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Zeuthen–Hicks Bargaining in Electronic Negotiations

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Abstract
We apply the Zeuthen–Hicks bargaining model in an empirical study of electronic negotiations. Using a typology of bargaining steps based on that model, we study to what extent actual steps conform to the predictions of the model, and the effects of conformity with the model on bargaining outcomes. Results indicate that the model predicts bargaining steps only slightly better than chance, but that steps conforming to the model lead to outcomes that are closer to the efficient frontier, closer to the Nash bargaining solution, and provide higher utility to the party using such steps.

Keywords Zeuthen–Hicks bargaining · Bargaining steps · Electronic negotiations

1 Introduction

The Zeuthen–Hicks bargaining model (Harsanyi 1956; Bishop 1964), which we will describe in detail in Sect. 2, is one of the few bargaining models which provide clear predictions on the offers and concessions that parties in a two-party negotiation will make throughout the negotiation process. However, this model has only very rarely been tested empirically. Most empirical papers which refer to that model only make use of its prediction about the bargaining outcome, i.e. the Nash bargaining solution, but do not consider individual bargaining steps.

Empirical research on bargaining steps so far has focused mainly on typologies of bargaining steps, referring to changes in different issues in multi-issue negotiations (Filzmoser and Vetschera 2008), or the utility values of the parties (Hindriks et al. 2007; Kersten et al. 2012). Since the Zeuthen–Hicks model also makes predictions about the extent of utility changes, we use it to develop a more fine-grained classification of bargaining steps.

Developing such a classification is not a research goal by itself, a classification of bargaining steps is useful if it allows to predict bargaining outcomes. Since the

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Zeuthen–Hicks model predicts that the negotiation process will converge towards the Nash bargaining solution, we use this solution (and its property of Pareto optimality) as a reference point and study whether bargainers who follow that model will indeed end up closer to the Nash bargaining solution. Furthermore, we also study the effects of different bargaining steps on individual outcomes.

For this empirical analysis, we use an existing data base of negotiation experiments conducted with the electronic Negotiation Support System Inspire (Kersten and Noronha 1999). This database was already used in several empirical studies (e.g., Roszkowska et al. 2017) and provides a large data set of controlled experiments using a single case.

The remainder of this paper is structured as follows. In Sect. 2, we provide a brief introduction to the Zeuthen–Hicks bargaining model. Section 3 reviews previous empirical literature utilizing that model. In Sect. 4, we develop our specific hypotheses and the measurement model used to test them. The empirical results are presented in Sect. 5 and Sect. 6 concludes the paper by summarizing it results and providing an outlook onto future research.

2 The Zeuthen–Hicks Bargaining Model

In this section, we review the Zeuthen–Hicks bargaining model. The presentation of the model mainly follows Harsanyi (1956), who formalized the earlier approach of Zeuthen (1930). The reader is also referred to Bishop (1964) for additional aspects of the model.

The model considers negotiations between two parties A and B. Denote an arbitrary party as $m \in \{A, B\}$, and m's opponent by $\overline{m}$. Similar to Rubinstein (1982), the model considers a sequential process, in which parties subsequently make offers which modify the solution they propose. In contrast to Rubinstein (1982), the model does not specify a priori that the parties alternate in making offers (although that is eventually implied by the model), but the party making the next offer is determined endogenously.

Consider a situation at step t, in which two offers $x_m^t, m \in \{A, B\}$ from the two parties A and B are on the table. Note that t refers to steps in the negotiation, and not to a continuous notion of time. There is no impatience, so parties are not concerned about calendar time. For the purpose of this exposition, it is also not relevant whether x_m is a scalar (such as wage in case of labor negotiations or price in a simple buyer–seller negotiation), or whether it refers to a vector of values in a multi-issue negotiation. The utility function of party m is denoted by $u_m(x)$.

Party m now has to decide whether to accept the offer $x_{\overline{m}}^t$ of the opponent or make a new offer x_m^{t+1}, which can be accepted or rejected by the opponent. Rejection by the opponent leads to termination of the negotiation. In that case, a disagreement outcome d is reached, and each party obtains the utility $u_m(d)$, which is the lowest utility of all possible outcomes.

The probability that opponent $\overline{m}$ will reject an offer x_m is denoted by $p_{\overline{m}}(x_m)$. The model makes two assumptions (Harsanyi 1956, p. 149) about function $p()$:

(I) *Perfect knowledge*, i.e., each party knows both parties' functions; and

(II) *Monotonicity*, the function $p_{\overline{m}}$ is monotonically increasing in $u_{\overline{m}}(x_{\overline{m}}) - u_{\overline{m}}(x_m)$. Monotonicity thus simply indicates that a party is more likely to reject an offer from the opponent the worse the opponent's offer is compared to the party's own offer.

Party m will accept the opponent's offer rather than taking the risk of making a counteroffer and possibly face rejection if the expected utility from the risky prospect of the counter-offer is less than the utility from the safe option of accepting the opponent's offer:

$$u_m\left(x_{\overline{m}}^t\right) > p_{\overline{m}} u_m(d) + (1 - p_{\overline{m}}) u_m\left(x_m^{t+1}\right) \tag{1}$$

From (1), one can determine a critical probability $p_{\overline{m}}^*$ at which party m is indifferent between accepting and making a counteroffer as

$$p_{\overline{m}}^*\left(x_m^{t+1}\right) = \frac{u_m\left(x_{\overline{m}}^t\right) - u_m\left(x_m^{t+1}\right)}{u_m(d) - u_m\left(x_m^{t+1}\right)} \tag{2}$$

If

$$p_{\overline{m}}\left(x_m^{t+1}\right) > p_{\overline{m}}^*\left(x_m^{t+1}\right), \tag{3}$$

it would be better for m to accept the opponent's offer rather than making the counteroffer x_m^{t+1}. In contrast, if $p_{\overline{m}}(x_m^t) < p_{\overline{m}}^*(x_m^t)$, party m can even insist on x_m^t and does not have to make a concession. Thus, in the current state of the negotiation, when offers x_m^t and $x_{\overline{m}}^t$ are on the table, $p_{\overline{m}}^*(x_m^t)$ can be considered as a measure of the strength or "determination" (Harsanyi 1956, p. 148) of party m. Party m is in that sense weaker than party $\overline{m}$ at step t if

$$p_{\overline{m}}^*\left(x_m^t\right) < p_m^*\left(x_{\overline{m}}^t\right) \tag{4}$$

