Revisiting Theoretical Exposition of Supply and Demand through ABM

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Abstract

This research helps enhance the traditional economic understanding of market dynamics by exploring the price adjustment mechanisms with the supply and demand model. The traditional supply and demand model often employs the Walrasian tatonnement process, which simplifies the movement towards market equilibrium as a centralized trial-and-error method in determining the equilibrium price, with no transactions at disequilibrium. This centralized approach presents a theoretical inconsistency with the neoclassical emphasis on decentralized markets as the foundation for achieving equilibrium. This paper aims to bridge this gap by integrating the Walrasian model with a decentralized perspective using a simple agent-based model (ABM) focused on the housing market. It demonstrates how decentralized trading, underpinned by profit maximization and arbitrage, naturally facilitates price convergence, offering a more empirically grounded and realistic representation of market processes. By doing so, this study not only complements the existing theoretical framework but significantly extends it by reconciling the theoretical depiction of market equilibrium with the operational realities of a competitive, decentralized marketplace. Using the ABM approach to explain S&D model dynamics can significantly enhance the student's comprehension of economic education.

Keywords: Supply and demand, Walras tatonnement, Decentralized markets, Agent-based model, Market equilibrium, Price adjustment.

Introduction

The traditional supply and demand (S&D) model helps understand the market dynamics of price adjustment and market equilibrium which has a pivotal role in the realm of teaching economics. Economics textbooks (Antonovics, Bernanke, and Frank, 2015; Brue and McConnell, 2014; Mankiw, 2021; Varian, 2014) aim to help understand the underpinnings of real-world market dynamics and the price mechanism that helps achieve the equilibrium. The Walrasian tatonnement is often used to explain the mechanism that leads to market equilibrium. It works in a centralized market where all the traders are supposed to submit their orders, from both sides of the market to the Walrasian auctioneer and that auctioneer announces a market clearing price i.e., the equilibrium price at which the maximum trades happen, and the surplus is maximized.

But the issue with this explanation of market equilibrium is that it is a centralized mechanism where trades can only execute once all the orders are collected from the market and one price

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can be calculated where maximum orders can go through. The S&D model explanation of how the market attains equilibrium illustrates a centralized mechanism of the market where the price is selected exogenously. Whereas neoclassical theory emphasizes the decentralized markets as a mechanism to achieve equilibrium. There exists a discrepancy in the explanation of how the model works and the theory about the market.

As the S&D model is widely used to analyze the ramifications of diverse economic policies, such as minimum wage, price control, taxation, and resource distribution, the students must understand the above-mentioned gap in the model and the theory. For decades, economics textbooks have expounded upon the fundamental tenets of the S&D model, which serves as a core concept elucidating the intricate economic relationships governing the behavior of economic agents in markets. However, the working of this model still needs to find the answer about how the market gets to the equilibrium.

The textbook S&D model, recognized as a static model that operates within the market equilibrium framework, raises questions regarding the actual attainment of this equilibrium. It expounds that there is no specific mechanism that shows how the market evolves and reaches equilibrium. The available conventional explanation lacks the intrigue and consistency inherent in the assumptions of the S&D model.

The S&D model explains the process of price adjustment towards equilibrium in two alternative frameworks. One is the mechanism of price adjustment amidst market disequilibrium i.e., excess supply or excess demand in the market, aimed at understanding the pathway back to competitive equilibrium. The second explanation is the centralized Walrasian auctioneer mechanism that allows trade only at an equilibrium price.

The first explanation of the market equilibrium mechanism is the response of economic agents when the market faces either excess supply or excess demand in a state of disequilibrium. The price converges back to equilibrium through the following process as explained in existing textbooks. In the case of excess supply (demand), sellers decrease (increase) the price of goods or services being sold (bought). This change in prices triggers positive (negative) shifts in demand (supply) until the market returns to equilibrium. However, this description of the S&D model is contingent on sellers' or buyers' ability to adjust prices, which contradicts the assumption of a competitive market that all economic agents are price takers. Hence, this explanation of the price adjustment process does not provide a satisfactory answer on how the market achieves an equilibrium[4].

An alternative explanation for achieving market equilibrium centers around the concept of the Walrasian auctioneer, a topic that is not commonly discussed within the framework of the S&D model in economics textbooks but is well-documented in the literature (Ackerman, 2002; Inoua

[4] The contradiction about the process of price adjustment to equilibrium is a longstanding issue that remains unresolved. Arrow, Block, and Hurwicz (1959) attempt to address this gap by introducing market power to the last seller in the market, who sets the ultimate price equating to the competitive equilibrium price. However, this explanation conflicts with the assumptions of a competitive market, where no economic agent should possess market power to influence prices.

and Smith, 2021). The role of the Walrasian auctioneer is to act as a market regulator, collects all the orders submitted by buyers and sellers, and allow all transactions to occur at a single equilibrium price that maximizes market surplus. If there is an excess supply or demand at the offered price, the auctioneer keeps revising the prices until the equilibrium is reached (Walras, [1874, 1896] 2014)[5]. However, two points are important to note here, First, the Walrasian auctioneer represents a centralized market, whereas the competitive market operates as a decentralized market. So, the explanation of the price adjustment process should also be done in a decentralized environment.

