# Market Design of Second-hand Vehicle Platform (CarMax)

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## 1. Context/ Economic Environment

The global Second-hand Vehicle market is a multi-billion-dollar industry. Also, the Second-hand Vehicle market in the US is substantial and continues to grow. Factors contributing to this growth include better vehicle quality, economic factors, and a growing acceptance and trust in the purchase of used vehicles, partly due to better vehicle history reporting tools. In our paper, we want to focus on the largest used car retailer in the United States, Carmax, as an example to examine the economics behind how the platform works and how to improve customer welfare.

CarMax is renowned for transforming the automotive sector through its distinct business approach. CarMax's fixed-price strategy is one of its best features. CarMax offers non-negotiable pricing on every vehicle, in contrast to typical car dealerships where price negotiations are commonplace. Customers' purchasing experiences are made easier and more stress-free by this open pricing policy. It gives clients a clear, upfront cost and solves one of the main problems associated with purchasing a car: bargaining over price. CarMax offers a wide range of vehicles to suit the needs and budgets of its diversified customer base. Their inventory includes nearly-new cars to older, high-mileage vehicles, ensuring something for everyone. This wide selection not only attracts a broad customer base but also establishes CarMax as a one-stop shop for different car-buying needs. One of the key services CarMax offers is the ability to buy, sell, and trade in vehicles. Their car selling process is streamlined, offering quick appraisals and providing offers that remain valid for a set period. This flexibility and convenience appeal to customers looking for a hassle-free way to sell or trade in their vehicles. A key component of CarMax's business strategy is quality. Every vehicle has a limited warranty and is put through a thorough examination process. Customers can trust the dependability and safety of their purchases because of this dedication to quality, which is important in the used automobile industry. CarMax provides a range of financing alternatives in recognition of the varying financial backgrounds of its clientele. Having several lenders allows for the accommodation of various credit profiles, hence increasing accessibility to car ownership. This approach broadens their customer base and enhances the overall customer experience by providing flexible payment solutions. In this paper, we aim to examine CarMax's current market design with different assumptions and propose a new market design (Top-Trading Cycle algorithms) that maximizes consumer welfare. By applying regression and simulation, this paper attempts to prove that the Top-Trading Cycle mechanism significantly outperforms the current CarMax market design in improving consumer welfare and enhancing the efficiency and fairness of the used car market.

## 2. Objective

Our paper critically examines the inefficiencies presented in Carmax's current market mechanism, akin to the random serial dictatorship matching algorithm and DAB mechanism, and predominantly identifies key components for improvement and puts forth two redesigned models involving several to many participants focused on maximizing participant welfare, defined to their utility within the second-hand vehicle trading platform. The existing Carmax model, characterized by randomly determined transaction orders, falls short in optimizing participant welfare and, to some extent, fails to meet the needs of individuals aiming to both buy and sell vehicles simultaneously. This deficiency stems from the model's limited consideration of consumers' diverse preferences and priorities. Advocating for a more sophisticated and participant-centric market design, our paper not only aims to enhance overall participant satisfaction and optimize market dynamics while improving the fairness and transparency of pricing mechanisms. By highlighting the limitations of the current random serial dictatorship model and Differential Auction-Barter mechanism, our argument emphasizes the urgency for change, positioning the proposed market design as a strategic and practical solution to these challenges. This transformative approach, in turn, promises to cultivate a more effective and participant-friendly second-hand vehicle trading platform that aligns with the market's evolving needs.

## 3. Initial Market Design（CarMax)

### 3.1 Random Serial Dictatorship Model

The Random Serial Dictatorship (RSD) model, employed in the operational process of Carmax, serves as a mechanism for allocating resources (vehicles) among a set of participants sequentially. This process involves establishing a random order for participants, where the first individual selects their favorite based on personal information and preferences. Subsequently, each successive participant chooses from the remaining options. Several key assumptions come into play for the RSD model to operate effectively. The primary premise is that the order in which participants make choices is entirely random, ensuring an impartial allocation process. Furthermore, participants are expected to make choices solely based on their individual preferences without engaging in manipulation. The model also assumes independence of preferences, signifying that the choice made by one consumer does not sway the preferences of others. It is crucial to emphasize that all participants are presumed to possess complete information about their own preferences and the available options.

