Local Market Effects with Heterogeneous Expectations

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Abstract. This study presents an agent-based model (ABM) to simulate a local economy, focusing on the influence of agent heterogeneity and spatial dynamics on economic outcomes. Through two experiments, the model explores factors such as competition, search costs, and spatial constraints. Results reveal emergent phenomena, including scenarios resembling Diamond's Paradox. While offering insights, the model lacks calibration to real-world data and external validation. Nonetheless, it provides a basis for further research on decentralized economic systems and as an example supporting the view of socio-economic systems as a type of Adative Complex System (ACS).

1. Introduction.

Understanding the dynamics of market prices and inflation through the lens of individual economic behaviors has long posed a challenge to economists. Traditional macroeconomic models, such as Dynamic Stochastic General Equilibrium (DSGE) models, have been widely adopted by central banks and policymakers for economic analysis and forecasting. However, these models have faced increasing criticism due to their reliance on strong and often unrealistic assumptions, such as fully informed rational agents, perfect competition, and instantaneous price adjustments (Colander et al. 2008; Stiglitz 2018). These assumptions oversimplify the complexities of real-world economic behavior and interactions, limiting the models' ability to capture the heterogeneity and adaptive nature of economic agents.

Agent-Based Models (ABMs) offer an alternative approach that can better represent the decentralized decision-making processes and emergent phenomena observed in econo-

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mies. By simulating the interactions of heterogeneous agents following simple behavioral rules, ABMs can generate complex macro-level patterns that arise from micro-level actions and interactions (Tesfatsion 2006; J. Doyne Farmer 2009). This bottom-up approach aligns well with Friedrich Hayek's perspective on the dispersion of knowledge in society, where individuals possess unique local information that guides their economic decisions (Hayek 1945).

Recent years have witnessed a growing interest in ABMs within the field of macroeconomics, with several central banks and research institutions exploring their potential for policy analysis and scenario testing. Notable examples include the European Central Bank's exploration of ABMs for stress testing financial systems (R. M. Bookstaber, Paddrik, and Tivnan 2017; R. Bookstaber 2017), and the Bank of England's use of ABMs to study the impact of macroprudential policies on the housing market (O Baptista et al. 2016). Inspired by Hayek's seminal work and the increasing adoption of ABMs in macroeconomics, this study aims to develop an agent-based model that simulates a local economy with multiple regions and markets, where households and factories interact as consumers and producers. I aim to explore how heterogeneous expectations and local decision-making among economic agents can influence broader variables such as inflation and market prices.

This project's overarching goal is to investigate how the spatial component of economic interactions and the introduction of search costs can affect phenomena like the dispersion of knowledge and bounded rationality among agents. Specific areas of focus include the impact of competition on consumer expectations and the emergence of scenarios akin to Diamond's Paradox, where search costs and product differentiation lead to price increases above competitive levels, despite the presence of numerous sellers (Diamond 1971; Anderson and Renault 1999). By accounting for the heterogeneity and bounded rationality of economic agents, this approach seeks to offer a more nuanced and realistic representation of economic phenomena, thus complementing and potentially enhancing traditional macroeconomic modeling techniques.

The structure of this paper is as follows: Section section 2 details the model following the conventions of the ODD protocol, emphasizing the submodules and their functions. Section section 3 presents the analysis of the experiment results, and the conclusions are discussed in Section section 4.

2. Methods. The proposed agent-based model aims to simulate a local economy with multiple regions and markets, where consumers and producers interact through market transactions. The model captures the spatial component of economic interactions by explicitly accounting for the distance between agents' locations and the markets they choose to participate in. This spatial aspect introduces search costs, as agents must expend effort (simulated as movement) to reach their desired markets.

Following Friedrich Hayek's theory, this model emphasizes the decentralization of knowledge in society, suggesting that individuals possess unique information about their specific circumstances that is critical for informed economic decisions. This idea contrasts the popular assumption that ***all*** economic agents 1) have access to perfect information and 2) have the tools or skills to make optimal decisions based on such information. In the proposed model, agents possess only partial information about the overall system but acquire perfect local knowledge through their interactions in the markets. This means that all agents are aware of global aggregates, like average price level, yet each of them have unique time-dependent local information, like local price at a given time step.