Both explanations of the price adjustment process in the S&D model appear to falter within the competitive equilibrium framework. However, integrating the agent-based model (ABM) can significantly enhance our understanding and elucidation of the S&D model in economics courses, effectively surmounting these objections.

Concerning the gap in the S&D model, this research aims to present an alternative explanation of price adjustment and equilibrium in a decentralized market environment. The agent-based modeling (ABM) approach serves as a powerful tool for illustrating to students the mechanisms through which markets achieve equilibrium. One of the standout advantages of employing this methodology lies in its simplicity and immediate applicability across various markets.

The article encompasses several key sections. Firstly, it critically examines the limitations inherent in the current pedagogical methods employed for teaching the S&D model. It introduces a potential strategy to address these shortcomings by introducing an unconventional Agent-Based Modeling (ABM) approach. Subsequently, the article established a foundation of the ABM model that offers an alternative exposition of the S&D model from the housing market. Finally, the concluding section summarizes the findings and outlines future directions for research in this direction.

Equilibrium: An Alternative Explanation

The S&D model provides students with a comprehensive framework to understand how market forces work and leads the market to equilibrium from disequilibrium. Applying the S&D model helps us understand how market forces govern various aspects of our economic lives and how market efficiency is useful in providing the best possible economic outcome. Market efficiency can be achieved by having all transactions at the competitive equilibrium level to maximize surplus from all possible trades (Mankiw, 2021).

The model works when the assumptions of competitive equilibrium are fulfilled i.e., availability of full information, no transaction cost, no search cost, a large number of buyers and sellers, all traders are price takers, and no government intervention.

As described, the two explanations for how the market achieves equilibrium are inconsistent with the competitive market assumptions. The first approach posits that economic agents

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[5] In the case of a Walrasian auctioneer, no transaction is made until the market price is found and then all agents are allowed to do transactions on that specific price i.e., equilibrium price.

autonomously react to situations involving excess supply or demand, thereby guiding the market toward equilibrium. However, the issue with this explanation is that the buyers and sellers are assumed to be price takers and, hence, cannot decrease (increase) the price in case of excess supply (demand). The second approach revolves around the concept of a Walrasian auctioneer who sets the market price at a level that maximizes individual surplus – and market surplus as a result – thereby facilitating successful transactions for intra-marginal traders. For the Walrasian Auctioneer, there is a centralized mechanism for the markets to determine the price whereas, it contradicts the fundamental condition of a competitive market i.e., markets are decentralized. Students often struggle to relate this explanation to real-world scenarios, as markets are not typically operated by a central auctioneer making the traders transact only at the equilibrium price level.

While the fulfillment of competitive market assumptions enables the S&D model to explicate the concept of market equilibrium, it still encounters limitations when explaining the process of equilibrium attainment. Consequently, students face difficulties in comprehending the S&D model. This research explains the process of how markets achieve equilibrium through ABM while considering the contradictions mentioned above.

Before going into the details of the model, it is important to first outline the existing limitations of the prevailing textbook explanation of how the market attains equilibrium. The prevailing constraints of the existing explanation of how the S&D model works are summarized below.

Table 1: Limitations in Explanation of Equilibrium Process

Point 1: Buyers and sellers are price takers and hence cannot adjust the price to attain equilibrium. S&D Model: Competitive market theory posits that the interplay of S&D forces inherently drives markets towards equilibrium when excess supply or demand. When disequilibrium, market participants adjust prices which helps restore equilibrium. Limitation: A limitation arises from the assumption of the competitive market that all traders act as price takers, thereby lacking the power to influence prices. Any deviation from this assumption contradicts the tenets of competitive market theory. *Upside of ABM:* The ABM offers advantages by providing insights into managing excess S&D even when all traders are price takers, facilitating the exploration of arbitrage in the market.
Point 2: Walrasian auctioneer is a centralized market setup whereas a competitive market works in a decentralized market. *S&D Model:* In the Walrasian auctioneer framework, all prices from both buyers and sellers are collected facilitating trade at the equilibrium price within a centralized market environment.

Limitation: In contrast, the competitive market operates in a decentralized manner, wherein individual buyers and sellers make independent decisions without external intervention and centralized mechanism. *Upside of ABM:* For a decentralized market, ABM offers the potential to achieve theoretical equilibrium as traders seek to capitalize on market arbitrage opportunities.
Point 3: All the trades take place at an equilibrium price and no trader expects to trade at disequilibrium. *S&D Model:* The Walrasian auctioneer mandates that all traders engage in transactions only at the equilibrium price, impeding trades at prices other than equilibrium. *Limitation:* In contrast, the competitive market operates as a decentralized system where individual buyers and sellers autonomously make decisions without external intervention. *Upside of ABM:* ABM demonstrates that despite trades occurring at disequilibrium, the market ultimately converges to equilibrium, illustrating its dynamic properties.
Point 4: The market is always in equilibrium as no trader is allowed to trade at any price other than the equilibrium price. *S&D Model:* The S&D model operates in a static framework, providing a snapshot of the market at a single point in time with no consideration of dynamic adjustments from disequilibrium to equilibrium. *Limitation:* In contrast, real markets work in a dynamic environment characterized by ongoing changes in factors affecting supply and demand over time. It is imperative to incorporate the dynamics of these changes into the model to accurately reflect market behavior. *Upside of ABM:* ABM enables traders to operate within a dynamic environment, allowing for trading opportunities to occur at any point in time at agreed-upon prices across the transactions.
Point 5: The model does not consider the time to reach equilibrium, but time is important to see how long it takes for the market to attain equilibrium. *S&D Model:* The S&D model, due to its static nature, omits discussion on the time needed to achieve equilibrium as it does not incorporate the temporal dimension. *Limitation:* Understanding the time required for market forces to restore equilibrium is essential to formulate concrete policy implications in real time.

