Cheap talk with *m* audiences

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1 Introduction

Every day, people make choices with respect to sharing information. They choose to strategically exaggerate or downplay. Real estate agents tell house sellers their house is of average appeal - that way the price they get for it is likely to sound good. At the same time, agents convince potential buyers how special the house is - hopefully, they accept a high price, resulting in a high commission.

In many situations you can expect a message to induce the receiver(s) to take a certain action in response. Your job interviewer chooses to hire you or not. The bank chooses to grant you a credit or not. You know this, and you anticipate on it. It gets difficult when you talk to different receivers at the same time. Would you still disclose your Friday night adventures when not only your friends but also your boss is on Facebook? Talking to them separately, you would probably tell a different story or at least leave parts out talking to your boss. In some situations however, it can be useful to disclose information publicly. When a company discloses its annual revenue, investors believe it. The reason for this is not only the approval of the accountant, but also the fact that the tax authority is provided with the same information. Sharing information publicly can make it credible.

The previous examples reveal two choices people make in communication. The first is whether to exaggerate, downplay or tell the truth. The second is whether to communicate privately (to one receiver at a time) or publicly (to more receivers at the same time). A last example of people who make these choices often are CEO's of big companies. They usually possess private information about the value of the company, and are surrounded by stakeholders who want to know the truth. These stakeholders could be investors, the board of directors, or internal managers. They all want to know the real value of the company. Based on that they respectively decide whether or not to (further) invest, reward the CEO or expand the company. The CEO has an incentive to exaggerate the value of the firm to some of them. He wants investors to think that the value of the company is high, so that they invest and he can let the company grow. He doesn't however want them to perceive the value of the company *a lot* higher than it is, since sooner or later they find out and this hurts his reputation. The CEO wants the board of directors to think that the company is doing really well, since the board decides how much to reward him. The internal managers need to hear the true story. They should only decide to expand when the company is actually doing well, otherwise they shouldn't. How should the CEO communicate? And should he talk publicly or privately?

The objective of this thesis is to investigate how senders communicate with more than one receiver, in a situation where they want the receivers to take different actions. Furthermore, it will be investigated when senders choose to talk privately and when they choose to talk publicly.

To this end, I extend the cheap-talkmodel of Crawford and Sobel (1982). My extended model has the following main features. First of all, there is one sender and there are m receivers. The sender has information that the receivers don't have[1]. This could be the value of the company that the CEO knows, but not the investors. Furthermore, the sender has an incentive to communicate different values to different receivers. The receivers want to know the truth; their expected utility is the highest when their action is equal to the state of the world.

Solving the model yields the following insights. When the interests of a sender and the receivers are so different, that they will not believe each other, communication could nonetheless take place when the sender talks to the receivers as a group. In that case it could be that the average interests of the group are in line with those of the sender, and therefore the group will believe the sender's message. It could also be the case that the average interests of the group are too different from those of the sender for communication to happen, while private communication is possible with some of the individuals. Based on a comparison of the interests of the receivers and his own interests, the sender decides whether to communicate publicly or privately.

2 Related literature

This thesis aims to contribute to the extensive literature on cheap talk and the research on multiple audiences. One of the first to write about cheap talk were Crawford and Sobel (1982). They describe cheap talk as non-verifiable communication that is costless to the sender. Therefore, as opposed to signaling[2], it is not necessarily credible. Crawford and Sobel develop a communication model with one

[1] In cheap-talkliterature, this kind of information is often referred to as the state of the world.

[2] A signaling game is described by Spence (1973) as a game in which messages become credible due to the cost of sending them.

sender and one receiver. They find that the receiver's expected welfare in equilibrium potentially rises when the interests of the receiver and the sender are more aligned. Furthermore, equilibria with more partitions are pareto superior to equilibria with less partitions. In his introduction to game theory, Gibbons (1992) solves a comparable cheap-talkmodel with one sender and one receiver. His steps to do so are repeated and extended by this thesis.

Farrel and Gibbons (1989) contributed to the cheap-talkliterature by adding an extra receiver, or as they call it, audience. They investigate the differences between private communication (with one receiver) and public communication (with more than one receiver). They find that public communication can discipline the sender to tell the truth, but also subvert the relationship between one sender and one receiver. Goltsman and Pavlov (2011) also extend a standard cheap-talkgame with more than one receiver. In their model, the utility functions of the receivers differ. The receivers thus do not only want something different than the sender; they also want something different than each other. Goltsman and Pavlov find that when the average of the biases of the receivers is high, private communication is preferred by the sender. The sender chooses to communicate publicly when the average bias of the receivers is low and the interests of the receivers are sufficiently different. This thesis also aims to investigate communication when the sender would say different things to the different receivers in private. Only now, this is a result of his own bias towards them; the receivers themselves all want to know the truth.

