Multiple equilibria resulting from game theory analysis of a negotiation between small family business and wholesaler under circular economy conditions

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Abstract

Our research on game theory tackles the problem of reducing food wastage delivered by local farmers to wholesalers. Food is wasted when the negotiated price between farmer and wholesaler doesn't meet the farmer's expectations. Skills and competences for Zero Waste and Circular Economy (ZW & CE) are becoming extremely important. In Europe, we are using per person 16 t/a (tons per year) of material, of which 5 t/a become waste. Although the management of the waste continues to improve, the EU economy currently still loses a significant fraction of potential 'secondary raw materials' in waste streams. According to McKinsey Global Institute, one of the reasons causing excessive depletion of natural resources is the volatility of resource prices, relative to labor costs, which helped to create the current wasteful system of resource use. Local farmers are referred to in this article as "small family businesses". In order to model the relationship between small family businesses, who have a typically weak bargaining power, and the wholesaler, who holds a stronger negotiating position, a non-cooperative two-player game with perfect information was played with six study groups. One game was divided into two parts – firstly, we found equilibrium in a situation when the wholesaler paid an unfair price to a small family business, and in the second part, after we had reduced information given to the wholesaler and played again, equilibrium was found in a case when a wholesaler agreed to pay a fair price. The outcome of the second part in every subgame with perfect equilibrium was the terminal history (U) which had a different payoff vector than the games before. Our game which consisted of 6 study groups showed the same results each time, despite the fact that the study groups didn't know how the game was played by their predecessors, and every study group was free to define their own payoff vectors.

Keywords: Game theory, Multiple equilibria, Bargaining power, Wholesalers, Smallholder farmers

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1 Introduction

In our paper, we analyze imbalances between the bargaining power of small family business and wholesalers, where the limited ability of local farmers to store crops tends to weaken their bargaining power during negotiations. If a negotiation is being used for setting up a proper price, an interaction can then be labeled as a game - the pricing mechanisms were usually designed with the expectation that a game between seller and buyer would be played. As law is usually made by lawyers, pricing mechanisms were always made by resellers, tracking their own interests instead of interest of smallholder farmers. Skimming pricing, for example, exceeds “traditional” profit margins by setting up a premium price for cutting-edge innovations that are delivered to the high-end customer segment. Penetration price on the other hand neglects total costs of delivery to the market and is aimed at jeopardizing a competitor’s abilities to survive in competitive environment. In this paper, we would like to assist in paving the way towards better farmer’s negotiation skills. The price premium enjoyed by wholesalers thanks to an information advantage over smallholder farmers produces high profit margins – however, not in the farmer’s pocket. This “rule” comes in spite of high volatility in this business environment. Additional costs that buyers may be exposed to include the overhead of establishing and managing a sourcing system and confirming and maintaining relationships with numerous smallholder farmers – this supplier cost-risk tradeoff is a persistent tension in the transformation of agricultural supply chains in the developing world (Michelson, 2016). These functions all occur within various market structures. Oligopolistic markets, for example, are characterized by a limited number of producers who make decisions about the quantities to be delivered to the market. This generates the potential for them to form cartels or pursue other practices that abuse their strong market position. There are various ways that actors can abuse a strong market position. Traders may take advantage of farmer ignorance of market prices and extract a rent from them by offering very low prices for their products (Courtois & Subervie, 2013). Played with 93 students, our game imitated an interaction between a local farmer and a wholesaler. A similar game was played by authors Courtois & Subervie in 2013. The authors studied how information about actual price levels affects the bargain and the balance of power, concluding that by equipping the farmer with accurate price information, he/she can avoid a negotiation failure. The study further revealed that farmers with access to realtime online information regarding commodity prices (e.g. the Market Information System mobile application) achieved significantly higher negotiated prices for maize and groundnut – about 12.7% more for maize and 9.7% more for groundnuts than what they would have received had they not possessed an access to Market Information System (Courtois & Subervie, 2013). The quality and complexity of information given to farmers plays a crucial role. For example, Esoko today uses mobile technology to enable farmers to save and borrow money to purchase inputs, receive tailored agronomic advice, and market their crops at harvest time[3]. In its second phase, our game is based on the knowledge that farmers have on alternatives to sell their products (besides other necessary information such as the real price, etc.). There are several studies that illustrate the importance of the complexity of information contributing to the "economic literacy" of farmers. While there is some evidence that market information dissemination does play a role in Uganda (Svensson & Yanagizawa, 2009), studies that focus on direct price information dissemination initiatives through mobile phones (Fafchamps & Minten, 2012) often do not show a significant effect on prices. The fact that the Community Knowledge Workers intervention led to a more optimistic outcome than those of other studies may be due to the fact that the Community Knowledge Workers model attempts to make information actionable by complementing it with additional information such as a trader directory. For instance, price information is useless if there are no alternative traders for the farmer to bargain with (Campenhout, 2017). Circumstances in India are very similar in the sense that the Indian government attempts to deliver multiple services to farmers, including, but not limited to, price information. Several tools available to Indian farmers are designed to ensure that they receive adequate price for their production. Generally, the governing body in India announces a minimum support price, the farmer's price floor, and organizes subsequent auctions through governmental agencies – the National Agricultural Cooperative Marketing Federation of India and Food Corporation of India. However, according to authors Banik et al., the government sometimes announces procurement dates a month or two after a harvest time, making it impossible for the small farmers to sell their produce at the minimum support price. These smallholder farmers do not have access to cold storage, and thus have no option but to sell their produce to the middlemen or traders (Banik et al., 2016).

