

Interest rate, prices and opinion spreading

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Abstract

The purpose of this model is to study, through agent-based simulation:

- the evolution of prices depending on the interest rate;
- the reciprocal influence among agents through the methodology of networks aimed at behavior in the stock market.

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1 Introduction

This model aims to spontaneously bring out some macroeconomic regularities - an approach defined *generative social science* by Epstein [2] - starting from a set of interacting agents, with the purpose of reaching phenomena like inflation and the behavior regarding changes in the interest rate, passing through the match between supply and demand according to an Hayekian market model [1].

The factors involved play the role of changing agents' behavior; the interest rate of bonds acts on both households and firms, the formers because they will compare the convenience with respect to the stock market, the latters because they will have a certain expectation about the goods market - and the economy in general - which changes also with interest rate; a gain in the stock market can induce the household to consume more in the market of goods even if it does not actually possess more liquidity, a behavior attributable to the real world for simple psychological reasons - and just because agents are not completely rational, otherwise the consumption will decrease when its affairs on the stock market go badly.

2 The Model

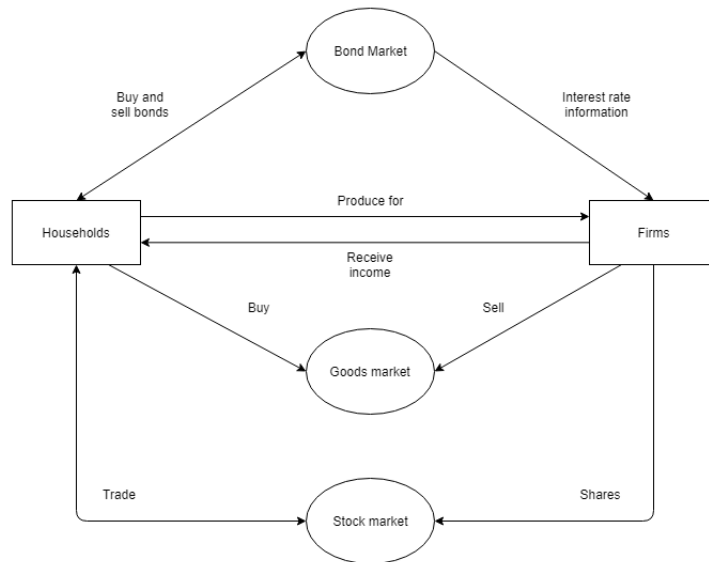


Figure 1: The diagram of the model

Agents:

- *Households*, who are hired by firms, produce, buy goods and bonds, trade stocks; their behavior can change several times over the chosen period.
- *Firms*, that hire households, sell goods and adapt their displayed price taking the interest rate into consideration.

Processes:

- *Goods market*, where households buy and firms sell products.
- *Stock Market*, where households trade their share.
- *Bond market*, where households can buy and sell bonds.

Behaviors:

- Adaptation in market
- Belief propagation

The proposed agent-based model, written in Python, focuses on the study of emerging *macro behaviors* starting from different classes of agents (Households, Firms) that interact with each other, through different processes (goods, stock and bond markets), according to certain behavioral rules (adaptation in the market, belief propagation in social networks).

The model is structured in cycles; the begin of a cycle is identified by a tick, and in each cycle, the agents perform some actions defined in a schedule. Through differences between schedules, one can observe and isolate the consequence of each variation.

The interest rate, externally scheduled, can take three values (High, Medium, Low) and the actions performed by the agents are different, based on its value.

Three different schedules are considered in the simulation: a monotonic increasing one, a monotonic decreasing one and a V shaped one; at the begin of each schedule, some cycles are performed at Medium interest rate, giving in this way an initial period of adjustment to the model.

2.0.1 The model in a nutshell

At first, some parameters are requested as input: in our simulations, we used 100 Households, 4 Firms, a 0.5 probability of having a trending agent. More inputs are required from the user regarding the choice whether there should be an influence network between the households (we used a 0.15 probability of

connection for the probability of connection), and the choice of the the unemployment modelling. Other variables of interest can be manually changed in a separate file. After the request of a seed, for the reproducibility of results, the environment is created. The environment is where the households and the firms are created and live, where the scheduled actions are performed and more in general where all the processes happen. In the environment, with every firm a corresponding book is created for the stock market: the book collect the offers by the households and automatically match the offers in a cycle for the shares of the firm. Whenever an action is performed, the agents who perform it are asked one at the time and chosen in random order in each cycle.

2.1 The first model: unemployment at zero level

In this first model, the households can work and produce, buy goods and bonds, trade stocks; the household has a disposable income used to consume, to buy bonds, provided that the proposed interest rate satisfies the household itself, or to buy shares in the stock market, depending on the convenience of buying shares instead of bonds.

Every household starts with some shares for each title and its behavior in the market could be of one of those two types:

- random agent, that randomly decides to ask, bid or hold with a probability based on the interest rate;
- trending agent, that decides to ask, bid or hold depending on the trend of each single title.

By winning in the stock market, it is possible for an household to increase its propensity to invest in certain shares, otherwise if the household were to lose, its propensity to invest in those shares would decrease.

The firm can sell products and vary their prices. The labor market is not modelized, so the firms employ all workers every cycle; these workers produce a single product, then receive the salary based on the average price of products sold by the firm during the previous cycle.

2.1.1 Version I: vanilla

	Agent	Action
1	Households	workAndProduce
2	Households	buyGood
3	Households	buyBond
4	Households	interactWithStockMarket
5	Firms	evaluateAveragePreviousPrice

Action: workAndProduce

Each household is hired randomly by a firm, produce a single good and receive

an income based on the average prices of the previous cycle.

Action: buyGood

The purchase of the good is subject to different constraints: the household must have enough disposable income, the firm must have enough goods in warehouse. If the purchase is finalized, the household will decrease its reserve price, otherwise the household will increase it. With different weights, but always with the same method, the firm updates its price a purchase is completed.

Action: buyBond

The household is able to buy bonds, basing its choice on the current interest rate: it buys bonds more willingly if the interest rate is high, less willingly if the interest rate is low.

Action: interactWithStockMarket

The household has a preference value for each one of the firms, and an action (Ask, Bid, Hold) to perform with shares of the firm itself. The action is based on the nature of the household itself (Random or Trending). Starting with the shares of the firm for which the household has more preference, the action is performed and the eventual matching is performed by the book of the firm.

Action: evaluateAveragePreviousPrice

At the end of the cycle, each firm evaluates its average selling price, quantity that will become the salary for the households in the next cycle.

2.1.2 Version II: evaluating household’s past consumption

	Agent	Action
1	Households	workAndProduce
2	Households	evaluatePastConsumption
3	Households	buyGood
4	Households	buyBond
5	Households	interactWithStockMarket
6	Firms	evaluateAveragePreviousPrice

Action: evaluatePastConsumption

If the household doesn’t buy any good for three cycles, it will increase its reserve price for goods.

2.1.3 Version III: from bonds to shares and vice versa

	Agent	Action
1	Households	workAndProduce
2	Households	evaluatePastConsumption
3	Households	buyGood
4	Households	buyBond
5	Households	interactWithStockMarket
6	Households	checkBondPriceAndConvert
7	Firms	evaluateAveragePreviousPrice

Action: checkBondPriceAndConvert

When the interest rate decreases, the households may convert their bonds into shares, vice versa when the interest rate increases, the household may convert their shares into bonds.

2.1.4 Version IV: firms evaluating the interest rate

	Agent	Action
1	Households	workAndProduce
2	Households	evaluatePastConsumption
3	Households	buyGood
4	Households	buyBond
5	Households	interactWithStockMarket
6	Households	checkBondPriceAndConvert
7	Firms	modifyPriceBasedOnInterest
8	Firms	evaluateAveragePreviousPrice

Action: modifyPriceBasedOnInterest

Taking changes in the interest rate into consideration, the firms modify their behavior keeping prices higher when there is a low interest rate, and being more flexible when the interest rate is higher.

2.1.5 Version V: euphoria for consumption

	Agent	Action
1	Households	workAndProduce
2	Households	evaluatePastConsumption
3	Households	buyGood
4	Households	evaluateEuphoria
5	Households	buyBond
6	Households	interactWithStockMarket
7	Households	checkBondPriceAndConvert
8	Firms	evaluateAveragePreviousPrice

Action: evaluateEuphoria

The household then checks if its shares value is increased or decreased; if the value has grown, the household feels richer and may consume more, buying an additional good.

2.1.6 Version VI: euphoria and sellers' adaptation of prices

	Agent	Action
1	Households	workAndProduce
2	Households	evaluatePastConsumption
3	Households	buyGood
4	Households	evaluateEuphoria
5	Households	buyBond
6	Households	interactWithStockMarket
7	Households	checkBondPriceAndConvert
8	Firms	modifyPriceBasedOnInterest
9	Firms	evaluateAveragePreviousPrice

All the actions are performed together: the first model is complete.

2.2 The second model: a network for opinion spreading

The choice of shares to buy in the stock market or the behavior to maintain on it can be influenced by the first neighbors, according to the Graph theory.

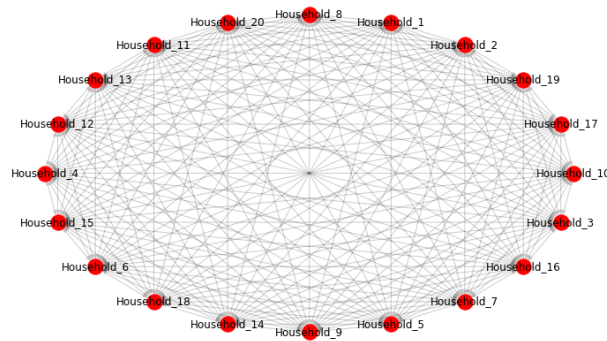


Figure 2: All the network connections

At first, an underlying complete digraph is created. Each node represents a household, each directed link represents the possibility of an influence, from the influencer agent to the influenced one. It contains all the possibles influences, and each link is weighted.

At each tick, given a probability p of connection, a subgraph is extracted from this underlying one, and is used as connection graph for the cycle: this procedure aim at modelling how an household can be influenced by random interaction with his community.

This connection network is a (n,p) Erdos-Renyi random directed digraph. For every household has an inner preference for shares of every firm, and every connection in the network is weighted, the influence can occur through a threshold mechanism based on the weight and the preference.

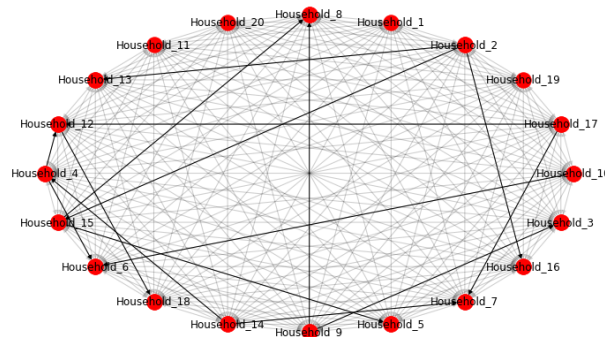


Figure 3: Network connections in a cycle

Each household filters its incoming influences from all its neighbors with this mechanism and, for each firm, the action it'll perform can change or not. If the action is changed, it's changed into the one that has been recommended more times by its neighbors.

At the end of the cycle, the household who changed its action for a firm evaluates the advice itself: depending on the actions it performed and the outcome of the stock market in the turn, the weight of the connection is increased or decreased.

Unlike in the first model, there are no explicit actions added in the schedules: these are automatisms which are consequence of the presence of the network structure.

2.3 The third model: implementing the unemployment

In previous models we have assumed that the worker decides where to work and can therefore do so without having to face any problems. Now, instead, we place an additional constraint: the firm accepts the worker if necessary.

The need for the company to hire workers is given by the amount of required goods, above a certain price, during the previous cycle. In this way, the firm is able to produce without excessive waste.

In order to make the model work, some actions have been modified: the household agent has the possibility to make two attempts both to look for a job and to buy a product. If the household agent doesn't have a job in the cycle, it has a lowered probability to buy the good, simulating the reduction of consumption of an unemployed worker.

To better observe the effects on prices in the goods market and in the stock market, we have assumed that the agents do not use the same disposable income to act on both, but that the stock market is based on separate savings.

2.4 The fourth model: all the effects together

In this model, all the previously analyzed effects are combined, thus considering both network theory and unemployment.

3 The results

3.1 Version I

When interest rates are low, prices in the goods market increase as firms tend not to lower the price, by making a forecast based on the interest rate. The household prefers to invest in the stock market instead of buying bonds, so the price of the shares increases.

On the contrary, prices decrease in the goods market when interest rates are high, since keeping stocks in the warehouse is a cost for the firms - as they would virtually lose the interest rate. The household prefers to buy bonds instead of investing in the stock market, so the price of the shares decreases.

3.2 Version II

The price of the goods tend to increase, due to te lack of matches between household and firm in the goods market. It should be noted that prices tend to

rise regardless of the interest rate. This effect will be compensated with the introduction of the warehouse action.

3.3 Version III

It is possible to observe that with the variation of the interest rate, the shares have a sudden movement in the price, based on the preference of the households who wish to transfer their investments from bonds to shares or vice versa.

3.4 Version IV

In the first and second models, prices remain stable or rise slightly when the interest rate is on the medium value; prices fall when the interest rate is high. In the third model, firms' action is accentuated, so much so that prices fall slightly when the interest rate is on the medium value and decrease sharply when the interest rate is high.

3.5 Version V

Since the first model, prices in the goods market have risen significantly, as earnings in the stock market are reflected in higher consumption for the same production. With the effect of euphoria, prices remain much more stable, even considering the interest rate changes during the various periods.

3.6 Version VI

The effects of the two previous versions are combined: in the goods market the prices vary both following the interest rate for the warehouse cycle and for the effect of a trend in the stock market; the overall result fully reflects the complexity of the combined actions.

3.7 Notes on network

Taking in consideration the network, the most important result is not the creation of a global trend; we observe a smoother transition between price trends, probably because when the interest rate changes its value, the influences prevail on the stock market's signals.

3.8 Notes on unemployment

If the actions of the first and the second models are maintained, we would reach 100% unemployment. By introducing the attempts to buy a good and to search a work, the unemployment rate stabilizes with a variance that depends on the number of attempts.

4 Conclusion

Maintaining the same interest rate for long periods can lead to artificial changes, perhaps desired by those who implement this monetary policy, but which will inevitably have unpleasant side effects.

The worst situation observed in this model is that in which the interest rate is kept low, an attitude that often appears with the intent to stimulate the economy, since both the goods market and the stock market are affected; the former because it can be affected by inflation - in our case due to the expectation of the sellers - the latter because it can be subject to so-called bubbles.

References

- [1] Robert L. Axtell. *Hayek Enriched by Complexity Enriched by Hayek*. Emerald Insight, 2016.
- [2] Joshua M. Epstein. *Generative Social Science: Studies in Agent-Based Computational Modeling*. Princeton University Press, 2007.