The critical probability for the opponent can be calculated analogously to (2). Thus, (4) can be rewritten as

$$\frac{u_m\left(x_{\overline{m}}^t\right) - u_m\left(x_m^{t+1}\right)}{u_m(d) - u_m\left(x_m^{t+1}\right)} < \frac{u_{\overline{m}}(x_m^t) - u_{\overline{m}}(x_{\overline{m}}^{t+1})}{u_{\overline{m}}(d) - u_{\overline{m}}(x_{\overline{m}}^{t+1})} \tag{5}$$

or equivalently (omitting time indices for brevity)

$$(u_m(x_m) - u_m(d) \cdot (u_{\overline{m}}(x_m) - u_{\overline{m}}(d)) < (u_m(x_{\overline{m}}) - u_m(d) \cdot (u_{\overline{m}}(x_{\overline{m}}) - u_{\overline{m}}(d)) \tag{6}$$

Note that the left hand side of (6) depends only on x_m, the offer of party m, and not on $x_{\overline{m}}$, while the right hand side cannot be changed by party m. Party m can therefore revert the relationship in (6) by changing its offer to increase the left hand side of (6), which is

$$N(x_m) = (u_m(x_m) - u_m(d)) \cdot (u_{\overline{m}}(x_m) - u_{\overline{m}}(d)) \tag{7}$$

Note that $N(x)$ is exactly the function that is maximized in the Nash bargaining solution (Nash 1950). Thus each step will increase $N(x)$. If the maximum of $N(x)$ is unique, which is the case e.g. if both utility functions are concave (Dias and Vetschera 2018), the process will thus converge to the Nash bargaining solution.

Since d is the worst possible outcome, we can without loss of generality set $u_m(d) = 0$ and simplify (7) to

$$N(x_m) = u_m(x_m) \cdot u_{\overline{m}}(x_m) \tag{8}$$

3 Empirical Studies

The Zeuthen–Hicks bargaining model makes several quite clear and therefore testable predictions about the bargaining process. Thus, it was frequently mentioned in literature in the context of analytical bargaining models (e.g., the surveys of Oliva and Leap 1981; Lewicki et al. 1992). Still, it has found only little attention in the empirical literature (Vetschera 2013), and most empirical literature that refers to this model only uses its predictions about the outcomes of a bargaining process, and not its description of the process itself.

A very early empirical paper that refers to Zeuthen–Hicks bargaining is Hamermesh (1973). The paper studies labor negotiations in the public sector, since in that sector both data on the offers made by the employers and demands by the union are publicly available. It presumes that both parties have utility functions that are linear in money, which would imply that the agreement should be in the middle of initial offers. It finds a significant deviation from the “split in the middle” solution, which is interpreted as evidence for considerable bluffing on the union side. Similar analyses on the same and another dataset were later performed by Bognanno and Dworkin (1975) and Bowlby and Schriver (1978). All these papers assumed symmetric utilities, therefore the solution that splits the difference between the initial offers of the two parties was considered as the Nash bargaining solution predicted by the Zeuthen–Hicks model. This assumption was criticized as unrealistic by Svejnar (1980), who developed specific payoff functions based on the profit of employers and total wage payments received by union members to obtain more realistic utility functions for the two parties.

Svejnar (1986) also provides a different interpretation of asymmetric outcomes. The paper acknowledges that the Zeuthen–Hicks model has both prescriptive and descriptive value and extends the model to take into account that the two parties may have different bargaining power, costs of disagreements, and risk attitudes. Asymmetries in the outcome are explained by these differences. The model is empirically tested on wage bargaining data from twelve firms.

That paper also formed the basis of a related stream of literature applying the Zeuthen–Hicks model to health economics to study the relative bargaining power of health insurance companies vis-a-vis other actors in that field. Brooks et al. (1997) applied the model by Svejnar (1986) to negotiations between health insurers and hospitals about the prices charged for operations, and Brooks et al. (1999) to negotiations between health insurers and pharmacies. The market for health insurance packages was studied by Maude-Griffin et al. (2004), who used the model to estimate the bargaining power of HMO organizations and employers in negotiations about commercial health insurance programs. These studies also used only final outcomes of the negotiations to estimate the power of actors.

One problem in the application of the Zeuthen–Hicks model to estimate bargaining power is that it requires data on the utility functions of parties. As Chambers and Echenique (2014) have shown, even if disagreement points and final outcomes are known, this information can be compatible with many different bargaining models as long as the individual utility functions are not known.

The Zeuthen–Hicks model not only makes predictions about the final bargaining outcome, but also about behavior in each step. Surprisingly, this feature of the model was only scarcely used in empirical research. To the best of our knowledge, Fandel (1985) is the only study that takes this perspective. He analyzed collective wage bargaining in the German metal industry and studied whether the predictions of the model which party makes a concession are correct. Results indicate that the model was able to correctly predict which side makes a concession in over 70% of the bargaining steps analyzed. In the present paper, we also take this dynamic perspective and apply the model to single bargaining steps, rather than to the final outcome of a negotiation.

4 Measurement, Hypotheses and Data

The predictions made by the Zeuthen–Hicks model can directly be translated into hypotheses for empirical research. The model predicts which party is going to change its offer, as well as the extent of that change.

Referring to the party making a bargaining move, we can directly formulate our first hypothesis:

H1 The party for whom condition (4), or equivalently condition (6) holds, will change its position and make a new offer.

The model further predicts that the new offer made by the party identified in H1 will revert the condition specified in inequalities (4) and (6). It is easier to operationalize this prediction using (6). Note that in inequality (4), both sides of the inequality depend on the offers of both parties, while in (6), each side of the inequality only refers to the offer of one party. We therefore can formulate our second hypothesis as follows:

H2 A bargaining step made by party m will lead to a reversal of (6), i.e. to $N(x_m) > N(x_{\overline{m}})$.