In our game, we consider that the information advantage enjoyed by the wholesaler gives the wholesaler more bargaining power over farmers. Our stance is based on studies like e.g. "Farmer suicides in India and the weather god". Major determinants of global value chain governance have also been described by Gereffi, Humhrey & Sturgeon and are available in Table 1. Of particular interest for the purposes of examining superior bargaining power is the category of captive value chains where power is exercised by "lead firms". In most cases, lead

[3] https://www.esoko.com/esoko-announces-restructuring-focus-m-commerce-data-collection/, accessed 17.8.2017

firms are modern retailers and supermarkets that drive the agri-food chain, linking daily grocery consumers with smallholder farmers around the world.

Table 1.: Governance types in Global Value Chain

Governance type	Complexity of transactions	Ability to codify transaction	Capabilities in the supply-base	Degree of explicit coordination and power asymmetry
Market	Low	High	High	Low
Modular	High	High	High	
Relational	High	Low	High	
Captive	High	High	Low	
Hierarchy	High	Low	Low	High

Source: Gereffi, Humhrey & Sturgeon, 2005

Our game is played under the conditions of a “captive” value chain where it is difficult for smallholder farmers to switch to other wholesalers. Farmers are therefore “captive” to them. These networks are often characterized by a high degree of supervision on the part of the wholesalers. Much work has already been done on the effect of legislation bans or other similar kinds of command-and-control mechanisms in wholesaler/famer pricing negotiations. For this reason, our research does not intend to analyse the effect of these types of command and control solutions. Rather, agricultural economists have performed relatively few studies of legislation aimed to protect growers, especially using contract theory (Wu, 2006; Wu, 2014). Our bargaining power analysis is intended to provide insight on the economic consequences of policies that attempt to correct market failures derived from the existence of incomplete contract enforcement and possible opportunistic behaviour from buyers with strong bargaining power in concentrated markets. These market failures may limit the contribution of agricultural contracts and improve the welfare of farmers. The analysis on the effects of the allocation of bargaining power on efficiency and distribution informs debates about what policies can achieve at what cost (Salas, 2016).

2 Game theory in general

In order to introduce game theory in this paper, we help ourselves with the description of famous prisoner's dilemma, being used for analysis of competitive/cooperative modes of behaviour. Robert Axelrod, a professor of Political Science and Public Policy at the University of Michigan, invited game theory experts to play in a computer tournament with the aim of studying decisions of players in a famous type of game called the prisoner's dilemma. In the prisoner's dilemma, two players not knowing about the decisions of each other are about to select a cooperative strategy or to defect. If the first prisoner chooses to cooperate and the other one decides to defect, defection yields a higher payoff. If both defect, it yields a lower payoff than in a situation when both cooperate. The dilemma is that if both defect, it yields to both worse payoffs than if both cooperate. Robert Axelrod invited experts to find a good strategy to be used in repeated interactions. The results and outcomes of this tournament and subsequent research are reported by Axelrod as follows (Axelrod, 1984):

- The problem is that in a world of unconditional defection, a single individual who offers cooperation cannot prosper unless some others are around who will reciprocate. On the other hand, cooperation can emerge from small clusters of discriminating individuals as long as these individuals have even a small proportion of their interactions with each other.
- This is the essence of the ratchet effect: Once cooperation based upon reciprocity gets established in a population, it cannot be overcome even by a cluster of individuals who try to exploit the others.
- For cooperation to prove stable, the future must have a sufficiently large shadow. This means that the importance of the next encounter between the same two individuals must be great enough to make defection an unprofitable strategy.

3 Details of our game

Our interaction consisted of a smallholder farmer and a wholesaler using a non-cooperative sequential game with various study groups comprising 93 students in total. We played our games with groups of students that were not game theory experts, in order to rely more on objective player intuition than on their expertise and knowledge-laden choices. Initially, games were played three times each with the same participants, however we decided to play with new groups with different participants given that the initial games delivered similar results. Table 2 shows the details of when our games were played.