5 The plots

5.1 The first model: unemployment at zero level

5.1.1 Version I

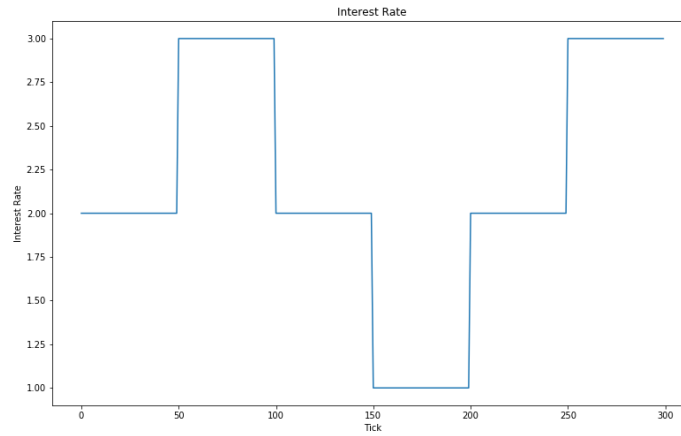


Figure 4: Interest Rate

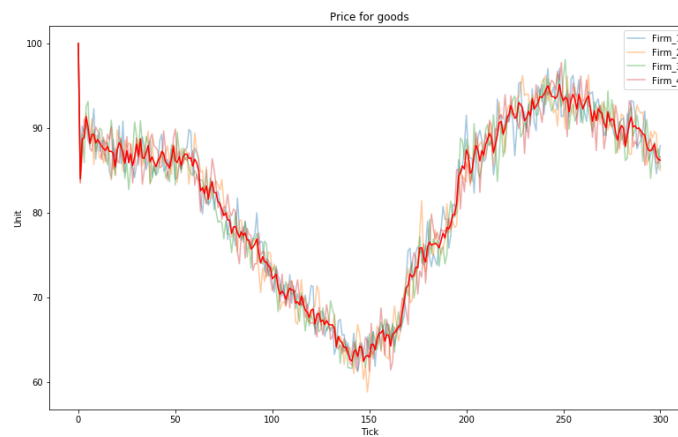


Figure 5: Price for goods

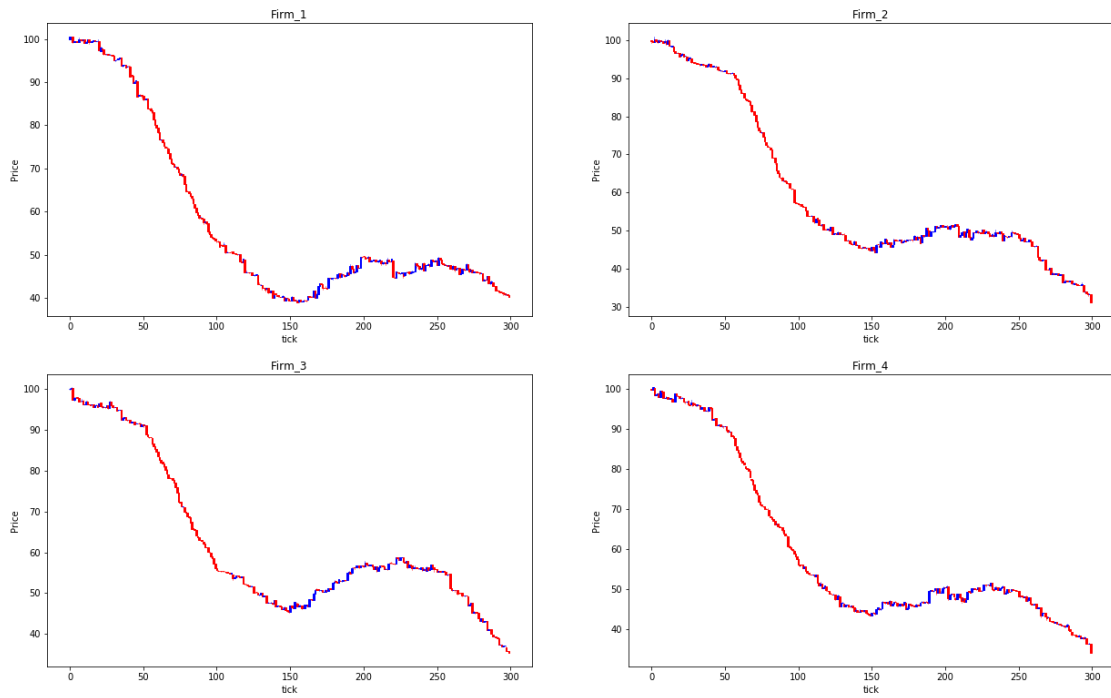


Figure 6: Prices in stock market

5.1.2 Version II

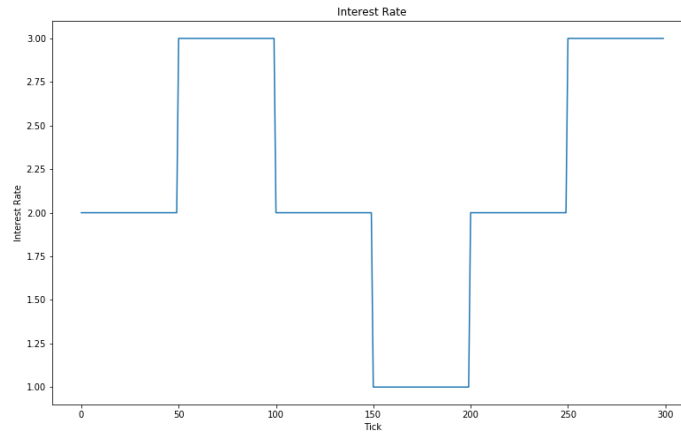


Figure 7: Interest Rate

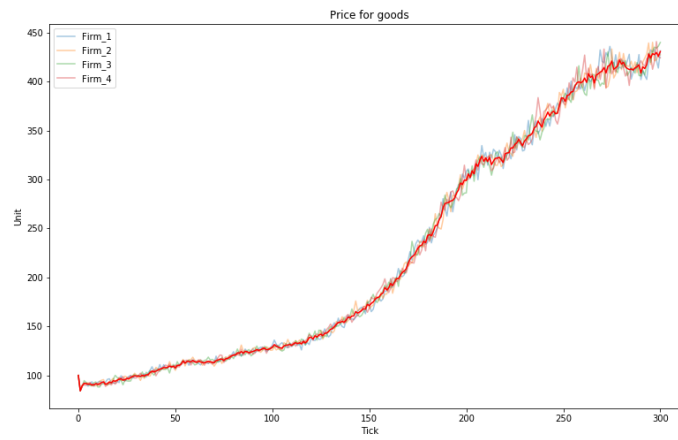


Figure 8: Price for goods

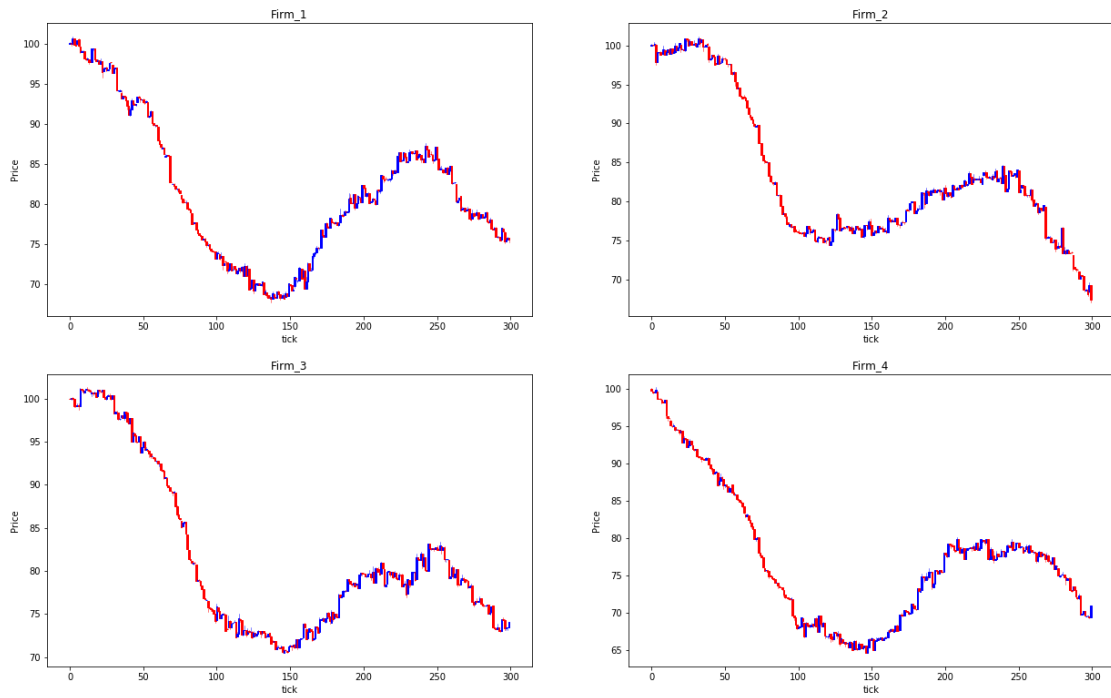


Figure 9: Prices in stock market

5.1.3 Version III

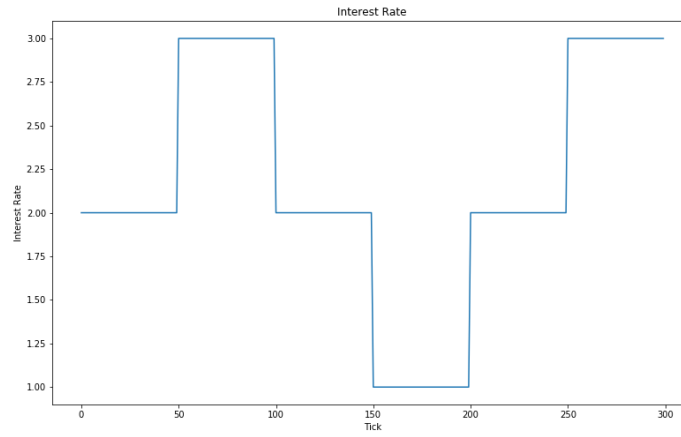


Figure 10: Interest Rate

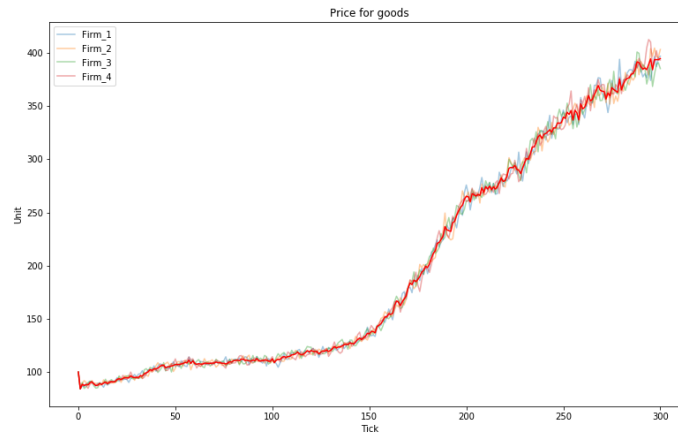


Figure 11: Price for goods

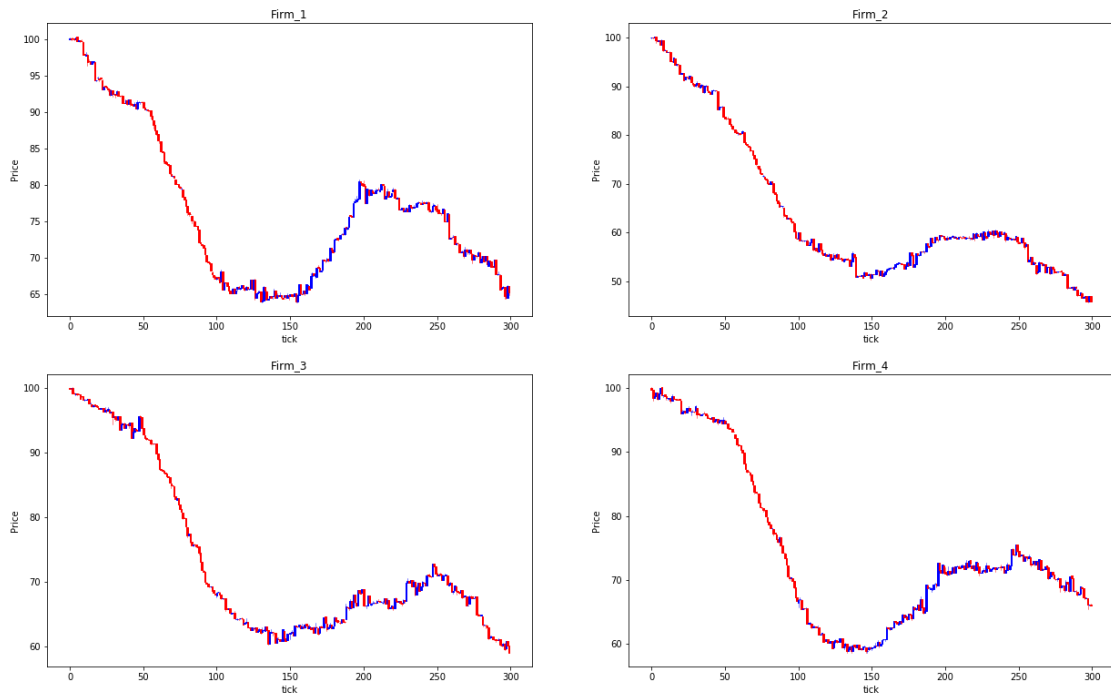


Figure 12: Prices in stock market

5.1.4 Version IV

Pyramid Interest Rate

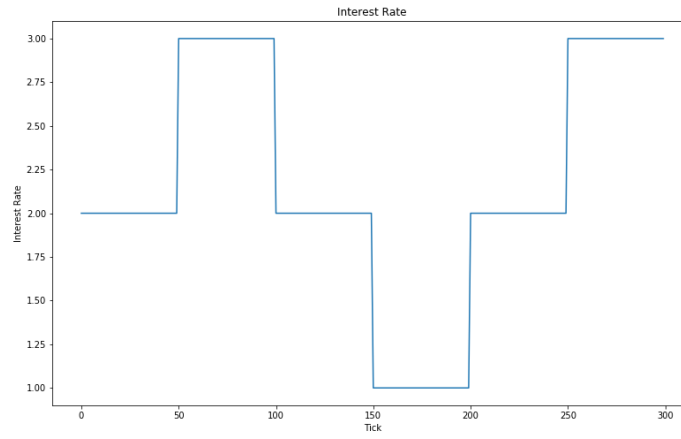


Figure 13: Interest Rate

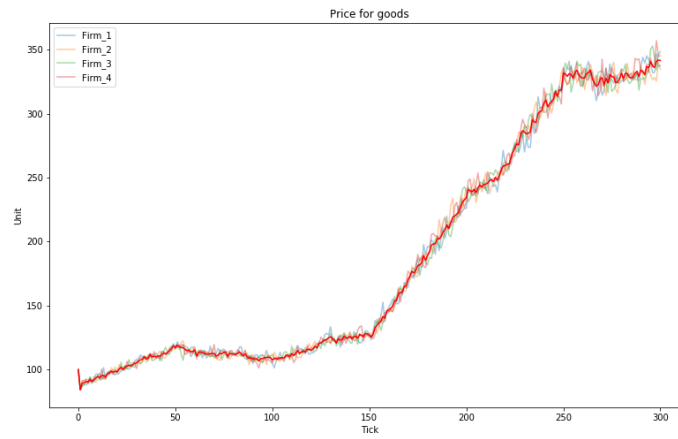


Figure 14: Price for goods

Increasing Interest Rate

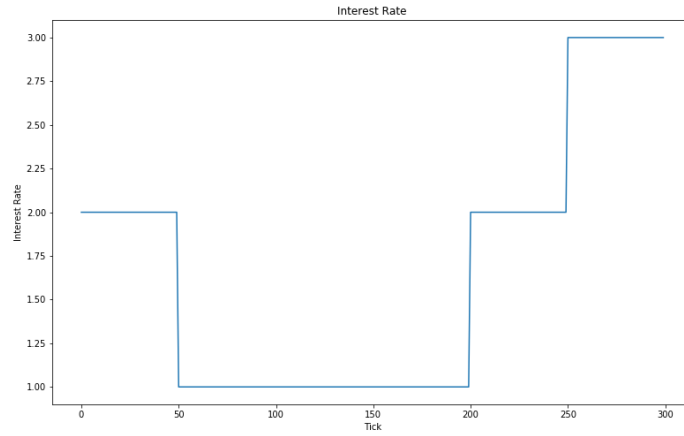


Figure 16: Interest Rate

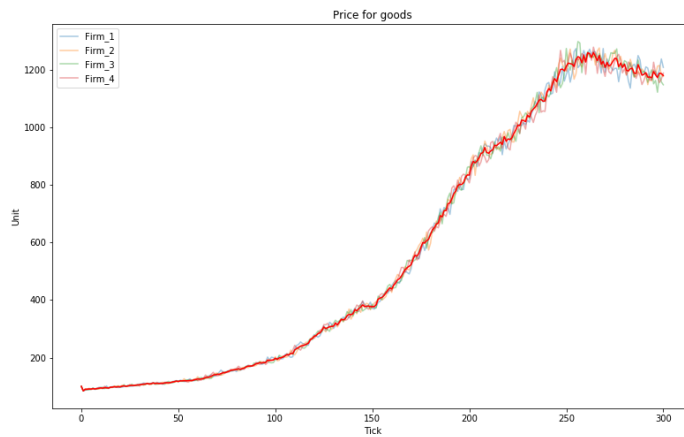


Figure 17: Price for goods

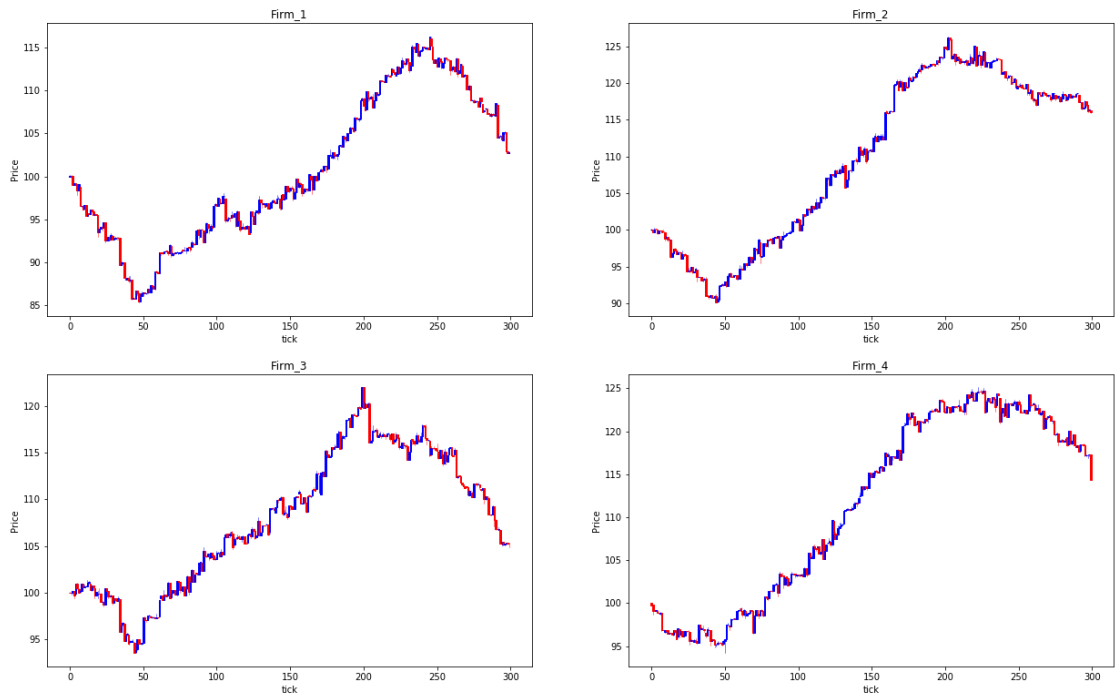


Figure 18: Prices in stock market

