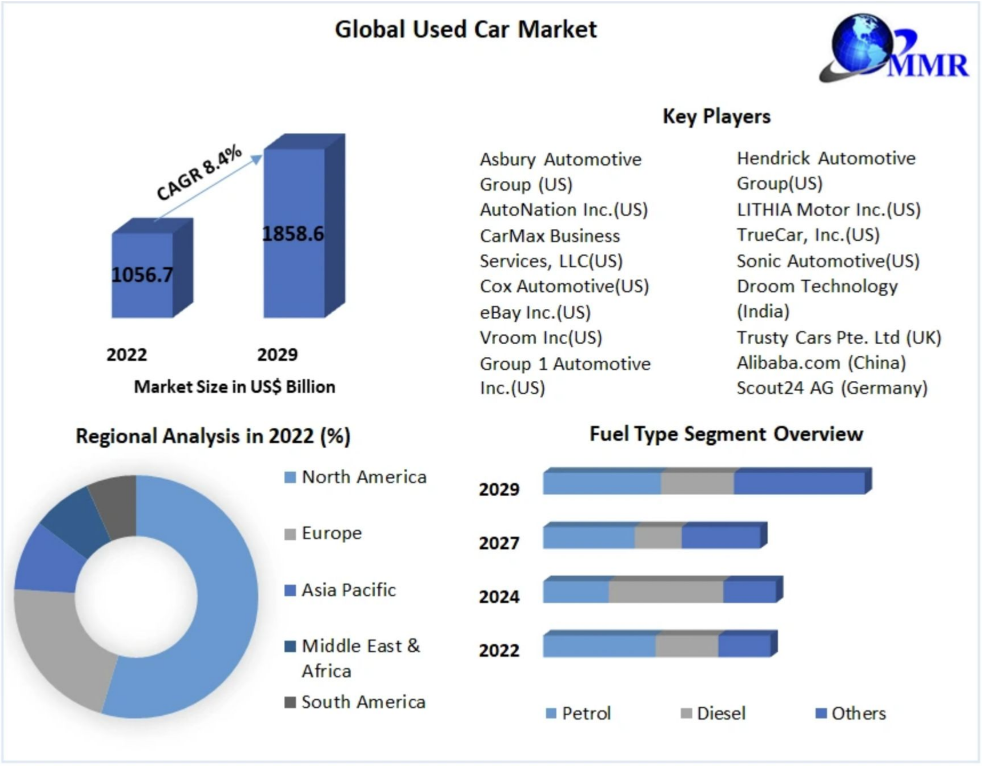
Market Design of Second-hand vehicle Platform(CarMax)

