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Bakalářská práce

2010 **Martin Hrachovec**

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BAKALÁŘSKÁ PRÁCE

Informational Cascades in Economics

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Akademický rok: 2009/2010

Prohlášení

Prohlašuji, že jsem bakalářskou práci na téma *„Informational Cascades in Economics"* vypracoval samostatně. Veškerou použitou literaturu a podkladové materiály uvádím v přiloženém seznamu literatury.

V Praze dne ………..…..   …………...………………..
Podpis

Poděkování

Rád bych touto cestou poděkoval panu Ing. Ivo Koubkovi za vedení mé bakalářské práce a za pomoc při řešení jak formálních tak obsahových stránek práce.

Abstrakt

Davové chování je jednou z oblastí, která ještě není příliš prozkoumána. Existují přístupy v sociologii, psychologii stejně tak jako v ekonomii. Jeden z takovýchto přístupů staví na takzvaných informačních kaskádách. Základem pro něj je Bayesův teorém a Bayesiánská ekonomie obecně. Tato práce proto nejdříve představuje tento rámec a poté základní modely informačních kaskád. Hlavním cílem je poskytnout úvod do problematiky informačních kaskád a upozornit na pronikání teorie s praxí. Proto jsou vysvětleny zobecnění základních modelů a rozebrány tři případy možného pozorování informačních kaskád v nedávné historii.

Klíčová slova: Informační kaskády, davové chování, Bayesiánská ekonomie, davové chování kvůli reputaci, bankovní runy

Abstract

Herd behavior is one of the fields that has not been explored much yet. Some approaches exist in sociology and psychology as well as in economy. One of the economical approaches is the one of informational cascades, building on the framework of Bayesian economics. This thesis first introduces Bayesian framework and then the basic models of informational cascades. Main aim of the thesis is to provide introduction to the topic and point out connections to the everyday life; therefore generalizations to the basic models are introduced and three practical cases of possible application of informational cascades elaborated.

Key words: Informational cascades, herd behavior, Bayesian economics, reputational herding, bank runs

Table of Contents

Introduction

> *"Men, it has been well said, think in herds; it will be seen that they go mad in herds, while they only recover their senses slowly, and one by one"*
>
> Charles Mackay
>
> (*Extraordinary Popular Delusions and the Madness of Crowds, 1841*)

Convergence upon similar or even same behavior is strikingly common. How is it possible for fashionable items to rise up explosively and then vanish as fast as they appeared? Is such a herding behavior desirable? But the main question to be answered is not the one of the desirability, but the one of reasoning behind such behavior and its efficiency. In the basic setting where people (agents) face similar decision problems, later decision makers are influenced by the decisions of others. So called social learning helps in clarifying the otherwise irrational behavior that can lead not only to herd behavior but also to so called informational cascades.

Informational cascade as a situation when *individual's action doesn't depend on his private information signal* (Bikhchandani et.al., 1992, p.1000) will be introduced in Chapter 2, first the Bayesian framework as a cornerstone of the whole concept is explained in order to make the rest of the thesis easier to follow. Since taxonomy in the field of herd behavior isn't completely agreed on, distinction between "herds and herding" and "informational cascades" is established before an introduction of two basic models of herd behavior, their assumptions, and properties.

Since informational cascades are quite theoretical concept as opposed to herds, results from empirical experiments will be presented to gain an insight of how consistent the theory is with reality. Later on, the strict assumptions of the basic models will be relaxed in following Sections which should provide wider range of applicability for real-life situations and allow for development of concepts also in financial economics. Despite wide range of topics containing at least fragments of informational cascading, besides laboratory setting different approaches might fit better. Therefore some alternatives to informational cascades are presented in Section 2.4.

Last Chapter is dedicated to enlarging the pool of examples that may be explained by the informational cascades approach. With cases from current history and from the local environment of the Czech Republic, the purely theoretical framework will be linked with everyday issues to provide better understanding and clarify the connections between informational and other approaches to herds and cascades. This shall lead to new viewpoints on rationale behind practical decision making and might uncover new directions of future research and analysis.

1. Bayesian Framework

1.1. Brief history of Bayesian methods

It is quite safe to assume that nobody will ever have (nor has had) perfect and complete information on all aspects of life, therefore some decisions had and have to be made under uncertainty. Reasoning as best as we can prior to each decision is part of everybody's every-day life, even though some do not realize that. Before learning mathematics or statistics, one is required to rely on intuition. As Jaynes (1986, p.2) writes, already Herodotus hundreds of years BC noted that a decision was wise despite terrible outcomes if the decision seemed to be the best according to all the available information at the time. It should have been only matter of time when someone expresses the intuitive logic as a mathematical model. First to describe the state of incomplete information mathematically was in the 18th century James Bernoulli. He defined the probability $p(X)$ of state *X* being true as $p(X)=\frac{M}{N}$ where *M* is the multiplicity of *X* (number of scenarios where state *X* is true) and *N* is the number of equally possible scenarios. Bernoulli was also the first one to prove the connection between above stated probability and the frequency of the state *X* $f(X)=\frac{m}{n}$ where *n* is the number of independent observations and *m* is how many times the state *X* was observed. Different approach was taken by Thomas Bayes, who instead of calculating the sampling distribution of Bernoulli, turned the formula around and provided a method called the inverse probability. However, the main outcome of his work was his name being used for the later developed concepts. The cornerstone of the methods was set by French mathematician and physicist Pierre Simon de Laplace, who formulated the rule called "Bayes' Theorem"[1]. Bayes' Theorem describes the process of probability updating based on two basic rules of probability theory:
Product rule states that $p(XY \mid Z)=p(X \mid YZ)\,p(Y \mid Z)$, sum rule then $p(X \mid Y)+p(\bar{X} \mid Y)=1$, where *XY* stands for "both *X* and *Y* are true" and $\bar{X}$ for "*X* is false". Since the states *XY* and *YX* are the same they can be we can rewrite the product rule

[1] Thomas Bayes never wrote such a formula, the name stems from the fact that Laplace was building on the work of Bayes. (Jaynes, 1986)

$p(XY \mid Z) = p(X \mid YZ)\, p(Y \mid Z) = p(Y \mid XZ)\, p(X \mid Z)$ and assuming the condition $p(Y \mid Z) > 0$ is met, we have the Bayes' Theorem as:

$$p(X \mid YZ) = p(X \mid Z) \frac{p(Y \mid XZ)}{p(Y \mid Z)}.$$

It simply states the way we "learn" and update the prior-information-based probability [$p(X \mid Z)$] after acquiring new information *Y*. The probability $p(X \mid YZ)$ is then called the posterior probability. Important feature of Bayes' Theorem is the possibility of multiple application, as the new information is being acquired. Then the posterior probability after the first updating becomes the prior probability for next step and so on. In the end, the assigned probability always depends on the total information gathered, regardless of its ordering.

These principles have been developed and even more generalized later on[2], but the general idea is perfectly expressed by Jaynes (1986, p.11): *"In Bayesian parameter estimation, both the prior and posterior distributions represent, not any measurable property of the parameter, but only our own state of knowledge about it. The width of the distribution is not intended to indicate the range of variability of the true values of the parameter, as Barnard's terminology led him to suppose. It indicates the range of values that are consistent with our priot information and data, and which honesty therefore compelts us to admit as possible values. What is "distributed" is not the parameter but the probability."*

One of the fields where such framework comes to use, are models of social learning. Since the above mentioned authors were mostly focusing on pure mathematics or physiscs, I would like to mention the founder of probability applications in sociology, Marquis de Condorcet. In his work the *Essay on the Application of Analysis to the Probability of Majority Decisions* from 1785, he states, among other famous results[3], that given the prior information of each decision maker being correct with $p > 0{,}5$, the probability of the group's decision being correct increases with the number of decision makers. The one who linked sociology with the subject of this thesis was Gabriel Tarde. In his work Tarde

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[2] Among others the most significant achievements belong to Harold Jeffreys, Richard T. Cox or Claude Shannon

[3] Another would be so called Condorcet's paradox, saying that majority preferences become intransitive with three or more alternatives

expresses the opinion that there is nothing as a group, what others view as a group is an aggregation of individuals and the reason these individuals act in the same way is imitation (the number of innovators that are imitated is quite small): "*The principal role of a nobility, its distinguishing mark, is its initiative, if not inventive character. Invention can start from the lowest ranks of the people, but its extension depends upon the existence of some lofty social elevation, a kind of social water-tower whence a continuous cascade of imitation may descend.*" (Chamley, 2004, p.14)

1.2. Basic Principles and Common Features[4]

Essential to all the models of social learning presented in this thesis is the common knowledge, meaning that all agents know the structure of the model. Following features are always present despite individual specifications of models in form of assumptions and other model adjustments.

Prior distribution for the state of the world

In greater generality that is beyond the scope of this thesis, let me define a state of the world $\theta \in \Theta$ according to a given probability distribution, where $\Theta \subset \mathbb{R}^n$. This distribution may or may not be known by the agents. However, all the possible states (values of θ) have to have positive probability assigned by agents[5].

Private information

In all models mentioned and presented later on, each agent receives a signal known only to him and not observable by others (what are usually observable are the actions of an agent). Each agent's signal s is informative on θ, which means that its probability distribution is dependent on θ.

Bayesian inference

Process how agents update their distribution is a case of the Bayes' Theorem and is here again explained in greater generality than will be used afterwards but creates a better picture of the scope of the topic. Let $f(\theta)$ be the prior density on the state of the world

[4] Based on Chamley (2004, p. 21-24)

[5] Agents do not rule out any of the possible states of nature before receiving their private signal or observing the behavior of others

and $\phi(s|\theta)$ the distribution of private signal s conditional on θ. Then the formula for distribution updating after receiving the signal s is as follows:

$$f(\theta|s)=\frac{\phi(s|\theta)f(\theta)}{\int\phi(s|\theta)f(\theta)d\theta}$$

It can also be rewritten as a so called *likelihood ratio*, which is most suitable for any model with only two possible states of the world. For the two states of the world θ_0 and θ_1 it holds that: $\frac{f(\theta_1|s)}{f(\theta_0|s)}=\frac{\phi(s|\theta_1)f(\theta_1)}{\phi(s|\theta_0)f(\theta_0)}$.

1.3. Binary Model

It is the simplest model expressing situation with bounded information, where there are only two states of the world possible $\theta\in\{\theta_0;\theta_1\}$ where $\theta_1>\theta_0$. θ_0 represents the bad state and is usually normalized to 0, and correspondingly θ_1 represents the good state and is usually normalized to 1. Also the private signal received by the agent is of a binary nature taking values of either 0 or 1 with following probabilities

		Signal	
		s=1	*s=0*
State of Nature	$\theta=1$	p	1-p
	$\theta=0$	1-q	q

Table 1: Probabilities of private signals under the Binary model

The learning process after obtaining the private signal can be expressed as

$$P(\theta=1|s)=\frac{P(s|\theta=1)\cdot P(\theta=1)}{P(s|\theta=1)\cdot P(\theta=1)+P(s|\theta=0)\cdot(1-P(\theta=1))}$$

Since the settings only allow for two states of the world we may also include the likelihood ratio form: $\frac{P(\theta=1|s)}{P(\theta=0|s)}=\frac{P(s|\theta=1)\cdot P(\theta=1)}{P(s|\theta=0)\cdot P(\theta=0)}$. Upon observing the private signal *s*, the likelihood ratio expressing the probability of θ is updated by the so called *updating* *multiplier* $\frac{P(s=1|\theta=1)}{P(s=1|\theta=0)}=\frac{p}{1-q}$ which attains values greater than 1 iff[6] $p+q>1$. In this case the signal s = 1 is called the good signal because it increases the probability of $\theta=1$. Conversely in case of $p+q<1$ signal s = 0 is the good signal while the multiplier increases the probability of bad state $\theta=0$.