Obviously, H2 can be tested only in cases in which H1 is fulfilled. We therefore use a slightly different formulation of the two hypotheses, that focuses on individual bargaining steps and asks whether the predictions of the Zeuthen–Hicks model are fulfilled. This can be done in two ways.

Consider a bargaining step made by party m. According to the Zeuthen–Hicks model, a step at time t will be made by party m if the *precondition*

$$N\left(x_m^t\right) < N\left(x_{\overline{m}}^t\right) \tag{9}$$

is fulfilled and will lead to the *postcondition*

Table 1 A classification of bargaining steps

Step type	Precondition	Postcondition	Nash increase
Unnecessary	No	Yes	Yes
Adjustment	No	Yes	No
Weakening	No	No	No
Wrong direction	Yes	No	No
Insufficient	Yes	No	Yes
Conformant	Yes	Yes	Yes

$$N\left(x_m^{t+1}\right) > N\left(x_{\bar{m}}^t\right) \tag{10}$$

To provide a more detailed analysis of the process, we can also consider steps that go into the right direction, independently of whether the move is sufficiently large. We therefore also define the property that a bargaining step is *Nash-increasing* as

$$N\left(x_m^{t+1}\right) > N\left(x_m^t\right) \tag{11}$$

Furthermore, since $N(x)$ depends on the utility of both parties, and could also be increased by a step that makes the party making the step better off (Dias and Vetschera 2018), we also consider whether step is actually a *concession*:

$$u_m\left(x_m^{t+1}\right) < u_m\left(x_m^t\right) \tag{12}$$

Hypothesis H1 then states that for each bargaining step the precondition is fulfilled, and H2 can be formulated that for each bargaining step, the postcondition is fulfilled.

The postcondition could also be fulfilled if a step is made by the wrong party (in which case the postcondition was also fulfilled before the step). Such a step could further improve the position of the already stronger party, weaken its position only to the extent that it still remains stronger, or weaken it even below the other party. Similarly, steps by the right party that fail to fulfill the postcondition can go in different directions. Thus, using the three properties of precondition, postcondition and Nash increase, we can classify bargaining steps as indicated in Table 1.

Note that in Table 1, the combinations yes/yes/no and no/no/yes are not possible, since if the precondition is fulfilled, fulfillment of the postcondition is only possible by an increase in the Nash objective function and vice versa. Figure 1 illustrates the different step types graphically.

Hypothesis H1 then implies that steps are of the types wrong direction, insufficient, or conformant, and hypothesis H2 implies that steps are of type conformant, unnecessary, or adjustment.

All conditions refer to utilities (and offers) of both sides. In the experiments we use for our empirical analysis, subjects did not know their opponent's utility functions. We therefore analyze hypotheses H1 and H2 not only for the true utility functions of

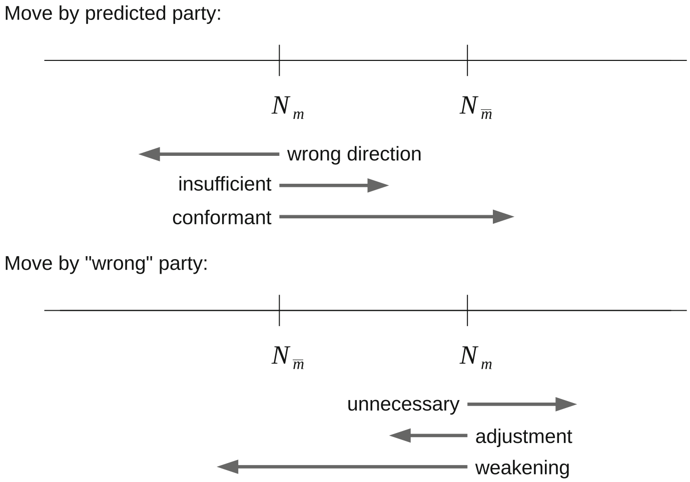

Fig. 1 Illustration of step types

both sides, but also for a model that assumes that both parties follow the fixed pie assumption, i.e. that they believe that their opponent's utilities are exactly the opposite of their own. Denote the utility value of the best possible outcome for party m by $u_m^{\max}$. Under the fixed pie assumption, the Nash objective function (10) is replaced by

$$u_m(x) \cdot \left(u_m^{\max} - u_m(x)\right) \tag{13}$$

assuming that the disagreement outcome is assigned a utility of zero by each party.

According to the Zeuthen–Hicks model, the process converges to the Nash bargaining solution, which is an efficient outcome. Therefore we can hypothesize that bargaining processes in which steps according to the model are more frequent are also more likely to reach such an agreement. This can be formulated in the form of the following hypotheses:

H3 If bargaining steps that conform to the model are more frequent in a bargaining process, then the process is more likely to lead to an agreement.

H4 If bargaining steps that conform to the model are more frequent in a bargaining process, and the process reaches an agreement, then that agreement is more likely to be efficient.

H5 If bargaining steps that conform to the model are more frequent in a bargaining process, and the process reaches an agreement, then that agreement is closer to the Nash bargaining solution.

Two aspects of Hypotheses H3–H5 require additional clarifications. First, there are several ways of determining whether a bargaining step conforms to the model. One can explicitly check the precondition, the postcondition and whether a step increases $N(x)$, or one can utilize the classification of bargaining steps as provided in Table 1. Both ways of testing these hypotheses offer the possibility of obtaining additional insights. When testing the conditions explicitly, it is also possible to analyze the impact of each condition separately and e.g. find out whether the effect of fulfilling the precondition in stronger than the effect of fulfilling the postcondition. Similarly, by utilizing the classification of bargaining steps of Table 1, one can not only test the impact of conformant steps, but also compare it to the effect of e.g. insufficient steps. Therefore, both methods will be utilized in the empirical analysis. Furthermore, "more frequent" might refer to either the actual number of such bargaining steps, or their share among all steps. Since there is no theoretical argument for either measure, we will also use both in our empirical tests.