ABM models are inherently decentralized and thus allows agents to form and act on their expectations based on both personal experiences as well as local market conditions. By simulating these dynamics, the model hopes to offer a more detailed understanding of how decentralized knowledge and individual decision-making contribute to the complexity of economic systems. Therefore, pushing forward the interpretation of socio-economic systems as a type of Adaptive Complex System (ACS).

Model Overview. In this section, we detail the structure and mechanics of the Agent-Based Model (ABM) developed using NetLogo to simulate a closed (i.e., no trade) local economy with no government. This model includes consumers, producers, and market patches as the main agents, each endowed with specific state variables and behaviors that interact within a simulated environment to explore economic dynamics.

The simulation operates within a 25x25 grid, with a centered origin, which abstractly represents the geographical distribution of a local economy. This grid is divided into regions, each containing a number of market patches, colored red, where economic interactions occur. The environment is structured to mimic real-world spatial economics where the physical distance between agents and markets affects decision-making due to associated search costs. Agents must expend effort (simulated as movement) to reach their desired markets, which influences their decision-making processes and economic outcomes.

The simulation follows a discrete sequence of events, where agents:

1. ***Target Market Determination***: Agents identify their target market by considering spatial proximity, local information (e.g., last price paid for consumers, last demand supplied for producers), and aggregate statistics (e.g., average price, average demand in the local economy). This process involves weighing the trade-offs between proximity and anticipated economic benefits.
2. ***Movement***: Agents move towards their chosen target market, with their movement governed by their current state (e.g., moving to the market, at the market, returning home).
3. ***Production and Consumption Decisions***: Once at the market, producers determine their output levels based on their demand expectations, costs, and market conditions, while consumers make consumption decisions influenced by their wealth, price expectations, and the available supply.
4. ***Market Interaction***: Agents engage in economic transactions within the market,

exchanging goods and adjusting market prices based on the balance of supply and demand.

5. ***Expectation Formation and Adaptation***: Agents update their price and demand expectations based on their market experiences and the aggregated information from the local economy. They also adapt their strategies (e.g., target market, consumption, or production levels) based on the outcomes of their last period actions and those of other market participants, capturing the dynamic nature of economic market interactions.
6. ***Return to Origin***: After five ticks at the market, agents return to their origin (household or factory) to prepare for the next market visit.

State Variables for Agents. Agents are assumed to have local information through experience and aggregated information through "government statistics". While global economic indicators such as average price levels are known to all agents, local market conditions can only be assessed through direct interaction, embodying Hayek's concept of decentralized knowledge. Thus agents adapt quickly to local changes while also sensing the average level of their variable of interest over the whole economy. Moreover,

The state variables associated with each agent type capture various economic factors that govern their behavior and interactions within the local economy, as detailed in Table 1.

[1]Coordinates are set based on the location of the household or factory patch to represent spatial initial conditions.

[2]The current version does not implement additional costs because producers are not capturing profits. The cost is mainly used by producers to check if they have paid more than the average of all producers.

[3]Markets must wait for producers to supply initial output so they all start with no quantity available for consumption.

[4]Base price is set to $10 to establish a starting point for market transactions.

Agent Type	Variable	Initialization
Consumers	wealth	$\sim$ Normal$(500, 50)$
	wage	$\sim$ Normal$(300, 15)$
	price-expectations	$\sim$ Uniform{"up","stay","down"}
	debt	~ 0
	demand	~ 0
	unmet-demand	~ 0
	last-price-paid	~ 0
	origin-x	Set based on household patch[1]
	origin-y	Set based on household patch[1]
	target-market	$\sim$ *Nobody*
	steps-to-market	~ 0
	state	"moving-to-market" initially
	ticks-at-market	~ 0
Producers	output	~ 0
	costs	Cost of supplying output[2]
	capacity	~ 150
	demand-expectations	$\sim$ Uniform{"up","stay","down"}
	last-demand-supplied	~ 0
	origin-x	Set based on factory patch[1]
	origin-y	Set based on factory patch[1]
	target-market	$\sim$ *Nobody*
	steps-to-market	~ 0
	state	"moving-to-market" initially
	ticks-at-market	~ 0 [3]
Market Patches	quantity-available	~ 0
	unit-price	Base price[4]
	market-capacity	~ 150