In detail, Carmax's operational process utilizing the RSD algorithm commences with user registration. They need to register accounts and create profiles. Subsequently, buyers are required to provide a list of their preferences, and sellers, in turn, register the vehicles they intend to sell. Once a vehicle is selected, it is promptly removed from the available list. The buyer and seller will confirm transaction details, with Carmax overseeing a seamless transaction. Following this, an evaluation system empowers participants to provide feedback, augmenting transparency and credibility for subsequent transactions.

In terms of allocation for RSD, as shown in the picture below, consider a scenario within a used car market involving five participants: Joe, Kathy, Bob, Nez, and Howard. Each participant has a unique preference ranking for the cars. For example, Joe prioritizes BMW most, followed by Honda, Toyota, Ford, and Rover; Kathy's preferences align differently, favoring Ford the most, followed by Honda, Rover, Toyota, and BMW; Bob prefers BMW most, followed by Rover, Toyota, Honda and Ford; Nez prefers Toyota most, followed by Honda, BMW, Rover and Ford; while Howard prefers Toyota most, followed by Ford, BMW, Rover and Honda. The participants are randomly ordered, with Bob, Joe, Howard, Nez, and Kathy as the sequence. In this order, Bob receives BMW, Joe gets Honda, Howard obtains Toyota, Nez gets Rover, and Kathy receives Ford. However, this allocation fails to maximize the overall utility. It would be more efficient if Bob received Rover, Joe got BMW, Howard obtained Toyota, Nez got Honda, and Kathy received Ford. This example illustrates the inadequacy of Carmax's market mechanism in place as it fails quite to work when considering optimizing the whole utility for all participants. Therefore, this drives us to design new models to rectify the existing shortcomings.

| 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 |

### 3.2 Random Serial Dictatorship Model(With Private Endowment)

In the Random Serial Dictatorship model with a private endowment, each participant enters the process with an individual endowment, typically an owned item. Similar to the traditional RSD model, participants are placed in a randomly determined order, which sets the sequence for their choices. This model, however, introduces a unique complexity when incorporating private endowments, as it can challenge the principle of individual rationality. Specifically, participants may end up with an item that is less preferred than their original 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 |

Consider a scenario in a used car market with five participants: Joe, Kathy, Bob, Nez, and Howard. Each owns a different car: Joe has a BMW, Kathy a Toyota, Bob a Rover, Nez a Honda, and Howard a Ford. Let's say the random sequence for choosing is Kathy, Bob, Howard, Joe, and then Nez.

In this sequence, Kathy, being first, opts for the Ford, her most preferred car, initially owned by Howard. Bob, going next, chooses the BMW, initially owned by Joe, as it's his top preference. When Howard's turn comes, he selects Kathy's Toyota. However, a complication arises for Joe. His preferred car, the BMW, has already been taken by Bob. Consequently, Joe settles for his second choice, the Honda, initially owned by Nez. Lastly, Nez, upon his turn, finds his preferred choices - Toyota, Honda, and BMW - are already taken by others. He is left to choose his fourth preference, the Rover, initially owned by Bob.

In this case, both Joe and Nez end up with cars that are less preferred than the ones they originally owned. This outcome illustrates a key challenge in the RSD model with private endowment: participants, depending on their position in the random order and the choices of others, may receive items that leave them worse off compared to their initial endowments. This scenario underscores the complexity and potential for suboptimal outcomes in allocation mechanisms where individual preferences and initial possessions significantly influence decision-making.

### 3.3 Carmax Model: A more complex model - Differential Auction-Barter Mechanism

In the first part of the used-car market design, we only consider the one-sided transaction among bidders, where the function and profits of the salesman are not considered in the market. In this part, we will introduce a more complex model called the DAB (Differential Auction-Barter) mechanism (Can, 2005) to further describe the used-car transaction platform. Unlike the Random Serial Dictatorship mechanism, the DAB mechanism additionally considers the role of salesmen in allocating used cars.

Under the DAB mechanism, bidders might have initial endowments of cars and are willing to sell, buy, or change cars in the market. If a bidder initially owns a car, she could submit a special barter bid to trade her car and some money directly for another car. For instance, the bidder could trade a BMW directly for a Toyota plus $5,000, and this barter bid is denoted as [Toyota, +5,000]. Bidders could also submit pure-money sale bids and purchase bids.