Table 2: Timetable – games played

No. of the game	Date	No. of students
1.	3.11.2015	29
2.	19.3.2016	26
3.	27.4.2016	5
4.	25.1.2017	15
5.	16.5.2017 (1st group)	7
6.	16.5.2017 (2nd group)	11
Total		93

Source: Own

The game was explained to every study group before the interactions began, including the principles of play. Each group was asked to assign their own payoff vectors respecting principles of rationality that have to be maintained throughout the whole game (players are ought to be making rational decisions). One game we played had a finite horizon (the length of negotiation is known before the start, it has defined its start and the end) and we derive equilibrium using backward induction. Every branch of a decision tree contains sets of sequences of actions. Our extensive game with perfect information consists of a set of sequences of actions (terminal histories) that runs from the start of the game to an action that ends the game. The start of the game is represented by the empty history.

A game definition:

$\langle N, H, P, f_{c,} (\Im_i)_{i \in N}, (u_i)_{i \in N} \rangle$ is a non-cooperative game in extensive form.

- N – a set of players
- H – a set of sequences of actions
- P – a player function that assigns a player to every sequence that is a proper sub-history of some terminal history (i.e.: To every point in each terminal history)
- f_c – preferences over the set of histories
- $(\Im_i)_{i \in N}$ – collection of player's information sets
- $(u_i)_{i \in N}$ – payoff function

In our game we work with stylized facts. Stylized facts are modeling situations that that occur in a farmer/wholesaler relationship. The goal of game theory in this case is to identify a position, where a negotiation is intended to equilibrate (a search for equilibrium in pure strategies). Payoffs are numbers, also called also utility, that reflects the desirability of an outcome for a player, for whatever reason. Payoffs are depicted as: $[\Pi_I;\ \Pi_{II}]$

- Π_I – payoff for wholesaler
- Π_{II}- payoff for smallholder farmer
- p_1- probability of occurrence (equals 1 in the entire game)

The calculation formula we used is as follows:

$$[\Pi_I * p_1;\ \Pi_{II} * p_1] = [\Pi_I;\ \Pi_{II}]$$

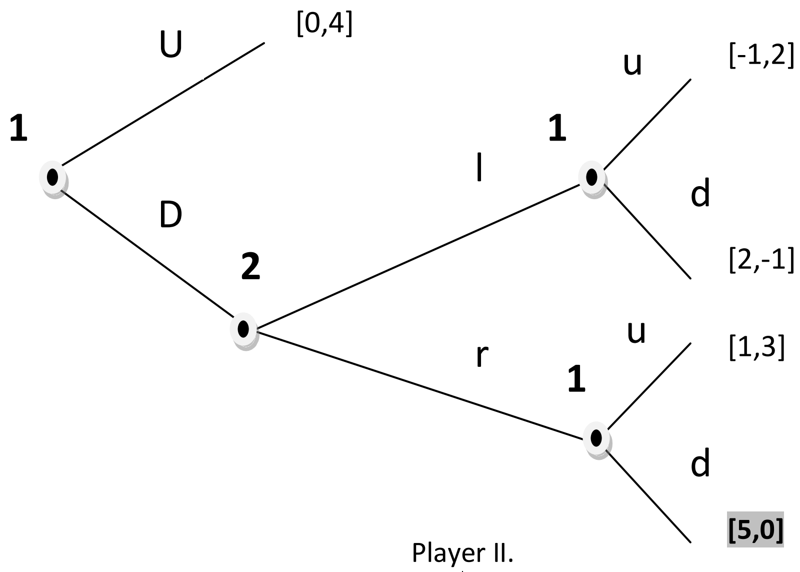
Initially, the interaction is modelled as a game with perfect information – where all information sets in the tree contain just one node, a singleton (Figure 1). The final state, however, is one of imperfect information (using behavioural strategies) where the information set of Player I. is a collection of player I's nodes among which I cannot distinguish (Figure 2). In Figure 2, the buyer doesn't know the previous decision of a smallholder farmer - whether a farmer had already begun a negotiation with another potential buyer or not. In our finite horizon game, we have two players. Player I. represents a wholesaler - a player with higher bargaining power. Player II. represents the supply side – smallholder farmers with lower bargaining power. The nodes are explained in Table 3. Figures 1 and 2 represent a detailed explanation of the game played on 3.11.2015. The following five games were structured in the same way, with different payoff vectors determined by the study groups (none of the study groups had any information about the results of each preceding group).

