A unionized oligoply with bounded rational agents

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Abstract

In this model I show why unions sometimes do not reduce wages, even if it will be profitable for themselves and the economy. The reasons are simple. When I allow unions and firms to be bounded rational agents with limited information, it is individually rational for unions to behave like this. Quantities firms produce approximate the collusive quantity with exogenous cost which would be an equilibrium result in a Cournot-Oligopoly Industrial Organization model. In addition this is a stable result and it is established even if firms only have sparse information about the environment and their decision rule is very simple. Hence, firms are the winners in our setting, compared to IO models. This is true on the condition that firms change quantities more often than wage bargaining takes place.

1 Introduction

How do unions and firms behave? Are they perfectly rational agents fully informed with all the information needed to maximize a profit or utility function? To my knowledge the strand of Industrial Organization (IO) literature concerning unionized oligopolies or, more generally, vertically connected markets solely assumes perfect rational agents.[1]

Unions in an upstream and firms in a downstream market have all the information that they need. The assumptions are extraordinary: firms know their own marginal cost, the marginal cost of their competitors, and the demand function of the product market. To behave optimally, firms maximize their profits according to a best response function showing the quantity they produce in response to any wage they and their competitors have to pay. Unions are also perfectly informed. They are aware of how all firms in the industry will react if they or their competing unions alter wages. Therefore, unions must have the same information that firms do. In addition, unions have knowledge about the behavior of the other unions.

[1]**Acknowledgement:** This paper was part of my PhD thesis and I am solely responsible for the content which does not necessarily represent the opinion of Frontier Economics. I wish to thank participants at the European Conference in Artificial Life, Lisbon; Bavarian Graduate Program in Economics Workshop, Nuremberg and the Seventh and Eighth Trento Summer School in Agent-Based Computational Economics, especially Leigh Tesfatsion for helpful comments. Also I would like to thank Klaus Wersching and Greg DeAngelo for their help and support. Furthermore, I am grateful to a number of persons at the Duesseldorf Institute of Competition Economics (DICE), Justus Haucap and Ulrich Heimeshoff in particular for their support during my PhD studies. All remaining errors are mine. Financial support by the Deutsche Forschungsgemeinschaft (SPP 1169/3) is gratefully acknowledged.

[1]See for examples of perfect rationality in unionized oligopoly models Naylor (2003), Haucap and Wey (2004), or Ulph and Ulph (2001). For a review of models with bounded rationality see the survey of Ellison (2006). He collects the current state of research in bounded rationality in industrial organization and points out the vital necessity for further research. Although Ellison collects an impressive amount of work, he states: "the field is not yet coherent and advanced as most fields surveyed at an Economic Society World Congress". In addition, none of his summarized papers deals with bounded rationality in vertical connected markets let alone unionized oligopolies.

The aim of my paper is to loosen these heroic assumptions. In my model, firms and unions do not have knowledge of all information about prices, cost, quantities, and best response functions they need. Moreover, they do not calculate best response functions but apply a much simpler decision rule. This is due to the fact that even if they were fully informed their capacities to find the right solutions for profit and utility maximization are also limited.

A model that is characteristic in its set–up for a unionized oligopoly model is chosen. I then introduce boundedly rational agents to this model. By this approach, I have the chance to compare boundedly rational agents with perfect rationality.[2] Using the recent and, for the unionized oligopoly, typical paper of Lommerud, Straume, and Sørgard (2006) as a starting point, I apply their model and modify it.[3] In their model each of the two unions sets wages for two of the four firms competing in Cournot fashion in one product market. As described above firms and unions are rational agents and fully endowed with all information. Thus, I take this model and modify the information sets and behavior of firms and unions.

To obtain results I apply agent–based computational economics (ACE). The idea of this approach is to model agents in a bottom–up approach and endow them with information and rules of behavior. Tesfatsion (2003) states "ACE is the computational study of economics modeled as evolving systems of autonomous interacting agents. Starting from initial conditions, specified by the modeler, the computational economy evolves over time as its constituent agents repeatedly interact with each other and learn from the interaction. ACE is therefore a bottom–up culture–dish approach to the study of economic systems." In my model firms and unions are the agents. Unions only have information about wages paid in the last periods, the number of workers employed in each of "their" firms, and the reservation wage of the industry. Firms know their own prices, wages, and quantities lasting previous periods. Furthermore, both unions and firms have a very simple decision rule telling them how to decide about wages and quantities in different states of nature. Initially, my agents are endowed with an initial information set and decision rules. After that, agents behave "on their own", and the results emerge in a bottom up way.[4]

My main results are that firms always profit from simple decision rule and limited information whereas unions suffer. If firms set quantities more frequently than unions change wage demands—I call this multiple product market loops—, firms act like perfect rational agents assuming wages to be exogenous and produce the collusive quantity. Results for quantities approximate the outcomes in Cournot oligopoly equilibrium with perfect rational agents for colluding firms with exogenous cost. Hence, quantities are reduced in comparison to the model of Lommerud et al., but wages can be either higher or lower. This is dependent on the starting point of my model. If wages are low in the beginning, the point where unions do not find it profitable to raise wages any more is lower than for higher starting wages. However, for high starting wages, unions always find it profitable to keep wages stable and not to reduce them.