Table 1: Initialization of state variables for each agent type in the NetLogo model

2.0.1. Design Concepts. The model is grounded in basic principles from classical and spatial economic theories. Market dynamics such as pricing and supply-demand equilibrium are not directly controlled but **emerge** from decentralized decision-making processes among agents. These processes are facilitated by a series of submodules detailed in Table 2, which categorize these functionalities and their roles within the simulation. Moreover, the following design concepts from the Overview-Design Concepts-Details (ODD) protocol are implemented in the proposed ABM.

Adaptation and Learning: Agents form and update their price and demand expectations based on their experiences and the aggregated information from the local economy. For instance, a consumer whose recent purchases have consistently been below the average market price might adjust their price expectations downwards, anticipating cheaper prices in the future. But if the market lowers its price enough, it may attract other agents; this generates interesting feedback loops. Conversely, a producer noticing a sustained increase in demand might scale up production. These adjustments are facilitated by the 'adjust-expectations' submodule, which recalibrates agents' expectations based on market feedback.

Sensing and Interaction: Economic transactions are conducted at the market patches, where the 'new-price' submodule updates the prices based on the supply-demand balance. If a particular market experiences a higher demand than supply, the price adjustment mechanism ensures prices rise, reflecting scarcity and incentivizing producers to increase supply. If demand exceeds supply, the price increases by up to 2%, scaled by the ratio of unmet demand to total demand. Conversely, if supply exceeds demand, the price decreases by up to 5%, scaled by the ratio of unmet supply to total supply.

Stochasticity: The model introduces variability in economic behaviors through probabilistic initializations, such as the distribution of wealth and wages among consumers. This stochasticity leads to diverse economic outcomes, illustrating how individual variations can influence macroeconomic trends like inflation and market stability.

Observation: To monitor the model's dynamics and assess the effectiveness of economic interactions, submodules like demand-expectations-plot and price-expectations-plot track changes in agents' expectations and market prices over time. This data helps in understanding the broader economic implications of localized interactions and decision-making processes. Their main purpose is to facilitate the experiments conducted to assess the model.

Category	**Submodule**	**Purpose**
Creating	create-households	Initializes consumer agents in household patches.
	create-markets	Initializes market patches.
	create-factories	Initializes producer agents in factory patches.
Movement	determine-target-market	Determines the target market for each agent based on proximity and other factors.
	move-towards-market	Moves agents towards their chosen market.
	return-to-origin	Sends agents back to their starting points after completing their market activities.
	return-to-market	Determines when agents should head back to the market from their origin.
Market Interactions	consumer-decision	Manages the purchasing decisions of consumers based on current market conditions and personal circumstances.
	producer-decision	Manages the production and pricing decisions of producers based on market demand and other factors.
Adjustments	new-price	Adjusts the price in market patches based on supply and demand dynamics.
	adjust-expectations	Updates the expectations of agents based on market outcomes and experiences.
Utilities	update-market-time	Updates the amount of time agents spend in the market.

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Category	Submodule	Purpose
	at-market?	Checks if an agent is at their target market patch.
	collect-market-prices	Get the unit-price of each market in the simulated economy. Used in Experiment 2.
	calculate-average-price	Calculate average price level amongst all markets in simulated economy. Used in Experiment 2.
	num-expect-up	Reporter for counting consumers expecting prices to go up. Used in Experiment 1.
	num-expect-down	Reporter for counting consumers expecting prices to go down. Used in Experiment 1.
	num-expect-stay	Reporter for counting consumers expecting prices to stay the same. Used in Experiment 1.
Visualizations	demand-expectations-plot	Visualizes the demand expectations over time for analysis.
	price-expectations-plot	Visualizes the price expectations to monitor economic sentiment among agents.