In addition, we can also study from an exploratory perspective which effect a bargaining process following the Zeuthen–Hicks model has on the individual outcome of a negotiator who follows that process (regardless of the steps made by the opponent).

To summarize our hypotheses, we have formulated two hypotheses about the bargaining behavior predicted by the model: which party makes a concession (H1), and the size of the concession (H2), and three hypotheses about the effect of behavior conforming to the model, that it will lead to more agreements (H3), to efficient agreements (H4), and to agreements that are closer to the Nash solution (H5).

To test these hypotheses empirically, we use a dataset from the Inspire database which was created from negotiations using the NSS Inspire (Kersten and Noronha 1999). All negotiations considered for this study were conducted using the Yowl-Pop case, which is a bilateral negotiation between an agent representing a singer and a music production company. These experiments were already used in several other empirical studies (e.g., Roszkowska et al. 2017) and are described in detail there. The case is a multi-issue negotiation concerning four issues. For each issue, there is only a prespecified number of options (four options for two issues, and three and five options for the other two issues), so that in total only $4 * 4 * 3 * 5 = 240$ agreements are possible.

Negotiations in Inspire consist of three phases. In a pre-negotiation phase, the utility functions of participants are determined. Inspire is typically used for cases involving multiple issues, so for each party an additive multi-attribute utility function on all issues is elicited using a conjoint measurement method. The utility functions are considered private information of the parties and are not revealed to their opponents. Inspire also allows later changes in the utility functions, however, cases in which this was done were excluded from the analysis to allow for an non-ambiguous measurement of utilities. In the actual negotiation phase, participants exchange offers and free text messages. Offers contain values for all attributes and are considered binding for the party sending the offer. There is no strict protocol, parties are free to send offers with or without messages, and do not have to alternate in sending offers. After parties reach an agreement, Inspire checks (using the utility functions) whether the agreement is efficient. If the agreement is dominated by some other possible contract, the system enters a post-negotiation phase, in which efficient contracts are proposed to the parties. In the present analysis, the post-negotiation phase is not included.

For the present study, we used data from six experiments conducted the years 2015–2017 with subjects from 19 groups. In total, this data set contained data from 365 negotiations. Since the Zeuthen–Hicks model assumes given utilities, but the Inspire

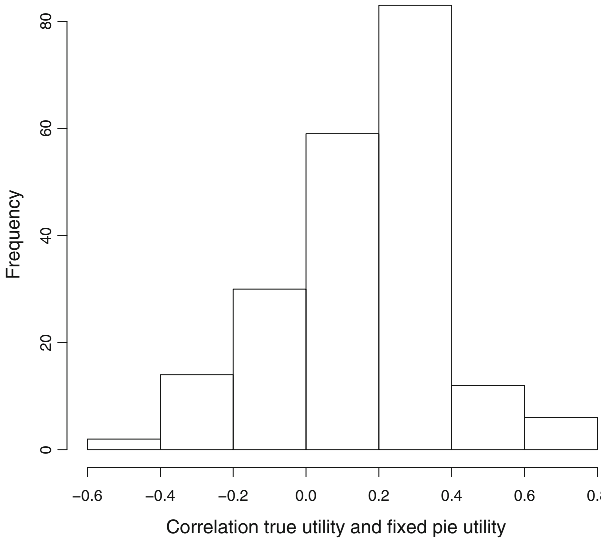

Fig. 2 Distribution of correlation coefficients between true utilities of the opponent and utilities assumed under fixed pie assumption

system allows users to re-estimate their utility functions during the negotiation, we restricted the analysis to those negotiations in which both parties performed only one utility elicitation. To be able to test for pre- and postconditions, negotiations also had to contain at least two offers from each side. After applying these restrictions, data from 231 negotiations (and 462 users) remained for this analysis. 206 negotiations (89%) reached an agreement, 25 did not. 273 users were female, 181 male, and 8 did not disclose their gender. In total, 1316 bargaining steps from these negotiations were analyzed.

5 Results

5.1 Structure of Bargaining Steps (H1, H2)

As we have already indicated, bargaining steps can be determined using the actual utility function of the opponent, or under a fixed pie assumption that the opponent's utility function is exactly the opposite of the focal negotiator's utility function. To estimate the potential effect of this distinction, we calculated for all pairs of negotiators the Pearson correlation coefficient between true utilities and utilities under the fixed pie assumption across all 240 possible offer packages. Figure 2 shows the histogram of these correlations. On average, preferences assumed under the fixed pie assumption are quite different from true preferences, the average correlation coefficient is only 0.163. However, as Fig. 2 also shows, there is a considerable variation, correlation coefficients range from -0.573 to $+0.740$. Therefore, we perform the analysis for both models.

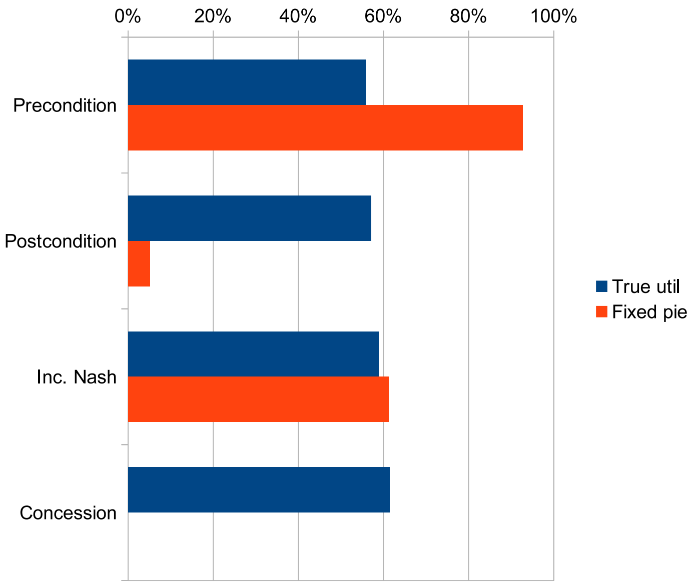

Fig. 3 Fractions of bargaining steps exhibiting different properties

Figure 3 shows the fractions of bargaining steps that fulfill the pre- and postconditions as defined in equations (9) and (10), that correspond to an increase in the Nash objective functions as defined in (11), and that are concessions (12), considering both true utilities and the fixed pie assumption.