Table 3 *Nodes in the played game*

	Player I. – wholesaler (buyer)		Player II. – smallholder farmer	
Abbreviation of player's decision	U (up in game theory jargon)	D (down in game theory jargon)	l (left in game theory jargon)	r (right in game theory jargon)
Description of player's decision	Player (buyer) offers fair price	Player (buyer) offers unfair price	Player (farmer) starts negotiation with other buyer	Player (farmer) does not start negotiation with other buyer

Source: Own

Figure *1:* Subgame perfect equilibrium in a game with limited choices for a farmer – equilibrium in pure strategies



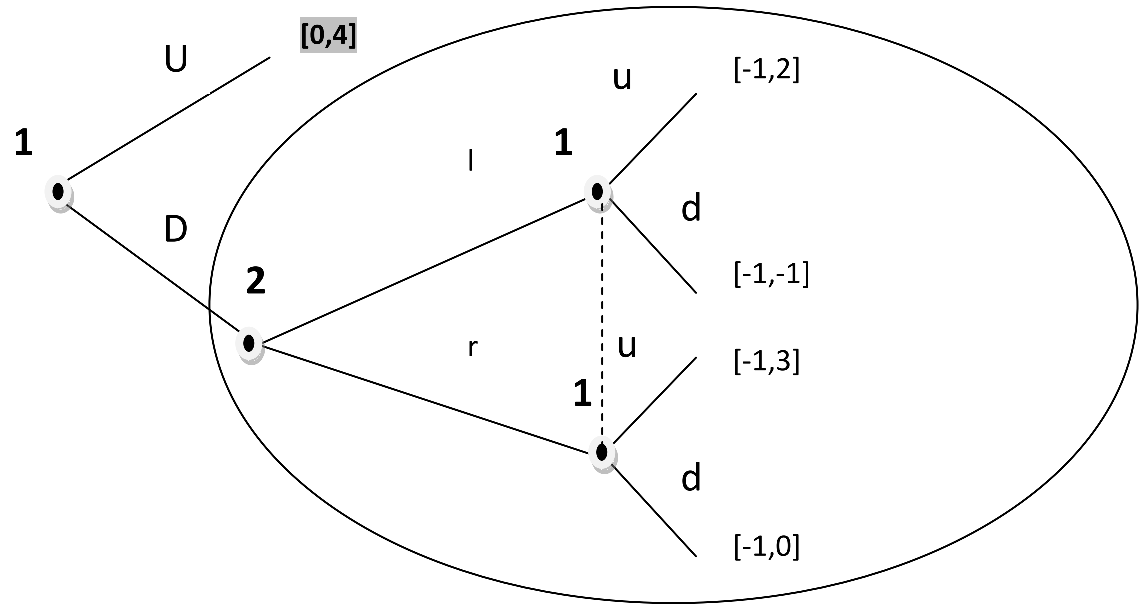
		Player II. l	r
Player I.	Uu	0,4	0,4
	Ud	0,4	0,4
	Du	-1,2	1,3
	Dd	2,-1	5,0

Source: Own

The usual price negotiation game (with farmer's lower bargaining power) is shown in Figure 1. The buyer offers a price, which is unfair (Player I. plays down), whilst the smallholder farmer does not have the option to negotiate with another potential buyer (there are various reasons for this, e.g. farmer is not informed about the immediate needs of other buyers), therefore, Player II. plays right. Sequentially, it is then Player I.'s turn, who plays down – offering an unfair price to the farmer. Under new conditions (depicted in Figure 2), the game theory analysis shows the equilibrium situation in the node with payoff vector [0,4] – the buyer immediately offers a fair price to the farmer at the beginning of the game and the game ends with a fair price being paid. See Figure 2. for details of the whole game and subgame.

The subgame perfect equilibrium is every strategy profile, in which Player I. plays U with the probability 1, and Player II., after history (D), plays r with probability 1. The outcome of the game in every subgame perfect equilibrium is the terminal history (U) with payoff vector [0,4]. Subgame perfect equilibria in pure strategies are (Uu,r) and (Ud,r). The difference between Figure 1 and Figure 2 is the change in the characteristics of the game. The second game depicted in Figure 2 has changed to include imperfect information of players, as the player I., after playing (D), doesn't know whether player II. played l or r.

Figure *2* Subgame perfect equilibria in pure strategies



		Player II. l	r
Player I.	Uu	0,4	0,4
	Ud	0,4	0,4
	Du	-1,2	-1,3
	Dd	-1,-1	-1,0

Source: Own

Payoff vectors for games 1-6 are depicted in tables 4 and 5. The calculated subgame perfect equilibria for the whole exercise are presented in Table 5 (the cells with shaded area). Subgame perfect equilibrium is every strategy profile, in which Player 1 plays U with the probability 1, and Player 2, after history (D), plays R with probability 1. In other words, switching into the game with imperfect information (the wholesaler became uncertain about whether the smallholder farmer would negotiate with different potential buyer) ensured a fair price offered to the smallholder farmer in every one of the six games played.

Game 1 → The outcome of the game in every subgame perfect equilibrium is the terminal history (U) with payoff vector [0,4]. Subgame perfect equilibria in pure strategies are (Uu,r) and (Ud,r).

Game 2 → The outcome of the game in every multiple subgame perfect equilibrium are histories (U) and (D) with payoff vectors [0,4] and [0,3]. Subgame perfect equilibria in pure strategies are (Uu,r), (Ud,r) and (Du,r).

Game 3 → The outcome of the game in every subgame perfect equilibrium is the terminal history (U) with payoff vector [0,11]. Subgame perfect equilibria in pure strategies are (Uu,r) and (Ud,r).