Upside of ABM: ABM operates within a dynamic framework, facilitating the tracking of the adjustment process and enabling evaluation of the time required for market forces to reach to equilibrium.
Point 6: All trades take place at equilibrium so every trader should be aware of the equilibrium price, but the equilibrium price can only be known after all the trades are executed. *S&D Model:* In a competitive market, it is assumed that all traders possess complete information about the market, including the equilibrium price. *Limitation:* The equilibrium price can only be determined after all trades have occurred, making it impossible to ascertain before transactions take place. Economic agents have access only to available public information, such as transaction prices, and lack access to information, such as budget or cost, and the equilibrium price. *Upside of ABM:* Even though traders not having full information about the market, ABM illustrates how the pursuit of arbitrage is enough to drive the market toward equilibrium.
Point 7: Surplus maximization can be achieved only when the equilibrium price and quantities are known before trading but it's not possible as traders can know about the equilibrium only after the trades take place. S&D Model: Buyers aim to maximize their utility, while sellers seek to maximize profits. Limitation: However, without knowledge of the competitive equilibrium price and quantity, achieving maximization is unfeasible. Consequently, market efficiency may not reach the levels predicted by competitive theory. Upside of ABM: Nonetheless, in ABM scenarios, even when traders lack information about the equilibrium price and quantity, they still attain maximized surplus consistent with the predicted of competitive market theory.

These points related to the S&D model require a new explanation especially to make students understand the dynamics of how markets reach equilibrium. To serve this purpose, the next section proposes an alternative to existing explanations of equilibrium mechanisms. This new exposition of the S&D model is provided for the housing market by incorporating ABM and is more closely relatable to reality.

An Alternative Exposition of the S&D Model

Experimental economics presents an alternative approach to understanding how markets achieve equilibrium, aiming to address the limitations of the traditional exposition of the Supply and Demand (S&D) model. Within the realm of experimental economics, the Oral Double Auction (ODA) serves as a useful tool for explaining the process of price convergence and the market transition from disequilibrium to equilibrium in a decentralized market, unlike the Walrasian auctioneer. Through repeated iterations over the periods, traders in the ODA market learn about the market dynamics, leading to the rapid emergence of equilibrium prices.

The ODA experiment market effectively explains the process of how the market achieves an equilibrium. In this context, the market does not possess a single price; however, a price eventually emerges over time. Despite its potential, the experimental explanation can be somewhat ambiguous in terms of aiding students' understanding of the experimental setup, the role of learning, and how it complements the S&D analysis. Additionally, the ODA framework does not fully address the issue of controlling human learning and rationality.

While experimental economics offers a promising avenue for overcoming the limitations of the conventional S&D exposition, it can be challenging to effectively demonstrate its working and underpinning to the students. Consequently, the Agent-Based Modeling (ABM) approach emerges as a potentially favorable alternative for its efficiency in terms of time and its ability to address various issues that experimental economics may not fully tackle.

Setting Up an ABM for the Housing Market

The development of ABM starts by employing a basic S&D model in the housing market that serves as an ideal illustration due to its relatability and ease of comprehension for students. To develop the model, it is necessary to first explain the underlying dynamics of the housing market, encompassing both the supply and demand sides.

On the demand side, the influx of new college students each year seeking accommodation in the vicinity of the college becomes a focal point. Suppose the college offers a four-year degree program and admits 10 new students annually[6], while 10 students graduate and vacate their housing each year. Let's assume these incoming students (S1, S2, S3, ..., S10) have varying maximum rental budgets (ranging from 100 to 1,000) that they can afford to pay for housing. This maximum rental budget (maxBudget), known as their redemption value, serves as an upper limit beyond which they cannot afford. They are faced with a decision to either pay the maximum feasible rent or opt for a lower rent to maximize their surplus.

On the supply side, there are identical houses (H1, H2, H3, ..., H10) available for rent each year, vacated by graduating students. Each house owner has a minimum amount required to rent (minRent) their property. The minimum rent ranges from 100 to 1000, increasing incrementally by 100 randomly across the houses.