According to both models, the precondition is fulfilled in significantly more than 50% of the offers according to a proportion test. Assuming true utilities, a bargaining step was made by the party who had the lower critical probability in 55.78% of all cases, which means the model predicted which party makes a move slightly more often than chance. However, it would easily be outperformed by a model that predicts that parties make offers in alternating order. Only 10.9% of all offers were made by the same party as the previous offer in a negotiation, which means that the simple prediction that parties make offers in an alternating sequence is true in almost 90% of all cases. For the model using the fixed pie assumption, the precondition was fulfilled in 92.71% of all bargaining steps. However, this does not necessarily mean that the model made the right prediction which party makes a concession so often. When using true utilities, the precondition can be fulfilled only for one party, the product of both parties' utilities for the two offers on the table is larger for one or the other offer. However, under the fixed pie assumption, each party compares the function for the two offers using different utility functions (their own function and its complement). Therefore, it is possible that the precondition is fulfilled for both parties, in that case, the model cannot predict which party is going to make a move.

As Table 2 shows, under the fixed pie assumption, the precondition was fulfilled for both parties in a large majority of all bargaining steps. In these cases, the model could not predict which party is going to make a move. Considering only the 180 bargaining steps in which the precondition is fulfilled for only one party, the model

Table 2 Number and fraction of bargaining steps in which the precondition under fixed pie assumption was fulfilled for either party

Precondition fulfilled for ...		
	Opponent	
Focal party	No	Yes
No	13 (1.0%)	83 (6.3%)
Yes	97 (7.4%)	1123 (85.3 %)

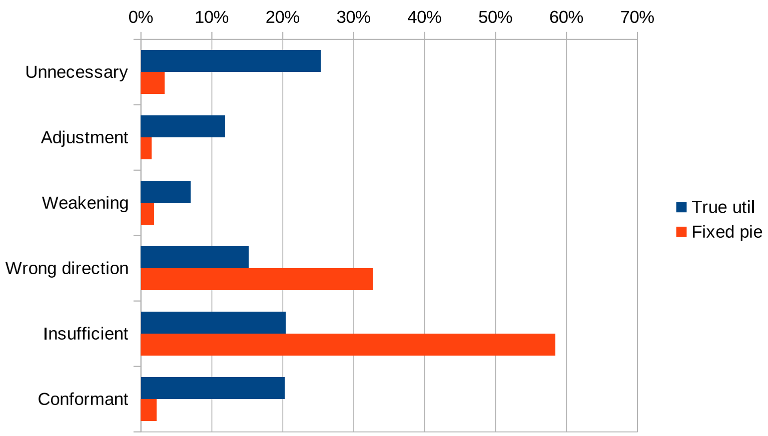

Fig. 4 Distribution of step types

would correctly predict the party making the move in 97 cases (53.9%), this fraction is not significantly different from 50%. Thus, we can conclude that hypothesis H1 is confirmed for the model using true utilities, but not under the fixed pie assumption.

Concerning the postcondition, the picture is rather different. According to the fixed pie model, the postcondition is fulfilled only in a small fraction of 5.17% of all bargaining moves. Considering true utilities, significantly more than half of the steps (57.1%) lead to a situation fulfilling the post condition.

A more detailed analysis is provided by Fig. 4, which shows the distribution of step types. In the model using true utilities, the large majority of moves made by the predicted party also goes into the predicted direction, although about half of these moves are insufficient in terms of size. Although in the model using the fixed pie assumption most moves are made by a party which has a lower Nash objective value, most of these moves do not lead to a higher Nash objective value under the fixed pie assumption. Almost 60% of the moves are classified as “Insufficient”, i.e. they go into the right direction, but not far enough. The second largest group consists of moves into the wrong direction, i.e,. the Nash objective function (as calculated using opposite preferences) decreases rather than increases. Only the model using true utilities classifies a comparatively large number of bargaining moves as being made by the “wrong” side in terms of the Zeuthen–Hicks model. Among these moves, the majority are unnecessary moves, i.e. the party which already has a larger value of the Nash objective increases its value further. There are also some moves in which

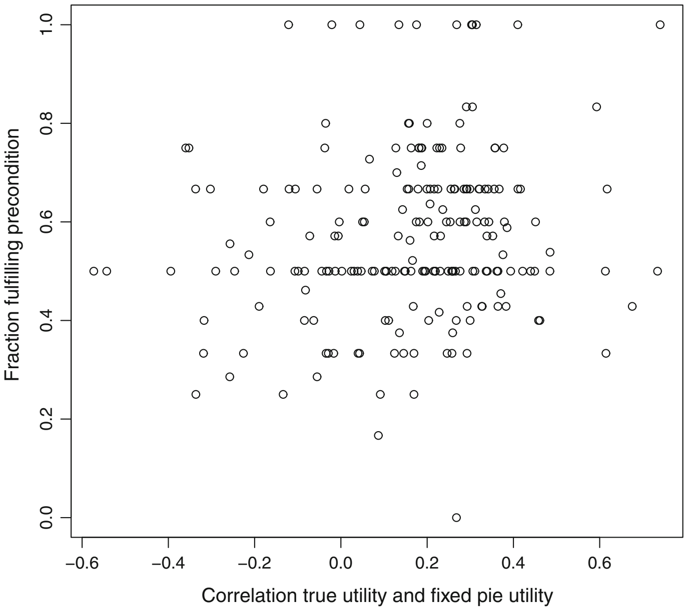

Fig. 5 Correlation between utilities versus share of steps fulfilling the precondition

that party decreases the value of the Nash objective function, but in only a few moves that party actually ends up in the weaker position.