Decreasing Interest Rate

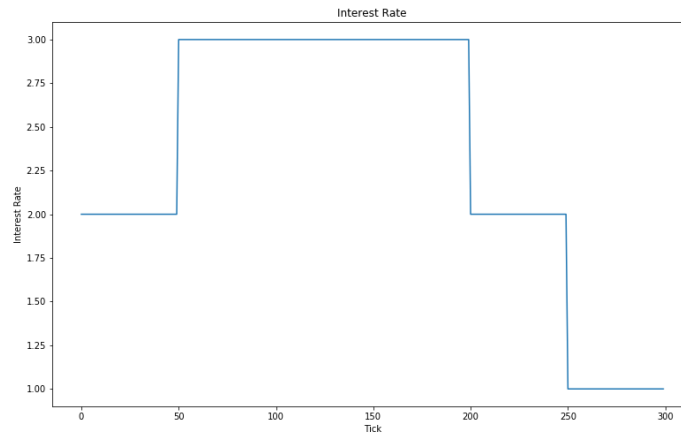


Figure 19: Interest Rate

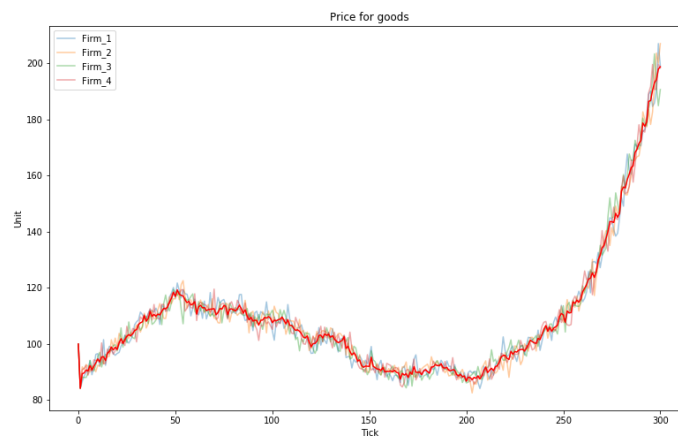


Figure 20: Price for goods

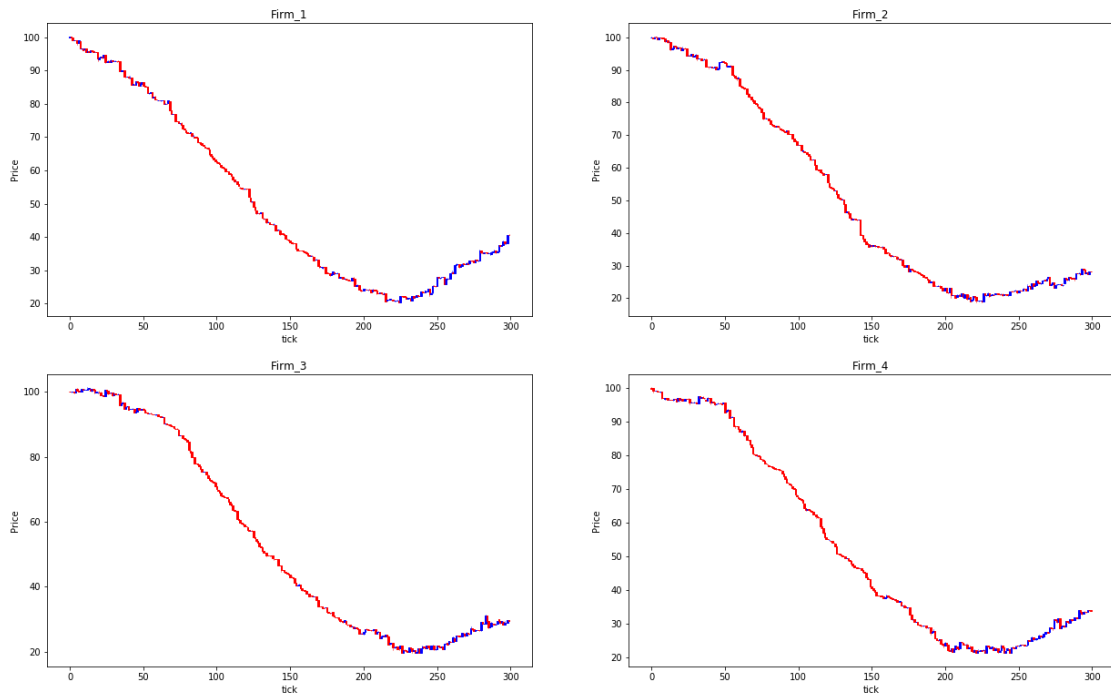


Figure 21: Prices in stock market

5.1.5 Version V
Pyramid Interest Rate

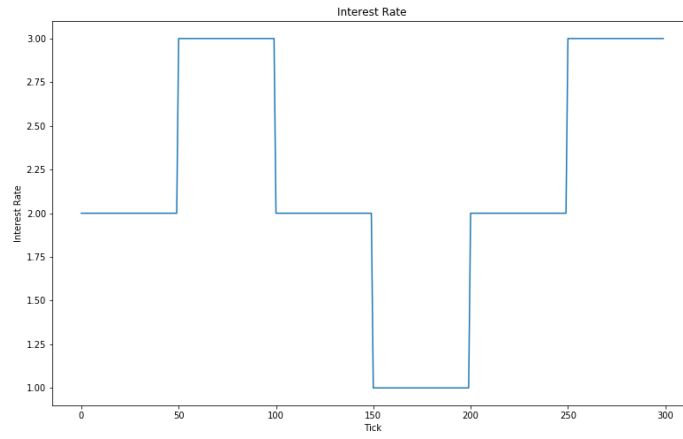


Figure 22: Interest Rate

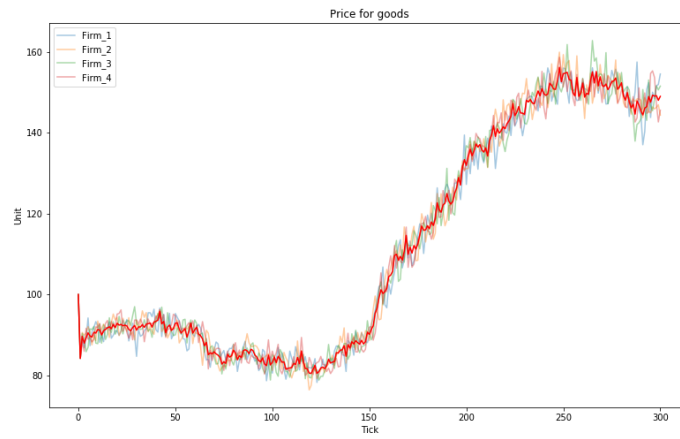


Figure 23: Price for goods

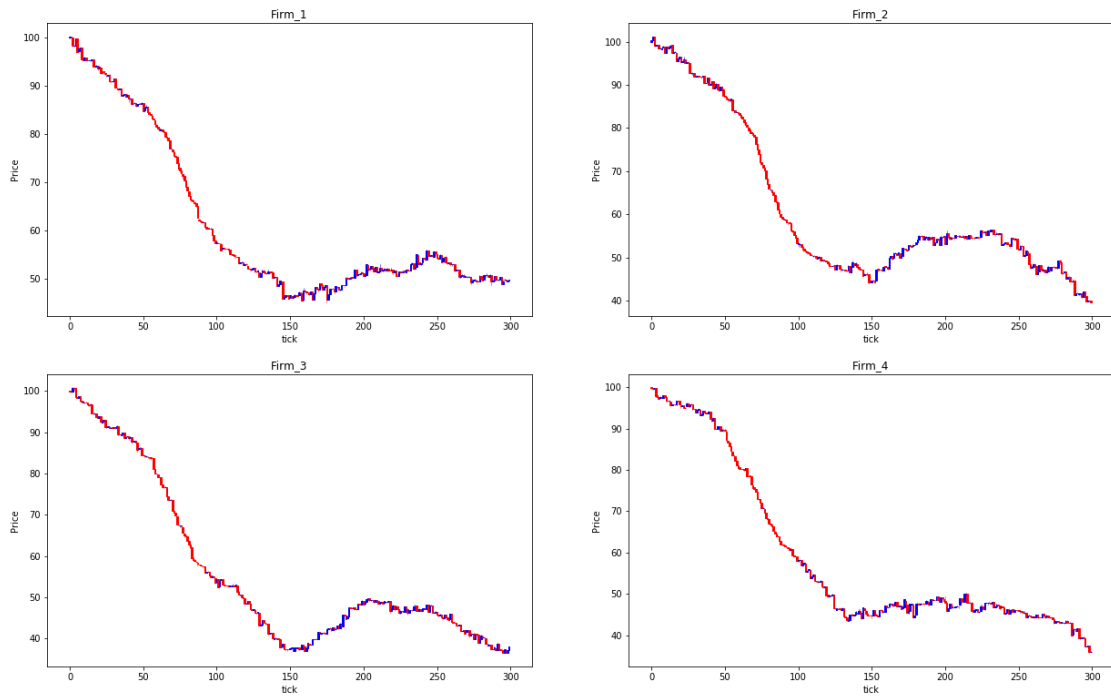


Figure 24: Prices in stock market

Increasing Interest Rate

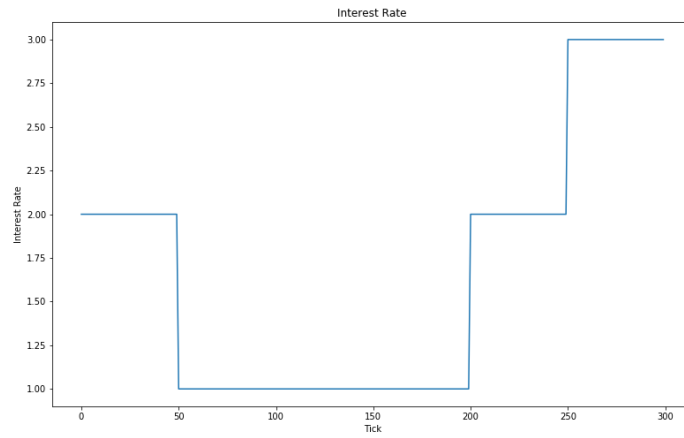


Figure 25: Interest Rate

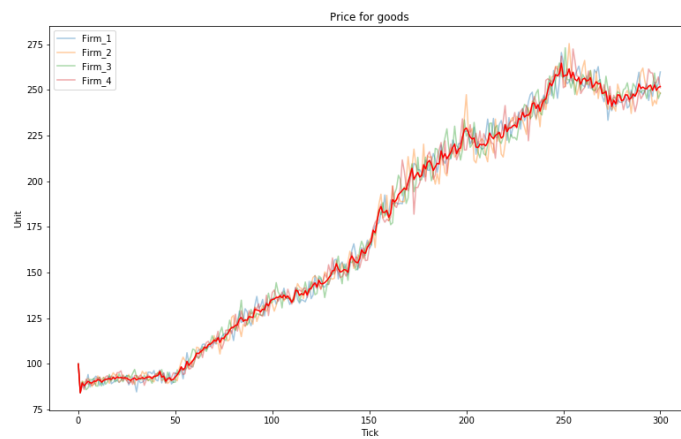


Figure 26: Price for goods

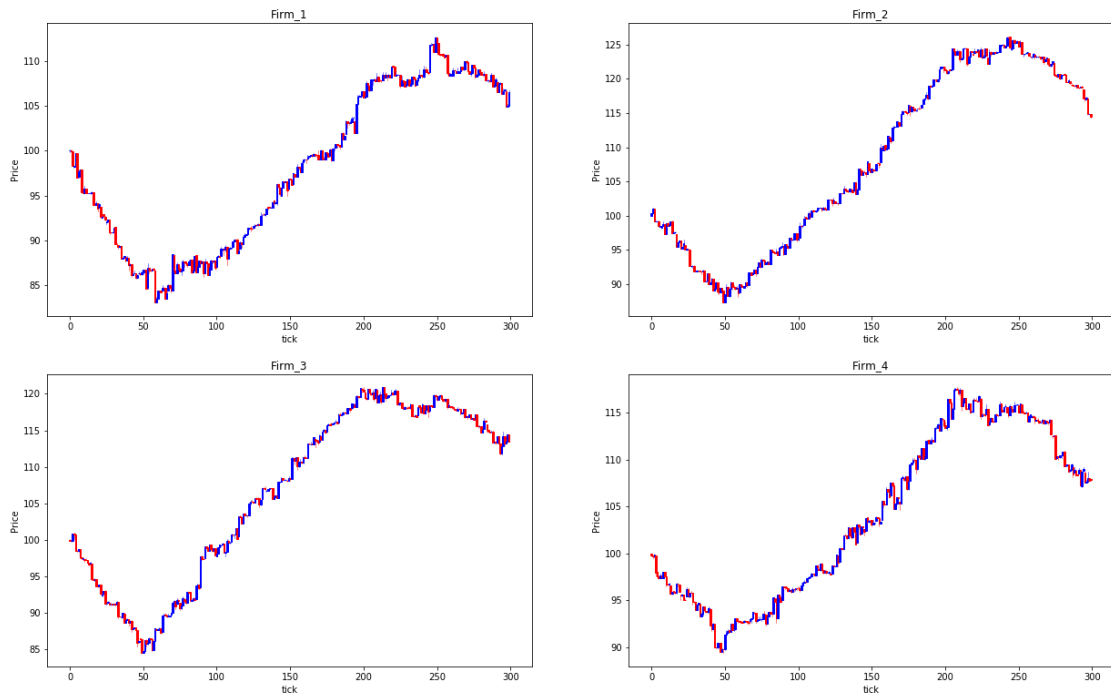


Figure 27: Prices in stock market

Decreasing Interest Rate

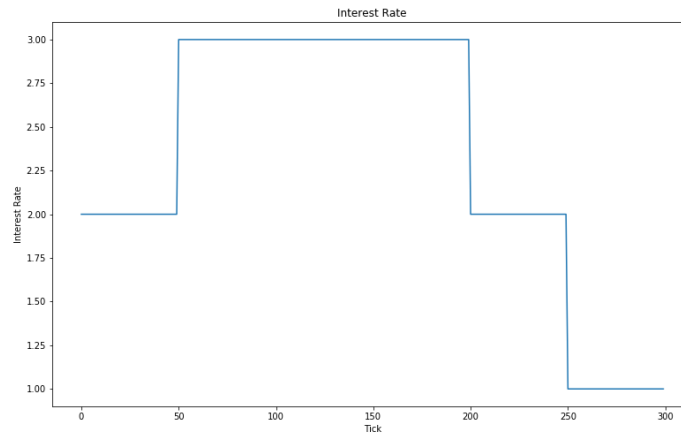


Figure 28: Interest Rate

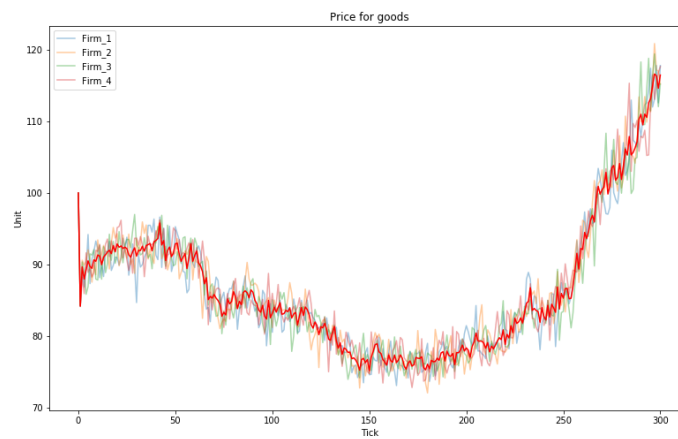


Figure 29: Price for goods

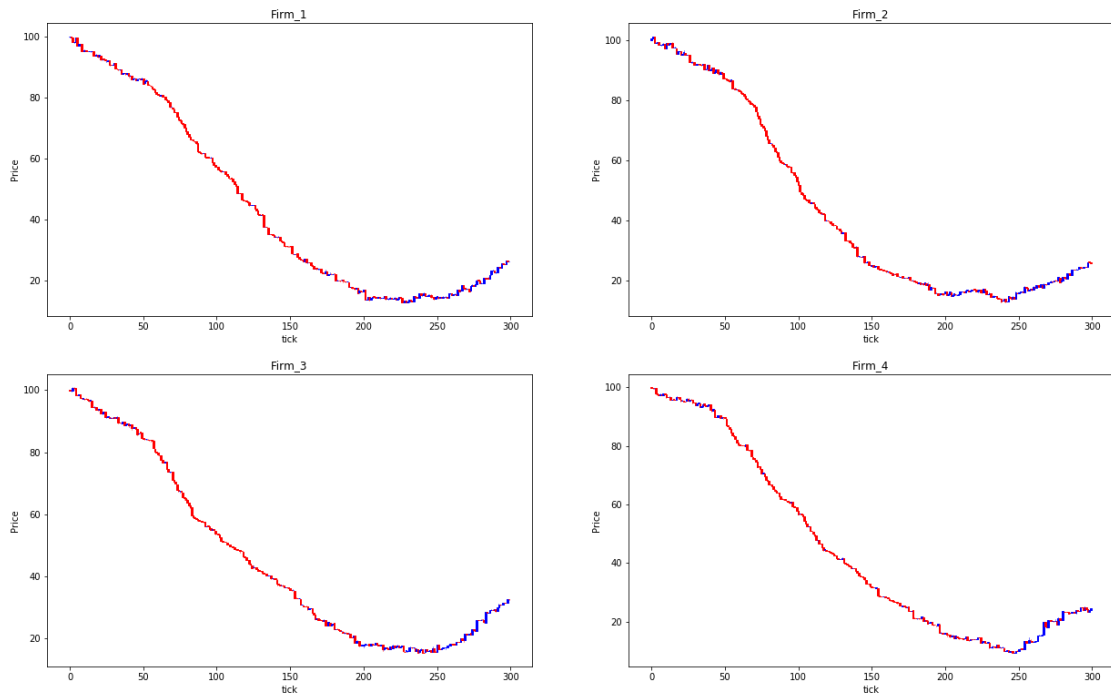


Figure 30: Prices in stock market

5.1.6 Version VI
Pyramid Interest Rate

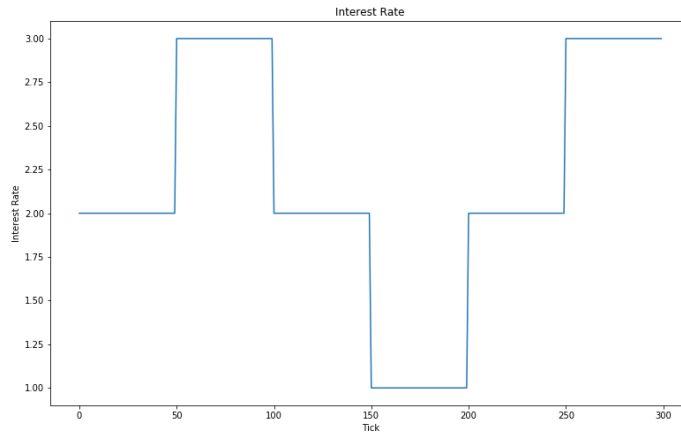


Figure 31: Interest Rate

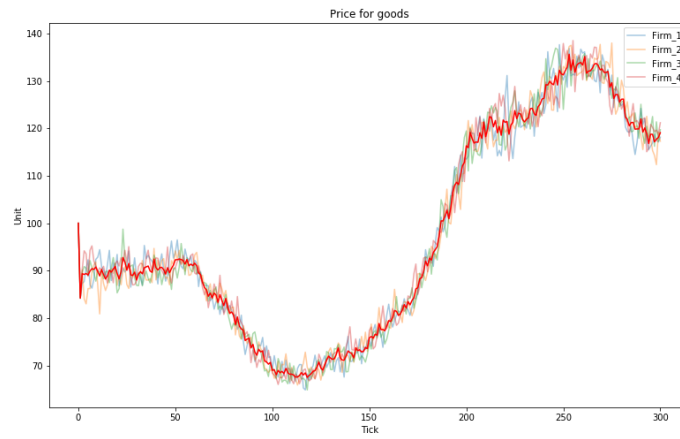


Figure 32: Price for goods

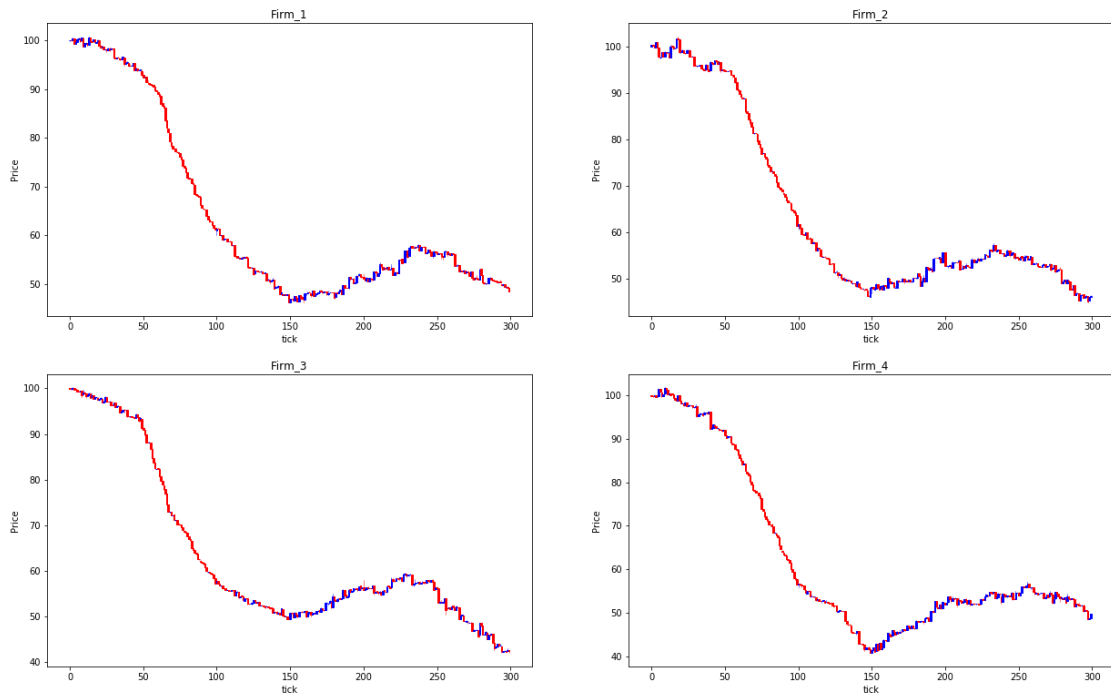