The paper is structured as follows. In section 2, I introduce the model of Lommerud et al. and my modifications to it. Afterwards, I need to describe some computational details to make my findings plausible. Results are presented in section 4. First, I allow firms and unions to change wages and quantities with the same frequency. Then I try to shed light on the question of how stable my results are. To be more precise, I test whether different initial values of unions and firms change my results. At the end, I present results for a setting with firms setting quantities more frequently than union wages. The last section concludes.

[2] The process of the alignment of models is also referred to as "docking" in the literature (e.g., Axtell, Axelrod, Epstein, and Cohen (1996)). Unlike this approach, I do not align two simulation models. I compare the results of a standard IO model with the findings of a simulation model.

[3] I do not try to find an answer to their international merger questions, I just focus on the setup of their model in the beginning.

[4] For more information about the agent based approach, see for example the handbook of Tesfatsion and Judd (2006) with Dawid (2006) as an example for an IO model.

2 The Model

In the Lommerud et al. model, as well as in my model, four identical firms and two unions are the agents. Each union is a monopolistic supplier for workers (i.e., all workers are unionized). The unions set firm–specific wages, each union for two firms in the downstream product market. To clarify it: there are no wage negotiations, unions simply set wages. The four firms compete in Cournot fashion in one product market. The game is characterized by the following steps:

- stage one: unions set wages in the upstream market, and
- stage two: firms set quantities in the downstream market.

The game is solved by backward induction. Firstly, firms produce differentiated products, and compete in Cournot fashion. For simplicity, firms need one worker to produce one unit of output n. Put differently, if firm i decides to produce n_i units this firm hires n_i worker and pays wage w_i to the worker. The product market is represented by an inverse demand function following Lommerud et al.:

$$p_i = A - n_i - b \sum_{j \neq i}^{4} n_j . \tag{1}$$

In the Lommerud et al. model (and different to my model), firms maximize their profit function π_i by choosing optimal quantities

$$\pi_i = (p_i - w_i - c)\, n_i , \tag{2}$$

with p_i being the price, w_i the wage and c other marginal cost of the firm. The derivative of the profit with respect to quantity can be written as a firm's best response function. In step two, unions maximize their utility function by a variation of w_i,

$$V_A = (w_1 - w)\, n_1 + (w_2 - w)\, n_2 \tag{3}$$

$$V_B = (w_3 - w)\, n_3 + (w_4 - w)\, n_4 \tag{4}$$

where w represents the industry reservation wage. At this point, unions know how firms vary employment (quantities) in response to wages. The employment n_i can be substituted by the best response functions of all four firms. The derivative of the utility functions yields an optimal wage level for unions. To sum up, in the Lommerud et al. model and in my model, unions have exclusive rights to set wages in the upstream market, and firms have the exclusive right to choose quantities and, therefore, employment in the downstream market.

In contrast to the Lommerud et al. model, in my model I want my agents to be endowed with less information: firms do *not* know the inverse demand function or best response functions of their competitors. They only know their own last period's quantities, product market prices, and wages. In addition, firm behavior is extremely simple and is modeled according to Lommerud et al. The idea here is to keep the model as simple as possible, and Day's rule[5] seems to be appropriate for this idea[6]: firms vary quantities to search for high profits. With given information about wage, quantity, and price each firm calculates its individual profit in accordance with Eq. (2). Hence, in every period firms vary quantities with full knowledge of past behavior. If they have chosen higher quantities last period and profits were rising, they do the same again. In

[5] A very similar idea was later published and named "learning direction theory". In several experimental studies it was found that participants' behavior could be explained by a similar decision rule. See for example Selten and Stoecker (1986), Selten and Buchta (1998), and Selten, Abbinik, and Cox (2005).

[6] Thanks to Oleg Pavlov for this suggestion.

other words, firms raise (reduce) quantities if they raised (reduced) their quantities last period. On the other hand, if firms suffer lower profits, they change their policy and do the opposite of what they did before (rise or reduce quantity).

Like firms, unions only have sparse information. They only know last period's wages, the number of employed workers per firm, and the reservation wage w. However, unions compute their utility applying (3) or (4). To achieve a high utility, unions vary wages from period to period: if last period's decision was utility increasing, the policy is repeated, (i.e., higher or reduced wages). That means, if a wage increase led to an increase in union utility, wages are further increased and vice versa. Otherwise, in case of a lower utility, unions switch their policy to the opposite of last period's decision. Applying this decision is not possible within mathematical IO models. I achieve results using a computer program written by myself. Due to this procedure, let me explain more computational details.

3 Computational Details

To obtain results with the agent–based computational approach a computer program, optimally written in an object–orientated language is necessary. I wrote my code in Java and each agent is programmed as an object with attributes and methods. Methods should represent the behavior, attributes the states of the agents. To be more precise, in my model, I programmed the union and firm agents, endowed with information I mentioned above. This information is stored in attributes. Additionally, as methods, both unions and all firms are endowed with Day's rules. In each period, firms and unions make decisions, and receive new information afterwards. This new information about actual wages and quantities is saved in their attributes again and is necessary for their next decisions.