What will be used in many of the models and does not have any influence on the generality is called the symmetric binary signal. In this particular case the probabilities from Table 1 are in "symmetry", meaning $p=q$. Usually the parameter p is called precision of the signal and s = 1 is considered a good signal in cases when p > 0,5. (Chamley, 2004, p.24)

Alternative to the binary model is the Gaussian model where both the state of the world and the private signals are random variables with normal distribution. Unlike in the Binary model the private information is not bounded in Gaussian model and can be therefore very strong (in extreme cases "irreversible" – agent will always follow his own signal), leading to the impossibility of occurrence of informational cascades. However, Gaussian model is once again not applicable to the issues author concerns himself with in this thesis.

[6] If and only if

2. Herd Behavior and Informational Cascades

Examples of agents taking the same or at least similar actions have been observed throughout the history and across all different aspects of life. Animals imitate each other in order to survive or in issues of mating and territory selection, however the most striking, and of course for the reader most relevant, are such decisions leading to herding made by people. As Bikhchandani et al. (1998, p. 152) cite the words of Machiavelli from the early 16th century: *"Men nearly always follow the tracks made by others and proceed in their affairs by imitation."* Lately more attention was given to the reasoning behind the phenomena other than pure intuition. Bikhchandani et al. (1992, p. 993) mention four basic reasons that lead to herd behavior and in extreme, well defined cases, even to occurrence of informational cascades. First are the sanctions on deviants (commonly found in totalitarian regimes, thus well known to the population of former Czechoslovakia), second are positive payoff externalities, also known as network externalities, where the benefits are the bigger the higher the number of agents who join. Third is the direct inclination towards conformity, which may very well be the reason for sudden popularity of egg-white omelets and other fashionable items. Fourth reason is the main focus of this thesis and can be described as communication. More precisely, agents are influenced by the information they gain from direct conversations with other agents or by observing their actions (other people's actions have especially high value to those deciding later in the sequence as it is said that "actions speak louder than words"). This process of decisions influenced by the information inferred from the previous actions of others is the example of social learning. Despite great differences between above described reasoning, it should be noted that all of the real-life examples aren't based exclusively on any single one of them. Other cultural, psychological or generally irrational factors have to be taken into account besides any possible combinations of the four basic rationales for herding.

It is however interesting to see on what bases do people make their purchasing decisions, which is then very useful for marketers. While the most important criteria differ significantly between developed and less developed markets, word-of-mouth is the only factor present in both markets in the top three influences in all three steps of the purchasing process. Value of private information is therefore of grand importance and with the rising use of the internet and social networks as a mean of sharing such information, positive word-of mouth generating informational herd externality will be ever more essential to real-life situations of companies as Figure 1 suggests.

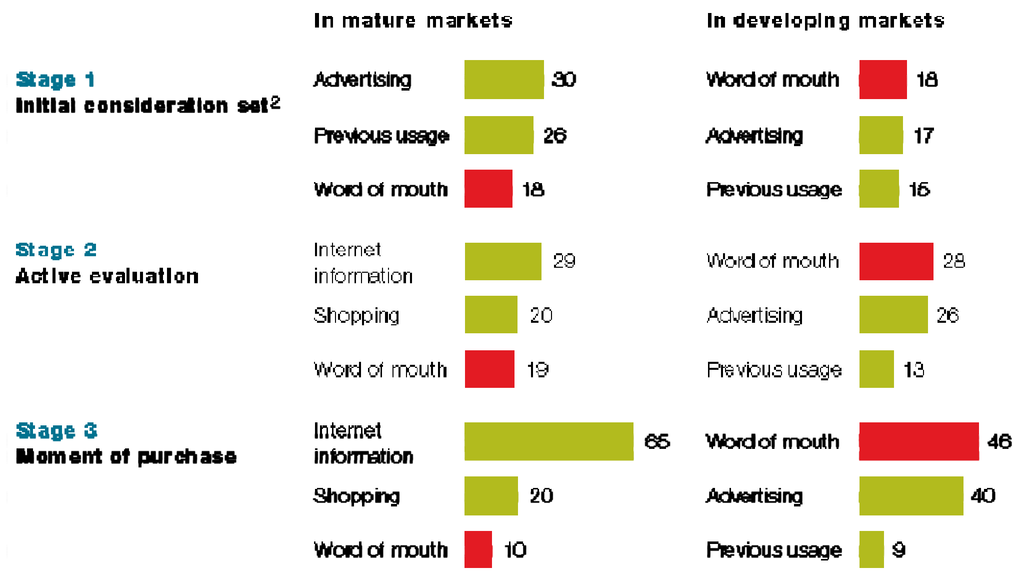


Figure 1: Top 3 factors that influence whether a product is considered at each stage of the consumer decision journey, mobile phone example [%]

Source: Bughin J., Doogan J., Vetvik O.J., A new way to measure word-of-mouth marketing, McKinsey Quarterly, April 2010

2.1. Difference between Rational Herding and Informational Cascades

It is important to define and differentiate correctly between herd behavior and informational cascades[7]. A herd is defined as an outcome where all agents take the same action after some period. Herd behavior is reversible and not all agents may be herding, therefore the possibility of the herd being broken contains some information and allows for some social learning (very slow but present). On the other hand informational cascades, as introduced by Bikhchandani et. al. (1992, p. 1000), are defined as the *case where individual's action doesn't depend on his private information signal*, or alternatively *case where all the agents in the model herd.* Information that is inferred from the history of

[7] A Comment to Scharfstein's and Stein's paper Herd Behavior and Investment (1990) by Ottaviani and Soerensen is clearly based on different definition of "herding" as authors of the original paper explain in their Reply. Scharfstein and Stein define herding equilibrium as the one where agent B always ignores his own information (thus resembling more the definition of informational cascade) while Ottaviani and Soerensen's herding is satisfied when agent B sometimes ignores his own information and follows agent A.

actions is superior to the private information of individual decision maker, leading to imitation of previous agents. Actions taken by agents in cascade do not contain any information for others and no social learning takes places. (Chamley, 2004, p. 60-64)

Distinction has to be drawn between two types of herding behavior. So called "intentional herding" falls into category dealt with above. It may not be, and as I will show later in this chapter, very often really is not efficient especially in special cases of informational cascades. The other type of rational herding is called "spurious herding" in which agents are facing similar decisions with identical information available. In the setting of rational agents even without observable actions this shall lead to a formation of herd. However this outcome will be efficient[8]. (Bikhchandani and Sharma, 2001, p. 282)

It should be pointed out as a summary, that in the framework of rational (Bayesian) agents, Bayesian learning with discrete actions and decisions being made sequentially, herd eventually arises in every model and repetition of the game, whereas informational cascades occur in only specific models.

2.2. Simple Model of Informational Cascades as the extreme case of Herd Behavior

Two pioneering works on the topic of informational cascades were published in 1992. Both Banerjee (1992) and Bikhchandani, Hirschleifer and Welch (1992) present a basic model of herd behavior. Even though Banerjee never uses the term informational cascades, his model also leads to situations where at some point all the subsequent agents disregard their private information and join the herd, thus forming informational cascade. The model of Bikhchandani et. al. is even more straight forward so let me introduce first the most illustrative setting of the model as it is laid out in their *A Theory of Fads, Fashion, Custom, and Cultural Change as Informational Cascades* (1992, p. 996-999).

We have a sequence of individual agents whose order is exogenous and known to all participants of the game. They face a decision whether to invest in a project or not.[9] Cost of investment C is equal to ½ and the payoff structure is such that the gain V is either one

[8] Bikhchandani and Sharma provide example of spurious herds if different investors have various investment (action) sets, as well as intentional herds being caused by not fully rational decision makers

[9] Bikhchandani et. al. use adoption or rejection of some general behavior, for author of this thesis investment into a project seems to be more illustrative

or zero depending on the state of the world, which have equal prior probability of ½. Agent i observes conditionally independent signal X_i about the state of the world taking place. Every agent's signal is either *good (G)* or *bad (B)* and conditionally dependent on the state of the world, meaning that G is observed with probability $p_i > \frac{1}{2}$ if $V = 1$ and B is observed with probability $1 - p_i$ if $V = 0$. In the simplest form of the model signals are identically distributed and it is the case of symmetric binary signal as described in section 1.3. Signal probabilities are depicted in Table 2. In this case, the expected value of adoption is clearly the posterior probability of the state of the world being $V = 1$. Last assumption we need before analyzing the decision making process of the game is the so called tie-breaking convention. We assume that if the agent is indifferent he flips a coin and therefore invests or doesn't invest with equal probability ½.

Signal Probabilities

		$P(X = G \mid V)$	$P(X = B \mid V)$
State of	$V = 1$	p	1-p
Nature	$V = 0$	1-p	p

Table 2: Binary signals

It is clear that the first agent always follows his signal, invests if he receives G signal and rejects the investment if he observed B. In case that first agent, Agent A, invests, second in line, Agent B, will infer that his predecessor has observed a G signal and will decide based on the signal he received himself in following way: will invest if he too has seen a G signal, however B signal will cancel out the inferred signal and Agent B is therefore indifferent and may as well flip a coin to decide[10]. Situation if first agent rejects the investment is analogous. Agent C finds himself in one of the three situations: both decision makers before him invested forcing him to invest even if he observes B signal, thereby starting the Up Cascade; both predecessors have rejected investment which leads him to disregard his own signal and not invest as well, thereby starting the Down Cascade; third situation is when one invested and the other did not – then his anterior probability of both states of the world before taking his signal into account is ½ and puts him into same position as Agent A (will decide based on his signal only). Again by analogy we can see

[10] The posterior probability of the state of the world being *V=1* is equal to ½, consistent with the Bayes' Theorem

that in this particular case Agent D will be facing same situation as Agent B, Agent E will be in position of Agent C and so on. However the probability that a cascade has started already after first few individuals is very high even for signal with quite low precision. Probabilities that a cascade has started after an even number of individuals N can be calculated as follows: a) $\frac{1-\left(p-p^2\right)^{\frac{N}{2}}}{2}$ for an Up Cascade; b) $\left(p-p^2\right)^{\frac{N}{2}}$ as a probability that no cascade has started and c) $\frac{1-\left(p-p^2\right)^{\frac{N}{2}}}{2}$ for a Down Cascade.. From these probabilities we can see that the noisier the private signals are (for p close to ½), the higher is the probability that cascade doesn't start. However, this value is falling exponentially with number of agents that make their decision. Table 3 shows the probabilities that cascade has started after certain number of agents made their decision, depending on the precision of the signal.

Probability of cascade already started							
N	**p = 0,501**	**p = 0,505**	**p = 0,55**	**p = 0,6**	**p = 0,7**	**p = 0,8**	**p = 0,9**
2	75,000%	75,003%	75,250%	76,000%	79,000%	84,000%	91,000%
4	93,750%	93,751%	93,874%	94,240%	95,590%	97,440%	99,190%
6	98,438%	98,438%	98,484%	98,618%	99,074%	99,590%	99,927%
8	99,609%	99,610%	99,625%	99,668%	99,806%	99,934%	99,993%
10	99,902%	99,902%	99,907%	99,920%	99,959%	99,990%	99,999%

Table 3: Probability that cascade has started after N individuals

Probability of the occurrence of a cascade is exceeding 99% after only 8 agents have made their decision even for very noisy signal. The probability also increases in the precision of the signal, however the most important change connected to the increasing precision is the increasing probability of the cascade being correct. Following probabilities of a) ending up in the correct cascade (an Up Cascade if *V=1*, a Down Cascade if *V=0*), b) not being in a cascade and c) ending up in the incorrect cascade after an even number of individuals is again taken from Bikhchandani et. al. (1992, p. 998):

a) $\frac{p\cdot(p+1)\cdot\left[1-\left(p-p^2\right)^{\frac{N}{2}}\right]}{2\cdot\left(1-p+p^2\right)}$; b) $\left(p-p^2\right)^{\frac{N}{2}}$; c) $\frac{(p-2)\cdot(p-1)\cdot\left[1-\left(p-p^2\right)^{\frac{N}{2}}\right]}{2\cdot\left(1-p+p^2\right)}$.