3. Analysis and Results.

3.1. Experiment 1: Consumer Expectations and Market Competition. In the first experiment, I investigate how the variation in the number of households and consumers within a local economy affects consumer expectations regarding future prices. Particular focus is places on understanding the impact of market competition on the anticipation of price movements.

The hypothesis posits that as the number of consumers in the local economy increases—suggesting heightened competition—there would be a corresponding rise in the number of consumers who expect prices to decrease. This is premised on the economic principle of delayed consumption due to expected deflation, where consumers postpone purchasing durable goods in anticipation of lower future prices.

Upon analyzing the correlation matrix, we observed a robust positive correlation between the number of consumers and the frequency of 'down' price expectations (see Figure 1). This result is in line with the hypothesized behavior, suggesting that an increase in market participants, while keeping the availability of markets and producers constant, enhances competition, subsequently driving prices down and influencing consumers to expect further price decreases.

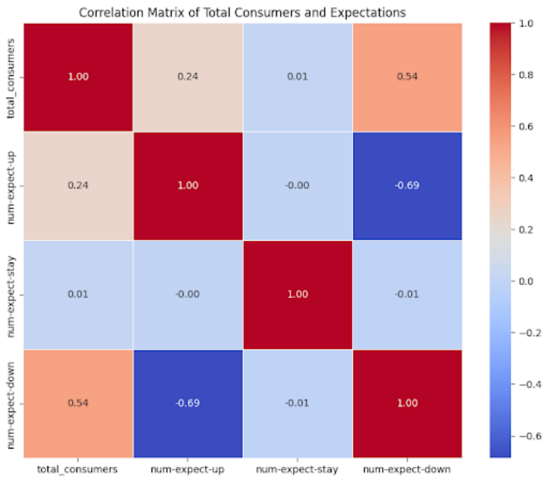

Figure 1: Correlation: Number of consumers vs. expectation type

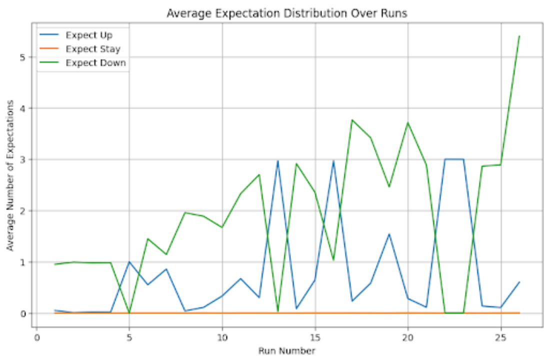

Figure 2: Average number of expectations by type

Figure 2's line plot reinforces this narrative, illustrating a clear upward trend in the average count of 'down' expectations correlating with an increased number of consumers. This visualization captures the essence of consumer sentiment over successive runs, echoing the theoretical underpinning of delayed consumption in the face of expected deflation.

3.1.1. Zero-Inflated Poisson Regression Analysis. To validate these findings and ensure statistical significance, a zero-inflated regression analysis was conducted. The data presented an excess of zero counts, which traditional count models often fail to address adequately. The Zero-Inflated Poisson (ZIP) model, designed to account for surplus zeros, incorporates two processes: a count model following a Poisson distribution and an inflation model for the excess zeros.

Table 3: Zero-Inflated Poisson Regression Results

Dep. Variable:	num-expect-down	**No. Observations:**	29237
Model:	ZeroInflatedPoisson	**Df Residuals:**	29235
Method:	MLE	**Df Model:**	1
Date:	Tue, 30 Apr 2024	**Pseudo R-squ.:**	0.1019
Time:	03:00:57	**Log-Likelihood:**	-44498.
converged:	True	**LL-Null:**	-49548.
Covariance Type:	nonrobust	**LLR p-value:**	0.000

	coef	**std err**	**z**	**P> |z|**	**[0.025**	**0.975]**
inflate_const	-2.0774	0.050	-41.818	0.000	-2.175	-1.980
inflate_total_consumers	0.1875	0.015	12.578	0.000	0.158	0.217
const	-0.3109	0.012	-25.448	0.000	-0.335	-0.287
total_consumers	0.3541	0.003	105.206	0.000	0.347	0.361