In relation to the Lommerud et al. paper, the assumption of boundedly rational agents with limited information is the only modification. However, some questions arise due to my different way of modeling.[7]

First, time structure is modeled slightly different. In Lommerud et al., unions decide about wages simultaneously. Afterwards, all firms decide at the same time. I tried to represent this setting as good as possible in programming code: my program chooses a union in a random fashion and this union sets wages using Day's rule. Subsequently, the program chooses the other union and this union set wages without knowing the decision of her predecessor. Afterwards, firms are chosen randomly and set quantities. After all firms have set their quantities independently, firms tell quantities to the product market. Prices are calculated by the same demand function as in the Lommerud et al. model (see Eq. (1)), but firms do not explicitly know this. Firms receive information on the prices they achieve with this quantity in the next step in time. With this price information firms calculate profits (Eq. (2)) to make the quantity decision for the next period.

Second, as another distinction to equilibrium models, agent–based computational models run for multiple periods to obtain results[8]. That is, firms and unions in my model make decisions about wages and quantities in several periods. I allow for a run of $10,000$ periods.

Third, to be able to find solutions in my computational model, I have to assess the value for some parameters. For the demand function, reservation wage, and other marginal cost, assumptions are necessary. I choose $A = 100$, $b = 0.9$, $c = 9$ and $w = 0$.[9] To have a reference, I calculate the results for these parameters in the Lommerud et al. paper, too.

[7] For a better understanding, see the pseudo code in the appendix to this chapter.

[8] I avoid the word equilibrium in my model to have a clear distinction from classical equilibrium models. For a further discussion about equilibria in agent-based models see Tesfatsion (2006).

[9] I run my model with different sets of parameters but my model is robust to varying parameter values.

Fourth, I have to start my model with *initial values*. This means that unions and firms start with a certain value for wages and quantities. To make appropriate decisions with my decision rule in the first period, firms and unions need a history of what has happened before my model started. Therefore, I create a random history, using the Lommerud et al. equilibrium as a guiding principle. Firms and unions are assigned with a randomly chosen value for wages and quantities normally distributed. The means are the equilibrium wages and quantities calculated for the Lommerud et al. paper. Using these appropriate values, prices, union utilities, and firm profits are computed. Due to this procedure, some firms and unions start to increase, some to decrease their decision variable in the starting period. I vary the *initial values* to test for stability of my results in section 4.2.

Fifth, I have to decide how much firms and unions can vary quantities and wages from period to period. For the sake of simplicity, I start with an equal decision *step size* of 0.1 for firms and unions. A variation of this parameter yields different results which are shown in section 4.3.

Sixth, unfortunately, programming the code does not lead to an *easy to show solution* like an equilibrium model. One possibility is that, as an outcome of the model, wages and quantities level off after some periods. Another possible result are fluctuating quantities and wages. In addition, some parameters in my model are set randomly which leads to results varying from run to run and within a run. It would not be appropriate to show only the results for one run after 10,000 periods as an outcome. Hence, I have to solve two problems: on the one hand, I have to receive solid results with the parameters set randomly. Thus, I run my model 100 times. On the other hand, I have to present my findings appropriately. Therefore I show average outcomes for 100 runs and the standard deviation among these runs. In addition, I would like to better characterize the process of stabilization in the 10,000 periods. A within–run standard deviation is not sound in this setting, I try to find a number specifying how long the model takes to level off. Thus, I calculate the average of the last 5,000 periods[10] and constitute a limit of 5% as an interval. Afterwards, knowing the upper and the lower bound, I search for the period after which the model stays firm between the bounds of $\pm 5\%$ of the average. I name this period *stable period*. For wages, for example, *stable period* is 295.90. To see it more precisely, Figure 1 shows the *stable period* for wages for all four firms in the first 1,000 periods. The precise *stable periods* in this representative run are 253, 306, 330 and 358 and the average *stable period* is 311.75.

After these preliminary explanations, let me now present my findings in the next section.

4 Results

4.1 One Product Market Loop—One Union Loop

In the beginning, I would like to present Figure 2 for one representative run and show my main results. Afterwards, I compare my average results over 100 runs with the Lommerud et al. model.

To obtain some first impression of what is happening in my model, Figure 2 for the first 1,000 of 10,000 periods is suitable. As I am only interested in averages for an industry, averages for all firms and unions are plotted here. Wages are initially set at a level of 25.03, stay stable for the first periods, decrease afterwards and stabilize around 12.38. Quantities start at a level of 14.04. They decrease faster in the beginning. When unions start to lower wages, firms increase quantities again and they finally level off at 12.30. Values for firm profits and union utility can be read on the ordinate on the right. The cumulative effects of lower wages and reduced quantities lead to firm profits of 407.20 at the end which is much more than the profits at the

[10]The number 5,000 is ad hoc. I choose a high number to be sure that our model has been stabilized.