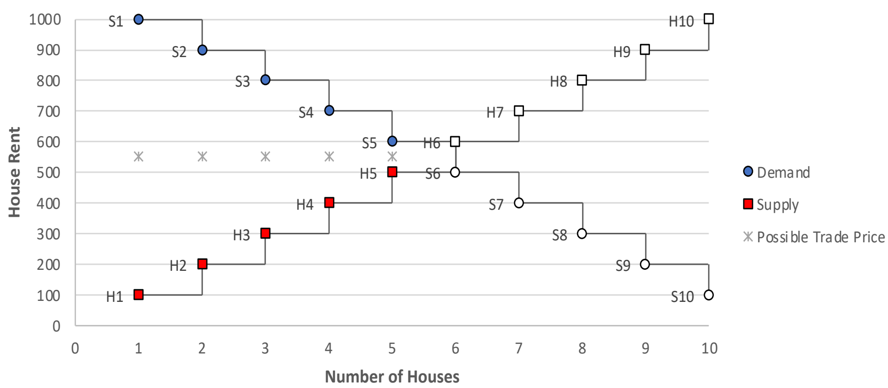
This S&D model of the housing market is built upon assumptions similar to the conventional model, including perfect information (where house prices are known to all), homogeneous goods (with identical houses), profit maximization (both students and house owners seek the best possible option to maximize their surplus), a decentralized market (all trades takes place at individual level without any intervention from market auctioneer), and free entry or exit (the

[6] To make the simulation more understandable for the readers a lower value is taken but the same simulation can be replicated for any number of students or houses.

ability of individuals to revoke previous contracts and enter new ones if they find it advantageous). This final assumption allows students and house owners to renegotiate contracts if they find that their previous agreement is no longer beneficial, and a better option is available.

As an initial step, we construct a conventional S&D figure based on the redemption values of students and the minimum required rent of house owners (as depicted in Figure 1). To create the S&D figure, the maximum budget (minimum required rent) of all students (houses) is arranged in descending (ascending) order (as shown in Appendix 1). The figure represents the theoretical equilibrium price (rent) and quantity (number of houses rented). The equilibrium rent falls between 500 and 600 (at 550), while the equilibrium quantity corresponds to 5 houses[7]. Students and house owners with the potential for trade are positioned to the right of the equilibrium point (the potential students are color-coded in blue, while the house owners with the potential to trade are represented in red).

Figure 1: Supply and Demand Model of Housing Market[8]



Now the results of simulations are divided into two segments. First, the stepwise result of one complete simulation is explained to understand the process through which the market achieves the equilibrium price. Here the details are provided across the periods. The second section encapsulates the overall results for all the 50 simulations.

Simulation Results – Single Market

After collecting the information regarding the maximum rental budgets of all students (maxBudget) and the minimum required rents of all house owners (minRent), we can proceed

[7] Here it seems the equilibrium number of rented houses is 6 but, if observed again, at a quantity of 6 houses the maxBudget of student S6 (circle at 6th house) is less than the minRent charged by H6 (house at quantity 6). So, the equilibrium quantity in this illustration is 5 houses.

[8] The students highlighted in blue color are the potential buyers (also known as intra-marginal buyers) and the house owners with red color are the potential sellers (or intra-marginal sellers). Theoretically, the trades should happen between these intra-marginal traders to ensure the attainment of maximum surplus in the market. Whereas all the students and house owners on the right side of equilibrium (with no color) are the extra-marginal traders as theoretically these traders are not in the best position to trade or if they trade then the market surplus may decline.

to apply the Agent-Based Modeling (ABM) framework to the housing market. The previously presented S&D figure merely represents the theoretical equilibrium point where the surplus of both students and house owners is maximized[9]. However, in a decentralized real market, there are no constraints imposed on traders to engage in transactions that maximize the overall market surplus. Instead, each economic agent seeks to maximize their surplus, which ultimately, over the periods, leads to the maximization of surplus for the entire market—a phenomenon famously referred to as the invisible hand. The objective of this section is to establish an ABM model that fulfills this purpose.

Corollary 1: Trades are sequenced randomly to investigate the potential for trade volume.

To achieve a completely random selection process, a random series is generated (Column 5, Table 1) and all students are arranged in a random order by sorting the corresponding randomized numbers in ascending order. Subsequently, each house owner is paired with a randomly selected student to determine their eligibility for trade.

It is the first round of trade between the college students and the house owners that leads to 6 successful and 4 unsuccessful trades. For three transactions, the actual transaction price is quite below the theoretical equilibrium price and above the equilibrium level for the other two transactions.

Table 1: First round of trade between students and house owners

House ID	minRent of House Owners	Student ID	maxBudget of Students	Randomized Numbers	Trade Price (maxBudget >= minRent)
H1	100	S8	300	0.90042	200
H2	200	S4	700	0.86467	450
H3	300	S3	800	0.81622	550
H4	400	S5	600	0.57840	500
H5	500	S9	200	0.47374	No Deal
H6	600	S1	1000	0.30018	800
H7	700	S2	900	0.22702	800
H8	800	S7	400	0.13454	No Deal
H9	900	S6	500	0.05112	No Deal
H10	1000	S10	100	0.03978	No Deal

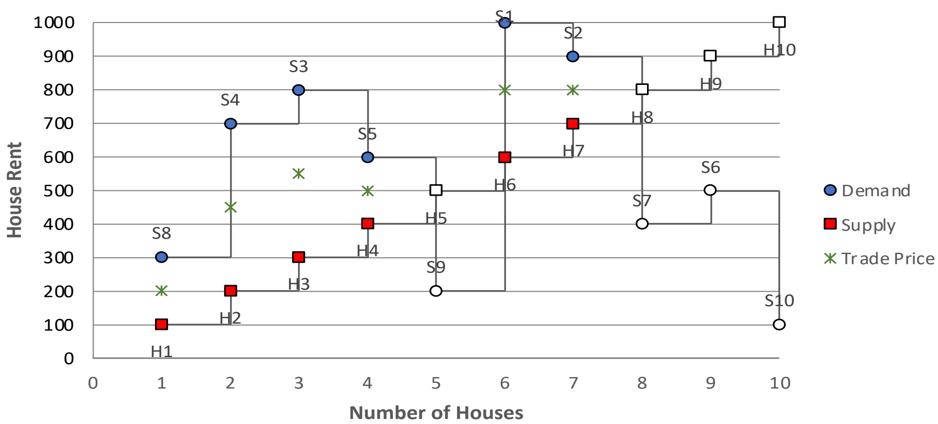
Corollary 2: Identify eligible trading pairs: students with maxBudget greater than or equal to house owners' minRent. Assume equal bargaining power on both sides of the market: transaction price is the mean of maxBudegt and minRent of potential traders.