Figure 33: Prices in stock market

Increasing Interest Rate

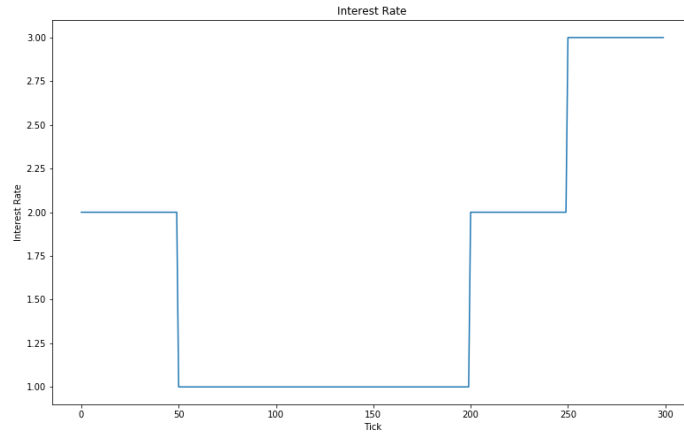


Figure 34: Interest Rate

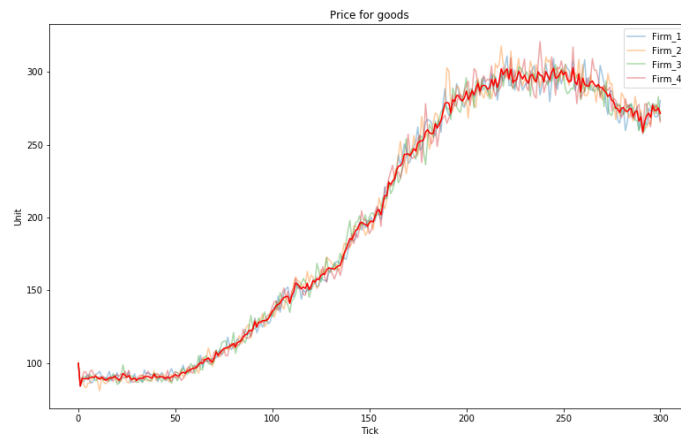


Figure 35: Price for goods

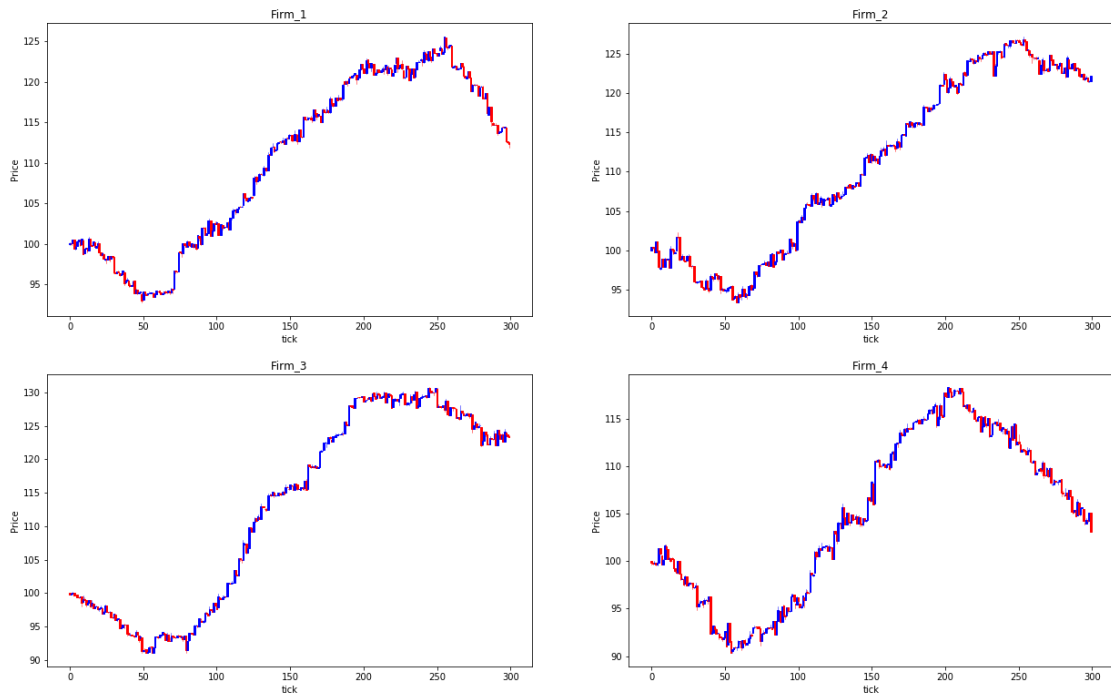


Figure 36: Prices in stock market

Decreasing Interest Rate

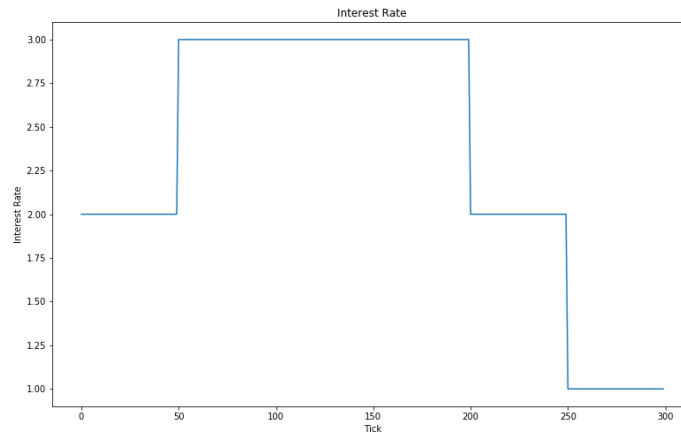


Figure 37: Interest Rate

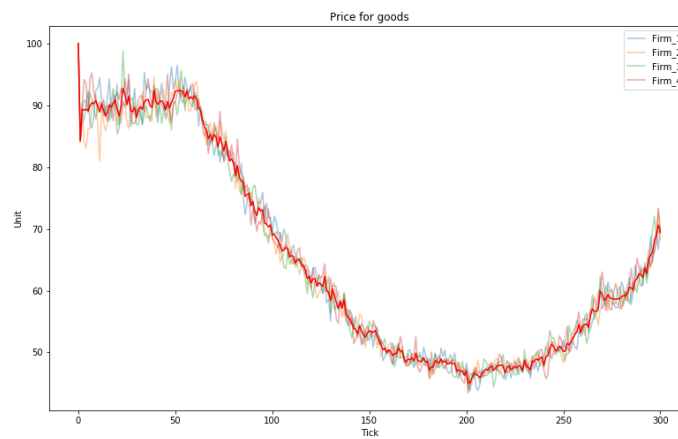


Figure 38: Price for goods

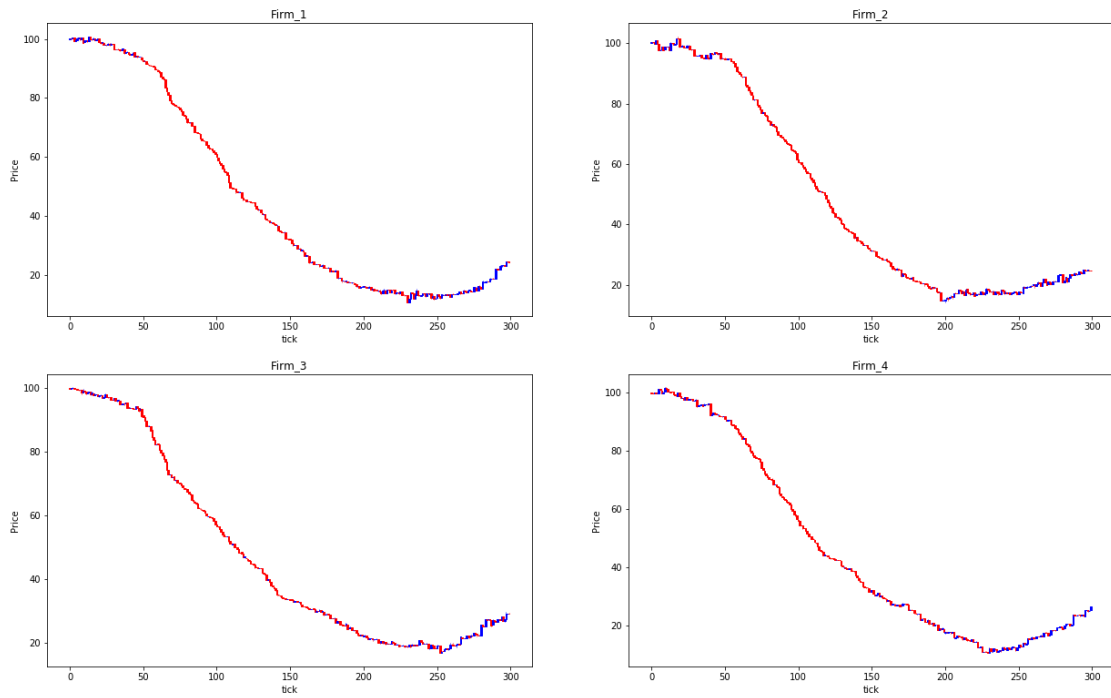


Figure 39: Prices in stock market

5.2 The second model: a network for opinion spreading

5.2.1 Version IV

Pyramid Interest Rate

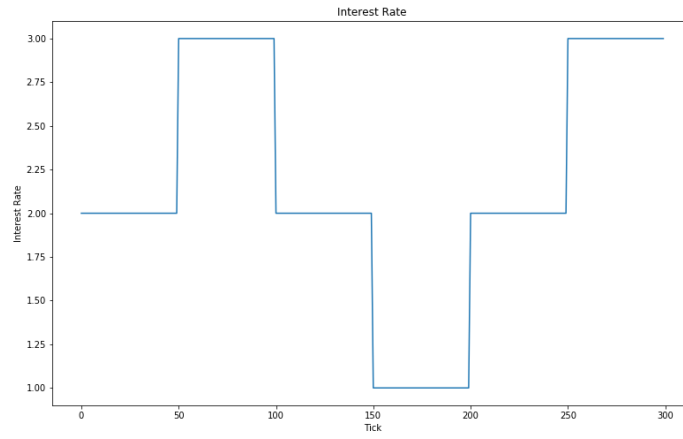


Figure 40: Interest Rate

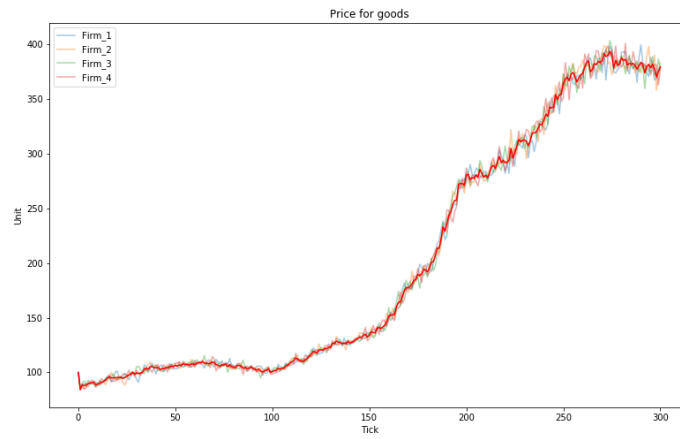


Figure 41: Price for goods

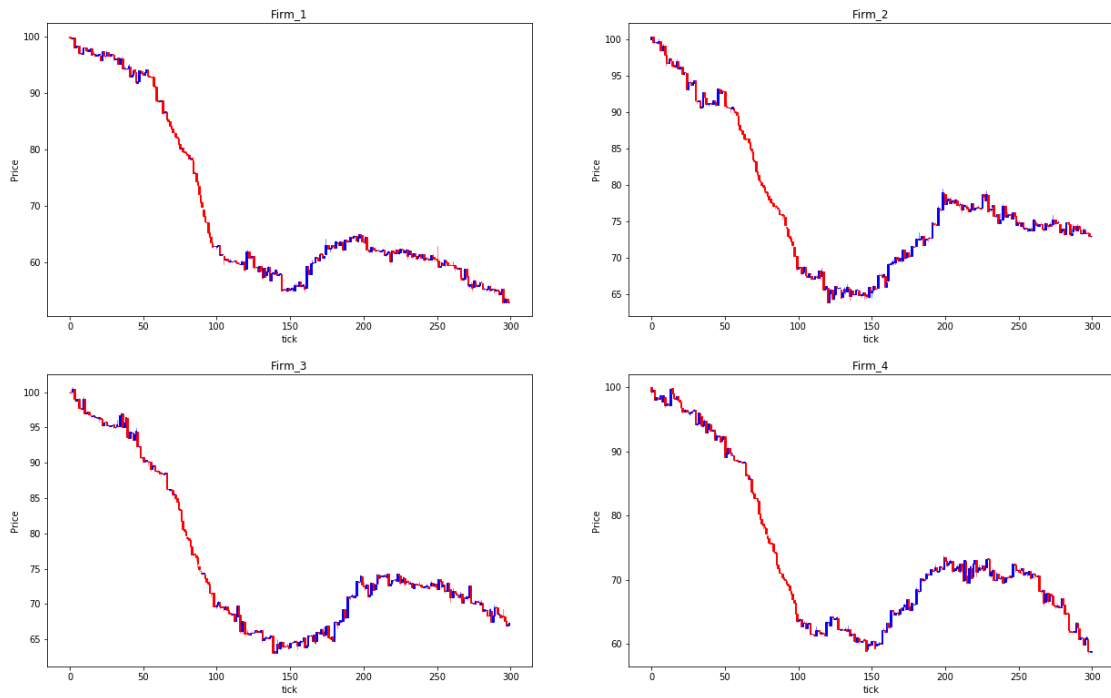


Figure 42: Prices in stock market

Increasing Interest Rate

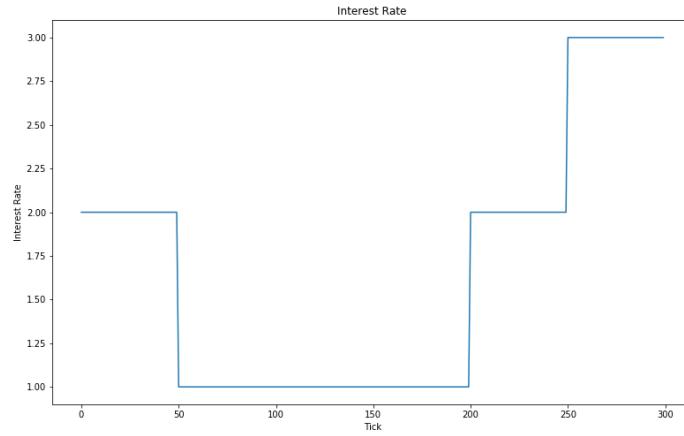


Figure 43: Interest Rate

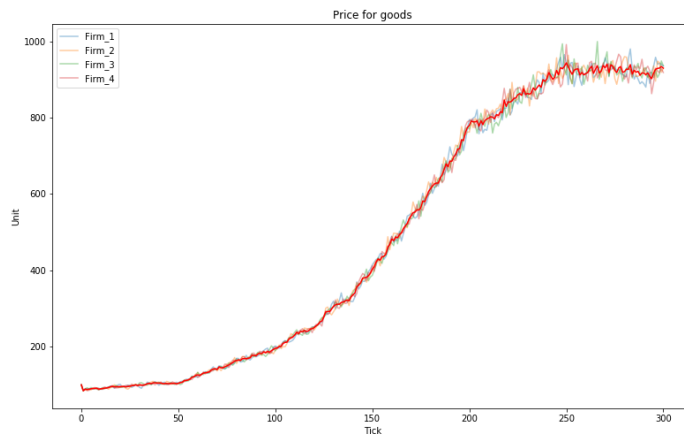


Figure 44: Price for goods

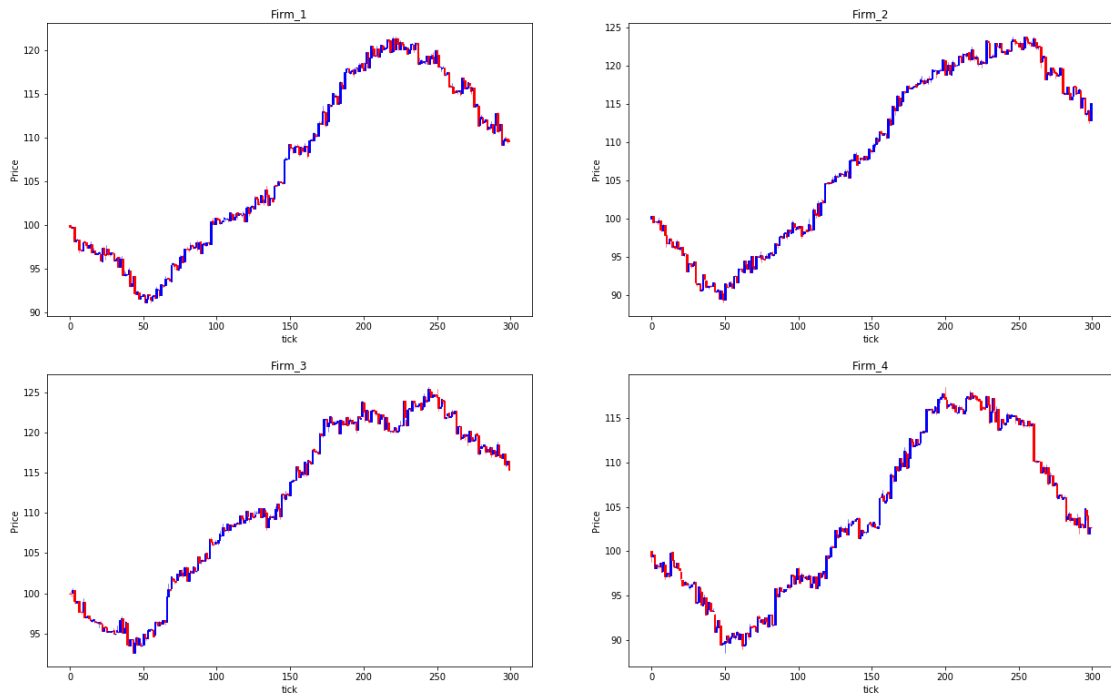


Figure 45: Prices in stock market

Decreasing Interest Rate

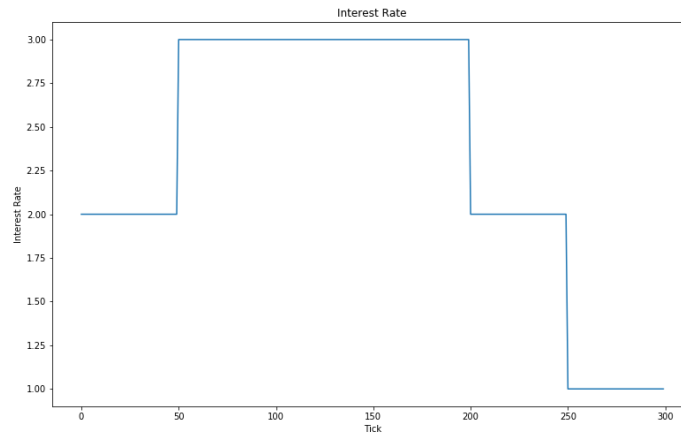


Figure 46: Interest Rate