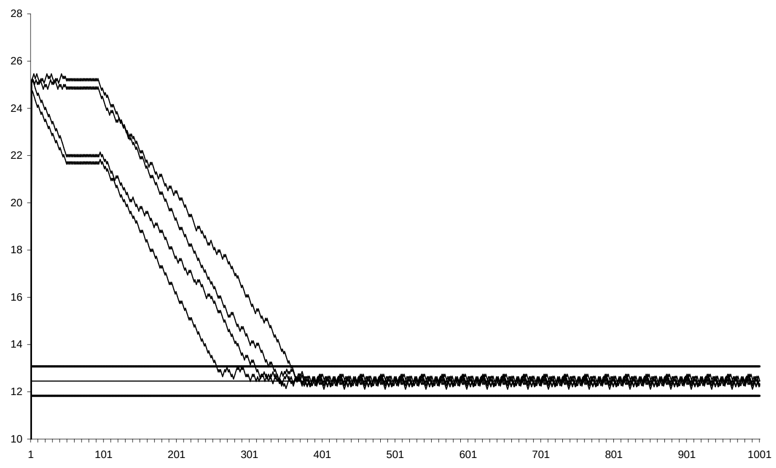

Figure 1: Wages, upper and lower bound, and average

beginning of 197.04. The proceeding is as follows: Firstly, profits decline a little bit. When firms reduce quantities and wages remain unchanged, firm profits increase. This can be interpreted as a collusion effect. The initial wages and quantities are calculated in a Cournot competition model. However, even in the standard IO models, firms obtain higher profits if all firms reduce quantities simultaneously, that is act collusively. Exactly this is happening here. The only difference is that a collusive quantity is not stable in IO models, while lower quantities in my model are stable. Afterwards, when unions lower wages and quantities are enlarged a bit, firms still gain, but the increase is flattened. Finally, with lower wages and lower quantities firms earn a much higher profit than in the beginning. Union utility starts at a level of 351.28, stays stable first, but decreases dramatically when firms reduce quantities. Reacting to this, unions reduce wage. However, the utility decreases but the decrease is less dramatically and at the end union utility stabilizes at about 152.30.

Conspicuously, the changes go on for about 300 periods and new wages, quantities, firm profits, and union utility stabilize afterwards. In Table 1[11] I show that the between runs standard deviation is low with 0.06 and 0.04 for wages and quantities. The variation of firm profits and union utility is higher with 1.2 and 1.02, respectively.

In comparison to Lommerud et al. average wages, quantities, and union utility decrease while profits increase. Hence, Day's decision rule and the limited information result in much higher profits for firms. The losers of my settings are the unions. They are not able to keep their wages stable, firms reduce quantities too much, and union cannot stop this behavior. Therefore unions suffer a great loss of utility.

Summary 1 *In one product market loop and with equal step size quantities, wages and union utility decrease while firm profits increase.*

[11] Lommerud et al. always show the utility of a union. My program calculates the utility one union gains by one firm, so I always show firm specific union utilities. To compare my findings with Lommerud et al., you just have to double my number.

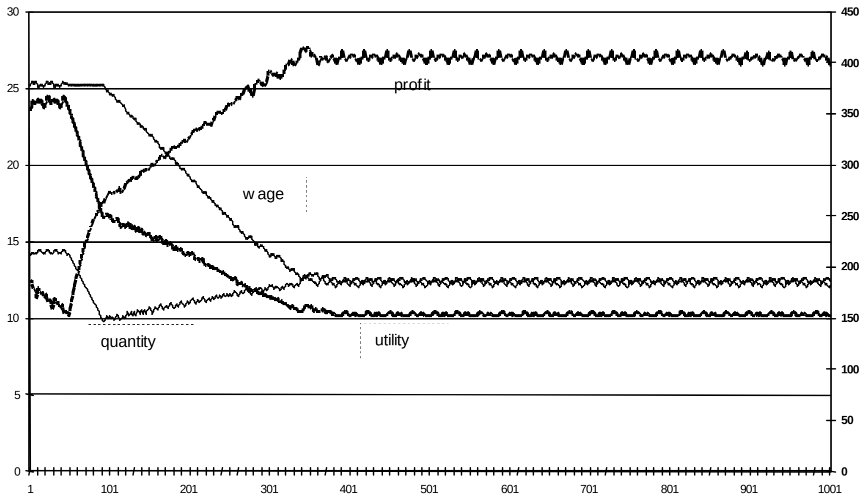

Figure 2: Wages, quantity, profit, and utility

	Lommerud	average	standard deviation	average *stable period*
w_i	25.03	12.38	0.06	295.90
n_i	14.04	12.30	0.04	247.91
V_i	702.56	152.30	1.02	299.78
π_i	197.04	407.20	1.20	272.15

Table 1: Model comparison

4.2 Different Initial Values

In the section above, I initialized my model with the Lommerud et al. values. To test the stability of my results, I try to find out what happens with different initial values. First, I start my model with the results of the section above. Not surprisingly, if I choose $w_i = 12.38$ and $n_i = 12.30$ as initial values, the results are as presented in the first rows of Table 2 in the appendix. As you can see, the results stay stable. As expected, the *stable period* becomes very low when I initialize my model with my results. Additionally, I test for different initial values. I set only one parameter differently, especially $w_i = 1$, $w_i = 40$, $n_i = 1$ and $n_i = 40$; the other is kept constant at the Lommerud et al. levels.

Obviously, the results are stable for all different initial values and the standard deviation is also nearly constant. There are substantial differences in the average *stable period*. This can be explained by the distance between the initial values and results. For a quantity of 40 and a wage of 25.03, quantity and wages have to fall by 27.62 and 12.73 units. This simply needs a longer time than an initialization of $w_i = 1$ and $n_i = 14.04$, where the wages have to increase by 11.39

and the quantity to decrease by 1.74 units. However, the average *stable period* is always in the first 10% of the *periods*.

Summary 2 *Different initial values do not change the results.*

4.3 Different Step Size

One parameter to vary in this agent–based model is the *step size* which indicates the variation of wages and quantities a firm or a union is able to introduce. Until now, *step size* was equal to 0.1 for firms and unions. To find out what happens with a variation of this assumption, I test for different initial values.