[9] The surplus for all economic agents (all students and house owners) can be maximized if they both trade in a specified sequence, called the Marshallian trading sequence but is not highlighted anywhere in the textbooks. This trading sequence exhibits that the surplus can only be maximized if the buyer with maximum budget (S1) trades with the seller of minimum cost (H1), and the buyer of second maximum budget (S2) trades with the seller of second minimum cost (H2), and so on. If all trades happen in this sequence, then the transaction price is going to be equal to the theoretical equilibrium price (as shown in Figure 1).

The selection process involves pairing students who approach house owners for trade, based on the condition that their maximum rental budget is equal to, or more than the minimum rent required by house owners (maxBudget >= minRent). For example, if house owner H1 requests a rent of 100, and student S8 can afford up to 300, they may decide to strike a deal at a mutually agreeable price of 200. Similarly, house owner H2 trades with student S4, as H4 sets a rent of 200, which falls within S4's maximum budget of 700. This trade occurs for 450.

This process is repeated for all homeowners who have students randomly approaching their properties. As a result, six successful trades take place between house owners and students. However, there are a few house owners whose requested rent exceeds the affordable budget of certain students, resulting in no agreement being reached. For instance, house owner H5 asks for a rent of 400, while student S9, who is interested in renting the house, has a maximum budget of only 200 and cannot afford the property. This information, as given in Table 1, can be shown in the figure as below.

Figure 2: Result of 1st Iteration in housing market



Corollary 3: Availability of public information to all the market participants is fully available after every trade.

Following the initial round of trading, all traders gain knowledge about potential trading partners, their potential gains, and the trading information (maxBudget and minRent) of other participants. To facilitate effective dissemination of information among students and house owners, the college hostel administration collects data at the end of each day regarding all potential trades and makes it available on the college website or notice board (as depicted in Table 1). This practice ensures the provision of complete market information, aligning with one of the assumptions of a competitive market. Traders are then able to review their initial provisional contracts and, if they perceive the availability of more favorable trade opportunities, they have the option to revoke their previous agreements and enter new contracts[10]. In essence, if any students or house owners identify more attractive possibilities

[10] Even the dissemination of possible transaction prices helps the traders to see if they shall look for new option or to settle down on the available option. For instance, for student S3 and house owner H3, the transaction price is already 550 and once they get to know the disseminated information at the end of the day they will see that they shall not look for any other option as some houses are rented out at very high price (H6 and H7 at the price of 800) and other are rented at lower prices (H1, H2 and H4 at price of 200, 450 and 500 respectively).

than those already availed until the start of the semester, they can terminate their previous tentative contracts and engage in new contractual arrangements.

Corollary 4: "Market arbitrage" incites students to seek cheaper housing options, while prompting house owners to lease their properties to students willing to pay higher rents.

This is the process of actively seeking the best available option and maximizing individual benefits which ultimately leads to market equilibrium. Each participant engages in a search for the most advantageous deal. Students seek houses with rents below average, while house owners search for students who are willing to pay above average rent. For example, based on the initial round of trading, the house owner of H1 observes that the rent being charged is the lowest, while students are willing to pay higher amounts. As a result, she may consider increasing the rent.

Similarly, students who are paying the maximum rent (S1 and S2) learn from the information published publicly that their rent amounts are the highest compared to other students. Consequently, they will actively search for more affordable housing options. This continuous effort by students to find cheaper houses and house owners to rent out at higher prices ultimately drives the market towards equilibrium, without the need for a Walrasian auctioneer. To facilitate arbitrage, it is assumed that all first-round contracts are tentative, allowing both students and house owners to withdraw if they have more favorable opportunities in the future.

Corollary 4.a. The initial arbitrage step involves pinpointing the most affordable house, determined by either the lowest agreed-upon rent (if already rented) or the minimum rent demanded by the house owner (if not rented).

The identification of the cheapest house is determined by examining the rental prices, either by selecting the house with the lowest rent if it has already been tentatively rented or by considering the minimum rent requirement for houses that have not yet been rented. In our specific example, house owner H1 is currently rented at a rate of 200, while all unrented houses have a minimum rent that exceeds 200. Therefore, in this scenario, H1 emerges as the most suitable candidate for the cheapest house.

Corollary 4.b. The initial arbitrage is gained by first selecting the student most favorable for the next trade.

The student either with the highest rented house or with the highest maxBudget (if not rented a house already) is the best candidate for the next transaction. In our example, the students with the highest transaction price are S1 and S2. All other students, who have not had a chance to trade yet, have maxBudget less than 800 (i.e., less than the rent of houses rented to S1 and S2). Therefore, in such a case, either S1 or S2 emerges as the best option for the next trade, and we shall choose both or any of these two randomly.