Since both Figs. 3 and 4 indicate a considerable difference between the frequency of step types determined using true utilities and step types determined using the fixed pie assumption, we also tested whether the frequency of step types within each negotiation depends on the correlation between the two utilities For this test, we calculated the correlation coefficient between the relative frequency of steps fulfilling a property or belonging to a certain type, and the correlation between true and fixed pie utilities. We could find a significant (but still weak) correlation only for steps fulfilling the precondition ($\rho = 0.153$, $p = 0.028$). Figure 5 illustrates that relationship. The figure shows that in negotiations where the fixed pie assumption provides a better approximation of the opponent's true utilities, typically a larger fraction of steps fulfills the precondition. However, there are still some negotiations where this correlation is very low or even negative, yet all steps fulfill the precondition as indicated by the row of points on top of the figure.

5.2 Impact on Agreement (H3, H4, H5)

Hypotheses H3–H5 relate the use of bargaining steps that conform to the predictions of the Zeuthen Hicks model to negotiation outcomes in terms of reaching an agreement, efficiency of the agreement, and its closeness to the Nash bargaining solution. Since the bargaining moves are the independent variables in these hypotheses, they should be measured in an objectively correct way. Therefore, we test the hypotheses only with respect to true utilities, and not using the fixed pie assumption.

Table 3 Bargaining moves having different properties in failed and successful negotiations

	Fraction			Count		
	Failed (%)	Agree (%)	Test	Failed	Agree	Test
Property						
Precondition	53.2	57.2	2289.0	3.320	3.160	2703.0
Postcondition	58.2	59.9	2287.5	3.320	3.243	2758.0
Inc. Nash	56.0	66.2	1969.5°	3.400	3.345	2612.5
Concession	64.9	66.2	2495.5	3.600	3.485	2689.0
Step type						
Unnecessary	23.5	26.1	2256.5	1.520	1.432	2733.5
Adjustment	13.4	10.5	2809.0	0.800	0.660	2806.0
Weakening	9.9	6.2	3067.5°	0.640	0.369	3088.5*
Wrong direction	13.4	11.9	2734.5	1.000	0.850	2815.5
Insufficient	18.6	21.7	2267.0	1.320	1.141	2618.0
Conformant	21.2	23.4	2350.0	1.000	1.170	2411.0

°$p < 10\%$; *$p < 5\%$; **$p < 1\%$; ***$p < 0.1\%$

Outcome properties are measured at the level of the entire negotiation. We therefore calculated the number and the fraction of bargaining steps exhibiting a certain property for each negotiation in order to be able to test the hypotheses at the level of entire negotiations. Table 3 shows these values in failed and successful negotiations. A nonparametric Wilcoxon test indicates only few weakly significant differences. Successful negotiations contain significantly more bargaining moves in which a party increases the Nash objective function of its offer (66.22% vs. 55.96%, $p = 5.4\%$), and significantly fewer weakening bargaining moves in which a party decreases the value of the Nash objective function so far that it falls behind the opponent (6.16% vs. 9.87%, $p = 5.9\%$). This effect is also significant when considering the average number of such steps in a negotiation (0.369 vs. 0.640, $p = 4.6\%$). While successful negotiations also contain somewhat more bargaining moves that fulfill the precondition, the postcondition, or that are concessions, none of these differences is statistically significant.

A logistic regression with agreement as the dependent variable led to very similar results, thus we do not present it here.

Hypotheses H4 relates the occurrence of bargaining steps that correspond to the Zeuthen–Hicks model to efficiency of an agreement (if one is reached) and H5 to its closeness to the Nash bargaining solution. Consequently, we can only use negotiations in which an agreement was reached to test these hypotheses.

Efficiency of the agreement could be measured as a binary variable, indicating whether the agreement is Pareto dominated or not, or as a metric variable by e.g. counting the number of dominating alternatives. In the present data, the distribution of this variable is heavily skewed: 52.9% of all agreements are efficient (i.e., not dominated by any possible contract), and an additional 28.2% of agreements is dominated by at most three other possible contracts. In contrast, one agreement was dominated

Table 4 Bargaining moves having different properties in negotiations with efficient and inefficient agreement

	Fraction			Count		
	Inefficient (%)	Efficient (%)	Test	Inefficient	Efficient	Test
Property						
Precondition	55.9	58.4	4895.5	3.216	3.110	5038.0
Postcondition	57.1	62.3	4545.0°	3.237	3.248	4894.0
Inc. Nash	61.6	70.3	4142.0**	3.134	3.532	4445.5*
Concession	65.1	67.2	5043.0	3.536	3.440	5205.5
Step type						
Unnecessary	25.2	26.8	4907.0	1.485	1.385	5287.5
Adjustment	11.9	10.1	5625.5	0.804	0.587	5729.5
Weakening	7.0	4.7	5617.5	0.381	0.312	5560.5
Wrong direction	13.7	10.2	6108.5*	1.103	0.624	6057.5*
Insufficient	21.5	21.9	5241.0	1.113	1.165	5208.5
Conformant	20.7	26.3	4603.0	1.000	1.321	4462.0*

° $p < 10\%$; * $p < 5\%$; ** $p < 1\%$; *** $p < 0.1\%$

by 75 other contracts. Thus, a large number of dominating alternatives occurs only in very few cases and we focus on the fact that an agreement is dominated at all.

As Table 4 shows, negotiations that end in an efficient agreement contain a significantly higher fraction and absolute number of bargaining steps that increase the Nash objective function, but fewer steps that go in the opposite direction. Furthermore, the absolute number of steps that conform with the model is significantly higher in negotiations leading to an efficient agreement. The fraction of such steps is also higher, but that difference is not significant.

Hypothesis H5 refers to the impact of step types on closeness of the agreement to the Nash bargaining solution. We first consider the possible effects of different properties of bargaining steps on that variable. As Table 5 shows, the different properties are highly correlated, both if one considers the fraction and the absolute number of steps having the different properties. Negotiations which contain a larger number or fraction of e.g. bargaining steps that fulfill the precondition are also more likely to contain many steps fulfilling the postcondition etc.