I try different values, being the same for firm and union. Results are presented in Table 3. For the average of wages, quantity, union utility, and firm profit, the numbers are relatively stable. Wages vary between 12.31 and 12.77, quantity is nearly constant between 12.29 and 12.31. Differently, but expectably, the standard deviation increases with a larger *step size* which is simply because the firms and unions are stronger in the sense that they can make more decisions and therefore the results are more variable. *Stable periods* are hump–shaped for a *stable period* interval of 5%. First, with a low *step size* the *stable period* is longer due to the longer time firms and unions need to achieve results. However, with a *step size* of 0.5 and a *stable period* interval of 5% the *stable period* approximates the last periods. The explanation is simply that unions and firms vary wages and quantities so much that my interval is too narrow, so it seems that my results never become stable. Hence, I test for different *stable period* intervals (10% and 15%) and achieve stable results again. In summary, a variation of the *step size* does not really matter for the average. As a tentative conclusion one can say that firms benefit from a lower *step size* and unions from a higher one. However, the variation is higher with a higher *step size*.

Summary 3 *A variation of the step size does not lead to very different results, but the higher the step size, the larger the standard deviation and stable period.*

4.4 Multiple Product Market Runs

Up to now I have tried to model my decision rule as similar as possible to the Lommerud et al. paper. In this section, I try to take advantage of the agent–based approach and make further changes. I analyze a situation in which firms vary quantities more frequently than unions can vary wages. This ought to be more realistic in view of the fact that wage–bargaining takes place less often than quantity setting of firms.

Thus, I start again with the initial values of the Lommerud et al. paper and allow for multiple product market loops. My results are presented in Tables 4 and 5. Firstly, it is worth paying attention to profits and union utility. In comparison to one product market loop firms always suffer. Profits are reduced even if firms are able to decide more frequently. In contrast, unions achieve a higher utility. The reasons for higher utility and lower profits are the cumulative effects of lower quantity and higher wages. However, the standard deviation rises with multiple product market runs, but the *stable period* is still low. Nevertheless, one has to be careful with the interpretation due to the definition of a *stable period*. A *period* is finished when unions take their turn to change wages. Therefore a *stable period* for wages of 26.69 for 10 product market loops signifies that unions, on average, are allowed to set wages of 36.96 and during that time, firms set 369.6 times the quantities.

A comparison of the results for multiple product market runs with the Lommerud et al. equilibrium yields the noteworthy result that unions suffer from multiple runs even if their wages stay the same or increase. They suffer from a loss of utility due to lower employment.

Nevertheless, my model results are an advantage for firms, even though wages are sometimes higher. Firms reduce their produced quantity and bring about higher prices. Overall, the effects made firms better off. Compared with the Lommerud et al. equilibrium, utility and profits are closer to Lommerud et al. in multiple product market runs than in one product market run.

In addition, *stable periods* become extremely low, just like the standard deviation of the *stable period* is extremely low. This is due to the fact that unions are not able to achieve a higher utility by a change of wages. To be more precise, unions do not gain a higher utility by increased wages for a large number of product market runs. Independently of their activity, utility is not positively affected and therefore wages stay firm.

Summary 4 *For multiple product market loops profits are lower and union utility is higher than for one product market loop. However, profits are higher and union utility is lower than in the Lommerud et al. equilibrium.*

Secondly, for a deeper understanding of the mechanisms, I focus on the analysis of a variation of wages and quantities. Outcomes for wages and quantities between 2 and 100 loops are noisy and not unidirectional. On average, unions set higher wages than in the Lommerud et al. equilibrium of 25.03 and in the outcomes for one product market loop. On the other hand, firms produce less with multiple loops than in one product market loop and the Lommerud et al. equilibrium. Remarkably, with an increasing number of product market loops, average wages approach the initial Lommerud et al. values for wages again, while quantity is still lower.

How can we explain these results? The relatively stable wages for multiple product market runs imply that there is no feedback through wage adjustments in four out of five periods. Hence, wages are almost exogenous for firms and maybe they try to maximize profits under this assumption. To test this, I calculate the standard IO results with wages as an exogenous parameter. Additionally, lower quantities than the Cournot oligopoly quantities indicate a collusive agreement and thus I suppose firms to behave collusively. I show optimal collusive quantities for firms given a specific union wage in an IO model as a line in Figure 3 and display my results as points with numbers indicating the number of product market runs. It is maybe surprising how closely my computational results approach the standard results for collusive behavior with given cost. Even though information for firms is very limited and their decision rule is simple, they are in a position to act like perfectly rational agents and achieve a stable collusive agreement. This leads to higher profits for firms than those seen in the Lommerud et al.–IO model with a non–collusive agreement and endogenous cost.