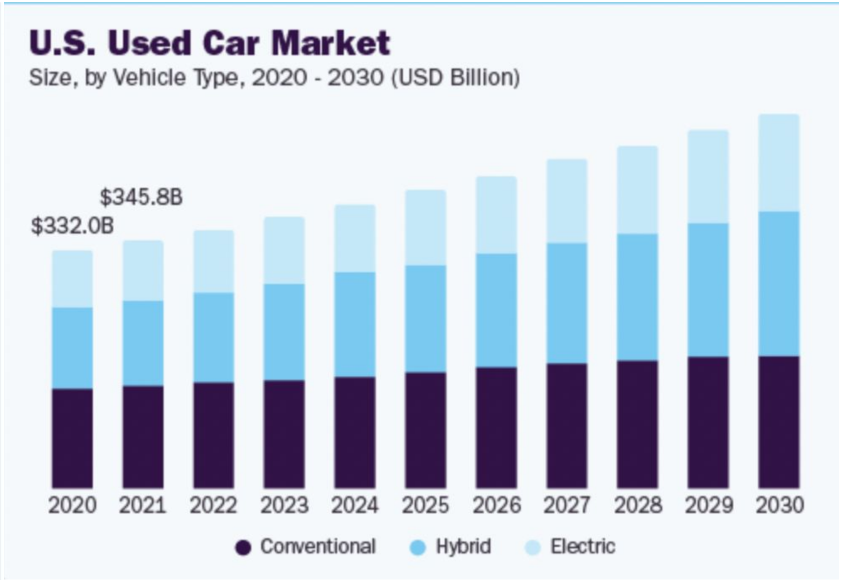
Group 2: Yidan Chen, Chen Lin

CONTENTS

01
Context/ Economic Environment

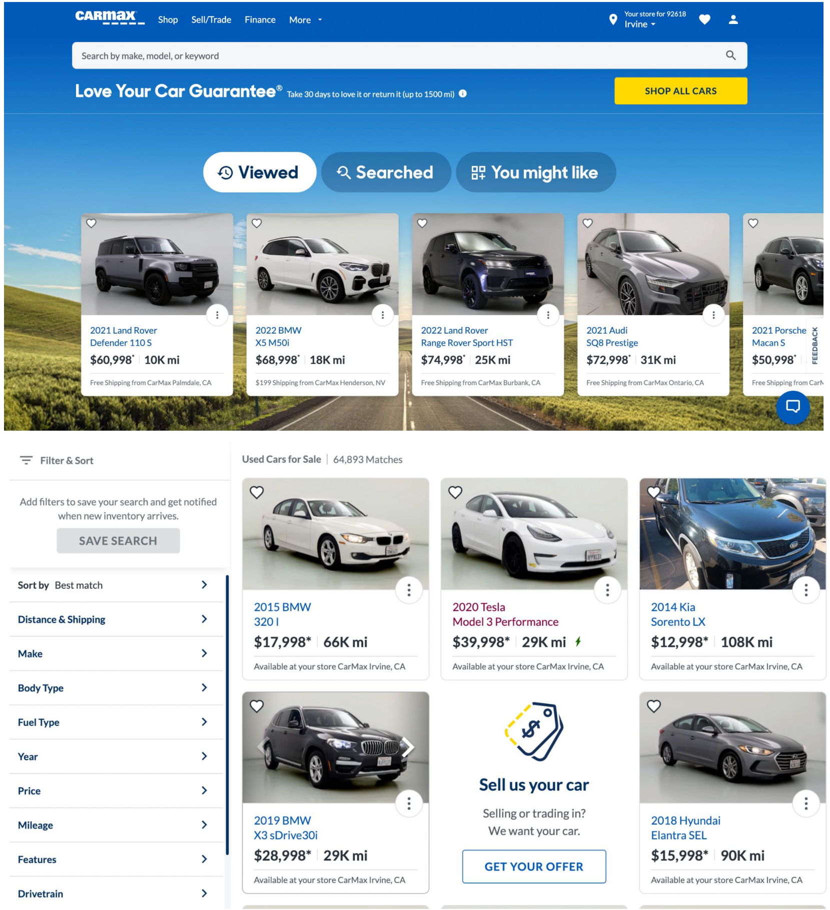
Context/Economic environment





Context/Economic environment

- CarMax : large used car retailer
  - No-Haggle pricing
  - Wide Selection of Vehicles
  - Car Buying and Selling Services
  - Quality Assurance
  - Financing Options



02
Objective of the whole market design

Why does the current market mechanism in carmax fail to work with respect to our objective?

- Carmax model: random serial dictatorship
  - Randomly determined order
- It could not maximize participant surplus and satisfy the participants who want to buy the car and meanwhile sell their own car.

- Identifying key components for improvement by evaluating the current market design of Carmax.
- Designing and illustrating a new model from several to many participants to maximize their welfare (U_i) more efficiently by ensuring fair pricing, transparency, and maintaining competitive market dynamics.
- $U_i = WTP - P$

  (The price might be influenced by mileage, year, brand…)

03

Random Serial Dictatorship Model

Key assumption:

(1) **Individual Preferences & Random Ordering**: Participants have clear, ranked preferences and are randomly ordered in each round for making choices.

(2) **One-Time Choice**: Each participant makes a single choice in their turn from the available options, based on their preference order.

(3) **No Strategic Behavior or Externalities:** Choices are made based on true preferences without strategic gaming, and one's choice doesn’t impact others' preferences or options.