There exists a salesman who plays a role in matching the purchase bids and sale bids. Notice that this paper states that the salesman could not keep or give away any used cars even if it is more profitable for the salesman to do so. For the salesman, it could capture all the bids from the bidders. In consequence, we suppose that under the DAB mechanism, the salesmen are able to arrange all the information and choose a specific allocation result to maximize its own profits.

Firstly, this paper is going to use a simple example to illustrate how this mechanism works and how the salesman maximizes its profits through working as an intermediary. Still we assume there are five bidders, namely Joe, Kathy, Bob, Nez, and Howard, and five cars, BMW, Toyota, Rover, Honda, and Ford in the market. Suppose the details of bids are presented as follows:

1) Joe owns BMW and wants to trade his BMW for $10,000+ Toyota

2) Joe owns BMW and wants to trade his BMW for $8,000+ Rover

3) Kathy owns Ford and wants to trade her Ford for $1,000+ Toyota

4) Kathy owns Ford and wants to trade her Ford+ $6,000 for BMW

5) Kathy sells her Ford for $11,100

6) Kathy sells her Rover for $10,800

7) Bob sells his Honda for $9,500

8) Nez bids Honda for $10,000

9) Nez bids Rover for $11,200

10) Nez bids Ford for $11,600

11) Howard owns Toyota and wants to trade Toyota +$1,500 for Rover

12) Howard owns Toyota and wants to trade his Toyota for Honda +$500

To keep the auction-barter mechanism as simple as possible but still fit the real-world situations, this paper follows Can (2005) idea to set the restrictions on the bids: 1) Barter bids will not be restricted in the market; 2) For each bidder if he submits two or more pure sale/purchase bids, only one sale/purchase bid could be realized in the cycle. With respect to the second restriction, it is reasonable to assume a single bidder will only purchase one car due to his budget constraint.

Then we are going to present this example as a combination of several cycles of bids, notice that items with the minus sign are the outlay of the salesman in the transaction, and items with the positive sign are the income:

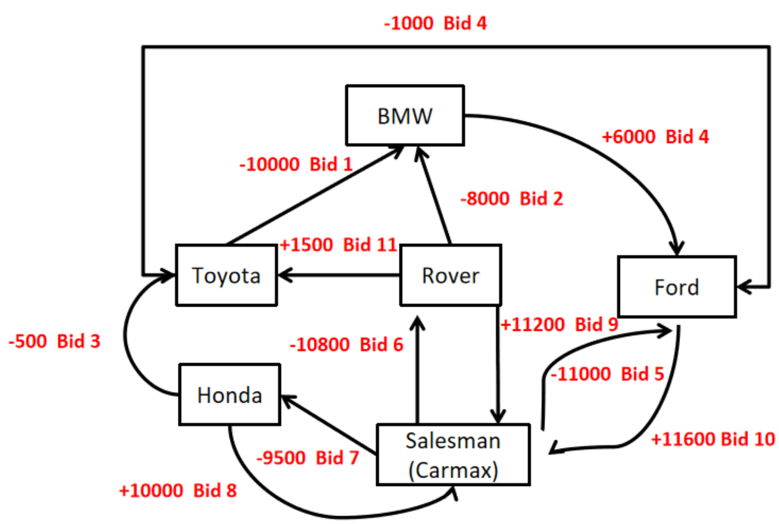


**Figure 1**

From the graph, it is clear that barter bids, sale bids and purchase bids consist of each transaction cycle. Ideally, the salesman (such as Carmax) tends to choose the cycle that maximizes its profits, calculated as the income of selling used cars minus the outlay of acquiring used cars from sale bidders. In this illustrative example, only bids 2, 3, 7, 10, and 12 would be picked by the salesman to process.

Back to the used-car transaction platform Carmax, in reality, there are even no bids in any transactions. As formerly mentioned in the introduction part, the price of each used car is simply set by the salesman (Carmax). Carmax sets the fixed price to either sell or acquire used cars and does not allow the bidding process or the bargaining process. In other words, Carmax applies the DAB mechanism as its basic business model but replaces all the pure sale and purchase bids with the fixed prices set by itself. As a result, it is reasonable to suspect that Carmax has some market power in manipulating bidders' requests and setting the fixed price to maximize its profits as a salesman.