Summary 5 *Quantities in multiple product market loops are lower than in the Lommerud et al. equilibrium and for one market loop. They approach the IO equilibria for collusive behavior with given cost.*

An explanation for this, at first glance surprising, result is the simple decision rule. To clarify the effects, assume that only two firms are in the market. Why do they not produce the Lommerud et al. equilibrium? Assume both start with this equilibrium quantity. In the next period, the first firm increases its quantity; the second lowers its quantity. Overall production and, therefore, prices are constant, however, the first firm has higher profits—due to a higher quantity produced—the second has lower profits. In the next period this leads to both firms producing one unit or output more. The first firm is doing that because the firm did the same last period and this increases its profits. The second increases output because this firm produced a lower quantity last period and due to that its profits decrease. So, the second firm changes its quantity setting behavior. To sum up, both produce one unit more, overall two units more than the Lommerud et al. equilibrium are produced and prices decrease. Hence, producing more

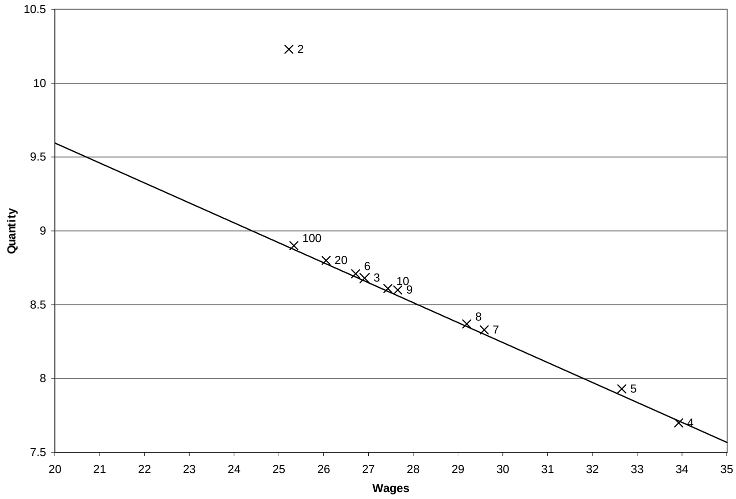

Figure 3: Collusive behavior?

than the Lommerud et al. equilibrium incurs losses for both firms. In the following period both reduce their quantities, overall production is again the Lommerud et al. equilibrium and profits increase for both. The firms follow this strategy (i.e., reducing quantities) until they reach the IO equilibria for collusive behavior with given cost. A deviation is not profitable, since it provokes a quantity increase by the competing firm, reducing profits for both. Therefore, both firms change their strategy again and reduce quantity until they reach the collusive quantity once more. So, this equilibrium is stable in contrast to the Cournot–Nash equilibrium, which is not stable in this setting.[12]

Wage changes are also worth noting: starting from wages above the initial values I find that they converge to the initial values after a sufficient number of product market loops. It is not obvious whether this movement results from the fact that my agent–based model yields these results or whether, in my model, wages tend towards the initial values. Thus, I try to find an answer by choosing different initial values for wages.[13] I took 50 product market loops as an example to strike a balance between a sufficient large number of product market loops to have stable wages and my computing time. Results are presented in Table 6. In this version of my model, unions are endowed with little information, that is, they do not obtain much data about what happens after their change of wages. The only information unions have is data about the change of their own utility after both unions alter wages once and firms alter quantities in various loops. In Figure 4, I show the mark–up unions charge in addition to their initial values. Obviously, unions increase wages more if initial wages are low than for high initial wages.

For low wages, unions increase wages while firms lower quantities until a further increase in wages does not result in a higher union utility. However, from an initial wage of about 25 on, unions do not find it profitable to increase wages much, they keep wages stable. In other words, even with low wages and quite a number of product market runs, unions can influence outcomes to their own benefit. Only with this information about the cumulative effect, unions do not simply keep wages stable; instead they increase their claims until a further raise does

[12] For a discussion concerning the stability, see Standish and Keen (2004).

[13] I also test different initial values for the quantity, but the results stay the same.

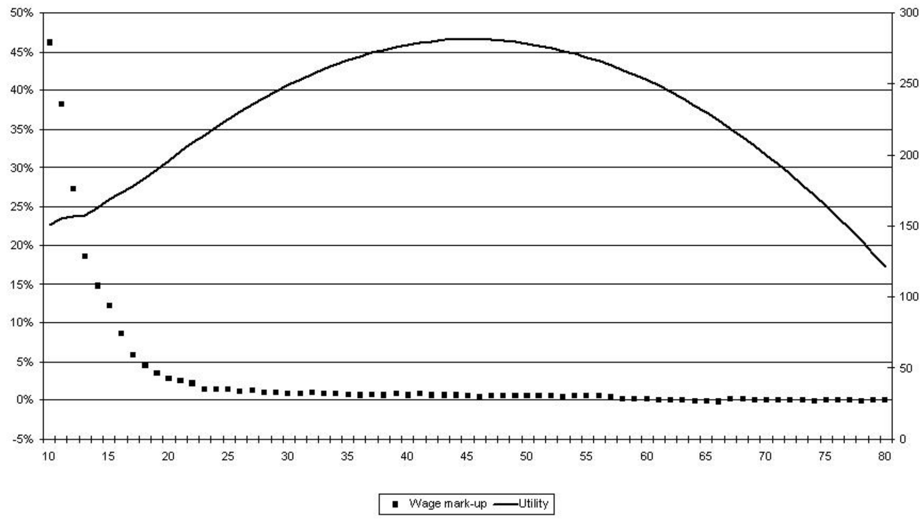

Figure 4: Mark-up and profit for different initial wages

not enhance utility any more. However, if initial wages exceed a certain amount then unions hold wages at their current level, but union utility declines compared to lower initial wages that unions would charge. This is true for initial values of the IO–value for monopolistic upstream and downstream suppliers of 45.5, being the maximal possible utility. For higher initial values, it would be better for unions to reduce wages. Nonetheless, due to the decision rule, unions do not benefit from a wage reduction. Once they try to lower wages, firms do not increase quantities enough during the 50 product market loops, so this policy seems to be irrational. Consequently, unions charge excessive wages, leading to lower utility for unions as well as lower profits for firms. The signals that unions receive are too infrequent.