Nice Properties of the Random Serial Dictatorship (RSD) Model:

- **Fairness**
- **Strategy-Proof**

Carmax operation process (Using RSD algorithm) :

- **User registration and preference registration:**
  Buyers and sellers register accounts and create profiles.
  Buyers submit a list of their preferences for the vehicle.
- **Vehicle registration:**
  Sellers register the vehicle they wish to sell and provide details.
- **Random order generation:**
  The system generates a random selection order for registered buyers.
- **Select and match:**
  According to a random order, buyers in turn choose their most preferred vehicle from the vehicles available on the platform.
  Once a car is selected, it is removed from the list of available vehicles.
- **Transaction confirmation:**
  The buyer and seller confirm the transaction details and complete the transaction.
  Carmax provides security and support to ensure that the transaction proceeds smoothly.
- **Evaluation system:**
  After the transaction is completed, the buyer and seller evaluate each other, which helps the future buyers to know the credibility of the seller when making decisions.

Joe	Kathy	Bob	Nez	Howard
B	F	B	T	T
H	H	R	H	F
T	R	T	B	B
F	T	H	R	R
R	B	F	F	H

Random Ordering of Buyers: First, we would randomly order the buyers. Let's say the order is Bob, Joe, Howard, Nez, and Kathy.

Joe	Kathy	Bob	Nez	Howard
B	F	B	T	T
H	H	R	H	F
T	R	T	B	B
F	T	H	R	R
R	B	F	F	H

Outcome:

- Bob gets car B.
- Joe gets car H.
- Howard gets car T.
- Nez gets car R.
- Kathy gets car F.

Pros and Cons for buyers:

- Fairness, Transparency, No Strategy Needed
- No Guarantee for Top Choice, Potential Wait Time

Pros and Cons for sellers:

- Faster Sales, Broader Market Exposure
- Price competition, Unpredictable timing of Sale

In summary, while the RSD algorithm provides Carmax with a more fair and transparent market operating model, it also introduces an element of uncertainty, especially when buyers are unable to get their preferred vehicle. For sellers, while the selling process may be faster, they may face stiffer price competition.

04

Random Serial Dictatorship Model(With Private Endowment)

CarMax APPRAISAL OFFER

Name: [redacted]
Address: [redacted]

Vehicle: 2017 CHEVROLET CAMARO 2D COUPE SS
Mileage: 11,149 **Engine:** 6.2L
VIN: [redacted]
Color: WHITE

Contact:
ORLANDO YOUNG

6072 - CAPITOL EXPRESSWAY, CA
Date:
08/01/2017

FEATURES CONSIDERED

POWER LOCKS
AM/FM STEREO
BOSE SOUND SYSTEM
REAR DEFROSTER
ABS BRAKES
POWER SEAT(S)
POWER MIRRORS
20 INCH PLUS WHEELS
SATELLITE RADIO READY
OVERHEAD AIRBAGS
POWER WINDOWS
AUXILIARY AUDIO INPUT
AIR CONDITIONING
CRUISE CONTROL
LEATHER & SUEDE SEATS
FRONT SEAT HEATERS
ALLOY WHEELS
TRACTION CONTROL
SIDE AIRBAGS
REAR SPOILER
MANUAL 6 SPEED TRANSMISSION
REAR VIEW CAMERA, BLUETOOTH TECHNOLOGY, RUN FLAT TIRES, SIRIUSXM TRIAL AVAILABLE, SMART KEY

CONDITIONS ASSESSED 5251

Front Seats:	Good Condition	**Rear Seats:**	Good Condition
Carpet:	Good Condition	**Transmission:**	Good Condition
Engine:	Good Condition	**Front Tires:**	Good Condition
Rear Tires:	Good Condition	**Wheels:**	Good Condition

APPRAISAL OFFER $30,000

This offer is valid until the close of business on 8/08/17.

However, some consumers may already own a car and want to buy a new car. In this case, they have **initial endowments.** With private endowments, serial dictatorship is **no longer individually rational** because consumers may end up with a car that is less preferred than their own endowment.