Corollary 5: "Recontacting" enables the termination of the existing tentative contract in favor of a more appealing contract.

To simplify the Agent-Based Model (ABM), we assume that better offers must deviate by $50, either higher for house owners or lower for students. As a result, the house owner with the lowest rent, H1, would increase their rent by $50 to $250. Subsequently, we identify the students who can afford to pay $250, which in this case includes S1, S2, and so on up to S8. Any of these students can randomly offer $250 to H1. However, before deciding to vacate the housing, student S8 considers that they have no other option but to pay at least $250. It is more favorable for S8 to keep house H1 and pay $250, as all other available houses charge more than $250.

On the supply side, we observe that the cheapest house, H1, receives a better offer. Conversely, on the demand side, we allow the student paying the highest rent to potentially shift to a relatively cheaper house. With regards to contracting the cheapest house, the highest paying student seeks a house where they can pay $50 less than their current rental amount. To begin, we need to determine the highest paying student, which could be S1 or S2, both currently paying $800 to the existing house owner. Upon learning that other houses are being rented at lower prices, they also desire to pay less than $800 and are willing to pay $750.

Table 2: Recontracting between Students and House Owners (Day 2[11])

House ID	minRent of House Owners	Student ID	maxBudget of Students	Trade Price – Recontract (maxBudget >= minRent)
H1	100	S8	300	250
H2	200	S4	700	450
H3	300	S3	800	550
H4	400	S5	600	500
H5	500	S9	200	No Deal
H6	600	S1	1000	750
H7	700	S2	900	750
H8	800	S7	400	No Deal
H9	900	S6	500	No Deal
H10	1000	S10	100	No Deal

The green shade highlights that the rent of H1 is increased from 200.

Both students (S1 & S2) have cheaper options and want to pay just 750 instead of 800. But house owners (H6 & H7) don’t want to have vacant houses. So, they agree to charge rent of $750.

Consequently, students S1 and S2 offer $750 to any house currently being rented for less than $750, which includes houses H1, H2, H3, and so on up to H7. Therefore, we randomly select two of these houses, say H3 and H7, and relocate S1 and S2 there. House H3 has a minimum rent requirement of $300, while H7 has a requirement of $700. As a result, H7 becomes vacant when S2 leaves to find a cheaper house, and the house owner, H7, is willing to renegotiate. Similarly, when S1 decides to vacate the house and informs house owner H6 that they have

[11] On the first day, every student just tried to get any house that comes in their budget and every house owner just tried to rent out their house if the rent is above their minimum rent requirement. Now on day 2, everyone gets to know about the market information and rent for each house and they think to look for a better option and save money while taking benefit of arbitrage in the market.

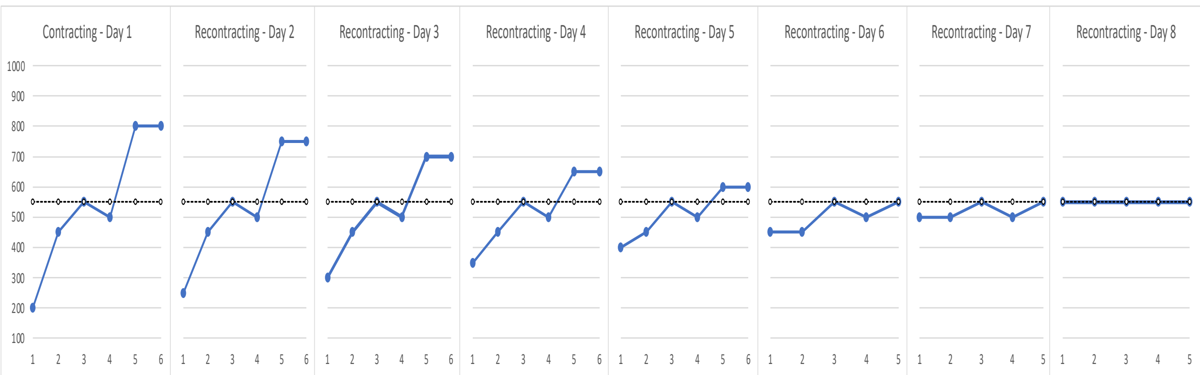
found another house renting for $750, H6 revises the rental terms and agrees with S1 to stay in H6 while charging a rent of $750 instead of $800. The student S1 sees no need to move to a new house when the existing house owner is willing to charge $750. Consequently, this leads to a decrease in the rent of both H6 and H7 from $800 to $750.

On Day 3, the process of Recontracting begins again based on the information posted publicly at the end of Day 2. On the supply side, house owners aim to earn more, and the owner of the cheapest rented house will increase the rent by an additional $50. On the demand side, students paying the highest rent will search for houses with low-rent houses[12].

The ongoing process of iterating between the forces of supply and demand will persist, continually adjusting the cheapest house and maximum rental payment until equilibrium is reached. It may require several iterations for all students and house owners to converge on the equilibrium rent. At equilibrium, no one will be able to find a more favorable option, resulting in everyone settling at a rent of $550. A detailed illustration of how transaction prices change each day can be found in Appendix 2. It takes a total of 8 days (or 8 rounds of recontracting for students and house owners) to reach the equilibrium rent.