Given the high correlation between properties, it is not meaningful to include all properties simultaneously into one regression model. We can only conduct a correlation analysis on each variable individually. However, one has to be aware that it is not possible to distinguish the impact of different properties. Results of this analysis are summarized in Table 6.

As could be expected, a higher fraction of steps that are fulfilling the properties also improves the agreement by bringing it closer to the Nash bargaining solution. Surprisingly, this relationship is less pronounced when considering the absolute number of steps. This could be an indicator of a decreasing marginal effect. If a negotiation already contains a comparatively large number of steps having a certain property, then

Table 5 Correlation coefficients between properties of bargaining steps

Fraction	Precondition	Postcondition	Inc. Nash	Concession
Precondition		0.3456***	0.3504***	0.0508
Postcondition	0.3456***		0.4067***	− 0.0105
Inc. Nash	0.3504***	0.4067***		0.2473***
Concession	0.0508	− 0.0105	0.2473***	
Count	Precondition	Postcondition	Inc. Nash	Concession
Precondition		0.8833***	0.7870***	0.7322***
Postcondition	0.8833***		0.7722***	0.7029***
Inc. Nash	0.7870***	0.7722***		0.7247***
Concession	0.7322***	0.7029***	0.7247***	

°$p < 10\%$; *$p < 5\%$; **$p < 1\%$; ***$p < 0.1\%$

Table 6 Correlation analysis between properties of bargaining steps and closeness of agreement to the Nash solution

	Difference in Nash objective	
	Fraction	Count
Precondition	− 0.282***	− 0.076
Postcondition	− 0.252***	− 0.063
Inc. Nash	− 0.231***	− 0.199**
Concession	− 0.115°	− 0.026

°$p < 10\%$; *$p < 5\%$; **$p < 1\%$; ***$p < 0.1\%$

more of the same steps might not bring the negotiation closer to the Nash bargaining solution. The obvious exception are steps that actually increase the Nash objective, they are always effective.

The problem of correlation is not present when considering step types, since these are mutually exclusive. However, when considering fractions, it is not possible to use all step types as independent variables, since the fractions always sum up to 100%. We therefore omitted the conformant steps, and analyze only deviating step types when considering fractions.

Table 7 shows the result of the regression analysis. The dependent variable in the regression is the difference between the optimal value of the Nash objective function (the value of the contract that maximizes the product of both utilities), and the product of utilities of the agreement. Since both visual inspection of a qq-plot and the Kolmogorov–Smirnov test indicated a significant deviation of the distribution of residuals from normal, we performed a robust regression using the `robustbase` package (Maechler et al. 2018) of the R statistical system (R Core Team 2018). Increasing the fraction of steps that contradict the model (weakening steps, steps in the wrong direction or insufficient steps) increases the distance to the Nash bargaining solution significantly. From the regression using the counts of steps it becomes clear that mainly conformant steps (which could not be included in the regression using fractions) bring the agreement closer to the Nash bargaining solution.

Table 7 Regression analysis of step types on difference to Nash solution

Step type	Fraction	Count
Unnecessary	161.8268	– 107.0569
Adjustment	769.8782	77.1896
Weakening	1447.1634**	137.8524
Wrong direction	948.8529*	104.9862
Insufficient	832.4497**	10.3262
Conformant		– 183.8803***
R^2	0.0997	0.1319

$^{\circ}p < 10\%$; $^{*}p < 5\%$; $^{**}p < 1\%$; $^{***}p < 0.1\%$

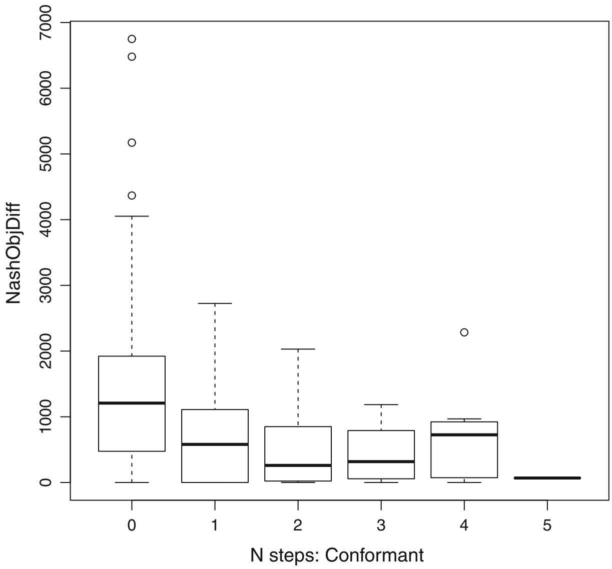

Fig. 6 Difference of Nash objective value of agreement to optimum for negotiations exhibiting a different number of conformant steps

The effects of an increasing number of conformant steps indicated by the regression results is also clearly visible in Fig. 6, which shows the distribution of differences in the Nash objective of the final agreement to the Nash bargaining solution for negotiations in which a different number of conformant steps was used.

The relationship between conformant steps and distance to the Nash bargaining solutions seems to be slightly U-shaped. While the distance of the agreement to the Nash bargaining solution decreases in negotiations that contain one or two conformant steps, it increases again for negotiations containing three or four such steps. However, it should be noted that Fig. 6 shows the evaluation of the agreement, not the situation directly after the conformant step. It thus might be that in negotiations which contain several conformant steps, subsequent steps of other types move the outcome away from the Nash bargaining solution. Figure 7 indicates that such a mechanism might indeed be at work. This figure shows the situation immediately after each conformant

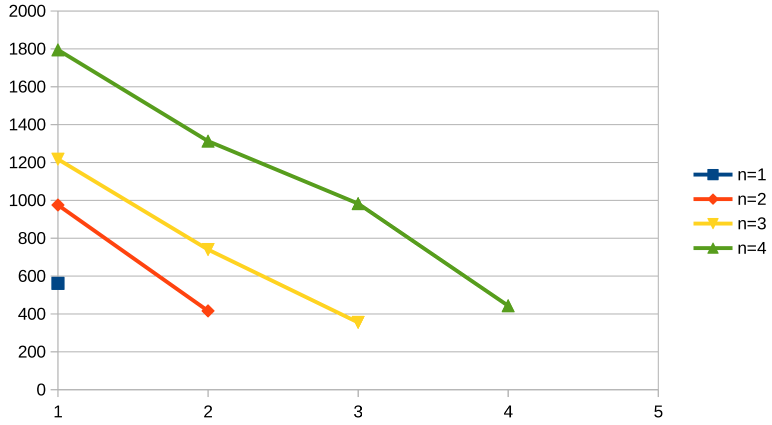

Fig. 7 Average difference of Nash objective value of offer to optimum after each conformant step in negotiations containing n conformant steps