For example: They want to sell, buy or change cars

- Joe owns BMW
- Kathy owns Toyota
- Bob owns Rover
- Nez owns Honda
- Howard owns Ford

Joe (BMW)	Kathy(Toyota)	Bob(Rover)	Nez(Honda)	Howard(Ford)
B	F	B	T	T
H	H	R	H	F
T	R	T	B	B
F	T	H	R	R
R	B	F	F	H

Assume the order is : Kathy, Bob, Howard, Joe, Nex

Both Joe and Nex receive cars that are less preferred than their own, and as a result, they are worse off.

<u>We need to improve the algorithm to maximize consumer welfare. So that they can get a car no worse than their own car.</u>

05

Top Trading Cycle Algorithm and Simulation part

Now we introduce a **Top Trading Cycle (TTC) Algorithm** with initial endowments as a mechanism to improve the original market design and reach our objectives in an used car market:

Key Assumptions:

(1) Assume that participants reveal their preferences on used cars and the trading platform captures the complete information.

(2) No money transfer in this TTC Algorithm, and assume participants' preferences are based on their utilities, which have already taken price into account.

Nice properties of TTC Algorithm Mechanism:

- Efficiency: assignment using TTC algorithm is efficient.
- Strategyproof: participants could not get better assignment by cheating.
- Individual rationality: no blocking coalition

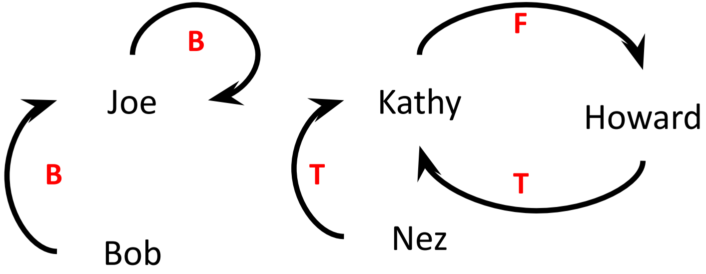
Firstly, we are still going to use this simple example to demonstrate how this mechanism will improve the participant welfare:

Joe (BMW)	Kathy(Toyota)	Bob(Rover)	Nez(Honda)	Howard(Ford)
B	F	B	T	T
H	H	R	H	F
T	R	T	B	B
F	T	H	R	R
R	B	F	F	H

Steps:

- Each participant points to the individual owning the object she prefers the most.
- If participant’s preferences form a cycle, then we assign the participant (in the cycle) the object owned by the individual she is pointing to.

Joe (BMW)	Kathy(Toyota)	Bob(Rover)	Nez(Honda)	Howard(Ford)
B	F	B	T	T
H	H	R	H	F
T	R	T	B	B
F	T	H	R	R
R	B	F	F	H



Matching Results:

- In the first cycle, Joe keep his **BMW**
- In the second cycle, Kathy get **FORD** and Howard get the **TOYOTA**
- Then we remove these three buyers and let the others keep their endowment

06

Comparison and Discussion

Comparison

TTC Algorithm

Joe (BMW)	Kathy(Toyota)	Bob(Rover)	Nez(Honda)	Howard(Ford)
B	F	B	T	T
H	H	R	H	F
T	R	T	B	B
F	T	H	R	R
R	B	F	F	H

Random Serial Dictatorship with private endowment

Joe (BMW)	Kathy(Toyota)	Bob(Rover)	Nez(Honda)	Howard(Ford)
B	F	B	T	T
H	H	R	H	F
T	R	T	B	B
F	T	H	R	R
R	B	F	F	H

- Under **TTC assignment**, no one gets worse off given the initial endowment.
- **Random Serial Dictatorship algorithm** might not be feasible when buyers own a car at the beginning.
- Since our objective is to maximize the participant's welfare (utility), we are going to use regression and monte carlo simulation to compute consumer welfare of the two algorithms to see if TTC is indeed better.