Figure 2 shows the graphical depiction of probabilities of the eventually always occurring cascade being either correct or incorrect depending on the signal precision. To make matters even more illustrative Figure 3 shows the decision making process and possible outcomes for first three individuals. This show s in major clarity two essential properties of informational cascades: i) They are path-dependent in a sense that the order of the signals received matters; and ii) They are idiosyncratic, meaning that small differences in initial events can make a big difference to the behavior of a large number of individuals. (Bikhchandani and Sharma, 2001, p. 288) Also as we see from Figure 2, even in the case of high precision signals informational cascades are error-prone. With the value of p = 0,7 the probability of correct Up Cascade is only 0,753 making the decision maker only 5,3% better of then if he (ceteris paribus) relied only on his own signal. With higher precision of p = 0,8 the differential in information contained in the cascade and the private signal is 5,7%. (Bikhchandani et. al., 1998, p. 156) The fact that private information of Agents involved in the cascade don't enter the mutual pool of knowledge stands behind the properties of informational cascades. These (negative) informational externalities can be either reduced by making the first group of Agents decide about their investment without observing the actions of others, or completely removed by transforming the model to one with observable signals which then enter the pool of knowledge regardless what the decision is and with large enough N always leads to the correct cascade.

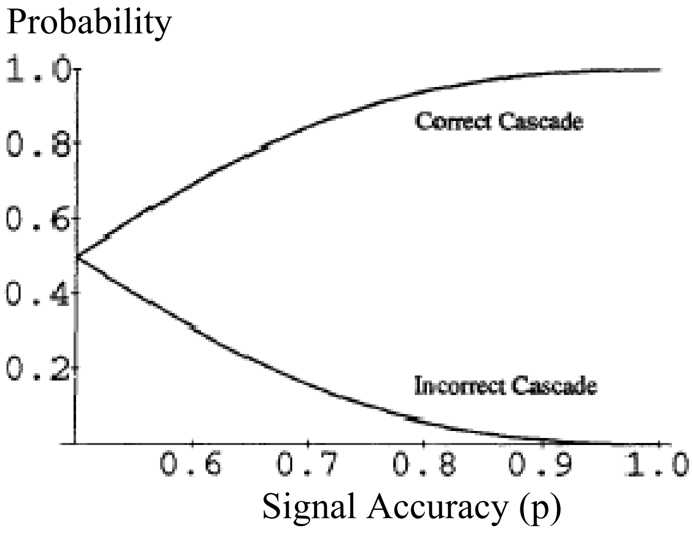
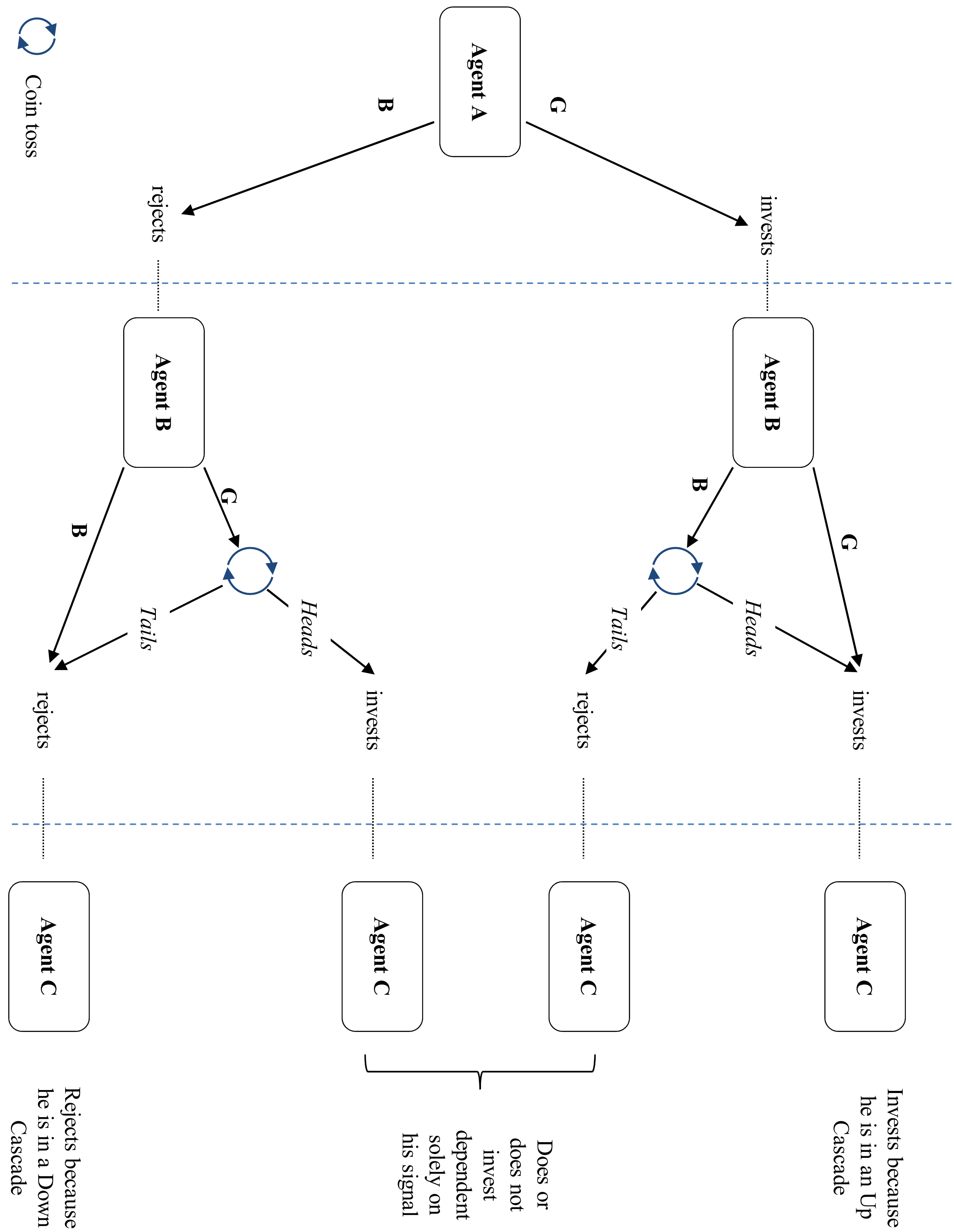


Figure 2: Probability of correct and incorrect cascade as function of *p*

Source: Bikhchandani et. al..: *A Theory of Fads, Fashion, Custom and Cultural Change as Informational Cascades*, Journal of Political Economy, vol. 100, no.5, 1992, p. 998



Agent A
G
B
invests
rejects
Agent B
Agent B
G
B
B
G
Heads
Tails
Heads
Tails
invests
rejects
invests
rejects
Agent C
Agent C
Agent C
Agent C
Invests because he is in an Up Cascade
Does or does not invest dependent solely on his signal
Rejects because he is in a Down Cascade
Coin toss

2.3. Generalizations, Fragility and Practical Experiments of the Simple Model

While the model in Section 2.2. is easy to grasp and very illustrative, it only applies in limited number of situations. Changes and generalizations might touch up on all the assumptions laid out in the Basic Model; not all agents need to receive a signal, the signal doesn't have to be binary, payoff structure might be altered, not even the timing of individual decisions has to be exogenous. This section of the thesis deals with several models where such alternations to the Basic Model are introduced, focusing on the implications and probabilities of occurrence of informational cascades as well as possible applications in more realistic settings.

Generalized Models

Bikhchandani, Hirschleifer and Welch (1992, p. 1001) show that under some generalization and quite mild assumptions cascades will arise with probability 1.[11] The assumptions of exogenous timing and observable actions are kept, however the payoff from investing (*V*) takes on a finite set of possible values $v_1 < v_2 < ... < v_s$ and the cost of adopting *C* is in such way that the decision is not trivial ($v_1 < C < v_s$). The prior probability of $V = v_l$ shall be denoted θ_l. Every agent receives a private signal x_i from a conditionally independent and identically distributed sequence of signals X_i that can have values of $x_1 < x_2 < ... < x_R$. Probabilities of p_{ql} (probability that agent receives signal x_q given a true gain from investment of v_l) are greater than zero for all *q* and *l*. Then for the payoff $V = v_l$ the cumulative distribution of X_i can be written as $P_{ql} = P\left(X_i \le x_q \mid V = v_l\right) = \sum_{j=1}^{q} p_{jl}$. The set of signals leading the agent *i* to invest is denoted J_i and decision of each agent reveals if he has seen an element of J_i or its complement. However, if J_i is empty or includes all possible signal values $\{x_1, ..., x_R\}$ then the decision of agent *i* (denoted a_i) provides no information to others about his realization. Let $A_i = \left(a_1, a_2, ..., a_i\right)$ be the history of decisions made by agents 1 through *i*. Then $J_i\left(A_{i-1}, a_i\right)$ is the set of signal realizations that leads

[11] The following draws heavily on Bikhchandani, Hirschleifer and Welch*"A Theory of Fads, Fashion, Custom and Cultural Change as Informational Cascades", Journal of Political Economy 100, no. 5, (1992)*

agent i to choose decision a_i (either invest, or reject). We can then express the conditional expectation of V by agent $n+1$ based on his own signal x_q and the history A_n: $V_{n+1}\left(x_q;A_n\right)=E\left[V \mid X_{n+1}=x_q,X_i\in J_i\left(A_{i-1},a_i\right),i\leq n\right]$ where agent $n+1$ invests if $V_{n+1}\left(x_q;A_n\right)\geq C$. Later individuals can then infer from a_{n+1} that $X_{n+1}\in J_{n+1}\left(A_n,a_{n+1}\right)$ where $J_{n+1}\left(A_n,invest\right)=\left\{x_q \text{ such that } V_{n+1}\left(x_q;A_n\right)\geq C\right\}$

$$J_{n+1}\left(A_n,reject\right)=\left\{x_q \text{ such that } V_{n+1}\left(x_q;A_n\right)< C\right\}$$

(Bikhcahndani et. al., 1992, p. 999-1001) After imposing assumptions of monotone likelihood ratio ordering of the conditional distributions $P\left(X_i \mid V=v_l\right)$[12] and one of non-existence of long-run ties ($v_l\neq C$ for all l) we can state that as the number of agents increases, the probability that cascade eventually starts approaches one. (Bikhchandani et.al., 1992, p. 1001) If an agent i is in a cascade his action clearly provides no information to others and next in line has the same history of actions at hand. Since the signal X_{i+1} is drawn from the same distribution as X_i, agent $i+1$ is also in a cascade as is everyone after him. The conclusion in such setting is that cascades will eventually start and they will last forever unless some of the factors change.

Similar model, that results in extensive herding, and in which cascades may start as soon as with the third decision maker was described by Banerjee in 1992. This model shares the sequential decision making with exogenous timing, Bayesian rationality of all agents and the structure of the game known to all. Specifically the problem is set as follows[13]: population of N risk-neutral agents sequentially decide in which from the set of assets indexed by numbers in [0,1] to invest. Returns to all agents from the same asset are the same, namely return to the investment into i^{th} asset $v(i)\in\mathbb{R}$ for all agents 1,…,n. There is a unique i^* such that $v(i)=0$ for all $i\neq i^*$ and $v\left(i^*\right)=x$ where $x>0$. All i have the same prior probability of being i^*. Each agent receives private signal about the value of i^* with probability α, however this signal is only correct with probability β. In case it is incorrect

[12] Means that conditional expectation of each agent increases in his signal realization

[13] Following section is based substantially on Banerjee, A.V.: *"A Simple Model of Herd Behavior", Quarterly Journal of Economics Vol. 107, 1992*

it gives no information about the true value of i^*. Agents are allowed to observe the actions of their predecessors but not whether they received a signal.