Overall, wages in multiple product market loops are always higher than in the equilibrium and in a single product market loop. Depending on the different initial wages, unions increase or keep wages stable.

Summary 6 *Wages in multiple product market loops are always higher than in the Lommerud et al. equilibrium and in one product market loop. Depending on the different initial wages, unions increase or keep wages stable.*

5 Conclusion

The idea of this model has been to assume less information endowment than standard IO models as well as boundedly rational agents. The basic trend in my model is that unions will have lower utility and firms will have higher profits than in the standard IO model for unionized oligopolies by Lommerud et al. With firms and unions setting wages and quantities simultaneously, quantities as well as wages are reduced. These results are stable for different initial values. However, when firms alter quantities more frequently than unions alter wages, firms achieve higher profits. The situation where firms set quantities more frequent than unions alter wages may in fact be the most realistic one. Here, firms are able to behave like perfectly rational agents and produce the collusive Cournot quantity with exogenous wage cost. It is remarkable that they achieve this result with very limited information and a very simple decision rule. Additionally, this collusive result is stable. Wages in multiple product market runs stay firm or unions raise them but they never reduce them. This is also true if the union suffers from a lower utility with this behavior because fewer workers are employed. This occurs because of the decision rule. Day's rule does not give unions the feedback they need. When they reduce wages, quantity increases for firms are too low to make a wage reduction profitable, or put differently, the quantity effect does not exceed the wage effect. Therefore, unions do not follow this policy. While these results may not be rational for a perfectly informed agent, they yield more realistic outcomes than currently predicted.

For policy recommendations, the behavior of firms is also more harmful than rational models predict: employment is reduced and prices are increased. The behavior of oligopolistic firms in a product market maybe worse with limited information than with perfectly rational agents.

A criticism of this model is that the decision rule by Day is much too simple and the information endowment of the agents is too limited. However, it is undeniable that information requirements and assumptions about the behavior in standard unionized oligopoly models are extremely high. I modeled the contrary extreme to obtain more insights, but I am aware of the fact that this is also unrealistic. Nevertheless I fell my model is helpful to give a hint about why unions do not lower wages even if it is not the best outcome in a standard model.

In addition, I must confess that my model is not an agent–based model in a strict sense. I introduce unions and firms as agents. Consequently, it would be more appropriate to build a model with heterogeneous workers being partly unionized and trying to maximize individual utility functions. These workers and managers as agents should together represent firms. Customers, on the other hand, should act in the product market and buy the end products as agents. The reason why I choose a much simpler setting with unions and firms as agents is simply to build a model nearer to the standard ones. This should lead to results easier to compare with the original ones so that I can focus on the changes due to bounded rationality and limited information.

For further research, it is necessary in my view to build an agent–based model in a stricter sense with workers, managers and customers as agents, optimally as heterogeneous agents with individual utility functions bargaining for best results. Then it would be appropriate to test results for different decision rules and information sets for all agents. That is, it would be great to have a model with heterogeneous agents, applying different learning strategies and to try to find out which settings give results nearest to the empirical facts.

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Appendix

A Pseudo Code for a Run

```
initialize firms; initialize unions;
begin  union loop
       begin      firm loop
                  repeat   choose randomly one firm
                  if       profits were rising
                  then     if     quantity was rising
                           then   rise quantity
                           else   reduces quantity
                  else     if     quantity was rising
                           then   reduce quantity
                           else   rise quantity
                  until    every firm was chosen once
       end        firm loop
       add the quantities, calculate price, tell firms prices
       begin      firm loop
                  calculate profits of the actual period
       end        firm loop
       repeat     choose randomly one union
       unions calculate utility
       if         utility was rising
       then       if       wages were rising
                  then     rise wages
                  else     reduce wages
       else       if       wages were rising
                  then     reduce wages
                  else     rise wages
       update memory of each union
       until      every union was chosen once
end    union
```

B Tables

	average	standard deviation	average *stable period*	average	standard deviation	average *stable period*
	$w_i = 12.38$ and $n_i = 12.30$					
wage	12.38	0.07	0.57			
quantity	12.30	0.04	0.39			
utility	152.32	1.15	3.78			
profit	407.17	1.26	0.07			
	$w_i = 1$ and $n_i = 14.04$			$n_i = 1$ and $w_i = 25.03$		
wage	12.39	0.07	108.06	12.39	0.07	386.00
quantity	12.30	0.04	79.00	12.30	0.04	367.47
utility	152.32	1.03	133.37	152.45	1.05	439.99
profit	407.17	1.20	96.46	407.04	1.22	398.40
	$w_i = 40$ and $n_i = 14.04$			$n_i = 40$ and $w_i = 25.03$		
wage	12.38	0.07	664.35	12.39	0.07	721.57
quantity	12.30	0.04	623.90	12.30	0.04	673.75
utility	152.25	1.11	689.72	152.36	1.05	729.65
profit	407.24	1.22	666.67	407.14	1.24	705.74