07

Regression and Simulation

Regression on real-world data

We randomly collected 150 sample used cars from the website of Carmax, containing the specific characteristics of used cars. We divided the price range of cars into 3 categories and collected 50 sample of each category. By doing a multiple linear regression, we want to find the significant characteristics of cars that determine price and hence calculate consumer welfare.

Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Price	150	38590.053	18671.787	10599	79998
Car age	150	4.353	2.938	1	11
Mile age	150	47633.333	33463.276	4000	129000
Horse power	150	287.507	103.647	84	577
Automatic transmission	150	.967	.18	0	1
Cruise control	150	.993	.082	0	1
Gas engine	150	.887	.318	0	1
Alloy wheels	150	.947	.225	0	1
Sun roof	150	.613	.489	0	1
BluetoothTech	150	.973	.162	0	1
Turbocharged Engine	150	.46	.5	0	1
Memory Seats	150	.56	.498	0	1

Regression on real-world data

To facilitate the computation and comparison of consumer welfare between different mechanisms, here we assume that consumer welfare is:

(1) $\boldsymbol{Utility_{participant\ i} = Willingness\ to\ pay_{participant\ i,t} - \ Price_t\ (where\ Utility > 0)}$

However, we don't know exactly the WTP (Willingness to pay) of consumers, so we make reasonable assumptions that WTP has a certain relationship with Price:

(2) $\boldsymbol{Willingness\ to\ pay_{participant\ i,t} = 105\%\ Price_t}$

Then we could do the multiple linear regression to estimate the price setting equation, and subsequently calculate the consumer welfare based on our estimations and assumptions:

(3) $\boldsymbol{Price_t = \alpha + \sum \beta_i \cdot Characteristic_{t,i} + \varepsilon_t}$

For example: 1.1 P = $\boldsymbol{\alpha}$ *mileage + $\boldsymbol{\beta}$ *year
P = $\boldsymbol{\alpha}$ /1.1m + $\boldsymbol{\beta}$ /1.1y

Regression Results:

Source	SS	df	MS			
				Number of obs	=	150
				F(10, 139)	=	85.03
Model	4.4648e+10	10	4.4648e+09	Prob > F	=	0.0000
Residual	7.2986e+09	139	52508090.6	R-squared	=	0.8595
				Adj R-squared	=	0.8494
Total	5.1947e+10	149	348635628	Root MSE	=	7246.2

Price	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
Carage	-1063.986	364.2907	-2.92	0.004	-1784.253	-343.7181
Mileage	-.1440469	.0318567	-4.52	0.000	-.2070333	-.0810606
Horsepower	115.0281	8.454437	13.61	0.000	98.31218	131.744
Automatictransmission	-12361.5	3877.395	-3.19	0.002	-20027.8	-4695.206
Cruisecontrol	774.0505	8214.567	0.09	0.925	-15467.61	17015.71
Gasengine	-3360.679	2043.132	-1.64	0.102	-7400.315	678.9558
Alloywheels	-4379.909	2917.956	-1.50	0.136	-10149.23	1389.409
Sunroof	2353.825	1535.435	1.53	0.128	-682.0033	5389.654
TurbochargedEngine	2361.185	1356.777	1.74	0.084	-321.4045	5043.774
MemorySeats	1520.223	1745.373	0.87	0.385	-1930.69	4971.136
_cons	31937.56	8466.896	3.77	0.000	15197	48678.11

Monte Carlo Simulation using R

Steps:

(1) Import two R packages “MatchingR” and “matchingMarkets”

(2) Assume participants’ utilities on used cars are subject to the uniform distribution [0,100], import the number of participants (n=5 here) and randomly generate their preference orders:

```
> utility <- matrix(runif(n^2,min=0,max=100),nrow=n,ncol=n)
> print(utility)
         [,1]     [,2]     [,3]      [,4]     [,5]
[1,] 28.75775  4.55565 95.68333 89.982497 88.95393
[2,] 78.83051 52.81055 45.33342 24.608773 69.28034
[3,] 40.89769 89.24190 67.75706  4.205953 64.05068
[4,] 88.30174 55.14350 57.26334 32.792072 99.42698
[5,] 94.04673 45.66147 10.29247 95.450365 65.57058
```

```
> TTCmatching_results<-toptrading(utils=utility)
> print(TTCmatching_results)
     [,1]
[1,]    2
[2,]    3
[3,]    1
[4,]    5
[5,]    4
```

atching results respectively, meanwhile calculate the

sult

```
> print(utility_results)
[1] 78.83051 89.24190 95.68333 95.45036 99.42698
```