Following three tie-breaking assumptions are presented in order to study the equilibrium decision rules[14]

1. *"Whenever decision maker has no signal and everyone else has chosen $i = 0$, he always chooses $i = 0$"*
2. *"When decision makers are indifferent between following their own signal and following someone else's choice, they always follow their own signal"*
3. *"When a decision maker is indifferent between following more than one of the previous decision makers, he chooses to follow the one who has the highest value of i"*

(Banerjee, 1992, p. 803)

First decision maker always follows his signal if he has one, otherwise he chooses $i = 0$. Second decision maker will imitate the first decision maker if he has no signal and follows his own signal if he has one. Third agent will face one of the four histories: $i = 0$ was chosen by both predecessors, one of the predecessors chose $i = 0$, both chose $i \neq 0$ and did agree or both chose different $i \neq 0$ (did not agree). The possible courses of action are generalized in Table 4 for all $k > 2$, some of them are however not applicable in the case of the third decision maker. They are all based on the three basic assumptions[15] and result in a simple implication, that "*once one option has been chosen by two people, the next person should always follow that option unless his signal matches one of the options that have been already chosen; in that case he should follow his signal*". (Banerjee, 1992, p.805-806)

Banerjee comes to the same conclusion that cascades will very often by "wrong". An incorrect cascade will occur unless the first agent with a signal or someone with a signal coming after him but before the first agent without a signal chooses the correct *i*. It can also be calculated that the probability of the correct option not being chosen by a single

[14] As Banerjee (1992, p.803) points out these assumptions are all made to minimize the possibility of cascades

[15] Only case that differs is the one where both predecessors chose $i \neq 0$ and third agent does have a different signal. Then it can be proven that he should ignore his signal and follow the herd (thus starting a cascade)

agent is $\frac{(1-\alpha)\cdot(1-\beta)}{1-\alpha(1-\beta)}$. It should be noted that author of the original paper uses the expression herd or herding in place of what we have defined as cascade.

	Decision maker k > 2							
	Has no signal				Has signal i_k			
History	Everybody else has chosen i=0	All choices already chosen except i=0 have been chosen by one person	Only one option other than i=0 has been chosen by more than one person	Two options other than i=0 have been chosen by one person	Some other person has chosen i_k	No one else has chosen $i = i_k$ and no option other than i=0 has been chosen more than once	No other person has chosen $i=i_k$ but one option other than i=0 has been chosen by more than one person	No other person has chosen $i=i_k$ but two options other than i=0 have been chosen by more than one person
Action	Choose i=0	Choose the highest of the already chosen options	Choose that option	Choose the lower of the two options	Choose $i = i_k$	Choose $i = i_k$	Choose that option	Choose the lower of the two options

Table 4: Courses of action depending on history for agent k > 2

Source: Banerjee, A.V.: *"A Simple Model of Herd Behavior", Quarterly Journal of Economics Vol. 107, 1992, p. 808* (Author's own graphical presentation)

Although the following should be placed under the subchapter of Empirical Evidence, to make it easier to follow I present the results of an experiment conducted by Alsopp and Hey in 2000 in this place. In line with results presented later, informational cascades do not occur as often as predicted by the theory. Behavior of tested subjects (agents)[16] does differ significantly depending on values of α and β, where convergence to behavior specified in Table 4 was noticed only with higher values of both parameters[17]. In general, strategies of agents differed according to their position in line as well as to the parameter values. Contrary to the theoretical framework, *"this volatility [in pattern of decisions] occurred within rather than between rounds."* (Alsopp and Hey, 2000, p. 130) After dropping the Assumption 1 of the original model, results showed increased herding that was broken later in the sequence, thus resulting in less informational cascades. However the origin of participants of the experiment and their familiarity with Bayesian updating is not clear. Moreover, reasoning behind individual decisions is unclear, which authors of the experiment recognized. (Allsopp and Hey, 2000, p. 131)

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[16] Tested subjects were awarded financial remuneration for choosing the correct (winning) option

[17] Only when α and β were both equal to 0,75 the predicted strategy was followed closely (Allsopp and Hey, 2000, p. 129)

Altruism, Fashion Leaders and Fragility

There are several ways how to allow for improvements in the overall efficiency of decisions. Positive information externality will be created for the later decision makers if the first *n* agents are restricted to decisions based solely on their private signal.[18] In large enough population and after allowing *n* to be sufficiently high, probability that correct cascade starts approaches one. More realistically, if e.g. first 15 decision makers were bounded to such an altruistic behavior[19] (and revealing their private signals in order to increase efficiency), cascade will, again, eventually start, but much later and with higher probability of being correct. Once again to simply achieve the best welfare outcome, not only actions but also private signals would have to be observable. (Banerjee, 1992; Bikhchandani et.al., 1992, Bikhchandani and Sharma, 2001)

Alternative, which however doesn't always lead to more efficient outcomes, is to include high-precision individuals in the population. Such "fashion leaders" can both magnify the pro-cascade tendencies as well as mediate them. All again depends on their exogenous position in the decision tree. If a fashion leader is the first one to decide followed by a less informed agent, informational cascade starts already with the second in line and is even less informative (and therefore less efficient) than in case with identical decision makers. On the other hand, positioning of a better-informed agent even very late in the sequence can lead to overturning the cascade and starting an opposing one while leading to a higher efficiency. As Bikhchandani et. al. (1998, p.160) write, such principle was included already in Talmud as judges were taking decisions in reversed seniority order to reduce influence of the more experienced ones (fashion leaders). Today, this can be avoided by sequential balloting.

So far all of the models resulted in a cascade that lasts forever, no matter if it is correct or incorrect one. As noted in previous paragraph, arrival of a better-informed individual can overturn the developments and lead to shattering of the cascade. This stems from a fact that cascades are built on very little information and, since our agents are Bayesian, they are aware of that. Cascades are fragile and can be broken by changes in underlying value of

[18] In models where all agents receive a signal they do follow it; in models where proportion of agents does not receive a signal those without one randomize.

[19] This can be achieved by either setting the individual return equal to an average return on investment of the whole population or by severely ex post punishments for imitators on the decision that turns out to be incorrect

investments, better informed individuals as mentioned before or public release of information (usually taking form of governmental decision, publishing of a study by research institution or more often even internet articles whose reliability however differ from source to source). Any release of information should add more information to the public pool of knowledge, however release of quite noisy information before the first agent's decision can lower welfare of some individuals.(Bihchandani et.al., 1992, p. 1005) On the other hand information published at a point where cascade has already started can only have beneficial effect as the individual decisions include no information to be inferred by others. If we go back to simplified example from Section 2.2., Table 5 shows the influence on probability that correct cascade occurs when 1000th agent makes his decision depending on the signal precision and number of public information releases.

Information Releases Influence

	No Release		**1 Release**		**10 Releases**	
p	Correct Cascade	Incorrect Cascade	Correct Cascade	Incorrect Cascade	Correct Cascade	Incorrect Cascade
0,55	56,45%	43,55%	58,57%	41,43%	67,67%	32,33%
0,65	69,50%	30,50%	73,96%	26,04%	89,86%	10,14%
0,75	81,00%	19,00%	86,33%	13,67%	98,26%	1,74%
0,85	90,65%	9,35%	94,80%	5,20%	99,89%	0,11%
0,95	97,24%	2,76%	98,84%	1,16%	100,00%	0,00%

Table 5: Increasing probability of correct cascade in p and in number of public releases of information

Source: Bikhchandani, Hirschleifer and Welch: *"A Theory of Fads, Fashion, Custom and Cultural Change as Informational Cascades", Journal of Political Economy 100, no. 5, p.1008 (1992)*

Endogenous Timing

Previous settings and factors can be also combined with relaxation of the assumption on exogenous order of agents' decisions. A special case with agents having various signal precisions and being given a choice to postpone their decision at some cost yields interesting results. Since the higher the precision of signal, the higher is the relative cost of delay, agent with the highest precision will move first, thus revealing he is in possession of the "best" signal. Since private signals of all other agents are inferior to the one of the first-mover, an immediate cascade of investments will follow in this equilibrium. (Bikhchandani et.al., 1998, p. 162) In different model with continuous time and endogenous timing of decisions, Zhang (1997, p. 190-191) shows additional characteristics of the equilibrium and properties of the outcomes. The agent with highest precision will indeed move first and explosive immediate cascade will follow. However there will be limited delay before the first decision takes place due to the fact that signal precisions are not publicly known at the beginning of the game and are only revealed by the decisions.

Timing of the decision, namely the delay, as intuition tells us, increases in number of agents participating and decreasing in the precision of the private signal. Since the cascade is based on decision of single agent, total welfare loss occurs and with increasing number of agents goes to infinity. Such results are robust even for set-ups with more than two possible actions and several states of the world as long as these numbers are finite. In such case *"[cascade] may not start immediately after the first mover takes his action, but once it starts we still get a sudden collapse in which everyone starts making the same investment at hte same time."*(Zhang, 1997, p. 201) Other way to add more information into the common pool of knowledge is by introducing noise traders who randomize both their decisions and timing, therefore their presence leads to longer waiting times even in the case with only two possible actions. (Zhang, 1997, p. 201)

Empirical Evidence on Informational Cascades from Laboratory Experiments

Theory tells us that in specific settings cascades will always occur and the probability that they start early is very high. Several experiments in laboratory settings were conducted to provide evidence that cascades wouldn't only occur on paper. Anderson and Holt's (1997) experiment included 72 students from undergraduate economic courses to provide for understanding of Bayesian updating; each subject was awarder financial remuneration for participation and then another depending on the results of the experiment (amount in cash for each correct identification of the state of the world) to provide motivation for rational decision making[20]. Design of the experiment was set in the form of a model from Section 2.2., with signal precision of $p = 2/3$ and 6 decision makers in each round. Their results show that in cases where it was rationally possible for cascade to start, this happened in 73%. Naturally errors occurred, namely when decision based on Bayesian updating was in contradiction with private signals, in 26% such of cases individuals followed their signal. Overall efficiency in means of actual payoffs compared with the maximum payoffs with

[20] In academic settings extra credit can be also used as motivation, however such practice is not recommended since it may force participants to maximize relative profit instead of absolute profit as required (Anderson and Holt, 1996)

given signals reached very high 91,4%, however if individuals only relied on their own signals disregarding other individuals decisions the efficiency would still reach 72,1% (Anderson and Holt, 1997, p. 12). Instead of Bayesian updating, more simple counting heuristic can be applied, therefore more rounds of experiment were conducted with asymmetric design. In this setup, possibilities of cascade occurrence are down to 70%. Most importantly more than 21% of decisions were inconsistent with Bayesian rationality, in case where counting heuristic gives no result this share rises to 34% and when counting heuristic contradicts Bayesian updating results show 50% success rate[21]. (Anderson and Holt, 1997, p. 20-21)

As can be seen, results of Anderson and Holt strongly support the theory, however the rationality of their agents has not been proven. Results from an experiment by Huck and Oechssler from Humboldt University conducted in 1999 provide evidence that even students that should be familiar with Bayesian updating rely more on their private signal. Huck and Oechssler (1999, p. 3) use design with different prior probabilities of state of the world and asymmetric signals as a part of the final examination, where students have to explain their decision as a part of the problem. Three different decision problems were used but overall only 53% decisions were consistent with Bayesian updating, paradoxically much better explanation for students' responses is the follow-your-own-signal rule which applies in 71,4% of cases. In comparison with only the more complicated decisions from experiment of Anderson and Holt, Huck and Oechssler note:*"These proportions (49,4% versus 65,8%)[of decisions in line with Bayesian reasoning and follow your signal reasoning respectively] are nearly identical to those of our experiment. That is, when it comes to applying the hard-nosed rationality Anderson's and holt's subjects were not better than ours"*[22](Huck and Oechssler, 1999, p. 7)

When the signals received by individual agents are continuous rather than discrete, situation changes substantially. Informational cascades should theoretically never occur however in the laboratory setting they are still reality. (Celen and Kariv, 2004, p. 485) In the setup where agents have to set a cut-off value of the continuous signal before receiving one it is possible to identify the difference between informational cascades and herds. Only

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[21] Success being choosing the decision based on Bayesian updating

[22] It should be noted that not a single completely correct explanation was given by the students, 25% of them at least tried to apply Bayes' rule (Huck and Oechssler, 1999)

agents that set their cut-off value at the minimum/maximum are considered to be in cascade, while ones who choose the same action from one point in a time on form a herd. Experimental results tell us that while herding took place in almost 65% of repetitions of the game, cascades occurred in almost 35%. Vast majority of cascades involved only last one or last two decision makers from the eight in each round, nevertheless *"although cascades are not a theoretical possibility [in this setting] they are a reality"*(Celen and Kariv, 2004, p.497) Results of continuous signals experiment are consistent with the findings of previously mentioned experiments in respect to agents overvaluing their private information.