The transaction prices observed during a recontracting process spanning multiple days are illustrated in Figure 3. It features the progression towards equilibrium through arbitrage mechanisms between randomly selected students and house owners. Initially, the agreed-upon rents deviate significantly from the equilibrium rent. However, as participants gain insight into market dynamics, their pursuit of individual interests prompts them to engage in recontracting to explore better arbitrage opportunities. Students residing in costly accommodations seek more affordable options, while house owners offering lower rents aim to secure higher prices. This individual pursuit of maximizing trade benefits and optimizing deals propels the housing market toward equilibrium. Over time, market arbitrage gradually reduces the disparity between actual rent and equilibrium rent. As shown in the recontracting Day-8, all the transactions happen at the equilibrium price.

Figure 3: Transaction prices over the Recontracting periods



[12] On Day 3, the cheapest house on rent is H1 at $250 who now wants to rent it out at $300. On the supply side, students S1 and S2 are paying a maximum and want to search for a house where they must pay a maximum of $700 instead of $750.

Simulation Results – Aggregate Analysis

The preceding section focuses on elucidating the fundamental characteristics of the trading mechanism within the single market along the temporal progression. This section focuses on a comprehensive analysis of aggregate simulation outcomes across 50 markets. The market efficiency is evaluated using multiple metrics, including the convergence of transaction prices to equilibrium, surplus accumulation, and bid-ask spread. First, the method to evaluate the trade surplus from the trades is employed as in the equation below.

$$E = \frac{\sum(maxBudget_i - P_i) + \sum(P_i - minRent_i)}{\varepsilon_c} * 100$$

Here P_i denotes the transaction price between the selected house owner and the student for a particular trade. The difference between the maximum budget of the student and the transaction price provides the surplus gained by the student for each trade while the difference between the transaction price and the minimum acceptable rent shows the surplus gained by the house owner across the trades. The term ε_c denotes the theoretically attainable surplus in a competitive market i.e., 2,500 for all the periods. The period-wise trade surplus is calculated across the periods, and it is observed that the surplus increases over time and eventually reaches the theoretically predicted surplus level (Panel A of Figure 4)[13]. An average market efficiency is found to be around 66 percent in period 1 which increases to 90 percent in period 6 and more than 98 percent in period 10 onward.

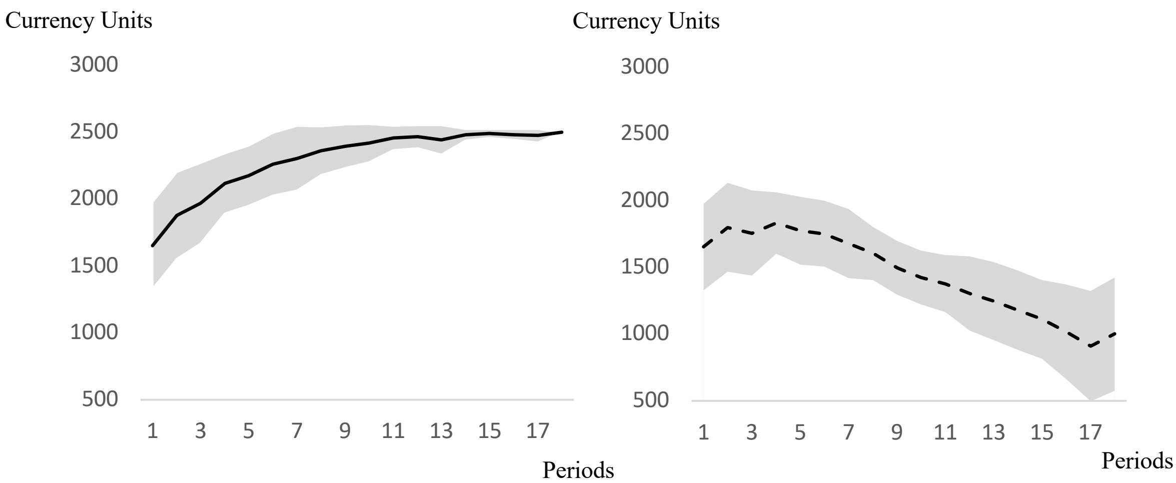
An observed increase in market surplus or efficiency over time is attributed to a reduction in the spread between the minimum acceptable rent set by homeowners and the maximum price students are willing to pay for housing. At the outset of each period, when transactions occur randomly between students and homeowners, the average disparity between their maximum budget and minimum rent stands at approximately 1650, gradually decreasing to only 1100 for subsequent transactions (refer to Panel B of Figure 4). This decline in spread is driven by the pursuit of maximizing gains while exploiting arbitrage opportunities, ultimately contributing to the escalation of surplus across periods.

Market traders can achieve a maximum surplus, and the market can attain efficiency, as posited by competitive equilibrium theory, solely through the pursuit of arbitrage opportunities within

[13] The solid line represents the mean value of trade surplus for all the markets. The maximum number of transactions observed in a single period is 20. The gray area around the solid line in Panel A shows the upper and the lower bounds. From period 18 onwards the trade surplus is found to be equal to the theoretical predicted surplus. The bounds for the last two periods (19 and 20) are not provided as trades happen only in these periods.

the market. These findings underscore the dispensability of adhering to intricate processes purportedly required to maximize gains from trades, as advocated in economic literature.