In the count model, the coefficient for the variable 'total_consumers' is statistically significant at 0.3541, suggesting a substantial increase in 'down' expectations with the addition of each consumer. The exponentiated coefficient ($e^{0.3541} \approx 1.425$) indicates that for every new consumer, the likelihood of a 'down' expectation rises by approximately 42.5%. The inflation component of the model also indicated significance with a coefficient of 0.1875 for 'total_consumers', indicating that a higher number of consumers diminishes the probability of observing no consumers with 'down' expectations.

These results validate the initial hypothesis, revealing that consumer expectations in the model are sensitive to changes in the local economy's competitive dynamics. The observed relationship between the number of consumers and price expectations underscores the importance of competition in influencing consumer behavior, particularly in the context of price anticipation.

The ZIP model's findings are particularly revealing, demonstrating that the model's consumers not only anticipate lower prices with increased competition but that this anticipation is statistically significant and has a material impact on consumer expectations. The dual nature of the ZIP model allows us to understand not only the typical behavior but also the instances of zero 'down' expectations, providing a comprehensive view of consumer sentiment in different market conditions.

3.2. Experiment 2: Market Prices Dynamics in Varying Market Structures. In the second experiment, the analysis shifts focus to the price dynamics across different markets within a multi-region local economy. This experiment was designed to explore the implications of varying market structures, specifically the number of markets per region and the total number of regions on market prices.

The hypothesis is rooted in the concept known as "Diamond Paradox," which suggests that while search costs and product differentiation initially foster competitive pricing, they can also create an opportunity for arbitrage. Should a market exploit this by increasing its prices, other markets may respond similarly, potentially precipitating market failure through hyperinflation.

As visualized in Figures 3, 4, and 5, the initial phase of the simulation showed a decline in prices towards equilibrium. However, in line with the "Diamond Paradox," a subsequent disruption occurred: a single market capitalized on an arbitrage opportunity, which resulted from costly search efforts and agents' adaptations in selecting their target market. This led to a cascading effect where other markets increased their prices in response, ultimately resulting in hyperinflation across the local economy.

3.2.1. Diamond's Paradox. The phenomenon known as "Diamond's Paradox" unfolds within our simulation in a particularly illustrative manner. The paradox arises under