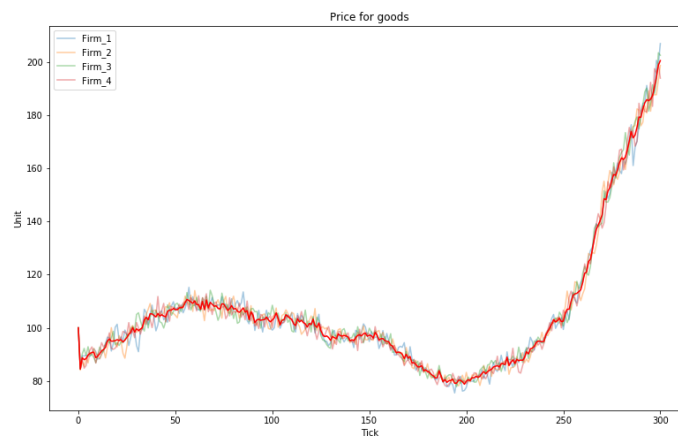


Figure 47: Price for goods

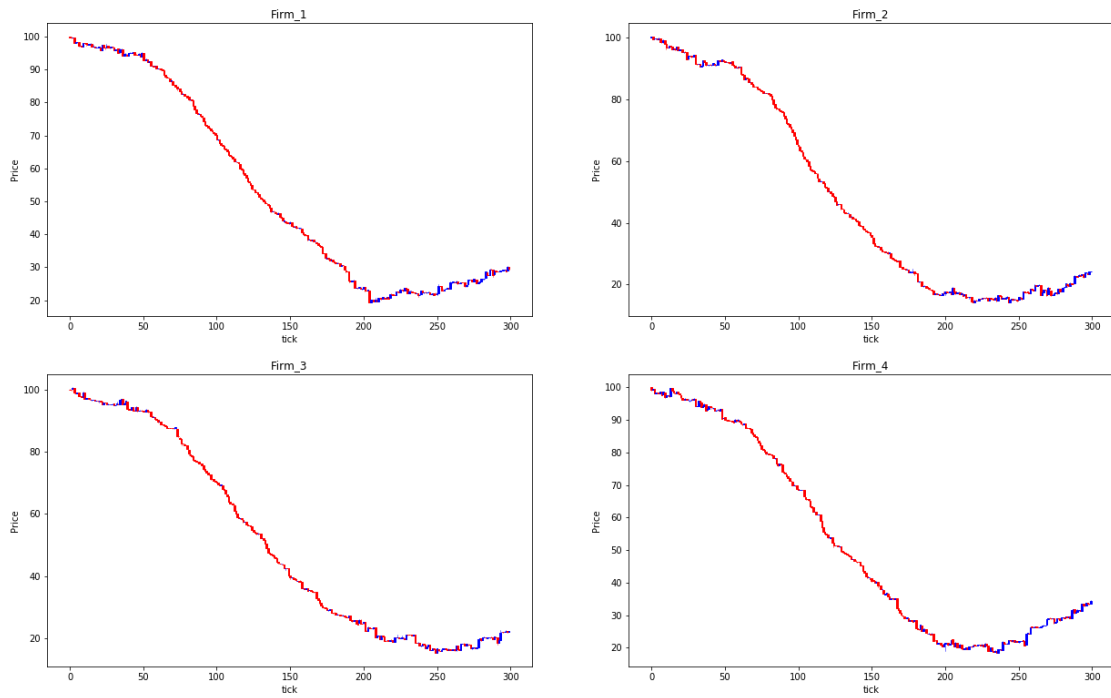


Figure 48: Prices in stock market

5.2.2 Version V

Pyramid Interest Rate

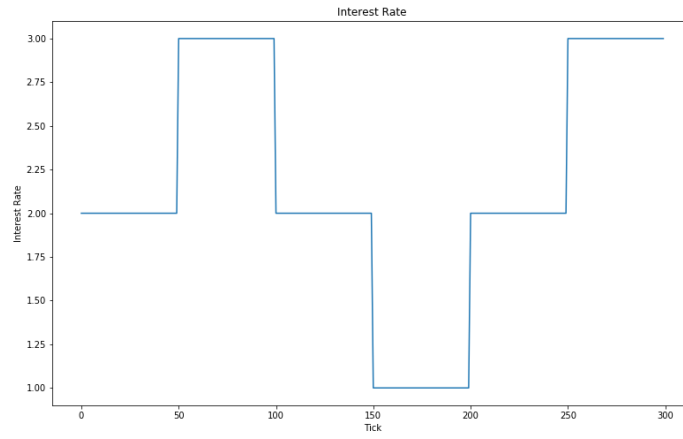


Figure 49: Interest Rate

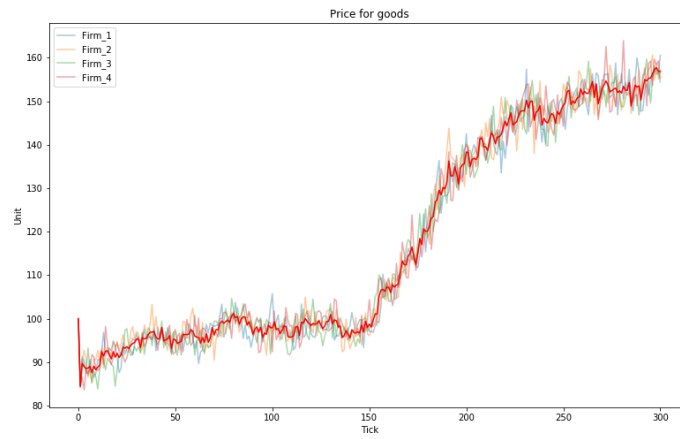


Figure 50: Price for goods

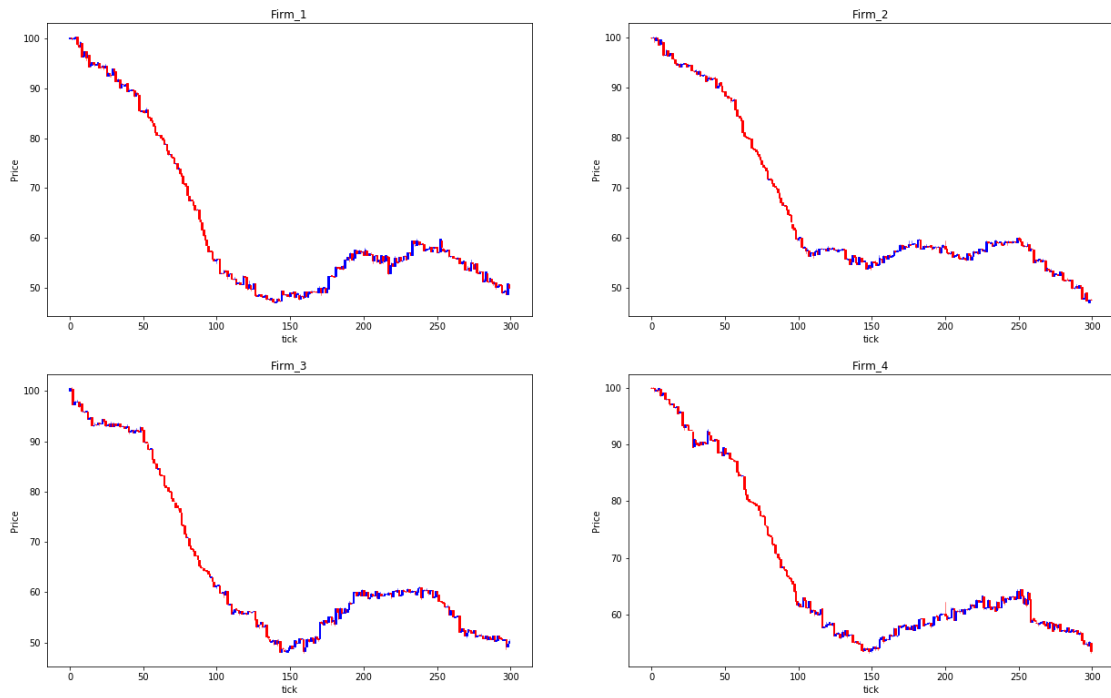


Figure 51: Prices in stock market

Increasing Interest Rate

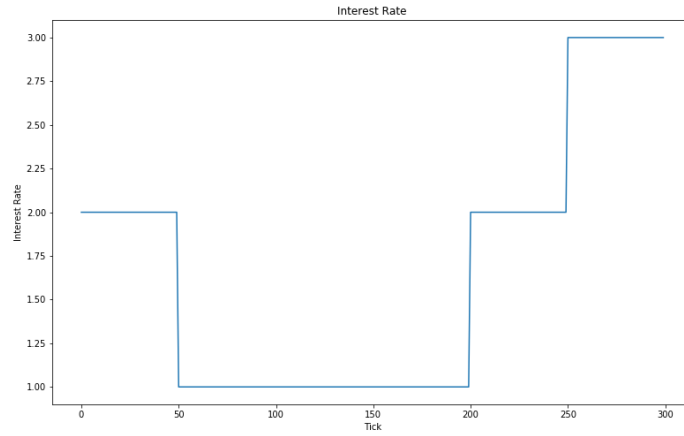


Figure 52: Interest Rate

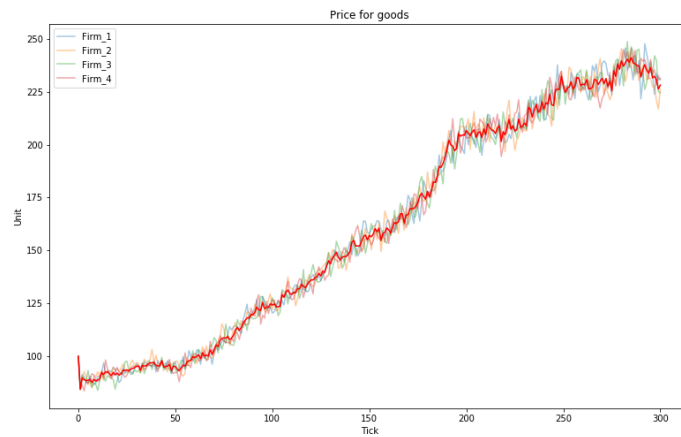


Figure 53: Price for goods

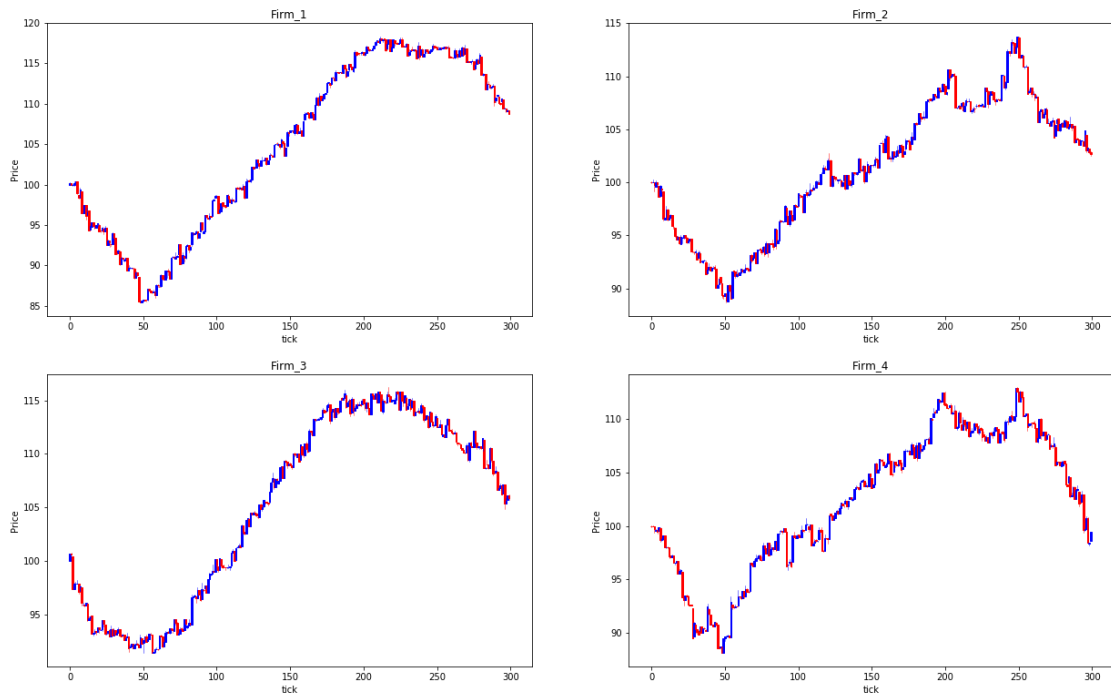


Figure 54: Prices in stock market

Decreasing Interest Rate

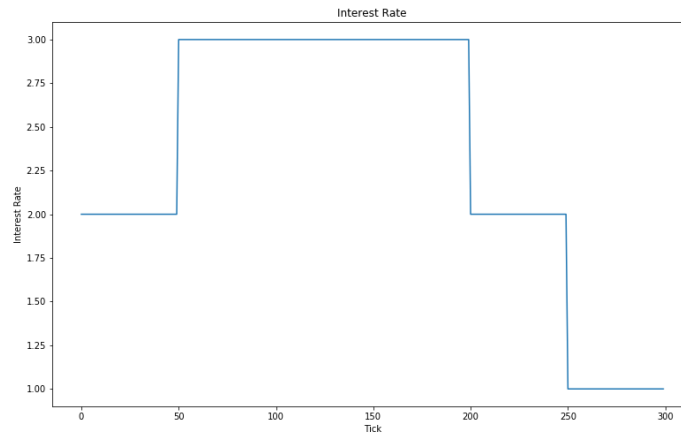


Figure 55: Interest Rate

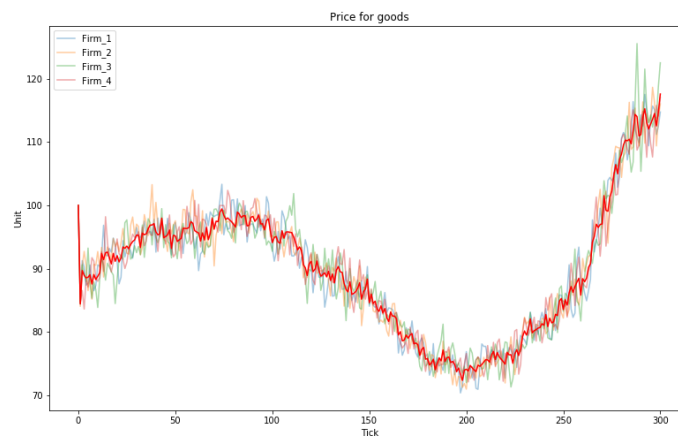


Figure 56: Price for goods

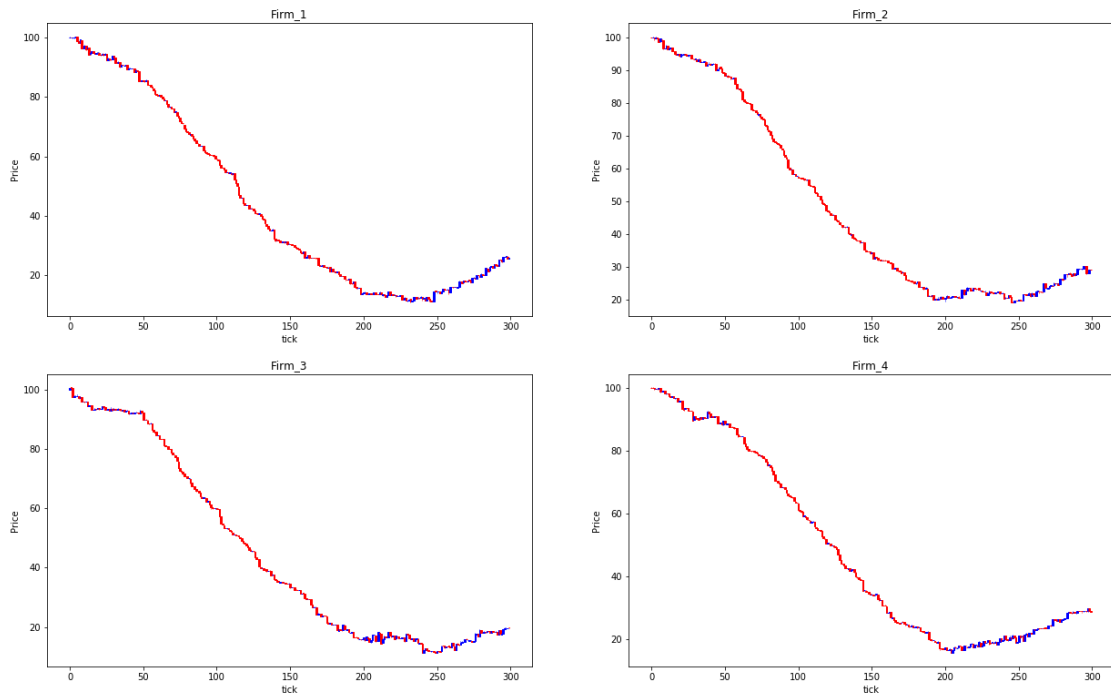


Figure 57: Prices in stock market

5.2.3 Version VI

Pyramid Interest Rate

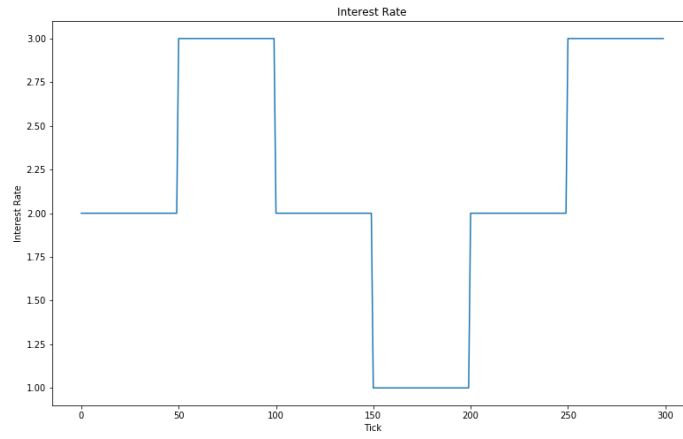


Figure 58: Interest Rate

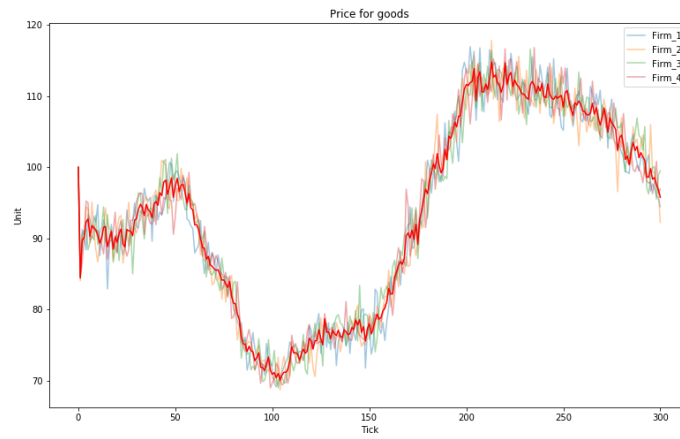


Figure 59: Price for goods

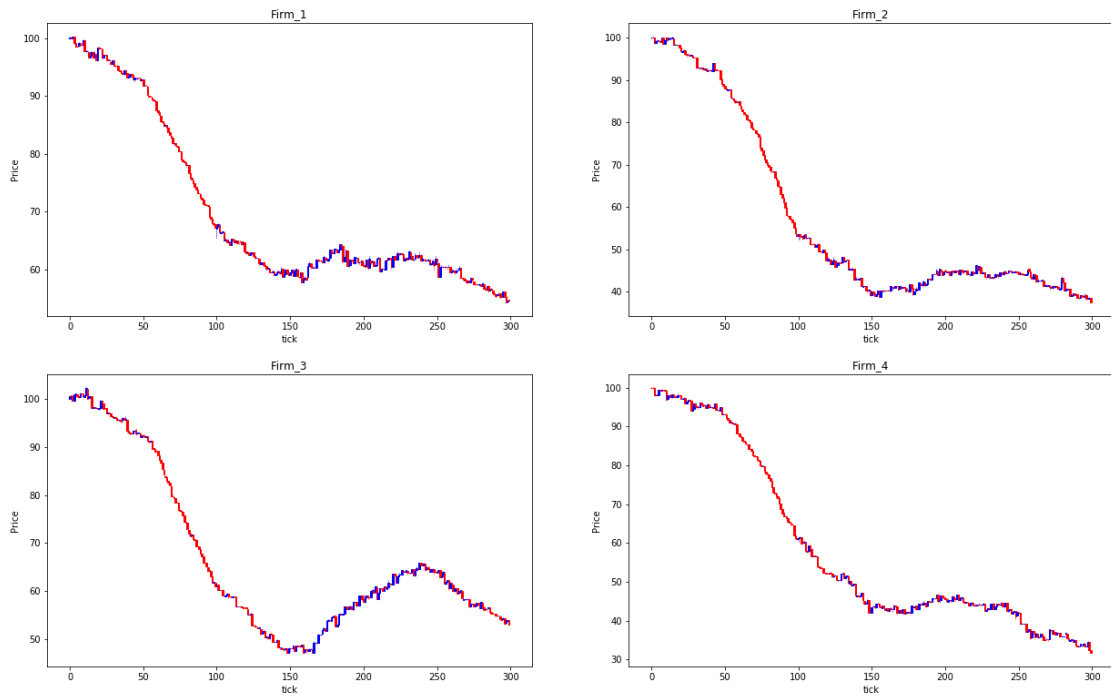


Figure 60: Prices in stock market

Increasing Interest Rate

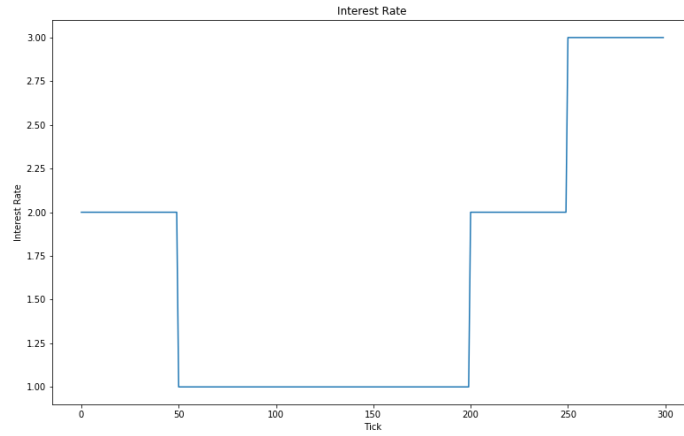