Figure 4: Mean Values for Trade Surplus and Bid-Ask Spread



Panel A: Mean Surplus over the Periods *Panel B: Periodic Bid-Ask Spread*

Another performance metric to be considered is the coefficient of convergence. This measure serves to evaluate the variability of transaction prices and the extent of deviation of these prices from the competitive equilibrium level. The coefficient of convergence (α) can be computed as follows.

$$\alpha = \sqrt{\frac{\sum_{i=1}^{X} (P_i - P_e)^2}{X}}$$

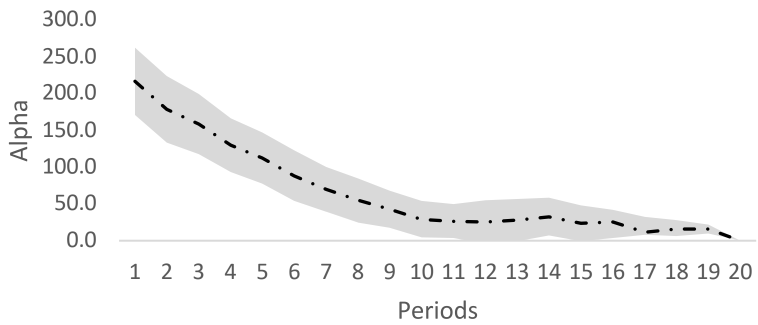
Here, 'X' represents the number of successful contracts in a trading period, P_i is the contract price of i^{th} contract, and P_e is the competitive equilibrium price. If all the contracts are made at a competitive equilibrium price, then the value of α equals zero showing no deviation of the transaction price from the competitive equilibrium price.

An average convergence along the periods is shown in Figure 5 below. For around 75 percent of the time, the convergence happens between periods 10 and 12 [14]. The high convergence of transaction prices towards competitive equilibrium prediction (550) shows that the high surplus achieved is supplemented because of the convergence of transaction prices and a decline in bid-ask spread over the trades. The results of maximum surplus attained, declining bid-ask spread, and price convergence to equilibrium are in line with theoretical prediction when traders just follow the arbitrage. In other words, the market arbitrage is enough to motivate

[14] An average of convergence coefficients is taken here but not for each period.

traders to maximize their surplus resulting in overall market efficiency, as explained in the invisible hand phenomenon.

Figure 5: Average Value of Convergence Coefficient



This process of pursuing arbitrage serves as a valuable demonstration of how the supply and demand model operates in real-world scenarios, moving beyond the traditional assumption of Walrasian tatonnement and many others. The Agent-Based Model (ABM) utilized in this study can be replicated for any other market, providing a more comprehensive understanding of the dynamics between supply and demand forces. Once this model is established and comprehended, we can delve into its realism, its alignment with real-world observations, and potential modifications to enhance its accuracy in replicating real-world outcomes.

It is crucial to acknowledge that the proposed ABM model operates under two essential assumptions. Firstly, it assumes full information, whereby all tentative contracts are promptly made known to all economic agents in the market, enabling them to make more informed counteroffers. Secondly, it assumes zero transaction costs, allowing students to transit from one house to another without being impeded by search costs or other frictional expenses. Both assumptions hold significant importance. The ABM can be further employed to elucidate how the model can be adapted and modified to accommodate changes when these assumptions are relaxed.

Conclusion

This paper presents a novel explanation of the supply and demand model, highlighting its usefulness in elucidating the functioning of real markets to students. The utilization of Agent-Based Modeling (ABM) offers numerous advantages over traditional approaches to teaching supply and demand, as it bypasses artificial conventions necessitated by the standard method, such as Walrasian tatonnement. Additionally, ABM allows for more efficient experimentation and explanation of the model's significance, avoiding lengthy time requirements.

To illustrate the workings of the S&D model, an ABM is employed in the context of the housing market, with students and house owners representing the demand and supply sides respectively. Even when matched randomly, as often occurs in real-world markets, the presence of arbitrage motivates both parties to seek better opportunities. Students who secure housing at high rents, upon becoming aware of this information published at the end of the day, strive to move to more affordable housing options to save money. Conversely, house owners are driven by the desire to rent out their properties at higher prices. This individual pursuit by both students and house owners ultimately guides the market towards equilibrium.

This straightforward yet powerful approach to explaining the S&D model proves valuable in helping students comprehend how real markets function. The agent-based approach to explaining S&D dynamics is more intuitive than conventional explanations of the model and requires less extensive exposition than double auction experiments. Moreover, it provides the advantage of relaxing or modifying assumptions, allowing for an exploration of how markets react to inefficiencies. By utilizing the ABM approach to elucidate complex yet fundamental concepts to students, economics education can experience a significant positive transformation.

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Appendices

Appendix 1: The maxBudget of students and minRent charged by homeowners constitute theoretical S&D

Student	maxBudget	House	minRent
S1	1000	H10	100
S2	900	H9	200
S3	800	H8	300
S4	700	H7	400
S5	600	H6	500
S6	500	H5	600
S7	400	H4	700
S8	300	H3	800
S9	200	H2	900
S10	100	H1	1000

Appendix 2: Recontracting Over Days