In short, the objective of the DAB mechanism is to optimize the salesman's profits rather than the bidders' total welfare. Therefore it is necessary for us to come up with a new market design that attempts to guarantee bidders' welfare.

## 4. Our Market Design: Adjusted Top Trading Cycle Algorithm

To improve the allocation results in the used-car market and reach our objectives, this paper intends to use the Top Trading Cycle (TTC) algorithm and its alternatives as the new market design. It is widely known that the TTC algorithm is often applied in the school assignment problem and housing market assignment problem (Shapley and Scarf, 1974). The TTC mechanism has some nice properties, for instance, it is Pareto-efficient, strategyproof, and individually rational (Shapley and Scarf, 1974). Different from the DAB mechanism, the TTC algorithm might be more bidder-friendly because the process of assignment is transferred to a process of one-sided matching which only takes the preferences and initial endowments of bidders into account.

At the beginning of the paper, we use the Random Serial Dictatorship (RSD) algorithm to describe how the used-car market with Carmax works. Although the RSD algorithm works well when bidders do not have any initial endowment (Bidders do not own a car but want to buy one), it does not work well when some bidders have initial endowments (Bidders own a car but want to change it). The TTC algorithm could deal with this problem and guarantee that participants are individually rational in the assignment.

**4.1 Original Top Trading Cycle Algorithm in the Used Car Market**

Now this paper is going to briefly introduce the original TTC algorithm with a simple example and then introduce our new design as an alternative to the original one. We still use the example in the former part, where Joe owns BMW, Kathy owns Toyota, Bob owns Rover, Nez owns Honda and Howard owns Ford. All bidders should submit their preferences given the pool of the used cars in the market, and then the TTC algorithm is applied to facilitate transactions:

| 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 |

**Table 2**

In the first round of the TTC algorithm, each participant firstly points to his favored cars, and if participants' preferences form a cycle, then each participant in the cycle will be assigned with the car owned by the other participant he points to. After that participants who have been assigned with new cars are removed from the algorithm, and the process repeats. Figure 3 illustrates the mechanism and its allocation result. Under the TTC algorithm, all bidders are better off or indifferent to their initial endowments.

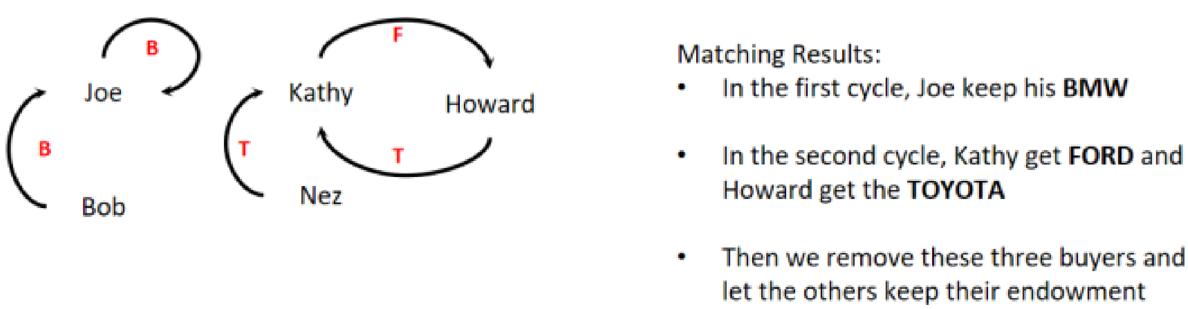


**Figure 3**

### 4.2 Top Trading Cycle Algorithm with Different Categories of Cars

In reality, there are various types of cars in the market, such as SUVs, trucks, crossovers, and sedans. In addition, bidders could have different budget constraints and different values of initial endowments so that they might have preferences and demands on used cars at a specific price level. This paper attempts to divide the used car market into different layers according to the price level and the used car categories. Here are several simple examples to demonstrate:

| Layer 1:<br>Price level : $10,000 to $20,000<br>Category: SUV | | | | |
|---|---|---|---|---|
| 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 |

| Layer 2:<br>Price level : $20,000 to $50,000<br>Category: SUV | | | | |
|---|---|---|---|---|
| Alice (BMW) | Bob(Rover) | Cate(Audi) | David(Porsche) | Edwards(Benz) |
| BMW | P | R | Be | BMW |
| P | A | A | P | R |
| A | BMW | Be | A | A |
| Be | Be | P | BMW | P |
| R | R | BMW | R | Be |

| Layer 3:<br>Price level: $50,000 to $100,000<br>Category: SUV | | | | |
|---|---|---|---|---|
| Amy (BMW) | Bean(Rover) | Chole(Audi) | Frank(Porsche) | Howard(Benz) |
| P | A | Be | A | BMW |
| BMW | P | A | P | R |
| Be | BMW | R | Be | A |
| A | R | P | BMW | Be |
| R | Be | BMW | R | P |