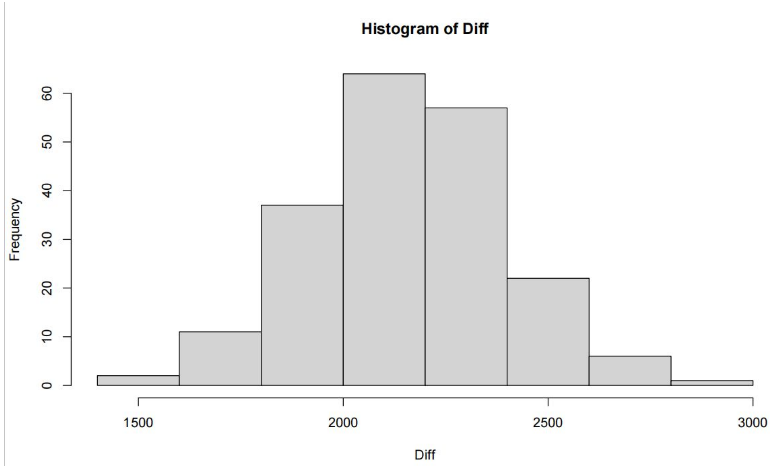
Monte Carlo Simulation using R

Steps:

(4) Compare the total welfare difference between TTC mechanism and Random Serial Dictatorship mechanism:

```
> Dif <- sum(utility_results) - sum(RSD_utility_results)
> print(Dif)
[1] 127.7987
```

(5) Conduct the simulation for 200 times, and observe the welfare differences between these two mechanisms again:



Observations in simulation:

(1) Assignment with TTC mechanism could contribute to increase participants' total welfare.

(2) As the number of participants in the market increases, the welfare gain is much more significant

07

Conclusion and Limitations

Random Serial Dictatorship

Top Trading Cycle Algorithm

Pros and Cons:

- RSD model: Ensures **fair** and **non-strategic** behavior, but may not always be the most efficient.
- TTC Algorithm: Shows greater **efficiency** and **strategyproof** ability, especially with a large number of participants.

The TTC algorithm may be a better fit for CarMax to maximize consumer welfare in a transparent and competitive market environment.

Limitations:

- **Model Assumptions:** Our model assume truthful reporting of preferences, it may not always align with the real world behavior where strategic manipulation can occur.
- **Market Dynamics:** We do not account for dynamic market factors such as fluctuating demand, price negotiation, time-based depreciation of vehicle value.
- **Consumer Behavior:** We assume that the consumer preferences are static and can be fully captured may not reflect the complexity of actual consumer decision-making processes.
- **Data Constraints:** The regression and simulation analyses are limited by the scope and accuracy of the data collected from Carmax. It may not represent the entire used-vehicle market.

Improvement: Auction Barter Model

In the Carmax model, it only considers the consumer (bidders of cars) welfare without the welfare of seller. However, in the used-car market, sellers of cars might also be the bidder of another car. As a result, there could be transaction costs under the Carmax matching model. Here we are going to introduce an special auction model named differential **auction-barter** (DAB) model to improve the efficiency of market. We assume this model is DAB-CY(differential auction-barter cyclic) version. This means that the salesman does not keep any vehicle and does not give away any vehicle for free.

This model account for trade-in feature of the platform.

Model Setup

In this market, there are 3 types of bids:

(1) sale bids

(2) purchase bids

sale and purchase bids are made in terms of money just like auctions.

(1) barter bids

Barter bids: item+ differential price = another item's value (trade)

The seller maximize their profit : revenue - cost

THE END

THANKS