Figure 61: Interest Rate

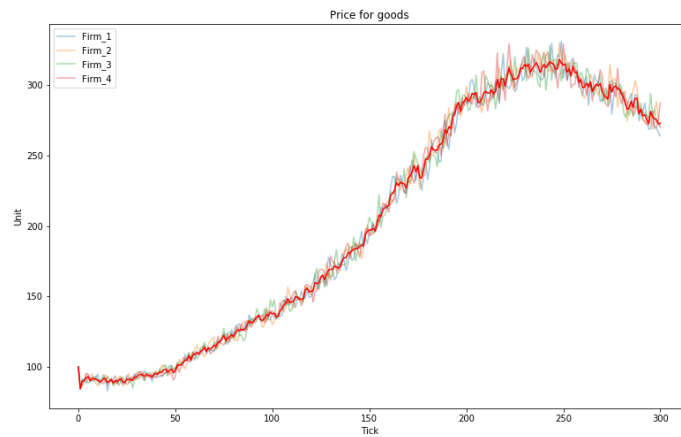


Figure 62: Price for goods

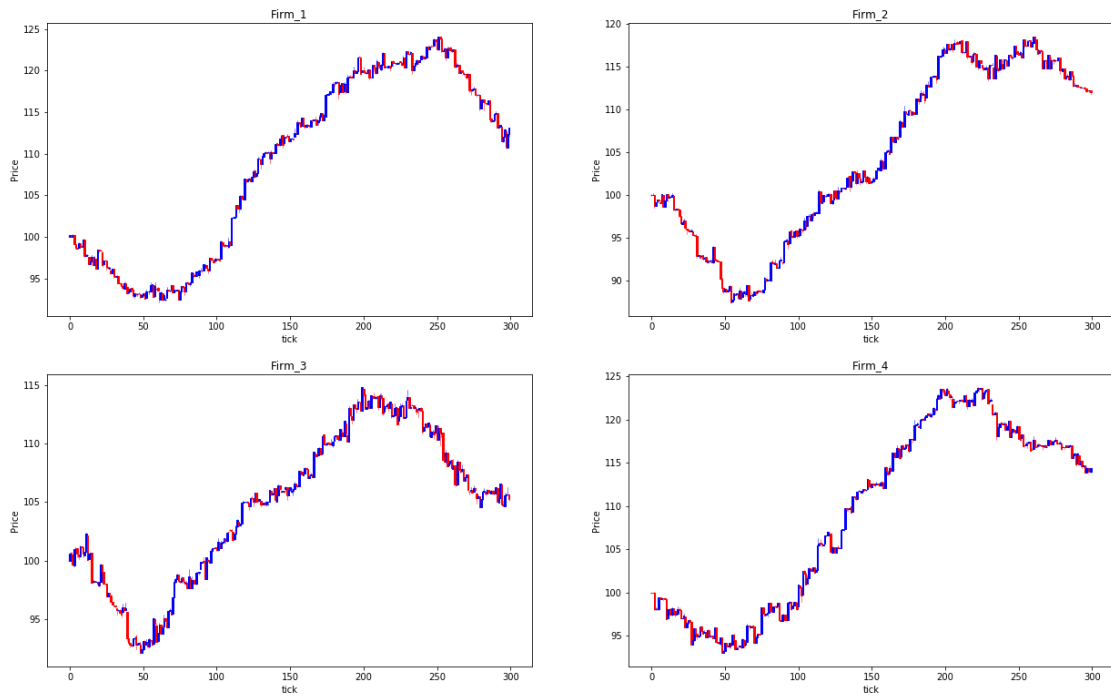


Figure 63: Prices in stock market

Decreasing Interest Rate

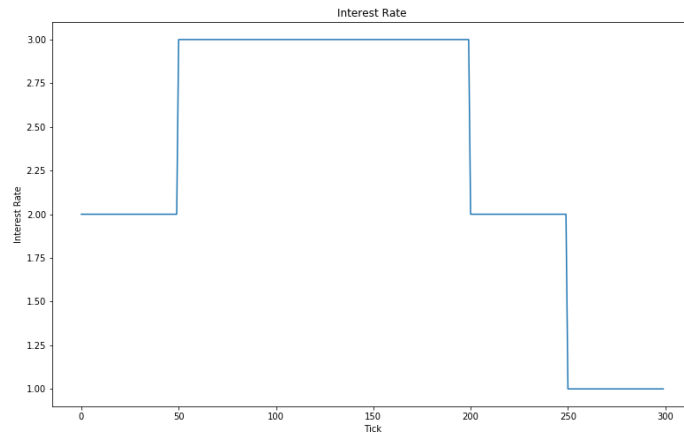


Figure 64: Interest Rate

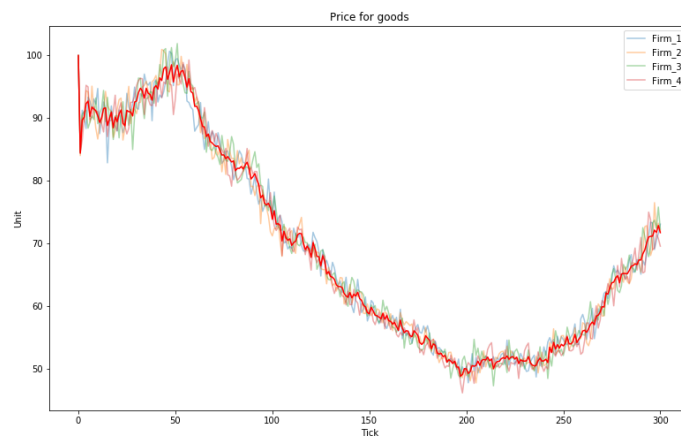


Figure 65: Price for goods

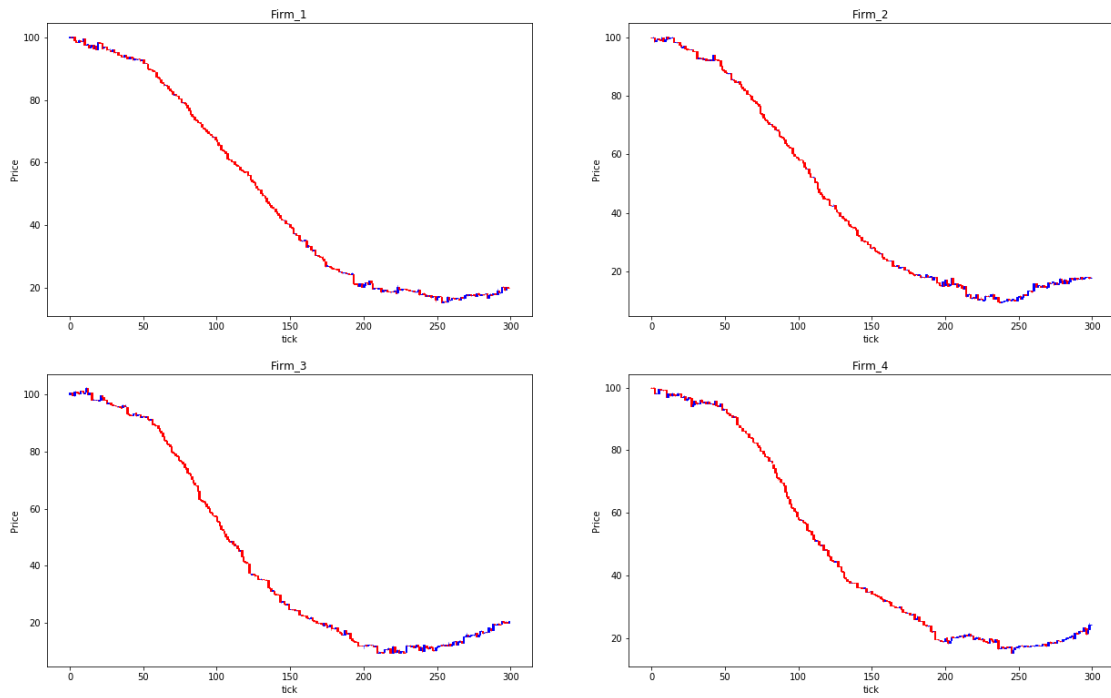


Figure 66: Prices in stock market

5.3 The third model: implementing the Unemployment

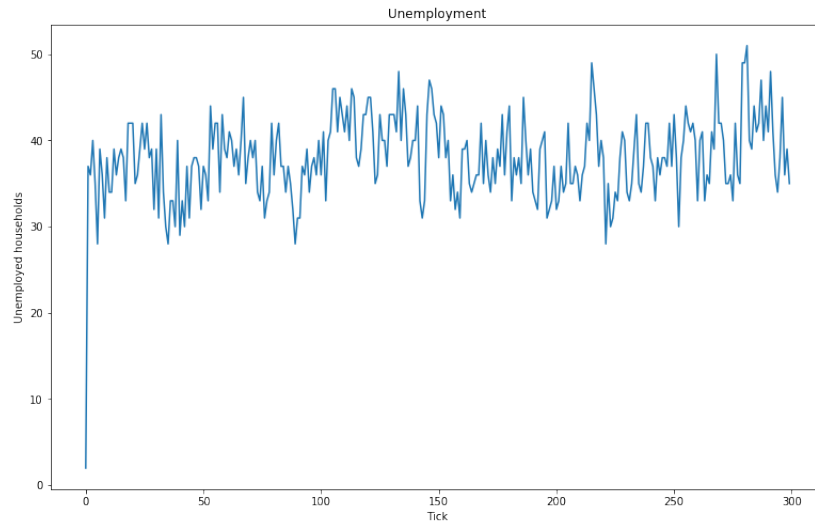


Figure 67: Unemployment rate

5.3.1 Version IV

Pyramid Interest Rate

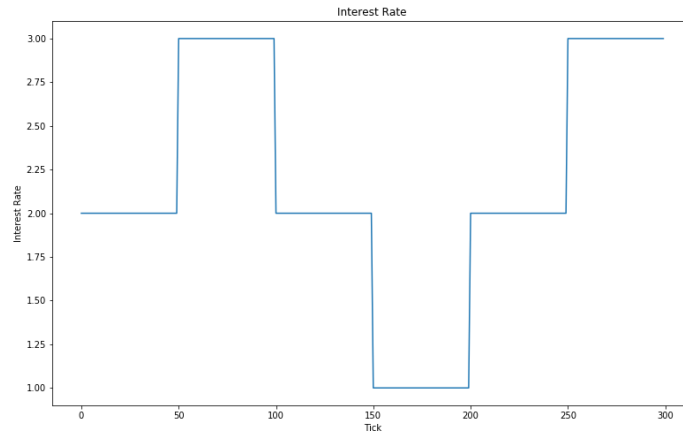


Figure 68: Interest Rate

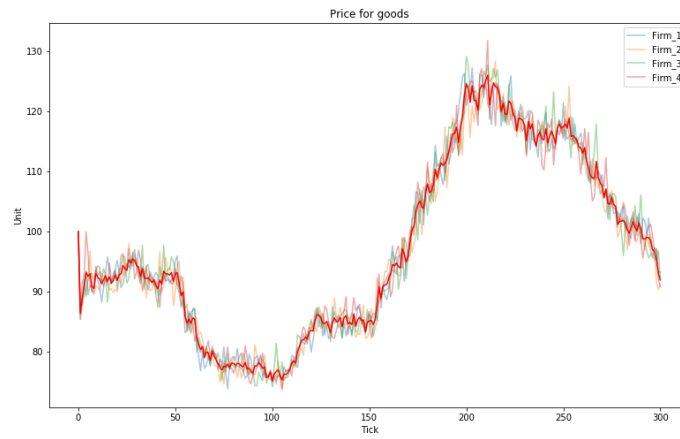


Figure 69: Price for goods

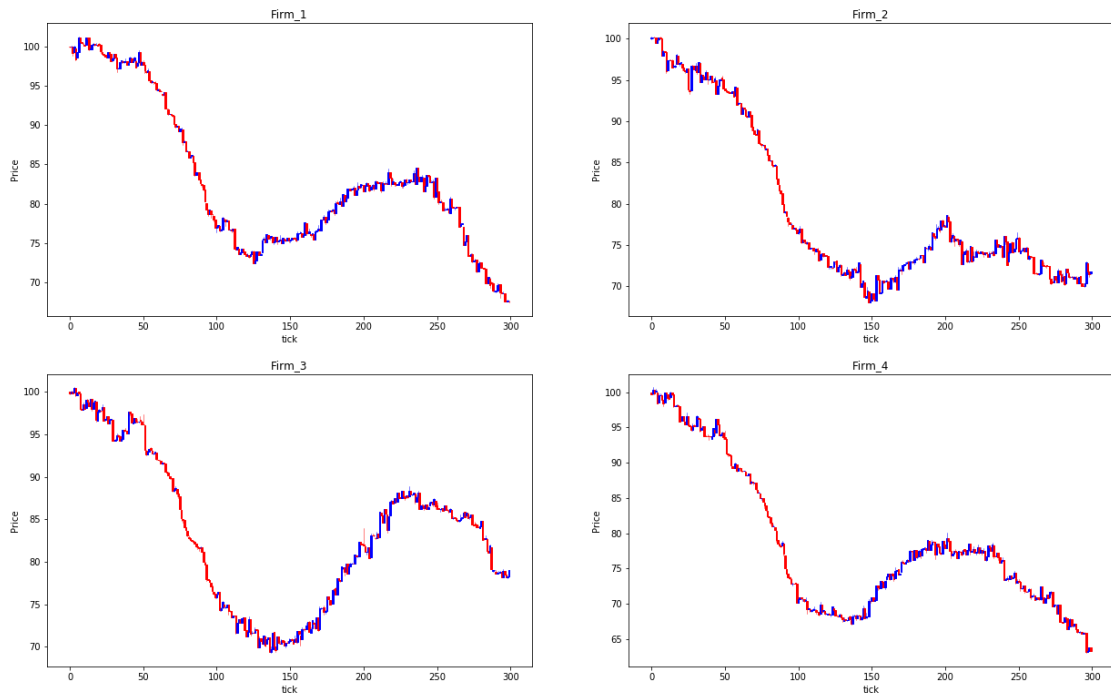


Figure 70: Prices in stock market

Increasing Interest Rate

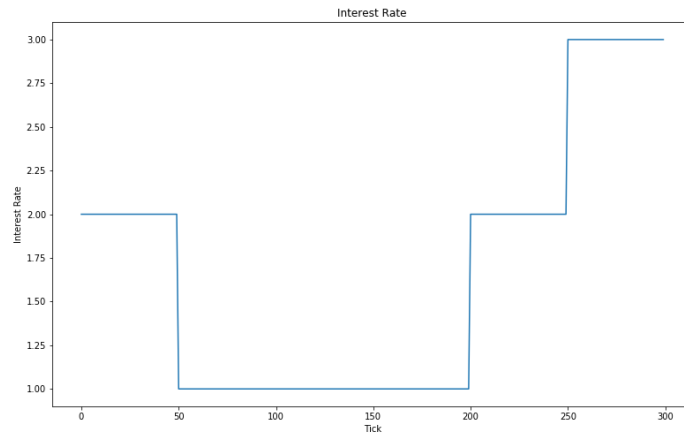


Figure 71: Interest Rate

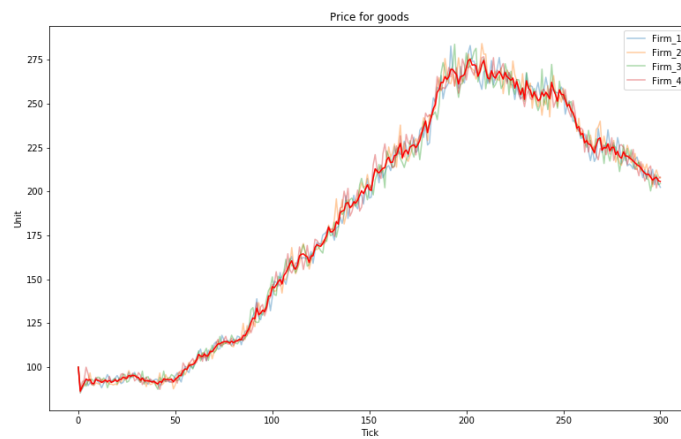


Figure 72: Price for goods

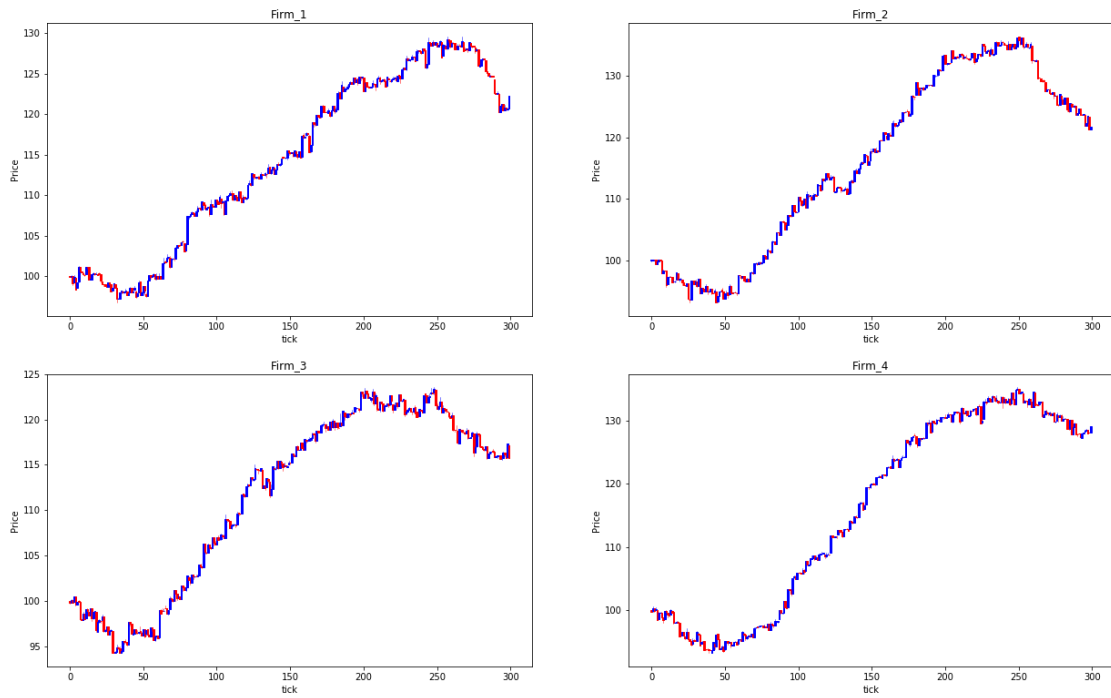


Figure 73: Prices in stock market

Decreasing Interest Rate

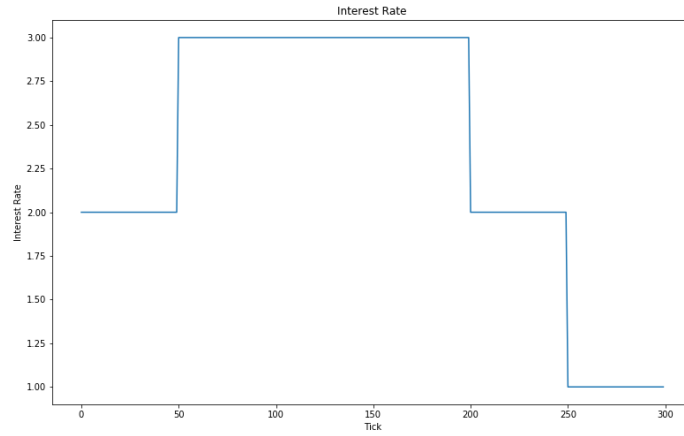


Figure 74: Interest Rate

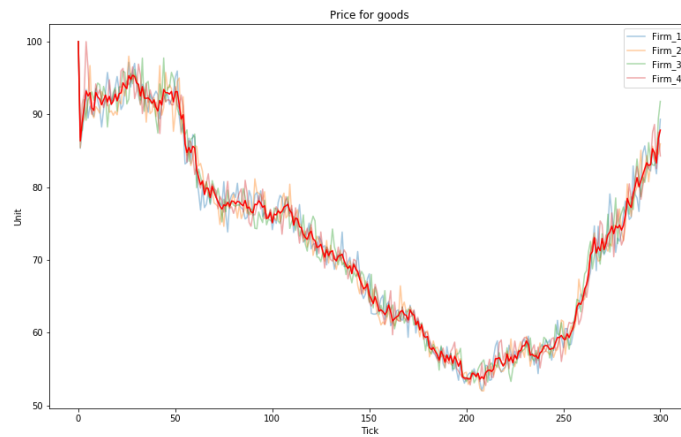