**Table 4**

After dividing the market into different layers, we still could apply the TTC algorithm to realize the efficient, strategy-proof, and individually rational assignments. Compared to the original one, our adjustment could improve the efficiency in allocating the cars by simplifying the assignment process and avoiding too many matching rounds.

## 5. Regression and Simulation

In this part, this paper is going to use the regression techniques and simulations to facilitate the comparisons between our market design and Carmax's business model. We randomly selected some cars on Carmax and collected their characteristics from the website, attempting to determine how Carmax sets the price for used cars. In addition, this paper also conducts some simple simulations with the use of programming to simulate how the current market mechanisms would operate and compare the bidders' welfare under different mechanisms.

**5.1 Regression**

$$Price_a = \alpha + \sum \beta_i \cdot Characteristic_{a,i} + \varepsilon_a$$

Here are the summary statistics of 150 randomly selected samples, the data includes the prices and various characteristics of sample used cars:

**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 |

**Table 5**

Then a linear regression model will be estimated to examine how the prices of used cars are determined, where a is the number order of used cars:

| | OLS model |
|---|---|
| Characteristics | |
| Car age | -1063.98**<br>(364.29) |
| Mile age | -0.144***<br>(0.031) |
| Horse power | 115.02***<br>(8.41) |
| Automatic transmission | -12361.5**<br>(3877.395) |
| Turbocharged engine | 2361.18*<br>(1356.77) |
| Constant | 31937.56***<br>(8466.896) |
| Observations | 150 |
| R-squared | 0.8595 |

**Table 6. Regression**

We omit the insignificant coefficients in the regression results. With the estimated coefficients and the price setting function, once we set the assumptions for the bidders' utility function and acquire the simulated assignment results from each matching mechanism, it is practicable for us to calculate and compare the total welfare of bidders after inputting the real-world data.

### 5.2 Simulations

This paper divides the simulation part into two sections. In the first section, this paper applies R to simulate the TTC and RSD mechanisms, to compare the bidders' total welfare under these algorithms. In the second part, this paper uses Python to simulate the Differential Auction-Barter mechanism. In the simulation, we notice that the average bidder's welfare under the DAB mechanism decreases as the number of bidders rises, which matches our statement that the DAB mechanism is applied to maximize the salesman's profit.

#### 5.2.1 Simulations of RSD and TTC Algorithm

Firstly, we import two R packages, namely "matchingR" and "matchingMarkets" to facilitate the simulation. These two packages allow us to input bidders' preferences and then get the assignment results. In the simulation, without the loss of generality, we assume each bidder's utility is subject to a [0, 100] uniform distribution. Then this paper will set the market size (number of bidders) and then run the Monte Carlo simulations 500 times for each market size n. Based on the simulation results, this paper could compare the total bidders' welfare under different mechanisms and examine whether our market design realizes our objectives. The results of our simulations are presented in the figures below:

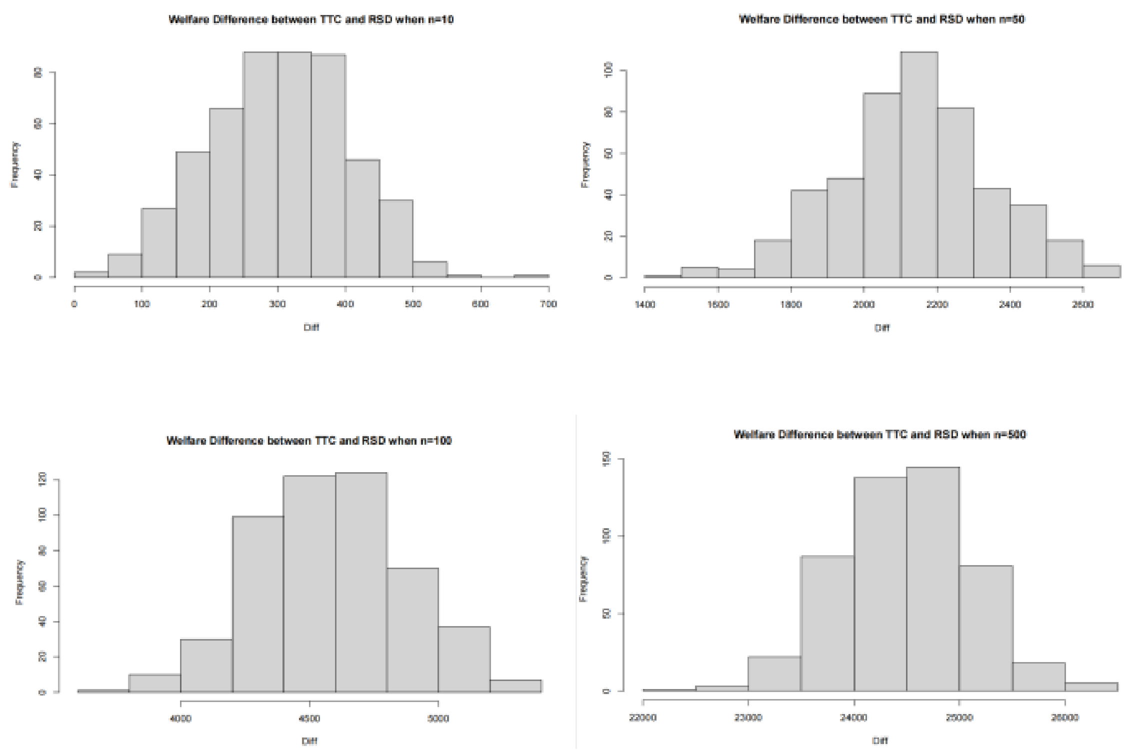


Figure 7

It is noticeable that as the market expands, the TTC algorithm is more advantageous than the RSD algorithm. This is a meaningful observation, indicating that the transaction platform could utilize the TTC algorithm to arrange the allocation of used cars and allow more bidders to be satisfied with their final assignments. However, TTC is still costly and time-consuming because the platform should collect information on bidders' preferences and conduct many matching rounds.

### 5.2.2 Simulation of simplified differential auction-barter (DAB) model

The simulation of the differential auction-barter (DAB) model was done in Python. It was a simplified simulation of the DAB algorithm with different numbers of consumer groups. There are several assumptions of the DAB simulation:

**(1) Generation of cars**

This simulation assumes that car prices are calculated by the regression obtained before with randomly generated car attributes age, mileage, horsepower, transmission type, and whether it is turbocharged. To align well with reality, the generated value of the 5 car characteristics all fall in a reasonable range with reference to Carmax's website as shown in this table:

| **Car attributes** | **Range** |
|---|---|
| Mileage | 0-150000 miles |
| Car age | 0-13 (2010-2023) |
| Horsepower | 130-350 hp |
| Transmission | 0 or 1 |
| Turbocharged | 0 or 1 |

**Table 8**

**(2) Assignment of Bids**

Consumers are generated randomly and the algorithm randomly selects part of the customers to have an initial endowment. This simulation has 3 types of bids: sale bids, purchase bids, and barter bids. Consumers with an initial endowment (pre-owned cars) have two options: they can sell their cars by engaging in the sales bids or engage in bartering bids. The decision to sell or barter their cars is random. The sale bids will occur if a buyer (with a Purchase Bid) is willing to meet or exceed the sale price. Based on the difference in price computation, a barter happens when two consumers can mutually profit from exchanging their cars. For consumers who do not have an initial endowment, they are randomly assigned with a purchase bid.