Game 4 → The outcome of the game in every subgame perfect equilibrium is the history (D) with payoff vector [1,6]. Subgame perfect equilibrium in pure strategies is (Du,r).

Game 5 → The outcome of the game in every subgame perfect equilibrium is the terminal history (U) with payoff vector [3,10]. Subgame perfect equilibria in pure strategies are (Uu,r) and (Ud,r).

Game 6 → The outcome of the game in every subgame perfect equilibrium is the terminal history (U) with payoff vector [300,1000]. Subgame perfect equilibria in pure strategies are (Uu,r) and (Ud,r).

Table 4 *Payoff vectors in a game with limited choices for a farmer*

			Player 2					
			l	r			l	r
Player 1	Game 1	Uu	[0;4]	[0;4]	Game 4	Uu	[0;10]	[0;10]
		Ud	[0;4]	[0;4]		Ud	[0;10]	[0;10]
		Du	[-1;2]	[1;3]		Du	[2;4.5]	[1;6]
		Dd	[2;-1]	**[5;0]**		Dd	[5;1]	**[7;3]**
	Game 2	Uu	[0;4]	[0;4]	Game 5	Uu	[3;10]	[3;10]
		Ud	[0;4]	[0;4]		Ud	[3;10]	[3;10]
		Du	[1;2]	[0;3]		Du	[6;7]	[5;9]
		Dd	[4;0]	**[5;0]**		Dd	[8;0]	**[10;4]**
	Game 3	Uu	[0;11]	[0;11]	Game 6	Uu	[300;1000]	[300;1000]
		Ud	[0;11]	[0;11]		Ud	[300;1000]	[300;1000]
		Du	[4;8]	[1;9]		Du	[600;800]	[400;900]
		Dd	[8;2]	**[10;4]**		Dd	[700;150]	**[1000;250]**

Source: Own

The difference between the datasets in tables 4 and 5 is due to the shift from a game with perfect information to that with imperfect information. By doing this, we were imitating the work of several NGOs that equipped smallholder farmers with software that provided accurate commodity price information together with suggestions about alternative ways to sell products. Equipped with such know-how, the bargaining power of smallholder farmers should be rising (Campenhout, 2017 or Courtois & Subervie, 2013). We were willing to implement this change using game theory tools with the respective interface. In Table 5, the smallholder farmer strengthened his/her bargaining power thanks to newly gained access to alternative selling strategies. The wholesaler's reaction to this (he/she was uncertain whether a farmer was negotiating with alternative middlemen or not) was predicted by game theory analysis of offering a fair price to farmer – expressed by our multiple subgame perfect equilibria in Table 5. As the wholesaler, under new conditions, was not able to distinguish between the previous decisions that the farmer had made (the wholesaler was unsure whether the farmer had begun negotiations with other potential buyers or not, enabled by new technology – e.g. software in a cellphone), the change in the payoff vectors was downgraded to the lowest level. The only exception was game 3, where a study group decided to downgrade to the new minimum as they considered that the new wholesalers' uncertainty was an even worse strategic position.

Table 5 *Payoff vectors in a game with extended choices for a farmer*

			Player 2					
			L	r			l	r
Player 1	Game 1	Uu	[0;4]	**[0;4]**	Game 4	Uu	[0;10]	[0;10]
		Ud	[0;4]	**[0;4]**		Ud	[0;10]	[0;10]
		Du	[-1;2]	[-1;3]		Du	[1;4.5]	**[1;6]**
		Dd	[-1;-1]	[-1;0]		Dd	[1;1]	[1;3]
	Game 2	Uu	[0;4]	**[0;4]**	Game 5	Uu	[3;10]	**[3;10]**
		Ud	[0;4]	**[0;4]**		Ud	[3;10]	**[3;10]**
		Du	[0;2]	**[0;3]**		Du	[5;7]	[5;9]
		Dd	[0;0]	[0;0]		Dd	[5;0]	[5;4]
	Game 3	Uu	[0;11]	**[0;11]**	Game 6	Uu	[300;1000]	**[300;1000]**
		Ud	[0;11]	**[0;11]**		Ud	[300;1000]	**[300;1000]**
		Du	[-1;8]	[-1;9]		Du	[400;800]	[400;900]
		Dd	[-1;2]	[-1;4]		Dd	[400;150]	[400;250]