Figure 75: Price for goods

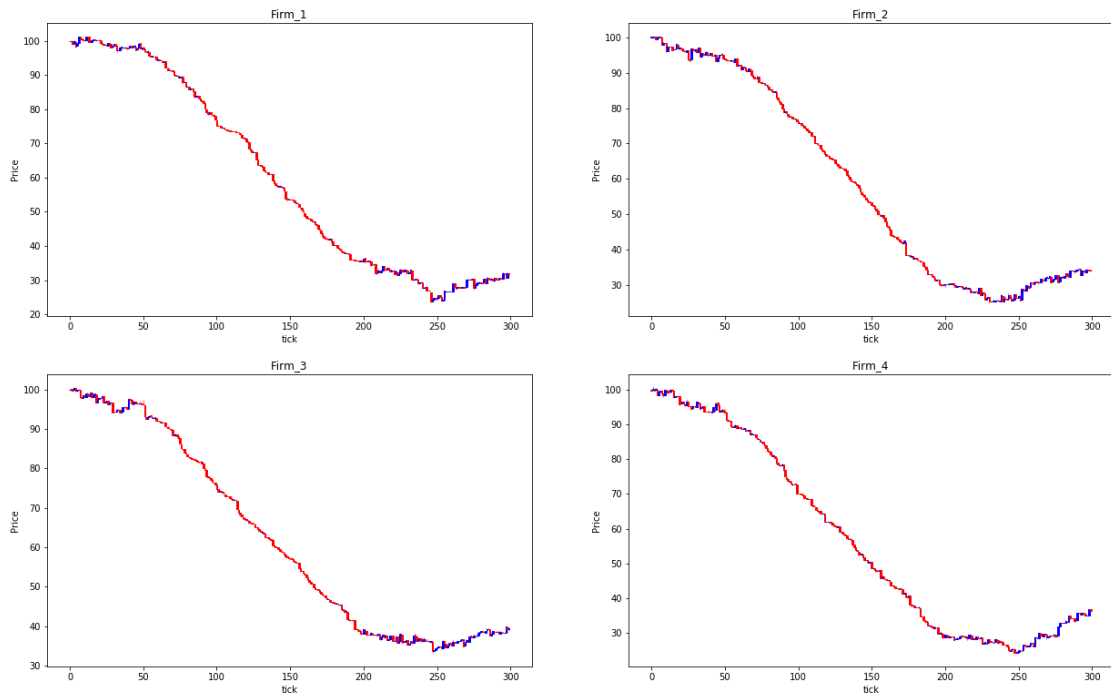


Figure 76: Prices in stock market

5.3.2 Version V

Pyramid Interest Rate

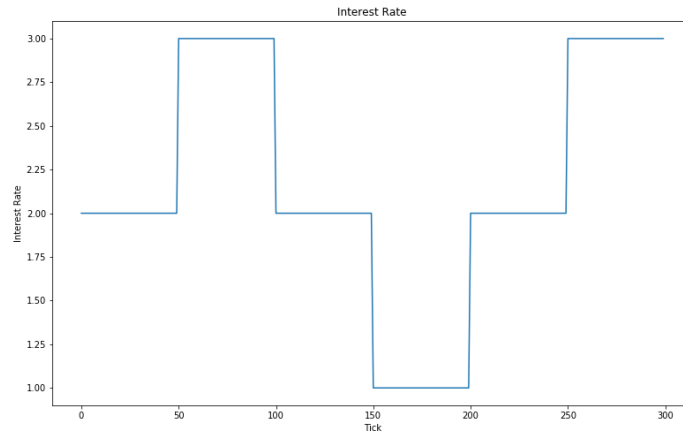


Figure 77: Interest Rate

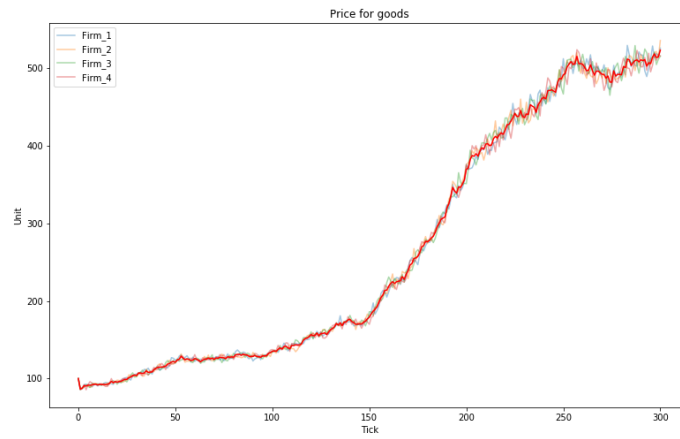


Figure 78: Price for goods

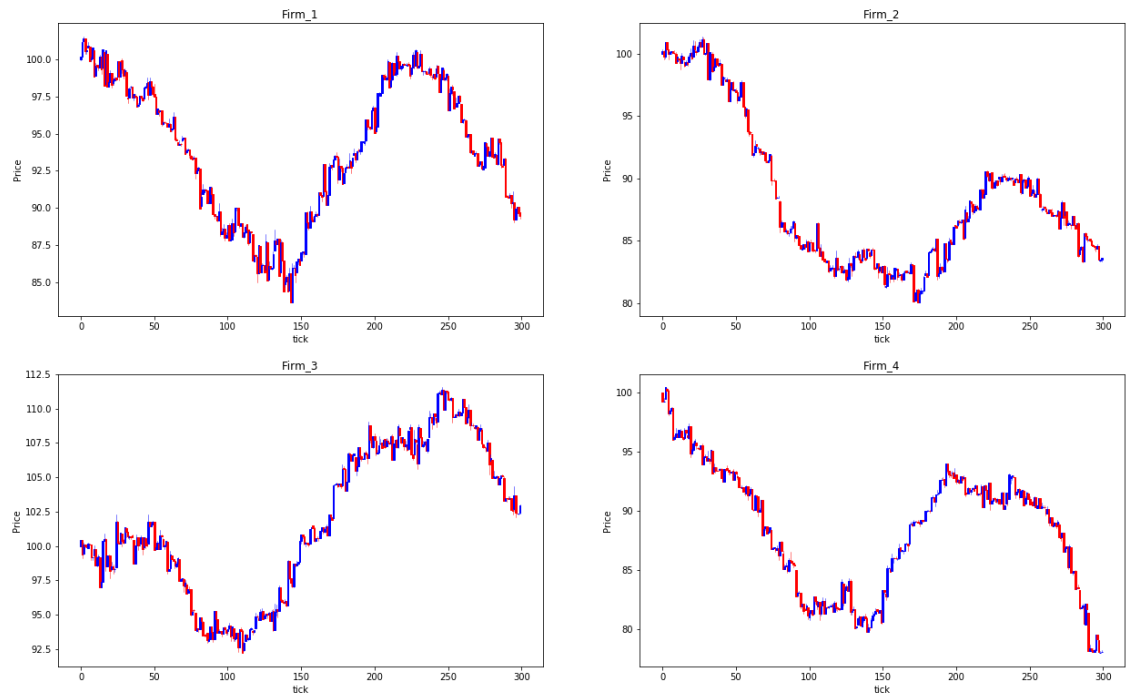


Figure 79: Prices in stock market

Increasing Interest Rate

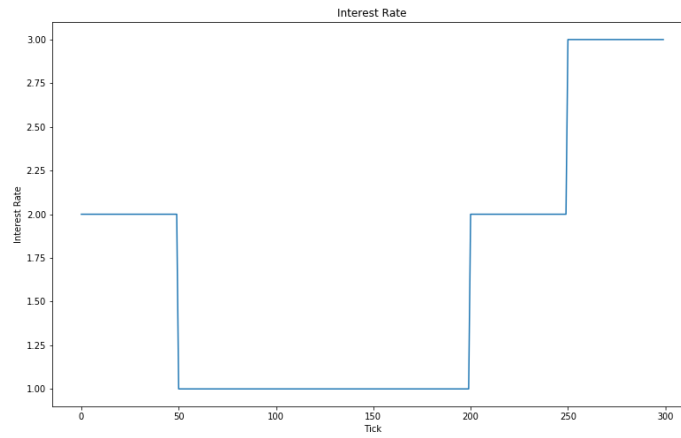


Figure 80: Interest Rate

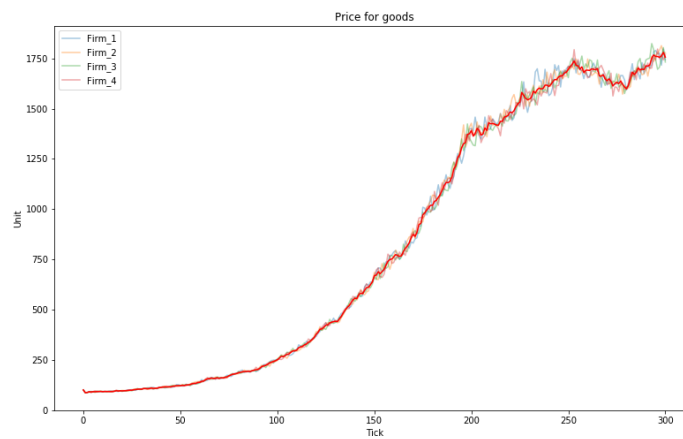


Figure 81: Price for goods

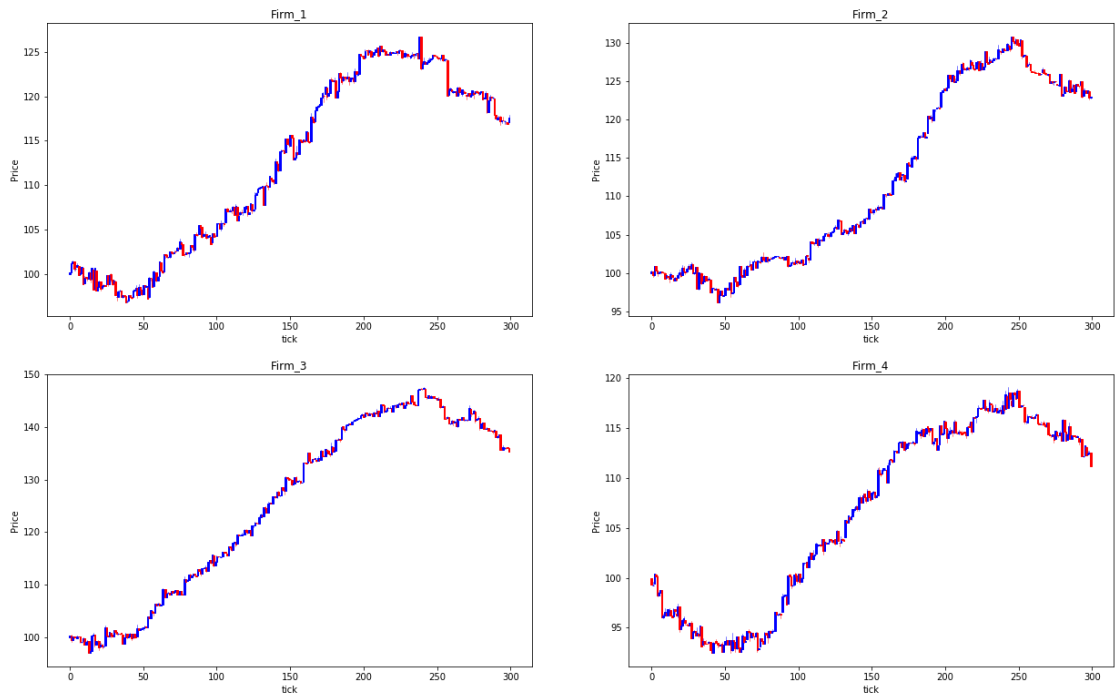


Figure 82: Prices in stock market

Decreasing Interest Rate

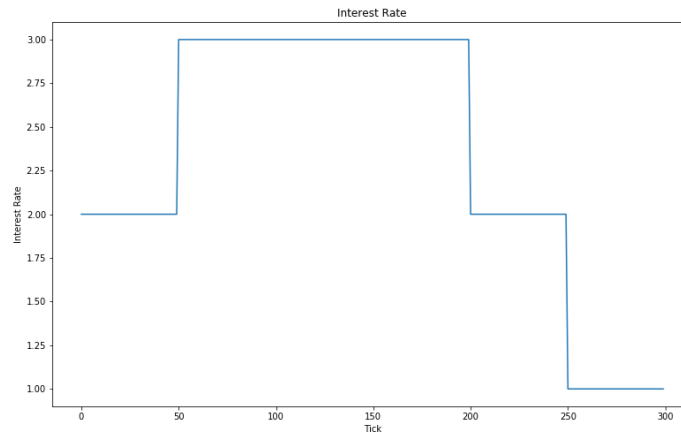


Figure 83: Interest Rate

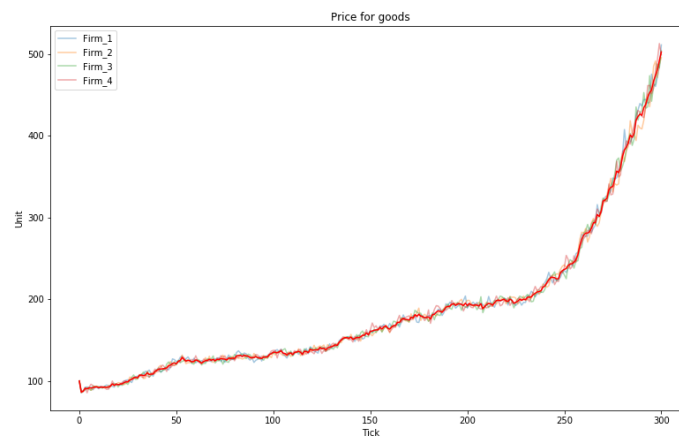


Figure 84: Price for goods

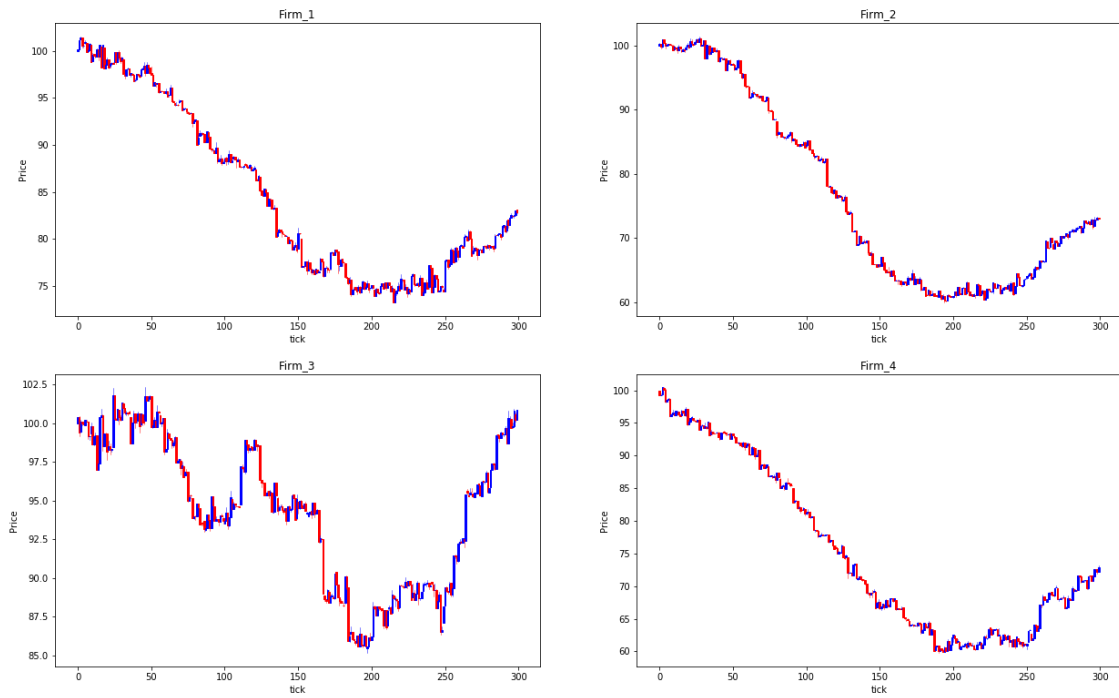


Figure 85: Prices in stock market

5.3.3 Version VI

Pyramid Interest Rate

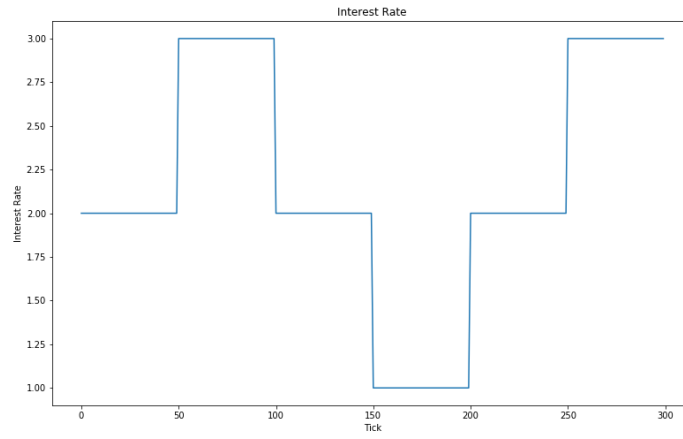


Figure 86: Interest Rate

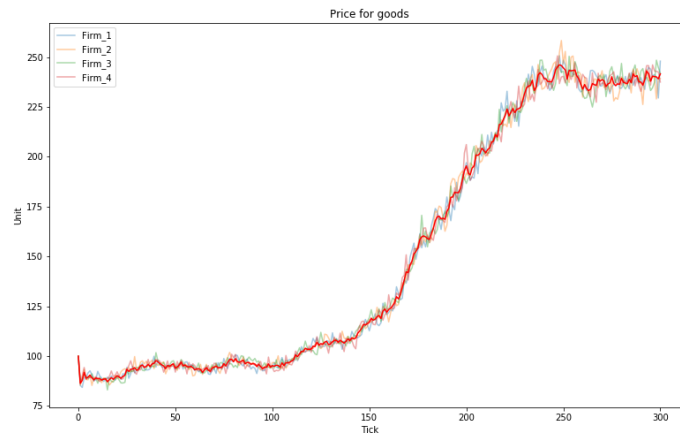


Figure 87: Price for goods

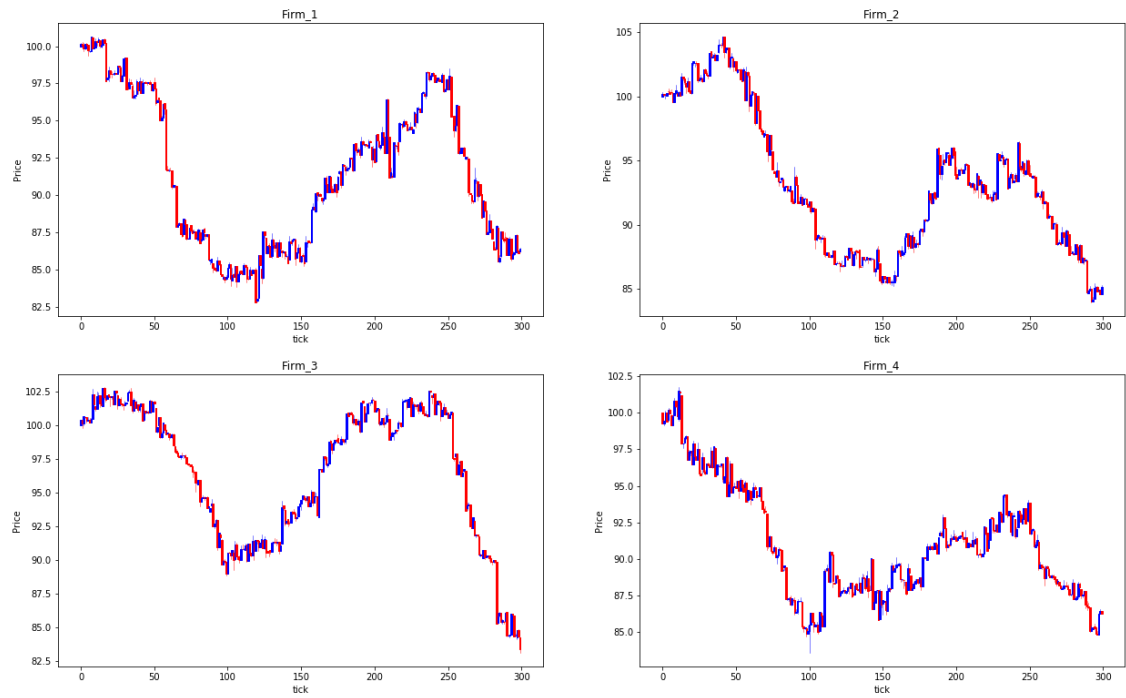


Figure 88: Prices in stock market

Increasing Interest Rate

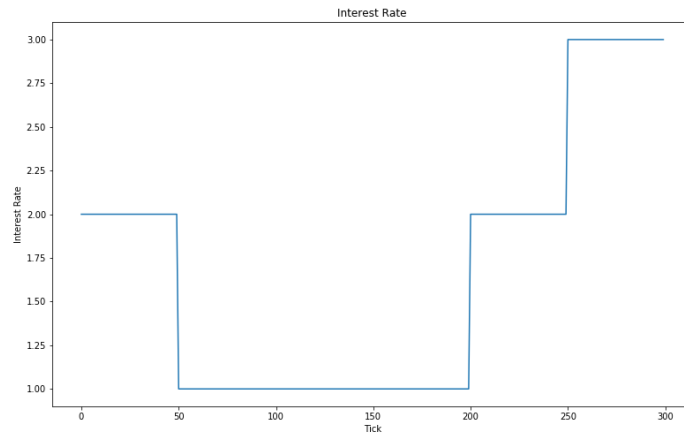