Bank runs

Extensive literature on herd behavior in financial markets exists, dealing with various examples, however these are mostly based on one of the three principles – payoff externalities, principal-agent models (reputational concerns) and informational cascades. (Devenow and Welch, 1996, p. 605) Once again, differentiating between the causes in real life is very difficult, however theoretical framework for the cause of interest is present. Principles of informational cascades are, under certain assumptions and simplifications, useful in explaining the phenomenon of bank runs. Even though such models concentrate heavily on the deposit contract designs and their efficiency, they show that *"in the absence of accurate information, information externalities and herd behavior of depositors can lead to runs on healthy banks."*(Yorulmazer, 2003, p. 8) The occurrence of bank runs is robust in respect to both risk neutrality of agents as well as to more than two states of the world, it might however influence the policy implications. (Chari and Jagannathan, 1988, p. 758) Runs on healthy banks can only be prevented by publishing detailed information of banks' performance and asset structure in combination with suitable deposit contract and liquidity support from central bank. (Yorulmazer, 2003, p. 30)

In specific settings where information on performance of share of the banks is available early, proportion of failures among those early-showers can trigger bank run on the remaining banks even though this would not otherwise happen. Here the influence of negative payoff externalities is as important as the information externalities. (Chen, 1999, p. 957) Important assumptions of this model are availability of bank-specific information, no costs imposed in the period between information revelation of first and second group of banks and the choice of specific equilibrium in case of multiple equilibriums. *"If failures* *of other banks were the only information available to depositors or if banks would suffer great losses supposing that depositors did not respond immediately to failures of other banks, then panic runs might be socially efficient "*(Chen, 1999, p. 964-965)

2.4. Other than Informational Approach to Herds and Cascades

Other reasons behind occurrence of herd behavior are mentioned in the relevant literature including e.g. compensation-based herding or attempts to build models of herd behavior with completely relaxed assumption of rationality of agents. However sticking to the topic of rational herding, author believes following approaches that differ from the purely informational models of previous sections are worth mentioning.

Reputational Herding

Model of reputational herding was first introduced by Scharfstein and Stein (1990) explains the behavior of investment managers or analysts, who are concerned about their reputation and hence about their future career prospects. The substantial difference to previous models lies in the agents optimizing their decisions with the payoff structure being in relative terms compared to the absolute returns. In case that both the investment manager and his employer are uncertain about the manager's ability to manage the portfolio, making same decisions as other managers do keeps the ability unrevealed, thus benefiting the manager who is, in relative terms, not underperforming. (Bikhchandani and Sharma, 2001, p. 291) If all the managers take the wrong decision, this would in the eyes of their employer be seen as an unlucky development of events instead of the mistake of the employee, the so called "sharing the blame" effect. (Scharfstein and Stein, 1990, p. 466)[23]

Scharfstein and Stein (1990, p. 467-476) consider two kinds of agents ("smart" and "dumb" managers) that take decision about investment in sequence. There are again two possible states of the world (high and low) on which depends the yield of the investment. The yield in high state is positive $x_H > 0$ while the low state results in loss $x_L < 0$ and these states occur with prior probabilities of α and $(1-\alpha)$ respectively. First Agent A

[23] Following section stems substantially from Scharfstein, D.S. and Stein, J.C.: "Herd Behavior and Investment", *The American Economic Review 80, no. 3* (1990)

makes the decision based on his private signal, however he doesn't know if he is the smart or the dumb manager. Being smart manager has a prior probability θ and they observe informative signals meaning that $P(s_G \mid x_H, smart) = p$ while $P(s_G \mid x_L, smart) = q < p$ where s_G and s_B are the good and the bad signal respectively. With prior probability $(1-\theta)$ the manager is dumb and receives a signal that is pure noise and it holds that $P(s_G \mid x_H, dumb) = P(s_G \mid x_L, dumb) = z$. To secure that the signal received doesn't contain any information about the agent's type, ex ante distributions of signals are identical for both types of agents. We can thus rewrite the probabilities of receiving good signal as $P(s_G \mid smart) = P(s_G \mid dumb)$, in other words as $z = \alpha p + (1-\alpha) q$.

			Type of manager	
			smart	dumb
		P/P	θ	1-θ
SotW	XH	α	p	z
	XL	1-α	q	z

Table 6: Prior probabilities of s_G in reputational herding

By direct use of the Bayes' Theorem we get the probabilities first Agent A assigns to the high state of the world after observing good and bad signal:

$$\text{Prob}(x_H \mid s_G) = \frac{P(s_G \mid x_H, smart) \cdot P(x_H) \cdot P(smart)}{P(s_G \mid x_H, smart) \cdot P(x_H) + P(s_G \mid x_L, smart) \cdot P(x_L)} +$$

$$+ \frac{P(s_G \mid x_H, dumb) \cdot P(x_H) \cdot P(dumb)}{P(s_G \mid x_H, dumb) \cdot P(x_H) + P(s_G \mid x_L, dumb) \cdot P(x_L)} =$$

$$= \frac{p \cdot \alpha \cdot \theta}{p\alpha + q \cdot (1-\alpha)} + \frac{z \cdot \alpha \cdot (1-\theta)}{z\alpha + z(1-\alpha)} = \boxed{\frac{p\theta + z \cdot (1-\theta)}{z} \cdot \alpha}$$

Same way we can show that $\text{Prob}(x_H \mid s_B) = \boxed{\frac{q\theta + (1-z)(1-\theta)}{1-z} \cdot \alpha}$. To make the investment problem interesting and corresponding to previous ones Scharfstein and Stein (1990, p. 468) set a condition on payoffs as:

$$\text{Prob}(x_H \mid s_G) \cdot x_H + (1 - \text{Prob}(x_H \mid s_G)) \cdot x_L > 0 > \text{Prob}(x_H \mid s_B) \cdot x_H + (1 - \text{Prob}(x_H \mid s_B)) \cdot x_L$$

To this extent is the model of reputational herding again just a generalized version of the simple model of herd behavior, with variable state of the world probabilities and two kinds of agents. The crucial difference is that the draws of signals for "smart" managers are perfectly correlated, resulting in probability of two good signals being observed by two smart managers being equal to p [24] [25]. Moreover, there is an assumption of partial correlation on smart managers' prediction errors which puts some inferential weight on the similarity of decisions. This results in an ex ante lower efficiency due to active manipulation of inference process by the smart managers.

In reputational herding model the managers do not maximize only the expected return on the investment but as a main priority the assessment of their abilities by the labor market $\hat{\theta}$ based on their decision. Following assumptions are made to interconnect and simplify the objectives: Managers are risk neutral and care only about their absolute ability assessment (relative evaluation can lead to different behavior as was discussed in 2.3.), there is a second round of investment decisions after the payoffs have been realized and the labor market has updated their views, in this second round there is no need to build up reputation therefore managers invest efficiently and managers' spot market wages are set to the economic value of their ability.

Given these assumptions Scharfstein and Stein (1990, p. 471) show that there does not exist a continuation equilibrium in which the second manager (manager B) would base his decision on his own signal. He either imitates manager A regardless of his private signal or does the opposite again regardless of his own signal. Let (s_a, s_b, x_i) denote the event of two received signals by managers A and B and the realized state of the world consecutively [e.g. (s_B, s_G, x_H)] and $\hat{\theta}(s_a, s_b, x_i)$ be the updated assessment of manager B's ability by the labor market. After expressing the updating rules for all possible events (only four different cases due to symmetry), it can be shown that a condition for an efficient equilibrium in which manager B decides contingent on his signal is in form of inequality

$$\hat{\theta}(s_B, s_G, x_H) \cdot P(x_H \mid s_B, s_G) + \hat{\theta}(s_B, s_G, x_L) \cdot P(x_L \mid s_B, s_G) \geq$$
$$\geq \hat{\theta}(s_B, s_B, x_H) \cdot P(x_H \mid s_B, s_G) + \hat{\theta}(s_B, s_B, x_L) \cdot P(x_L \mid s_B, s_G)$$

and that it doesn't hold. There are two factors that result in this inefficiency. First describes the fact that a manager B is compensated for making the right decision in absolute terms, that is investing prior to x_H and not investing prior to x_L. It can be written as $\hat{\theta}(s_B, s_G, x_H) > \hat{\theta}(s_B, s_G, x_L)$ and $\hat{\theta}(s_G, s_G, x_H) > \hat{\theta}(s_G, s_G, x_L)$. This factor works indeed in

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[24] As opposed to the case of independent draws where the probability would be p^2; independent draws are the case for one smart and one dumb manager or two dumb managers.

[25] Condition of perfect correlation can be loosened to partial correlation (Scharfstein and Stein, 1990, p. 468)

favor of the efficient equilibrium, it is however overturned by the second factor that can be described as a payoff to imitation. If we hold the correctness of the decision fixed, the payoff for imitating manager A is higher than for contradiction. Formally:

$\hat{\theta}(s_G, s_G, x_H) > \hat{\theta}(s_B, s_G, x_H)$ and $\hat{\theta}(s_G, s_G, x_L) > \hat{\theta}(s_B, s_G, x_L)$

Existence of an equilibrium where manager B always mimics manager A can be proven through updating rules and the fact that if manager B deviates by not investing when A has invested, labor market believes that he has observed s_B[26]. Manager B would have to have a large enough incentive to deviate. In a case that manager A sees a bad signal and does not invest the incentive to deviate for manager B would have to outweigh the posterior assessment by labor market equal to θ[27] which is valid in case he imitates. Two cases for different signals of manager B are as follows: for s_B must hold that $\theta \leq \hat{\theta}(s_B, s_G, x_H) \cdot P(x_H \mid s_B, s_B) + \hat{\theta}(s_B, s_G, x_L) \cdot P(x_L \mid s_B, s_B)$ for him to deviate, and for s_G: $\theta \leq \hat{\theta}(s_B, s_G, x_H) \cdot P(x_H \mid s_B, s_G) + \hat{\theta}(s_B, s_G, x_L) \cdot P(x_L \mid s_B, s_G)$. Stronger incentive, as common sense also tells us, is upon observing the good signal but the right hand side is still only equal to $\frac{\theta}{(1+\theta)}$, meaning that manager B will never deviate. (Scharfstein and Stein, 1990, p. 472-473)

While there is no information contained in decision of manager B, for the first-moving manager A holds that his abilities can only be evaluated upon the absolute outcome of the game. Sharfstein and Stein show that his decision making based solely on following his own signal is part of the equilibrium. This equilibrium is robust also for more than two agents taking part in the game. Since manager B's action contains no information, manager C is in the exact same situation as his predecessor and same rules apply for him as for manager B. Therefore no information will be added to the common pool of knowledge but the signal of manager A and the cascade will start with manager B already. Although the assumptions are quite restricting, this model can be applied to situations in corporate investment where the principle of sharing the blame is often observed as well as in internal

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[26] Conversely if manager A has not invested and B deviates by investing, labor market believes manager B has received s_G

[27] There is no revision when the two managers take the same action

corporate decision making where career prospects are at stake, causing managers to follow the first-observed decision resulting in originally improbable consensus.