Source: Own

4 Conclusions

Creating the conditions that allow smallholder farmers to receive a fair price for their products would have three main implications. The first implication relates to the circular economy. In general, food is a non-recyclable commodity and so it is impossible to completely close the loop in this regard (notwithstanding cases related to fertilizer production and waste-to-energy systems). A great deal of work to reduce waste is required in any given farmer/wholesaler relationship. Food is wasted not just at the end of its life cycle – if no deal is reached between the farmer and wholesaler, then significant amounts of crops that couldn't reach value chains of food processors or supermarket chains are wasted. Secondly, our game theory analysis confirmed that a costly command-and-control approach aimed at improving conditions for smallholder farmers is not the only possible solution. A market-based approach appears to enable smallholder farmers to access updated price information and alternative sales channels options. This tends to improve their chances to receive an adequate remuneration for their work. A third implication besides farmer's higher financial gains from transactions is the promotion of peacebuilding business practices – actions that contribute to the stabilization and rehabilitation of conflict affected areas. It is generally acknowledged that poorly paid miners in Eastern Congo (the extraction of conflict minerals), who are being exploited by local guerillas, would switch to farming if it would generate fair returns for them. All the variations of the game results we generated in Table 5 delivered a fair price for smallholder farmers. This correlates with research results of authors cited in this article and leads us to believe that “fair-trade” intentions, if elaborated well, may represent a significant aid not only to small family businesses in the field of agriculture, but also in other industries like for example fast fashion where fast pace of new fashion trends pushes prices down quite quickly, which affects mainly smallholder producers supplying fashion houses.

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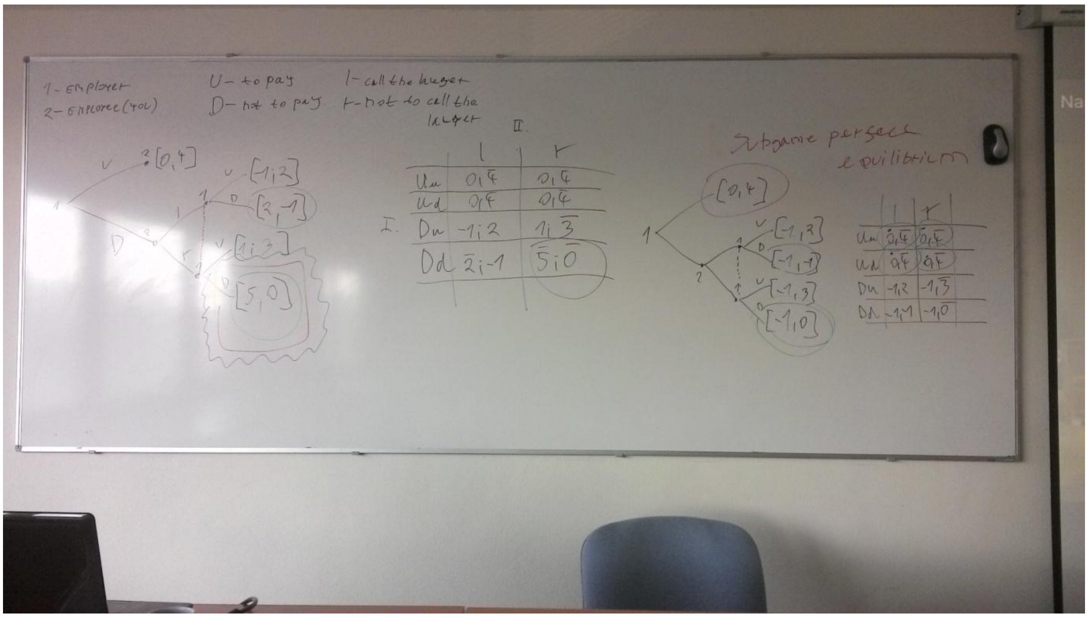
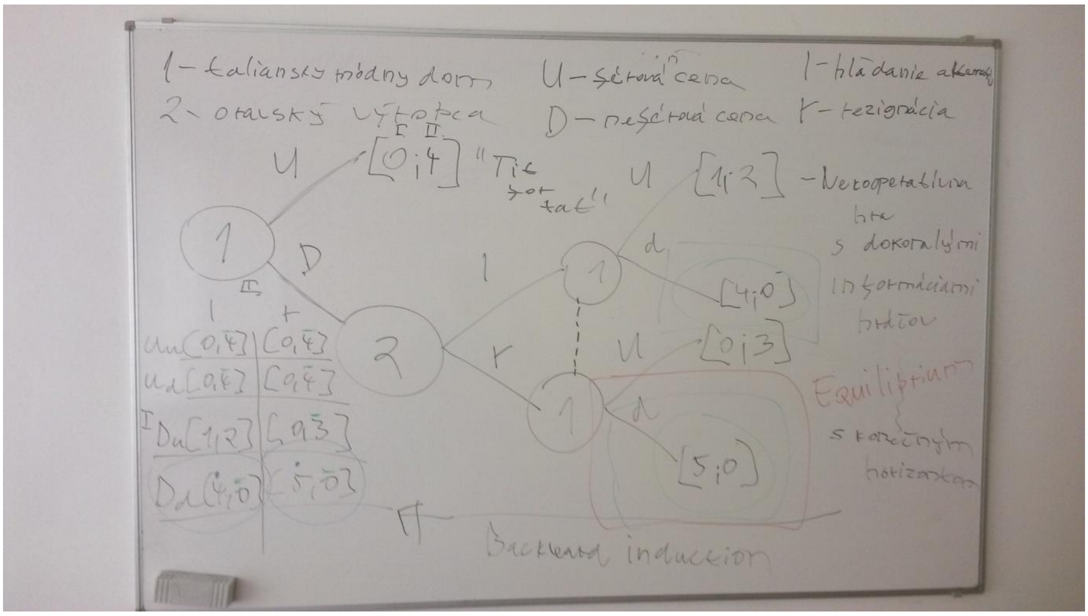
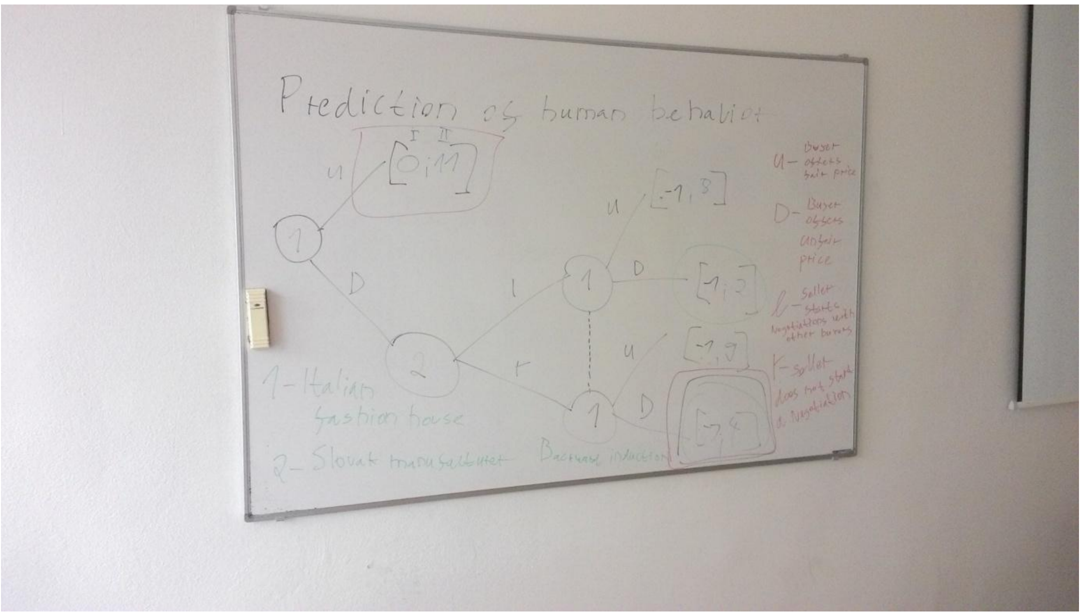
Appendix