Table 8 Average difference in Nash objective to optimum after the last conformant step and in the agreement

	Conformant steps			
	$n = 1$	$n = 2$	$n = 3$	$n = 4$
After last conformant step	561.50	416.00	355.17	443.33
Agreement	684.16	506.72	431.33	661.92

step in negotiations containing $n = 1$ to $n = 4$ conformant steps. $n = 5$ is excluded because there was only one negotiation that contained five conformant steps.

Several features of Fig. 7 are remarkable. First of all, the three lines for $n = 2$ to $n = 4$ are almost parallel, and end at approximately the same level. Thus, negotiations containing more conformant steps start out at a point more distant to the Nash bargaining solution, and reach a level that is comparable to negotiations containing fewer such steps only at their last conformant step. The resulting levels are very similar for these negotiations, and in all cases the offer on the table after the last conformant step is considerably closer to the Nash bargaining solution than the final agreement. This difference is illustrated in Table 8, which shows the average difference in Nash objective values after the last conformant step and in the final agreement for these negotiations

5.3 Individual Outcomes (Exploratory Analysis)

To study the effect of different steps on individual outcomes, we perform a similar analysis as Table 7 considering only the bargaining steps of one party and the outcome of that party. Table 9 shows the result of two robust regression models, in which the individual utility of a party was regressed on the fraction and number of steps

Table 9 Regression analysis between properties of steps and utility of agreement to the party using the steps

	Fraction	Count
Property		
Precondition	1.7750	1.1027*
Postcondition	− 6.7939***	− 1.5628***
Inc. Nash	11.6334***	4.2674***
Concession	− 10.6049***	− 4.5375***
R^2	0.223	0.223
Step type		
Unnecessary	− 3.2064	− 0.2500
Adjustment	− 18.2631***	− 4.8541***
Weakening	− 6.5052	− 2.2462
Wrong direction	− 1.9012	− 0.5966
Insufficient	5.5176**	3.2842***
Conformant		1.6062*
R^2	0.175	0.160

$^{\circ}p < 10\%$; $^{*}p < 5\%$; $^{**}p < 1\%$; $^{***}p < 0.1\%$

exhibiting the different properties in the upper part and on the fraction and number of steps of different types in the lower part.

Bargaining steps do have a significant impact on the outcome of the player making that step. While it seems to be beneficial that the right party makes a bargaining step and increases the value of the Nash objective function, fulfillment of the postcondition (i.e. going beyond the value of the opponent) as well as concessions have a negative impact on the moving party's utility. Similarly, a high fraction or number of insufficient steps (which do not fulfill the postcondition) has a positive impact on the utility of the player. Adjustment steps are on the one hand steps in which a negotiator (moderately) toughens his or her position. However, at the end, the postcondition remains fulfilled, and the negotiator's utility is decreased by frequent use of such steps. The frequent use of steps that correspond to the Zeuthen–Hicks model also has a positive effect, although insufficient steps that stop short of giving in as far as predicted by the Zeuthen–Hicks model are even more beneficial.

6 Discussion, Conclusions and Future Research

To the best of our knowledge, this is the first paper that applies the Zeuthen–Hicks bargaining model to electronic negotiations. Our results have shown that on the one hand, the descriptive performance of this model is rather limited. Only in about 55% of all cases, a bargaining move is made by the party predicted by the model. Although this level is significantly more than chance, the difference to 50% is not large. This somewhat disappointing result is in contrast to Fandel (1985), who reported a 90% confidence interval of [72%, 90%] for the fraction of steps conforming with the model. One reason for this difference could be that we utilized experiments with student subjects, while Fandel's data is based on actual negotiations between professional bargainers. One could thus speculate that the experience of professional bargainers brings them closer to following the model. However, even the upper bound of Fandel's confidence interval has only about the same predictive accuracy as assuming that the parties alternate in making their offers.

Thus, the applicability of the Zeuthen–Hicks model as a descriptive model of actual negation processes is limited. In contrast, our results show that the model could be useful as a prescriptive tool to inform bargainers about useful steps. Following the model's recommendations is indeed beneficial. Negotiations in which a larger number of bargaining steps conforms to the model lead to better outcomes in terms of efficiency and closeness to the Nash bargaining solutions. These steps are also beneficial for the individual negotiator, albeit not as much as steps that go into the right direction, but not as far as the model would predict.

This line of reasoning points towards two possible extensions of our present research: If experience leads negotiators to follow the model more closely, this effect could already be observable during one negotiation. The data we have used contains only few interactions in each negotiation, so we cannot test this effect with the present data. However, in longer negotiations, it might be interesting to see whether steps conformant with the model become more frequent over time. Experience could also be seen as a personal characteristic of the negotiator. Thus, one can study whether personal characteristics of negotiators, such as experience, but also e.g. gender, age, or education, influence how closely a negotiator's bargaining steps follow this model. In particular, combining the model with questionnaire-based data on a negotiator's preferred bargaining style could lead to interesting insights. Limited experiments with the data set available have provided no conclusive results, but this data set contains only few usable personal characteristics.

The present paper has developed a methodology to study the Zeuthen–Hicks model empirically in data from electronic negotiations. This methodology can be applied to many different data sets, which will allow to generalize our results and also hopefully to study whether individual characteristics of negotiators have an influence on how closely their bargaining behavior fits the Zeuthen–Hicks model. The present paper is thus just a first step in establishing the Zeuthen–Hicks model as a tool for empirical research on negotiations.

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