### (3) Calculation of Consumer Welfare

This simulation assumes consumer welfare is calculated in the following way:

a. For purchase bids: WTP = 1.05 P, Consumer welfare= WTP - P

b. For Sales bids: Consumer welfare = the price of the car sold

c. In barter bids:

1) For consumers who sold their car, they get a differential price plus an inferior car, Consumer welfare = differential price

2) For consumers who get a car by trading their inferior car plus a differential price, Consumer welfare = WTP (car the consumer get) - WTP (the car consumer preowned and trade away) - differential price

With these preset assumptions, we ran simulations of different market sizes with 5, 10,50,100,500 consumers. We used the Monte Carlo simulation to run each simulation of different market sizes for 100 times and calculate the average consumer welfare. The simulation results are shown in the table below:

| the Number of Customers | Average of **Average Consumer Welfare** over 100 simulations |
|---|---|
| 5 | 1987.94 |
| 10 | 1846.76 |
| 50 | 1784.22 |
| 100 | 1744.05 |
| 500 | 1696.23 |

**Table 9. DAB simulation results**

It is noticeable that average consumer welfare decreases with an increasing number of consumers in the DAB simulation.

## 6. Comparison and Limitation

### (a) Comparison between our market design and the DAB mechanism

To roughly compare our market design and the DAB mechanism, this paper attempts to conduct 100 times Monte Carlo simulations again to examine how bidders' welfare would change under our replaced mechanism. Unlike the simulation results under the DAB mechanism, this paper finds that the average consumer welfare is increasing as the whole market expands (approaching the real economic environment). Therefore, from this perspective the application of the TTC algorithm in the used-car market is advantageous over the DAB mechanism, and help us reach our objectives to optimize bidders' welfare.

| the Number of Customers | Average of **Average Consumer Welfare** over 100 simulations |
|---|---|
| 5 | 1763.37 |
| 10 | 2008.21 |
| 50 | 2325.96 |
| 100 | 2393.47 |
| 500 | 2470.93 |

**Table 10. TTC simulation results**

### (b) Limitations

While our proposed CarMax market design significantly improves existing models, it is also critical to acknowledge certain limitations. Firstly, our model’s assumptions about true reporting preferences may not be consistent with real-world behavior, where strategic manipulation of preferences may occur. This discrepancy presents a challenge to predict market outcomes accurately. Furthermore, the model does not take into account dynamic market factors, such as demand fluctuations, price negotiations, or depreciation of vehicle values over time, which are critical to a rapidly evolving used car market. Besides, we assume that consumer preferences are static and fully captured, which may oversimplify the complex decision-making process of actual consumers. In addition, data limitations in our regression and simulation analyses, primarily from CarMax, may not fully represent the diverse used car market. These limitations suggest that while our model offers theoretical improvements, its practical application requires careful consideration of these factors. In the end, in our simulation part, there are some technical difficulties for us in directly comparing the DAB mechanism and our market design as the former one is related to the auction and the latter one is actually a matching mechanism.

## 7. Conclusion and Discussion

This paper presents an in-depth examination of CarMax's market mechanism, identifying inefficiencies in its Random Serial Dictatorship (RSD) model and proposing a more effective approach through the Differential Auction-Barter (DAB) model and the Top Trading Cycle (TTC) algorithm. The RSD model falls short in optimizing the remaining participants, especially those looking to buy and sell a vehicle simultaneously. However, DAB models add complexity and better represent real-world transaction processes, while TTC algorithms are expected to improve efficiency and participant satisfaction. Our analysis through regression and simulation shows that the new model can significantly improve fairness, transparency, and overall participant welfare in the Second-hand Vehicle market.

From the limitations of our study and the complex dynamics of the used car market, our paper paves the way for more detailed empirical research. Future research should aim to incorporate dynamic factors such as fluctuating demand, changing consumer preferences, and the practical challenges of implementing complex market mechanisms like the Differential Auction-Barter (DAB) model and the Top Trading Cycle (TTC) algorithm in a real-time market environment. Moreover, a deeper analysis of consumer behavior through the lens of behavioral economics could elucidate the intricacies of decision-making processes in the Second-hand Vehicle market. Bridging the gap between theoretical models and practical applications, future research has the potential to validate our findings and provide actionable insights that could revolutionize the industry. While challenging, this effort is expected to make significant contributions to the field of market design and consumer welfare.

## References

Özturan, Can. "Used Car Salesman Problem: A Differential Auction–Barter Market." *Annals of Mathematics and Artificial Intelligence* 44, no. 3 (July 2005): 255–67. https://doi.org/10.1007/s10472-005-4691-z.

## Appendix

Original coding in R and Python are attached in the following pages with simulations of (1) the RSD and TTC model and (2) the Differential Auction Barter (DAB) model