Availability Cascades

The concept of availability cascades is quite new compared to informational or reputational cascades. It is best described as a combination of the two mentioned approaches to herding behavior of individuals. The essential notion for this concept is the one of availability heuristics which can be described as *"a pervasive mental shortcut whereby the perceived likelihood of any given event is tied to the ease with which its occurrence can be brought to mind."* Moreover, *"Cognitive psychologists consider the availability heuristic to be the key determinant of individual judgment and perception."*(Kuran and Sunstein, 2007, p. 685). In more simple words *"Availability is a cognitive heuristic in which a decision maker relies upon knowledge that is readily available rather than examine other alternatives or procedures."* (Availability Heuristic, as retrieved from http://heuristics.behaviouralfinance .net/availability/ on May 2nd 2010). Here the agents not only take an advantage of information that they can observe from others and which would be costly to obtain otherwise, but they consider the information reliable (with high precision), based solely on the fact that it is available. And since it can be said that the probability of an event is estimated on the basis of how easily instances of it can be brought to mind, influence on individual probability assessment just adds additional weight to the already available and influential information. (Lemieux, 2003, p. 20)

Main setback of this approach in the light of this thesis is the quasi-rationality of agents relying on this heuristic. But as Kuran and Sunstein (2007, p. 689) argue this might not be the issue in case of imperfectly informed real agent. As could be seen in section 2.3., agents in reality do not always act "Bayesian" and use the heuristic due to the limited ability to process information.[28] This theory is especially useful in explaining why risk regulations (both environmental and of individual products) are often based on public opinion movements that are opposed to the results and recommendations of science. One of the recent examples worth further exploration might be the case of the mandatory

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[28] *"People who seek to minimize search and decision costs, and who look for reliable information about a particular risk, may do best to form their assessments according to what incidents come most readily to mind. It is true, however, that the availability heuristic can produce systematic and persistent misperceptions. It also appears that people resort to this heuristic more than they would if they were perfectly rational."* (Kuran and Sunstein, 2007)

proportion of bio-fuel being added to the conventional gasoline despite unclear scientific results on the environmental consequences.

Interpersonal communication

Approach studied by Robert J. Schiller combines economy with anthropology and social psychology while studying the mechanisms of information transmission within groups. Despite informational cascades being a useful concept he argues, that for different groups arriving at different equilibriums (cascades) because of different random private signal realizations of first few group members, there are “too many first movers” for a cascade to start. Instead he proposes that there is an always-present way for idle exchange of information and thoughts he calls “conversation”. This should lead to a collective memory of a group and collective conventions, nevertheless these need not be correct and sometimes are counterproductive[29].

Modern history of human kind created specialized environments to facilitate information exchange, still these “structured environments” are dominated by ordinary conversation. (Schiller, 1995, p. 183) Consistent with the argument in the beginning of Section 2, media show lower effectiveness in opinion transmission than interpersonal conversation. On the other hand direct face-to-face interpersonal conversation has some common rules that lead to the localized specialization of the outcome, while more abstract matters are not discussed in depth. One has to infer information on such topics from conversations centered on other matters, therefore the opinions should differ between groups and throughout time. Schiller (1995, p. 185) offers explanation for volatility of mass behavior as combination of informational cascades and differences in group properties, namely the nature of information transmission in the group, that he calls informational “cascades facilitators”.

Framework of different herd behavior explanations is well depicted in Figure 4.

[29] As well as in informational cascades framework, actions of the group are error-prone

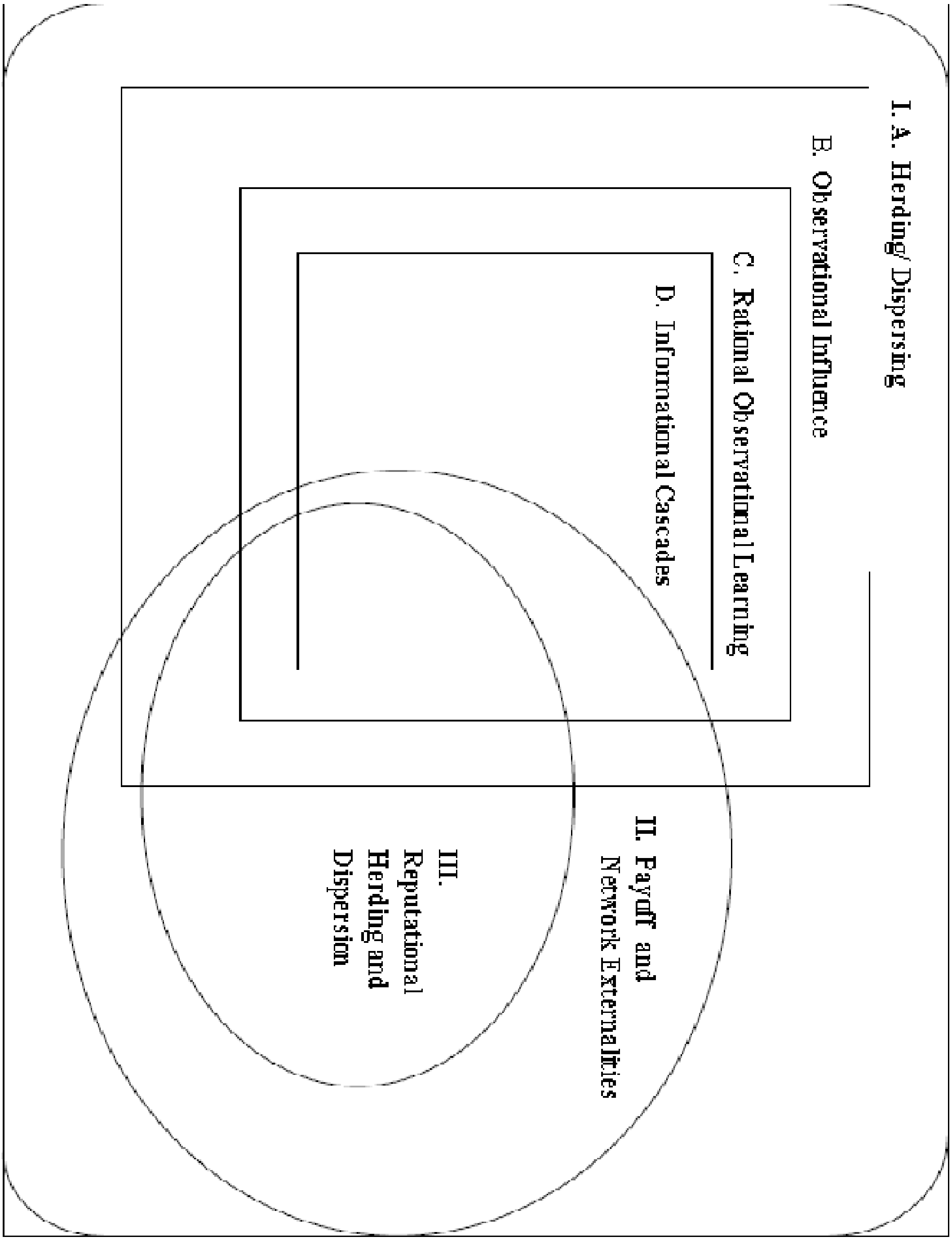

Figure 4: Herd behavior framework

Source: Hirschleifer D, Teoh, S.W.: “Herd Behavior and Cascading in Capital Markets: A review and Synthesis”, 2001, p. 57 (Figure 1)

3. Practical examples of Informational Cascades Framework Applications

Features of informational cascades can be found throughout various aspects of our everyday life and across different "industries". Starting with the profound tale of two restaurants, principles of informational cascades are applied to explain some more complex phenomena, it should be noted that in the strict form in which informational cascades were defined in Section 2.1., they only occur in laboratory settings. Evidence from zoology shows great rate of imitation, when animals are allowed to witness the behavior of others. Information externalities also have place in politics, where the disproportional influence of first decision makers in American presidential elections was mitigated by introduction of the "Super Tuesday". Moreover in many countries including the Czech Republic, opinion polls are not allowed to be published for certain time period directly preceding the elections in order to reduce the influence of such statistics on the voters. Developments of medical practices include multiple examples of information based inefficiencies. Cascade of bleeding as a treatment common in 19^{th} century was broken in the 20^{th}, at one point very frequent operations of hysterectomy and tonsillectomy were based on just little positive information and therefore performed lacking sound evidence of its necessity. (Bikhchandani et. al., 1992 p. 1010-1011; and 1998, p. 167)

Information transmission and its effects play major role in marketing activities as well as companies' choice of its branch location. The former is illustrated by the story of management experts Michael Treacy and Fred Wiersema, who secretly bought 50 000 copies of their own book, hence sending it on the bestseller list despite inferior reviews. However, bestseller reputation was enough to maintain high sales and the position on the bestseller list without further intervention. (Bikhchandani et. al. 1998, p. 151) Similar situation was recorded among freely downloadable applications (games). After the authors of the experiment manipulated the number of downloads in favor of one of the games, namely increasing it by 100%, this game then recorded share of more than 55% of all the new downloads after the manipulation. (Chamley, 2004, p. 59-60) This can be considered as an explanation for marketing slogans as "Used by 9 out of 10 chefs", as well as banners on new apartment buildings saying "Last apartments for sale". The latter case is based on strikingly common clustering of branches of competing financial houses, even if socioeconomic and crime data are accounted for. In general business decisions exhibit convergence on the same action (as was explained in section 2.4., this may be not only due to the informational externalities, but also due to the reputational concerns of managers who take such business decisions). To present the characteristic of cascades being error-prone, short-lived decision to invest in construction of wooden plank roads is mentioned in the literature, as well as adoption of hybrid corn by Iowa farmers, where the Down Cascade of not planting lasted for 9 years before being finally reversed. (Bikhchandani et. al., 1998, p. 165)

Several applications are found in the financial markets. Long time CEO of Halifax Bank of Scotland Sir Peter Burt says: *"It is sometimes said that the definition of a good banker is that he is the last lemming to go over the cliff."*[30], comparing bankers to the famous imitating characters. With (unrealistic) assumption of fixed prices, informational cascades can (partially) explain stock market bubbles and subsequent crashes. In more realistic settings, cascades could apply to asset-pricing markets if prices do not move instantaneously and smoothly. (Devenow and Welch, 1996, p. 610) Fact that Initial Public Offerings (IPOs) occur quite often in waves and the new stocks follow the same pattern of rapid growth in price succeeded by steady devaluation and stabilization[31] is mentioned by Welch (1992, p. 465-469). Despite a short history of Prague Stock Exchange (PSX) and only few IPOs, propositions made by Welch seem to hold as IPOs appeared in pairs (or more) of unrelated companies (ECM and Pegas in year 2006; companies AAA Auto, VGP and VIG over span of 5 months between September 2007 and February 2008) (*České firmy IPO nemají rády aneb zlomí se prokletí našeho kapitálového trhu?,* as obtained from ipoint.financninoviny.cz/ceske-firmy-ipo-nemaji-rady-aneb-zlomi-se-prokleti-naseho-kapitaloveho-trhu.html on 15.4.2010; *Official website of the Prague Stock Exchange,* www.bcpp.cz/dokument.aspx?k=Historie-Burzy as on 15.4.2010) and example of Zentiva, the first ever IPO on PSX, shows fast and substantial increase of stocks value right after the offering, followed by decrease and stabilization. (Havlíček D.:*"Nové tituly na burze cenných papírů – opět o krok dál"*, as obtained from www.in-finance.cz/clanek/nove-tituly-prazske-burze-cennych-papiru, 15.4.2010) The appli-cability of herd behavior to financial crises is feasible under assumptions of continuous investments and endogenous

[30] As retrieved from www.timesonline.co.uk/tol/news/uk/scotland/article6030865.ece on 9.5.2010

[31] Reasoning stems from the fact that for the issuer it is favorable to underprice the initial offering

continuous timing of actions[32]. (Chari and Kehoe, 2004, p. 128) Another information-based herding literature deals with the phenomena of bank runs as was mentioned in Section 2.3. and practical example of which will be presented later.