Table 2: Different initial values

		firm and union *step size*					
interval		0.05	0.5 0.1	0.15	0.2 0.05	0.05 0.05	0.01 0.05
average	w	12.77	12.72	12.71	12.47	12.34	12.31
	q	12.31	12.30	12.29	12.30	12.30	12.30
	V	157.10	156.35	156.29	153.29	151.77	151.34
	π	401.58	402.32	402.44	406.11	407.74	408.19
stable period	w	9897.81	1205.54	56.21	253.79	581.78	2783.37
	q	9724.18	2218.93	138.11	364.52	471.19	2183.20
	V	9128.10	2521.45	431.93	1167.43	580.53	2769.09
	π	5332.31	1545.45	43.44	487.41	527.49	2501.64
standard deviation	w	0.35	0.35	0.33	0.13	0.03	0.01
	q	0.19	0.18	0.19	0.08	0.02	0.00
	V	5.61	5.45	5.18	2.01	0.54	0.10
	π	6.54	6.32	5.91	2.48	0.65	0.13
standard deviation *stable period*	w	992.10	3176.75	10.41	841.83	41.41	188.47
	q	1623.02	4104.79	849.80	1258.58	72.71	338.21
	V	2815.15	4292.21	1627.96	2960.86	35.54	165.77
	π	4970.85	3559.51	14.10	1791.44	66.97	309.05

Table 3: Different but symmetric stepsizes

		product market loops							
		1	2	3	4	5	6	7	8
average	w	12.38	25.22	26.91	33.92	32.65	26.71	29.58	29.19
100 runs	q	12.30	10.23	8.68	7.70	7.93	8.71	8.33	8.37
	V	152.30	257.89	233.66	258.24	255.89	232.75	244.17	243.09
	π	407.20	285.97	277.48	222.31	231.48	279.30	255.96	258.78
stable period	w	295.90	6.43	29.36	292.55	151.93	21.59	97.01	79.95
	q	247.91	24.06	27.94	281.48	140.85	12.57	80.41	63.26
	V	299.78	22.35	29.14	243.67	121.81	14.64	78.57	60.74
	π	272.15	22.74	26.76	294.51	164.98	22.44	100.99	83.70
standard	w	0.06	1.40	0.37	4.93	4.46	0.78	3.96	3.00
deviation	q	0.04	0.40	0.07	0.80	0.63	0.14	0.56	0.43
	V	1.02	4.64	2.29	14.30	15.63	3.77	14.22	12.10
	π	1.20	20.65	4.48	44.07	36.30	8.28	32.31	25.23
standard	w	22.38	31.95	13.32	161.93	98.78	19.67	105.18	77.34
deviation	q	38.23	30.03	13.03	172.24	107.89	10.50	106.71	76.46
stable period	V	21.39	28.15	13.06	134.33	80.63	8.96	83.70	58.22
	π	33.87	31.68	18.38	174.01	115.97	20.93	111.83	84.27

Table 4: Different product market loops (1-8)

		product market loops					Lommerud
		9	10	20	50	100	
average	w	27.56	27.43	26.05	25.38	25.33	25.03
100 runs	q	8.60	8.61	8.80	8.89	8.90	14.04
	V	236.86	235.69	229.08	225.86	225.64	702.56
	π	272.06	273.26	285.12	290.94	291.36	197.04
stable period	w	41.43	36.69	10.55	0.25	0.00	
	q	22.20	22.70	3.75	0.02	0.01	
	V	25.99	25.90	4.30	0.02	0.02	
	π	45.36	36.29	12.24	0.49	0.02	
standard	w	1.22	1.77	0.92	0.42	0.35	
deviation	q	0.22	0.27	0.16	0.09	0.08	
	V	5.24	7.75	4.34	1.79	1.43	
	π	12.73	16.53	10.15	5.69	5.10	
standard	w	35.66	39.55	21.59	1.68	0.00	
deviation	q	29.94	32.44	8.73	0.18	0.13	
stable period	V	27.39	29.11	9.77	0.23	0.15	
	π	41.59	40.59	23.69	2.72	0.15	

Table 5: Different product market loops (9-100)

		wage							
		1	10	15	25	35	45	55	80
average	w	14.80	14.61	16.82	25.33	35.28	45.24	55.26	80.03
100 runs	q	10.31	10.35	10.05	8.90	7.56	6.21	4.87	1.51
	V	152.09	150.75	168.79	225.58	266.81	281.27	268.66	120.95
	π	392.65	394.46	371.88	291.40	209.78	141.48	86.32	8.13
stable period	w	160.54	65.97	22.76	0.24	0.01	0.00	0.00	0.00
	q	112.40	20.88	1.60	0.04	0.33	1.22	1.99	33.97
	V	158.28	63.64	19.81	0.05	0.25	1.13	1.84	33.60
	π	141.15	45.99	11.74	0.40	0.50	2.11	105.24	1063.72
standard	w	2.03	1.55	1.11	0.45	0.41	0.41	0.41	0.39
deviation	q	0.29	0.23	0.16	0.09	0.09	0.09	0.09	0.09
	V	16.81	12.86	8.45	2.00	1.07	1.92	3.12	6.40
	π	22.21	17.62	12.44	5.93	4.78	4.11	3.19	0.95
standard	w	38.45	30.46	21.31	1.84	0.10	0.00	0.00	0.00
deviation	q	34.01	21.69	5.49	0.29	0.70	0.95	1.79	257.56
stable period	V	37.20	29.14	19.97	0.34	0.76	0.44	1.23	257.42
	π	39.22	29.90	17.69	2.49	2.21	5.14	705.79	3064.81

Table 6: 50 product market loops