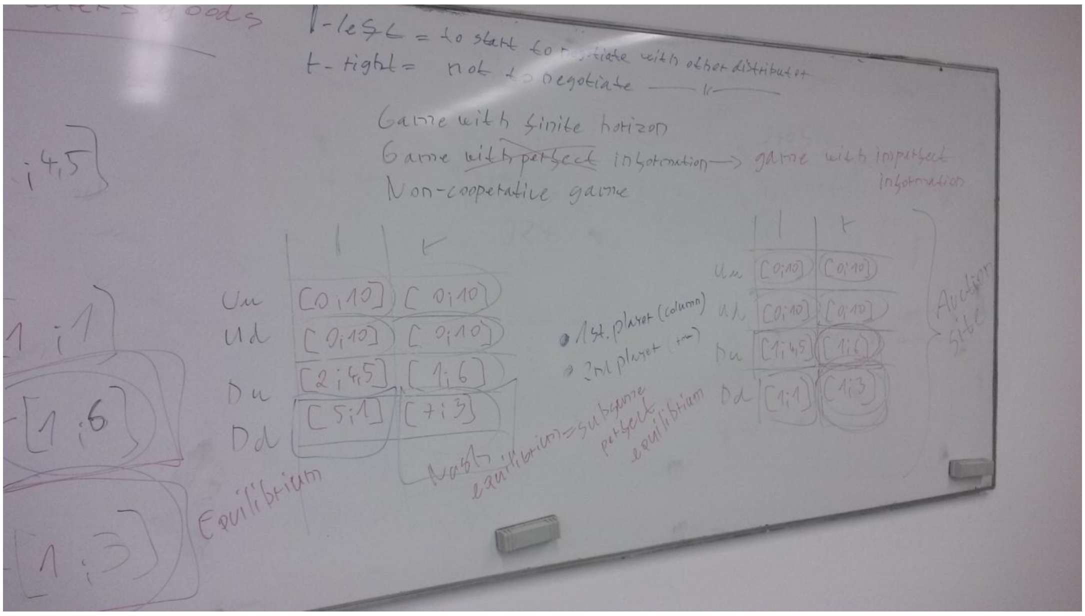
Appendix 1: Game played 3.11.2015



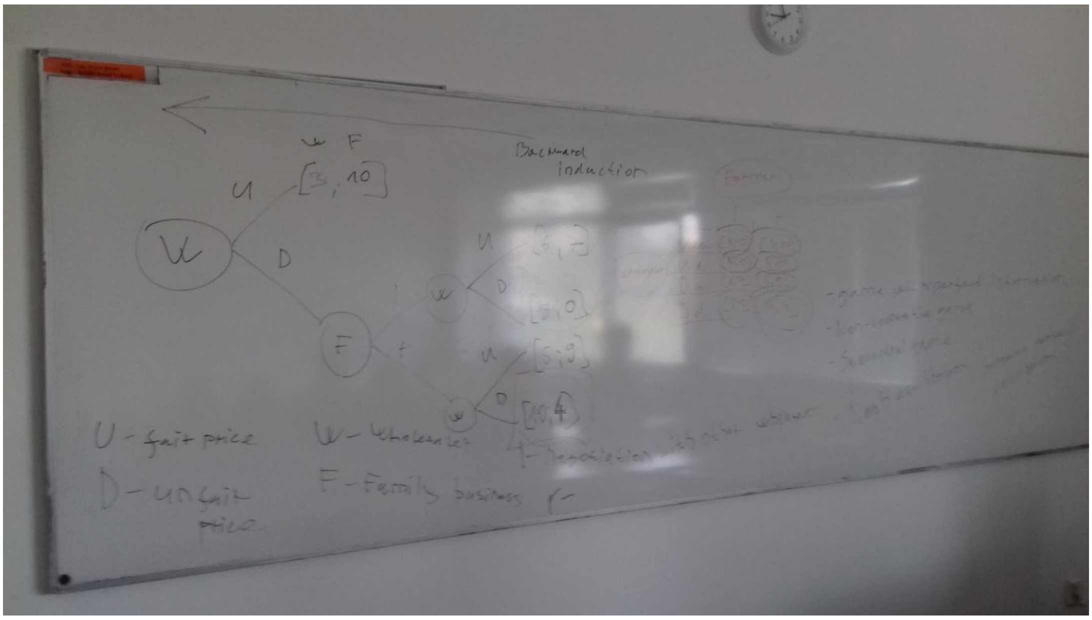
Appendix 2: Game played 19.3.2016



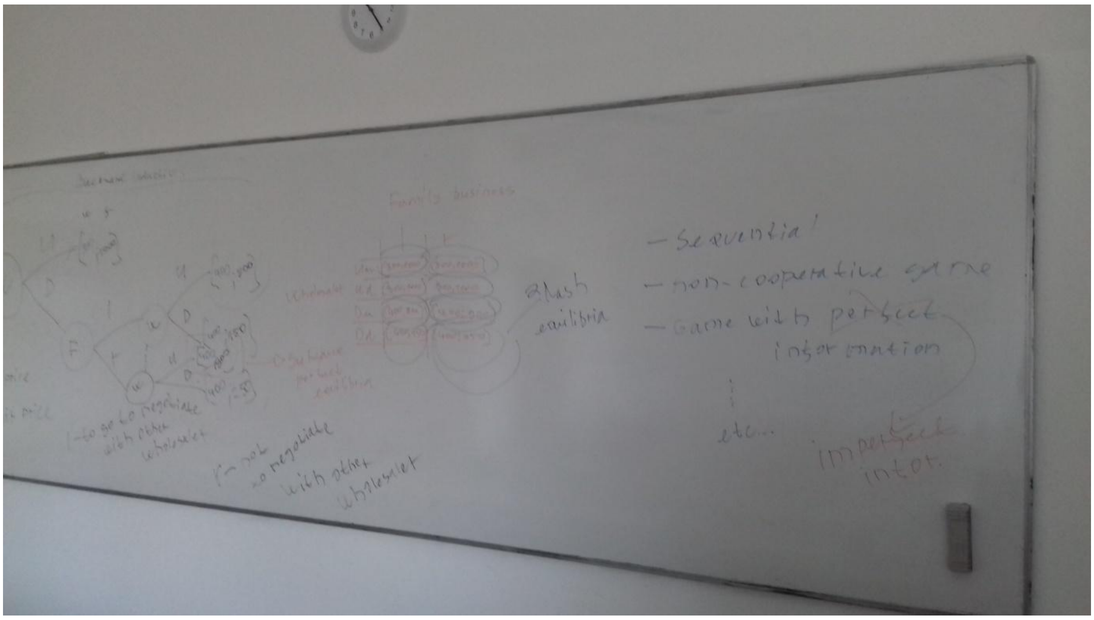
Appendix 3: Game played 27.4.2016



Appendix 4: Game played 25.1.2017



Appendix 5: Game played 16.5.2017 (1st group)



Appendix 6: Game played 16.5.2017 (2nd group)