In the following subsections I will not be building specific models as the purpose of this section is to show various examples from reality in the specific light of the framework described in the previous sections. I shall concentrate on fulfillment of the assumptions and prerequisites for the informational cascade to occur, especially on the following: Is the structure of payoffs similar enough for all the agents taking part in the game?; Are the private signals about the state of the world received by agents non-decisive?; Can the actions of previous decision makers be observed by next in the sequence without imposing any excessive cost?; Is any of the other three reasons for herding besides informational externalities applicable in this particular case?

3.1. Czech Republic's Credit Unions Bank Run as Informational Cascade

Credit Unions have long history in the Czech Republic, however the modern history started only as late as 1996 and can be described in 4 stages. First year of legal existence was characterized by foundation of high number of Unions and slow increase in deposits. Years 1997-1999 showed rapid increase in both number of Unions and especially amount of deposits. Third stage began already in 1999 and caused a severe consolidation of this part of the financial sector including substantial losses and possible bank runs. Fourth stage started with the new legislation in 2004 and lasts until now. (Zprávy o činnosti Úřadu pro dohled nad družstevními záložnami 1999-2001, available at http://www.cnb.cz/cs/dohled_financni_trh/souhrnne_informace_fin_trhy/archiv/druzstevni_zalozny/index.html)
Let me emphasize in the beginning, that the poor institutional framework[33] gave too much room for moral hazard and some of the law suits are still not settled. This provides for mere speculation of the true reason for collapse of most of the sector. I do believe though that framework of informational cascades is applicable to some extent.

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[32] Application of such models on the events of years 2008 and 2009 would be an interesting challenge for near future

[33] No professional qualification was required, registered capital requirement was as low as CZK 100 000, the regulatory office has not enough power to prevent e.g. transmission of resources (usually an embezzlement) to daughter companies etc.

Year	Number of registered Cus	Volume of deposits [CZK mil.]
1996	45	176
1997	66	1 267
1998	76	4 484
1999	133	10 450
2000	134	10 700
2001	134	10 984

Table 7: Development of Credit Unions until 2001

Source: Zpráva o činnosti Úřadu pro dohled nad družstevními záložnami 2001

As this is the case of endogenous timing, release of information resulted in a sudden onset of a cascade, this time meaning a bank run on Credit Unions. Given the detailed coverage in all media channels, this information came virtually at no cost to depositors. Chen's setting with information on a share of institutions from the sector leading to a cascade is confirmed in the interview with Ján Franek, chairman of the Board of Directors Fio Credit Union (at the time of the interview): *"... some of the Unions were managed poorly either because of unrealistic plans or due to moral hazard incentives of their management. Unfortunately it were the largest and best known Unions. After release of information about their problems, panic occurred and members of almost all Unions started to withdraw. ... such a run is a problem for every financial institution and even large banks often cannot handle it"*[34] (Pavel Nesejt: Řada malých záložen zanikne, říká Ján Franek, z Fio, družstevní záložny, 24.5.2004 as obtained from http://www.finance.cz/zpravy/finance/37850-rada-malych-zalozen-zanikne-rika-jan-franek-z-fio-druzstevni-zalozny/ as of 28.4.2010)

Other properties of informational cascades as mentioned at the end of introductory part of Chapter 3. are fulfilled as well. Besides some possible insider information none of the depositors could receive a decisive signal about collapse of an institution before it actually happened. Payoffs to individuals can be best characterized as a liquidity constraint in case of a bank run and the following bankruptcy. Even though Guarantee Fund for Credit Unions was heavily underfinanced, Czech government issued almost CZK 6 bn funds to cover the deposits of individuals.

[34] Author's own translation from Czech language

More than 55% of all active Credit Unions from the end of 1999 when the crises began weren't operating freely at the end of 2001. However it seems that most of the bank runs triggered were correct ones and on financially unsound companies. Developments of 44 financially healthy institutions during the turmoil show that the panic did not spread throughout the sector.[35]

	1999	2000	2001
Number of economically sound CUs	44	44	42
Total assets [CZK mil.]	586,91	725,22	1 019,92
Total volume of deposits [CZK mil.]	445,46	526,27	935,70
Total number of members	5 798	7 511	9 213

Table 8: Sound CUs development throughout the crises of 1999-2001

Source: Zprávy o činnosti Úřadu pro dohled nad družstevními záložnami 2000 a 2001

After acceptance of law that came in force in May 2004, required registered capital increased to CZK 35 mil and higher standards are required for managers of Credit Unions (have to be approved by the regulator). Duty of regulator was passed on to the Czech National Bank as of January 1st 2006 and was transmitted in reality in April of the same year. Under such circumstances severe consolidation took place and nowadays only 14 Credit Unions are active in the Czech Republic with total 38 771 members, total assets reaching almost CZK 15 bn. and the registered capital requirement being exceeded more than twice. (Association of Credit Unions, www.asociacedz.cz/ as of 5.5.2010)

Due to heavy punishments for managers from Czech jurisdiction, it seems that moral hazard is together with institutional deficiencies the main reason behind the Credit Unions bank runs and crises in 1999-2001. However informational externalities surely played role and closer investigation of individual Unions situation could be the next direction of research. Until now the only clear example of incorrect informational bank run remains the case of Banka Bohemia from 1994. (Renata Pražáková: Co dělají zkrachovalé banky?

[35] It should be noted, however, that 6 institutions that were managing more than 60 % of all deposits of the sector were under bankruptcy as of end of 2000

13.9.2002, www.finance.cz/zpravy/finance/23459-co-delaji-zkrachovale-banky-/ as of 5.5.2010)

3.2. Smoking bans as Informational Cascades

It would be too broad topic to focus on the whole world, therefore the author of this paper decided to examine the situation in Europe, where the current developments resemble behavior under an informational cascade. The historical evidence (although not very old) proves, individual decision makers, in this case state or local governments, were acting in sequence. The first "pioneer" in anti-smoking legislation was Ireland with its act from 29th March 2004, completely forbidding smoking at workplaces without option of a designated smoking room. More countries then followed the suit, even though neither the size, nor the international reputation of Ireland are among the top in EU. Norway pretty much copied the law in June of the same year and Italy joined in early 2005.

It's very hard to observe any immediate impact of these regulations, therefore the followers might have been acting on the signals inferred from Ireland, Norway and Italy rather than on their own private consideration of pros and cons of such step, thus making it possible to argue for an informational cascade. In 2007 and 2008 three major European players joined the anti-smoking force.[36] Presence of Great Britain, France and Germany (although not all of the individual states) might help the rest of the European Union to adopt similar regulations despite their rejections until today.

It is a little bit questionable what exactly is the payoff of let's say prohibiting smoking in restaurants and pubs, in order to protect non-smokers. Anyway it is quite safe to expect smokers in Ireland to be unhappy about it as much as smokers in for example France or Germany. Moreover the pub owners wouldn't appreciate such a ban either, being afraid of losing customers and government putting such a practice in place runs a risk of losing next election. Also an expected decrease of smokers share in population after prohibiting to smoke in these public places will be expected, as for example Albania passed the law mainly with this purpose. These "payoffs" are then safe to be said approximately the same, or at least of same nature in any European country that decides to adopt the policy.

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[36] Based on information obtained from
http://www.ensp.org/files/legislation_on_smokefree_workplaces_oct2006.pdf, and
http://www.epha.org/a/1941

Another condition that needs to be satisfied for an informational cascade to take place is one of noisy information about the state of the world. Since our example is more complex and complicated it needs a little more abstract view. Given a wider range of payoffs it is even harder to gather sufficient evidence on how the decision is going to influence the future and what state will take place. Any kinds of surveys among population, which seem to be the best way of getting some sound information, are in the end far from reliable and the limited information the decision makers are able to obtain is very, very "noisy".

To allow for previous decisions to have influence on the next one that is to decide, they have to be observable and since such prohibitions on smoking are applied through legislation, it is not only available for the next in line but virtually for anyone in the world. Most of the time authorities are even proud of their accomplishments, making it almost impossible to miss the previous decisions.[37] However, it is hard to tell, what the motivation factors, that led to bans on smoking in restaurants and pubs were. And since the situation differs substantially between the individual countries, taking cultural background[38], economical situation etc. into account, observing previous decisions doesn't tell that much about applicability and possible consequences in their own country. More on this is continued below.

It is quite obvious that it is in the general interest of the European Union to establish wide-spread smoking bans to reduce the health care costs associated with smoking, especially with passive smoking. The EU commission has made certain remarks suggesting that EU wide anti-smoking legislation will eventually be introduced by the EU throughout Europe, if the individual countries themselves are unable to provide sufficient protection for nonsmokers.[39] Therefore one could simply consider the implementation of smoking bans by several EU governments in the past few years a reaction to the threat of EU action. However, if we take into account the dynamic interactions among the countries and the lack of sophistication that the EU threat possesses, author argues that this aspect plays at most a minor role in the explanation of the phenomenon.

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[37] On the other hand rejections of anti-smoking legislation aren't making headlines and acquiring such information comes at higher costs

[38] E.g. Scandinavia has high share of non-smoking tobacco substitutes to cigarettes, therefore banning smoking in restaurants shouldn't come at as high cost as in e.g. France where it was considered as part of its culture

[39] http://www.eurotopics.net/en/presseschau/archiv/archiv_dossier/DOSSIER13988-An-EU-smoking-ban

On the other hand there is a lot of evidence supporting the idea that we are indeed talking about an informational cascade in this case. The fact that we have a limited number of countries that for the most part took sequential decisions is identical to the general model of informational cascades. As we argued above there is also noise involved in the information as to which consequences the introduction of a smoking ban is going to have. The countries do not know if the health care benefits will outweigh the tax-decreases from cigarette sales, restaurant turnover and tobacco producers. The governments also do not know which effect the legislation will have on their general approval rates in opinion polls. If these governments had the opportunity to investigate cases in countries that already introduced these policies their own information uncertainties would decrease. This seems to reflect the actual happenings in the EU. Once countries saw that Ireland had successfully banned smoking from bars and restaurants they became more confident in making this decision themselves. It is very likely that the actions in Ireland revealed information that those other countries took into account when discussing the matter in their own parliaments. It is also very interesting to observe the dynamics of the decisions made. As can be seen in the table and the graph below, the frequency of the introduction of the bans increased during the observed period. While in 2004 and 2005 only the "brave" countries[40] implemented the new legislation, the majority of countries joined between 2006 and 2008, with an actual sudden change in the beginning of 2008. What is also interesting to observe is that similar countries joined at times close to each other. See for instance Spain and Italy, or Germany and France. This provides further support that this is an example of informational cascade. The countries seem to value information from neighboring countries or countries that share other identical features higher, since information from those countries are less noisy.