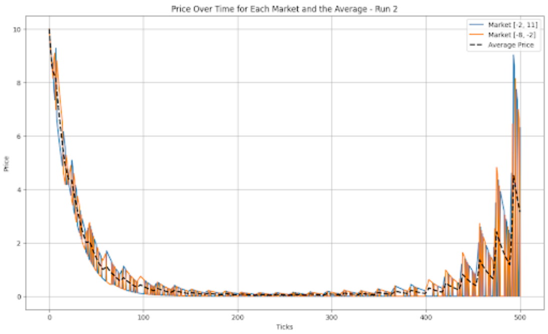

Figure 3: Prices of 2 markets

Figure 4: Prices of 15 markets

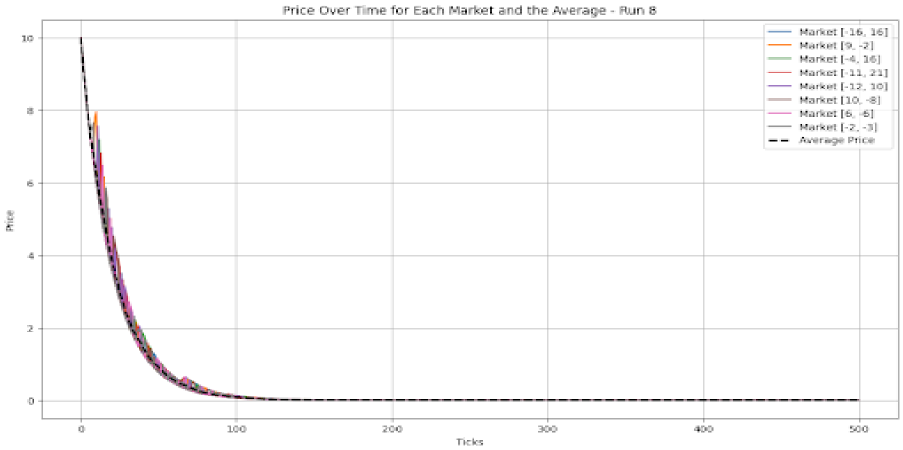

Figure 5: Prices of 8 markets

specific market conditions—where consumers, in pursuit of lower prices, gravitate towards a market offering costs just shy of a monopoly's. Producers, attracted by this aggregation of demand, flock to the market in question. The consumers' reluctance to continue their search due to associated costs and cheap prices results in an opportunity for the market to hike prices substantially. Once this initiates, a domino effect is triggered, as other markets increment their prices, causing an inflationary spiral that culminates in a market failure characterized by hyperinflation.

Interestingly, the model's probabilistic nature—stemming from heuristic-based agent behavior—allows for variability in outcomes. In some runs, such as experiment number 8, the "Diamond Paradox" does not manifest, highlighting the stochastic element of market dynamics within the model. This stochasticity reflects the unpredictability inherent in real-world economies, where outcomes can diverge based on the nuances of agent behaviors and interactions.

While the model presented in this study offers valuable insights into the dynamics of local economies and the role of agent heterogeneity in shaping economic outcomes, it is important to acknowledge its limitations and areas for further exploration. In the following Conclusion section, we discuss these limitations in more detail and propose avenues for future research aimed at addressing these challenges and extending the model's applicability.

4. Conclusions. In this study, we developed an agent-based model (ABM) to simulate a local economy with multiple regions and markets, aiming to investigate the influence of agent heterogeneity and spatial dynamics on economic outcomes such as market prices and consumer expectations. Through the analysis of experimental results, key insights have been discovered, shedding light on the emergent phenomena within decentralized economic systems and the practical utility of ABM approaches to macroeconomics.

The model's exploration of agent-based dynamics in a spatially distributed economy highlights the role of individual decision-making and local interactions in shaping macro-level outcomes. By explicitly incorporating elements such as heterogeneous expectations, bounded rationality, and spatial constraints, the model has demonstrated promising potential to capture nuanced dynamics that are often overlooked in traditional macroeconomic models.

However, it is important to acknowledge the limitations of the model and the scope for further refinement and extension. Firstly, the initialization of parameters in the model is not calibrated to real-world data, representing a simplification that may limit the model's predictive accuracy. Additionally, the absence of external validation poses a challenge in assessing the model's fidelity to empirical observations. It is essential to recognize that the primary goal of this study was not predictive accuracy but rather to explore the potential implications of agent-based dynamics in an abstracted economic setting.

Future research efforts could focus on several avenues to address these limitations and enhance the model's robustness and applicability. Firstly, incorporating empirical data to calibrate the model's parameters could improve its realism and predictive power. This would involve gathering data on key economic variables such as consumer preferences, production costs, and market dynamics, and integrating this information into the model's initialization process.

Furthermore, extending the model to incorporate additional factors such as government interventions, external shocks, and feedback loops with other economic systems could provide a more comprehensive understanding of real-world economic phenomena. By enhancing the model's complexity while maintaining its computational tractability, researchers can explore a broader range of scenarios and policy implications, informing decision-making processes in both academic and policy spheres. Effectively leveraging the ABM framework as a "virtual laboratory" to test localized policy interventions under various simulated scenarios.

In conclusion, this study represents a step towards bridging the gap between macroeconomic theory and agent-based modeling, offering new insights into the dynamics of decentralized economic systems. While the model presented here is not without its limitations, it serves as a valuable foundation for future research aimed at understanding and addressing the complexities of real-world economies. I cannot wait to continue developing this framework.

Appendix A. An example appendix: Code. All replication material (i.e., NetLogo code, Python notebook for data analysis, and Behavior space spreadsheets) can be found in the Github repository. Previous versions to the final ABM model are included in the 'Final Project' folder.

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