Figure 89: Interest Rate

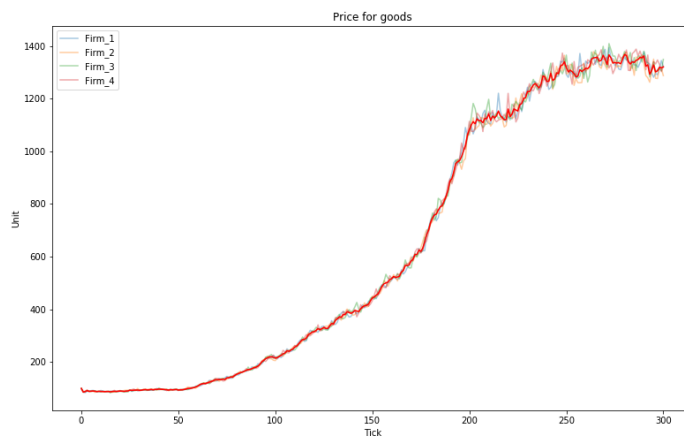


Figure 90: Price for goods

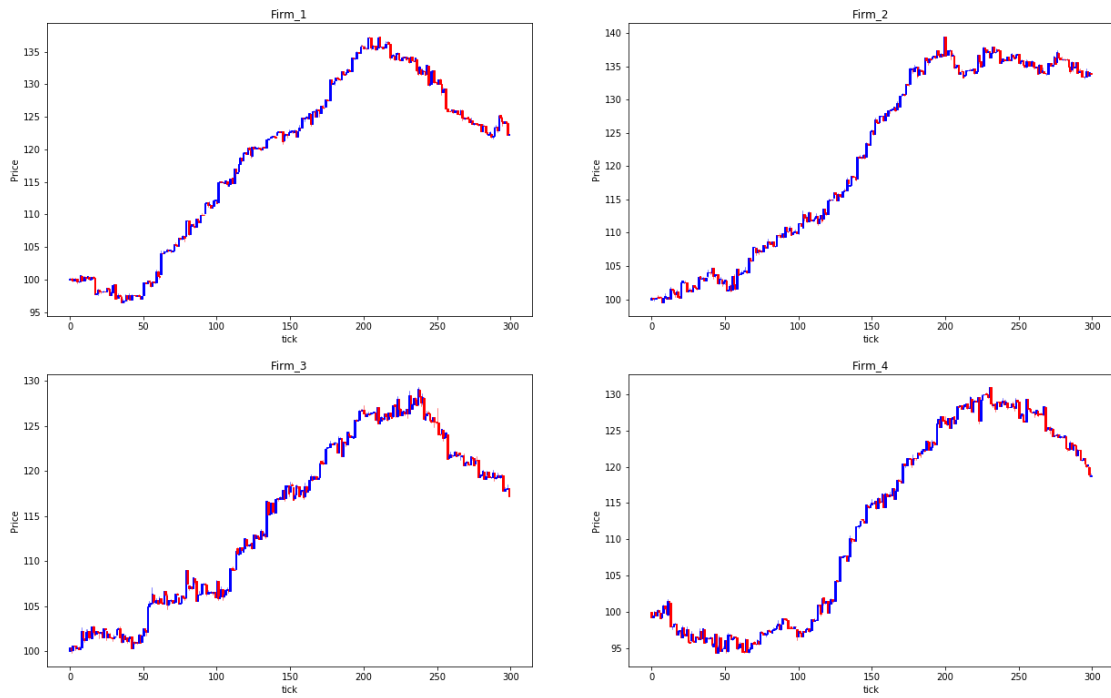


Figure 91: Prices in stock market

Decreasing Interest Rate

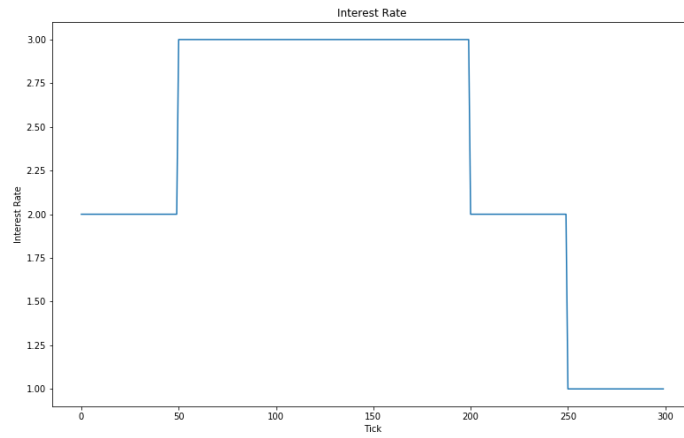


Figure 92: Interest Rate

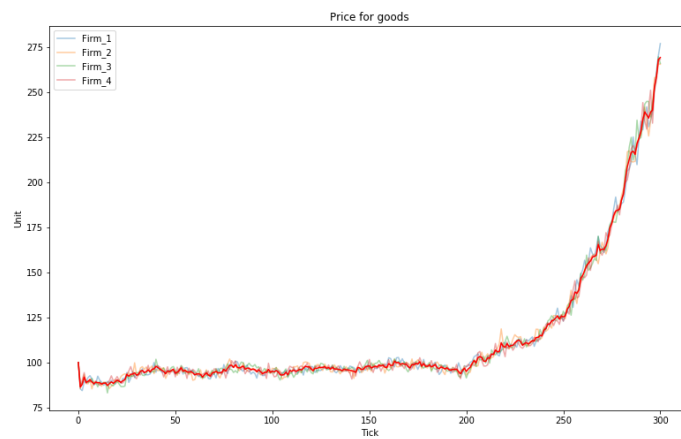


Figure 93: Price for goods

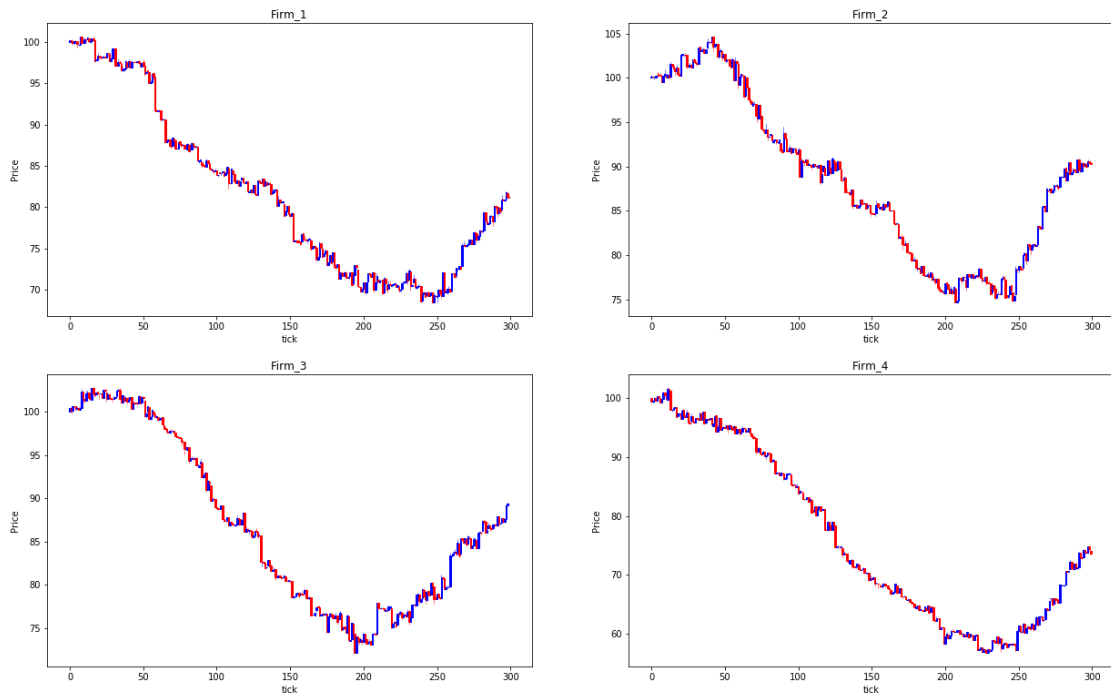


Figure 94: Prices in stock market

5.4 The fourth model: all the effects together

Pyramid Interest Rate

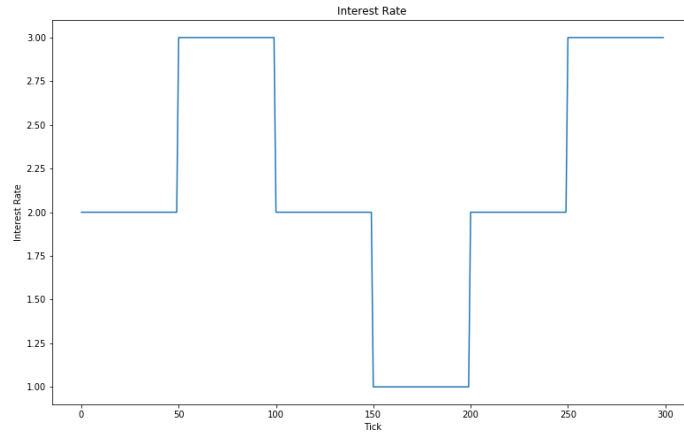


Figure 95: Interest Rate

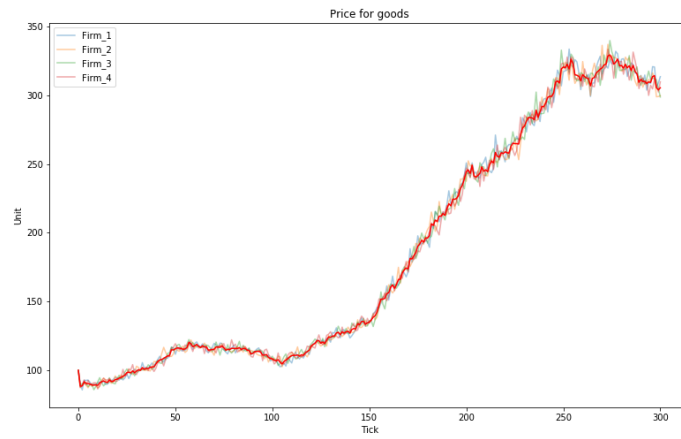


Figure 96: Price for goods

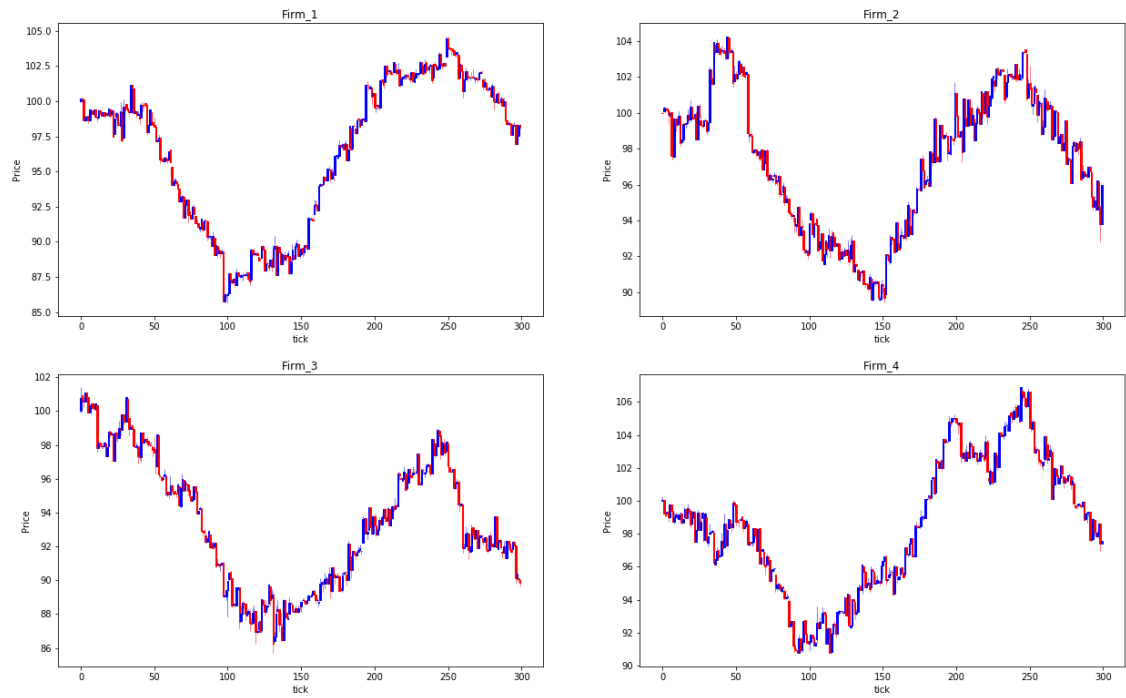


Figure 97: Prices in stock market

Increasing Interest Rate

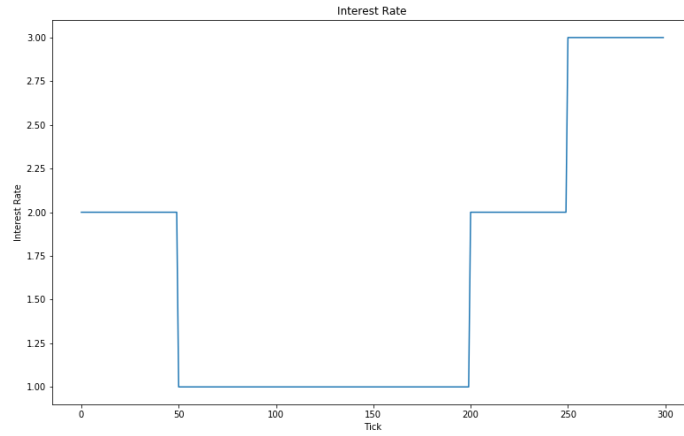


Figure 98: Interest Rate

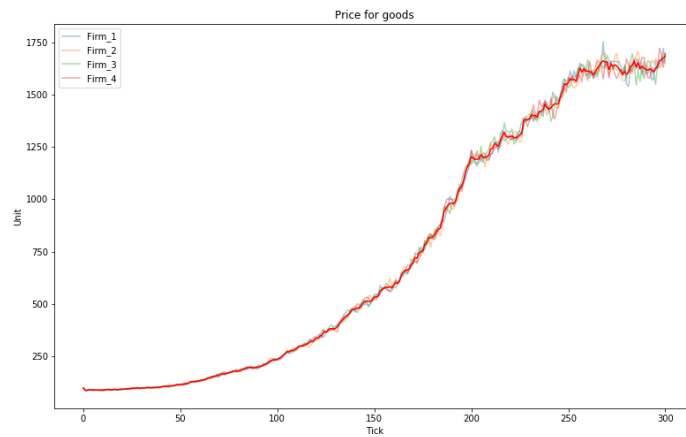


Figure 99: Price for goods

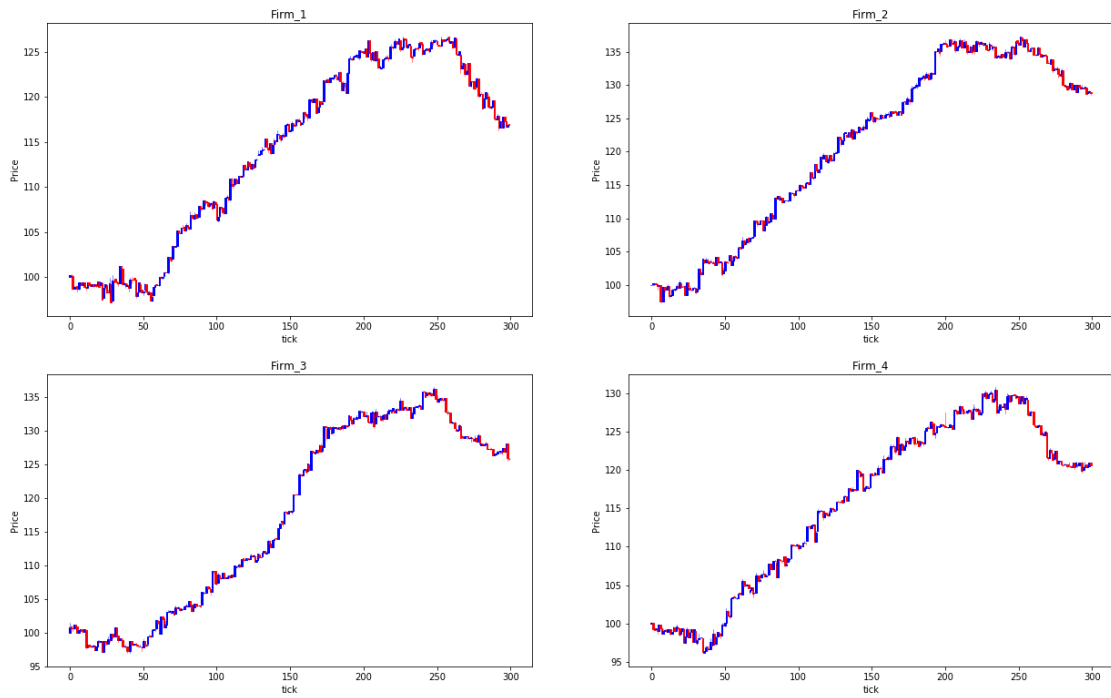


Figure 100: Prices in stock market

Decreasing Interest Rate

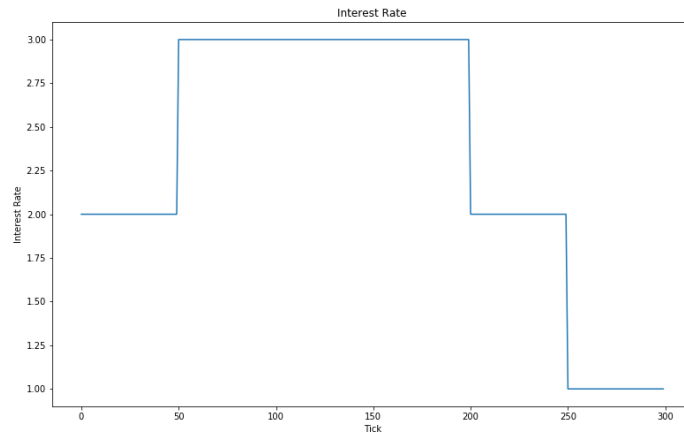


Figure 101: Interest Rate

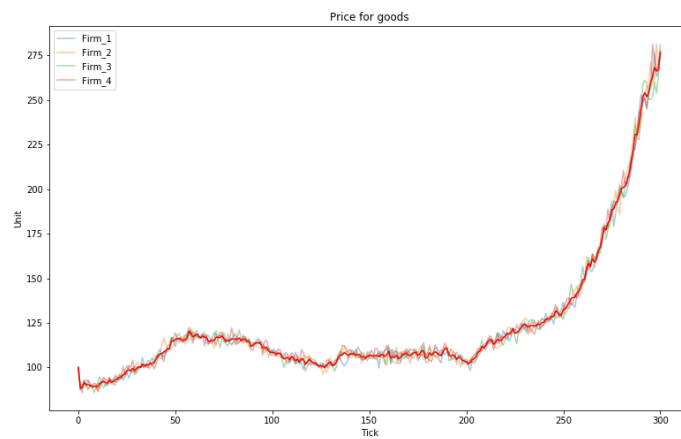


Figure 102: Price for goods

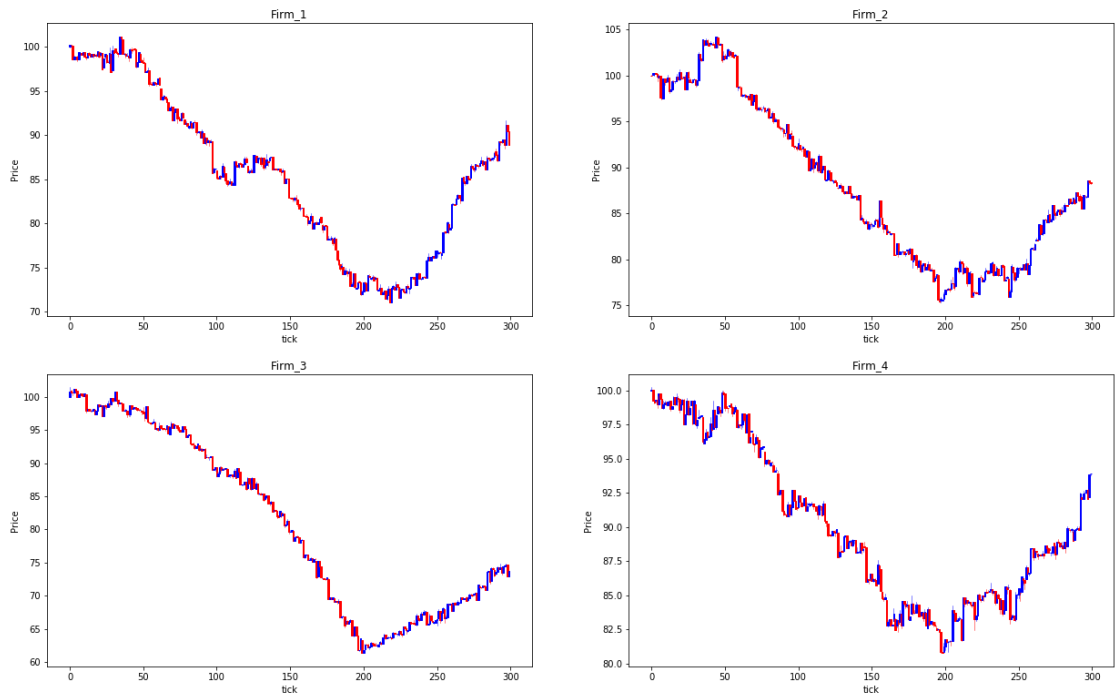


Figure 103: Prices in stock market