An informational cascade may especially occur in cases where governments imitate the policies of foreign governments, without taking into account the differences in the characteristics of their countries. It would for instance be possible that a smoking ban cannot keep an Irish person from going to the pub around the corner, while it may have an impact on the decision of a Swedish person. This would especially be a sign of an informational cascade, since one party/government makes a wrong decision by valuing the

[40] or those with the strongest aversion towards smoking

information of another government higher than their own and ending up making the wrong decision.[41]

Country	Date
Ireland	Apr 04
Norway	Jun 04
Italy	Jan 05
Sweden	Jun 05
Spain	Jan 06
Scotland	Mar 06
Latvia	Jun 06
Netherlands	Jul 06
Luxemburg	Sep 06
Belgium	Jan 07
Iceland	Jan 07
Wales	Apr 07
Northern Ireland	May 07
England	Jul 07
Germany	Jan 08
France	Jan 08
Portugal	Jan 08
Austria	Jan 09
Croatia	May 09
Switzerland	May 10

Table 9: Acceptance of anti-smoking legislation in European countries

Source: <http://de.wikipedia.org/wiki/Rauchverbot# Gastronomie, as of 16.4.2010>

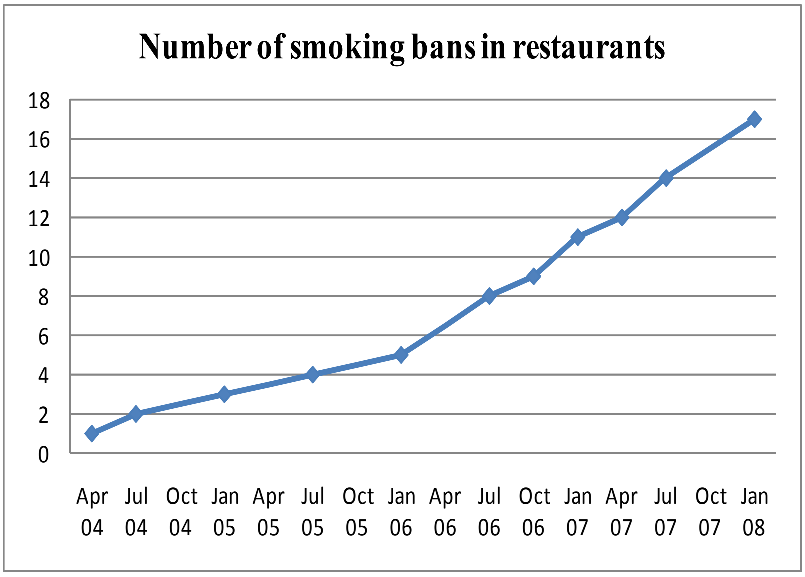

Figure 5: Dynamic development of total amount of countries that introduced a smoking ban in restaurants

Source: <http://de.wikipedia.org/wiki/Rauchverbot# Gastronomie, as of 16.4.2010>

The case of a smoking ban can be seen as part of a government policy informational cascade. If faced with a difficult policy decision, a government has several options. It can analyze similar problems that occurred in the past, it can consult experts and run simulations, or it can observe and learn from the behavior of other nations. It would be interesting to analyze the first two cases with regard to informational cascades as well, but

[41] Of course it would also be an informational cascade if all the decisions taken were right

here we shall focus on the third option. As already mentioned this example presents a case in which an informational cascade is formed by using informational content that is revealed through the actions of another government. The array that includes possible cascades of this type does by far succeed the example of a smoking ban. There can be all kinds of policies that are being implemented on the basis of international experience. Examples can include traffic rules (such as the "points system" implemented in the Czech Republic in 2006), general safety standards, tax regimes or welfare policies. There has to be one additional restriction to our classification. Our example only includes those types of cascades where the governments' payoffs do not depend upon their interaction. Also, situation would change completely had the EU passed a directive that would have had to be transposed into national legislation of each member state.

3.3. New Technology Decisions as Informational Cascade

Technological advances are rapid, and often there is a war between industry standards. Which standard will be adopted and which standard will disappear. Examples of industry standards, or dominant designs, are widespread. The most commonly known dominant design is probably the QWERTY keyboard. A 'war' that has recently been fought was the next generation DVD-war. A couple years ago, two systems have been introduced that offer DVD's in high definition (HD) quality; Blu-Ray and HD-DVD. As was predetermined to happen, only one of these two survived this war and became the industry standard. In this section, the case of the next generation DVD-war is under investigation.

The process by which a dominant design is 'chosen' is very much like an informational cascade. In the case of the next generation DVD-war, the purchase of either a Blu-Ray or a HD-DVD player should be viewed as an investment project. This investment project will have a positive payoff as long as the system chosen becomes the industry standard. For example, if Blu-Ray would become the industry standard, the previous investment into HD-DVD player will equal to a welfare loss; since no DVD's compatible with this player will be available in the stores anymore. The decision makers in this case are individuals, buying a new generation DVD player, DVD player producers, and DVD disc producers. All these decision-makers have to make the same decision: adopting Blu-Ray or HD-DVD. The number of decision-makers is very large for sure and can in principle be infinitely large.

For the issue of dominant designs and the specific case of the next generation DVD-war, all conditions needed for a cascade are satisfied:

Payoffs of all different decision-makers respond in a similar way to the decision made. For example, if Blu-Ray would be the future ‘state of the world’ (i.e. Blu-Ray becomes the industry standard), everyone who has adopted the Blu-Ray system will receive a positive payoff whereas everyone who has adopted the HD-DVD system will receive no, or net negative, payoff. There is no chance for two decision-makers who have made the same decision to receive different payoffs (i.e. positive and negative).

Prior to a decision each decision-maker would reasonably try to gather information. Online sales numbers are available but often not completely up-to-date. [42] Information is widespread however very noisy since no-one is sure and most probably some sources will claim an industry standard while the battle has not entirely been fought yet. This doesn’t only hold for individual consumers but also for producing companies.

As mentioned under above, decision-makers are informed about sales numbers of each system. The reliability and quality of this information depends on numerous factors, most importantly the source and its costs. Transaction costs of obtaining such reliable and detailed information seems to be too high for individuals, while corporations such as Sony would have its own sales data and resources available. An individual consumer would thus have more coarse information about the previous decision made. Considering decision made, not only sales numbers for the system would be important, also adoption of the system by the different (crucial) producers is very important. With this information known, a situation of herd behavior is likely to arise. More people adopting the same standard increases the likelihood of this standard becoming dominant design.

As already mentioned, the specific case of the next generation DVD-war is an example of the general situation of battles for dominant designs or industry standards. There is only something to gain if one makes the right decision, and following the herd is usually a wise choice. Other examples of this general situation are the war over the video systems (VHS vs. Betamax) and “gasoline-powered car engine being challenged by hybrid, electric, and fuel-cell alternatives.” (Michael Histen: *“Dominant Design”*, July 2 2008, as obtained from http://michaelhisten.blogspot.com/2008/07/dominant-design.html, 06.04.2010)

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[42] Websites such as http://blu-raystats.com provides a great amount of news and statistics.

Dominant designs and wars over them usually arise in cases where technology and widespread adoptions are important.
However, since Toshiba, one of the major HD-DVD producers quit their production and other major players in the market announced they would adopt the Blu-Ray system (David Katzmeier: *"It's official: Toshiba announces HD DVD surrender, February 19 2008",* as obtained from http://news.cnet.com/8301-17938_105-9874199-1.html?tag=rb_content;rb_mtx, 06.04.2010), it is not surprising that Blu-Ray indeed has become the industry standard. As it is common in real life cases, only some parts of informational cascades can be identified. With different precision of information available to agents (individuals compared to corporations), this could be thought of as an example of Fashion Leaders case. Also the large corporations do have chance to exploit their dominant position among producers in their favor. It has to be said that the assumption of payoffs being independent on action of later individuals is broken. Developments of Blu-Ray market share in the high resolution video media was growing steadily since the introduction of both HD-DVD and Blu-Ray discs. No explosive cascade took place even though it could have been expected, especially after the announced end of HD-DVD production. Author believes that costs for purchasing of the Blu-Ray system were too high for HD-DVD owners to make them switch. With rapid developments of technology such customers will prefer to wait for the successor of Blu-Ray rather to invest in it.

Next "dominant design war" that has already started is the one in the electromobility field. Not only are there several concepts of environmental-friendly vehicles (semi-hybrids, full-hybrids, conventional vehicles with power saving features etc.), but also different kinds of batteries can be used requiring unified charging stations[43] to allow for international sustainability and development of electromobility. In author's opinion is the future in hands of lobbyists, electricity generating companies and large car manufacturers, however it will be interesting to observe if informational cascades will be applicable to the phenomenon.

[43] Also difference between high-voltage and low-voltage charging and socket designs may play a role in selecting the dominant standard

Conclusion

Herd behavior is an ever-present phenomenon in real life and very complex issue to deal with. Therefore the Bayesian framework was first introduced to give a basic understanding of principles on which the theory of informational cascades builds. In situations with imperfect information one can always rely on his intuition, however assumed rationality of agents prevents them to do that and leads to more exact findings. Even though the restrictions and assumptions of binary model are quite limiting for applications in reality, basic models help to explain how limited social learning can lead to occurrence of inefficient cascades and show that under such assumptions not only does the cascade eventually start every time, but with high probability it starts very early even for quite noisy private signals.

Even though theory suggests very frequent occurrence of informational cascades, practical experiments did not confirm such powerful results. Given all theoretical assumptions, even in laboratory settings agents failed to decide according to Bayesian updating and the rationality assumptions was the one that was usually broken despite academic background of agents. More simple and intuitive heuristics proved to be applied frequently, while resulting in many correct answers especially in trivial cases or cases with quite informative signals. This causes great difficulty in distinguishing the rationale behind individual decisions and led to an unproven confirmation of the theoretical findings. Another experiment may therefore be designed in the future, asking all agents exactly for their motivation behind the decision, perhaps with additional financial remuneration for correctly explained rationality in Bayesian sense.

Introduced extensions to the basic models provide better connection to the real-life issues as can be seen in case of the so called fashion leaders. Models with endogenous timing can be then better applied to financial markets and financial economics, although the requirement of constant or at least very sticky prices makes informational cascades framework almost inapplicable to the stock market. However, full rationality can hardly be expected throughout the society as a common characteristic of a decision maker. Alternative approaches, especially the ones combining Bayesian rationality with cognitive or social psychology, shall fare better as they take broader range of factors into account.

The last section of the thesis focuses on three case-study examples which all show potential for informational cascades as a viable explanation of the development. Each one of the cases combines the basic principle of informational externalities with different reason for herd behavior. While bank run on Credit Unions wouldn't be possible without payoff externalities as is stressed in the simple model extension, example from the Czech Republic shows other than informational reasoning in the background of the run. Since the panic didn't spread out to the whole sector, information cascade, if there was any, was reversed and the Credit Unions sector is nowadays stabilized.[44] Thorough investigation and analysis of the financial situation of individual CUs before the crises would be needed to determine the correctness of the run and is a possible course of future research.

Other two cases show that not only individuals (people) can be part of the cascade, as governments and corporations are included in the role of decision-making agents. The introduction of anti-smoking legislation throughout Europe can be explained by local conformity and information externalities and while payoffs won't be well observable for a long time, this cascade can cover a span of multiple years. Another contributing factor can be the fear of sanctions on deviants while European Union expressed intentions to make anti-smoking legislation mandatory to some extent for their members. Nevertheless, due to inefficient punishments for deviating from even more serious commitments under e.g. Stability and Growth Pact, I do not believe such fear plays major role. As of the war for dominant technical design, herd behavior clearly occurred and the fashion leaders among the decision-makers persuaded others to converge on the Blu-Ray standard. The phenomenon of electromobility will be an interesting field to follow for indications of informational cascades principles.

[44] New legislation and larger competences of the regulator are however the main reasons behind this

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