Recently, different researchers shifted from theoretical to empirical research about cheap talk. Battaglini (2013) finds that in his experiments people happen to behave quite similar to what could be expected based on cheap-talktheory on one sender and one receiver. Sobel (2013) points at many areas within the cheap-talkresearch field that are in need of experimental evidence. Sobel (2011) earlier wrote an extensive overview of the literature on cheap talk.

3 Model

My model is an adjusted version of Crawford and Sobel's (1982) cheap-talkmodel. There is a sender and there are m receivers. The sender knows the state of the world $\theta \in \Theta = [0, 1]$; the receivers don't. The sender sends a message about θ to the receivers. After the receivers receive the message, they choose action $a \in \mathbb{R}$. The sender's utility is determined by equation 1.

$$U^S(a_1, a_{2,...}, a_m) = \sum_{i=1}^{m} -(a_j - \theta - b_j)^2 \tag{1}$$

When there is one receiver, the utility of the sender is determined by $-(a_1 - \theta - b_1)^2$. The utility of the sender depends on θ and on the actions of the receivers. From his utility function it follows that the sender's preferred action of player j is $\theta + b_j$. Parameter b_j represents the sender's preference with respect to the actions of the players. The further away the actions of the players lie from $\theta + b_j$, the lower is the utility of the sender. This holds for positive as well as negative variations.

The receivers' utility is determined by equation 2.

$$U_j^R(a_j) = -(a_j - \theta)^2 \tag{2}$$

From equation 2 it follows that the receivers want their action a_j to be equal to θ: they want to know the truth.

This sequential model is solved applying backwards induction. First, the optimal responses of the receivers are determined. Next, the optimal responses of the sender are found. The optimal responses of the sender involve the choice what message to send and whether to communicate publicly or separately. In the case of separate communication, receivers don't share their received messages with each other.

Gibbons (1992) solves this model for one receiver. He explains that there is always a pooling Bayesian equilibrium. More interesting is the question whether *non* pooling perfect Bayesian equilibria exist. These are equilibria in which all players' strategies are optimal responses to each other. Furthermore, Bayes' rule[3] applies, according to which players calculate the odds of former event A (the value of θ), given event B (the message of the sender).

[3] According to Bayes' rule, the probability of event A given event B is calculated as follows: $P(A|B) = \frac{P(A) \cdot P(B|A)}{P(B)}$.

4 Analysis

In the following subsections, partially pooling equilibria are characterized for one, two and m receivers in the case of two and n partitions. Finally, the maximum possible number of partitions (n^*) is calculated.

4.1 Two partitions

4.1.1 One receiver

Suppose that when θ lies in the interval $[0, x_1)$, senders send one message ("low") while a θ in the interval $[x_1, 1]$ induces senders to send another ("high"). After receiving the message ("low" or "high"), receivers choose an action that optimizes their expected payoff. Their optimal response is the action that lies in the middle of the indicated partition. A message "low" thus induces a receiver to take action $\frac{x_1}{2}$ and a message "high" leads to action $\frac{x_1+1}{2}$. In order for a two-step equilibrium to exist, a sender who knows θ to be x_1 must be indifferent between sending "low" and "high". His expected utility from sending either of these messages must be equal at $\theta = x_1$. The expected responses from the receivers to both "low" and "high" are inserted into the utility function of the receiver. Utility from both messages is set equal in equation 3. Furthermore, θ is replaced by x_1.

$$-(\frac{x_1}{2} - x_1 - b_1)^2 = -(\frac{x_1 + 1}{2} - x_1 - b_1)^2 \tag{3}$$

From equation 3 it can be derived that $x_1 = \frac{1}{2} - 2b_1$. This means the following. When $b_1 = 0$, and the interests of the sender and the receiver are, thus, the same, $x_1 = \frac{1}{2}$ and lies exactly in the middle of $[0, 1]$. In that case, the partitions are of the same length. This is intuitive: the sender wants the receiver to take action[4] $x_1 + 0$, but is limited to indicating one of the two partitions. He is indifferent between actions that surround his preferred action at equal distance (like $-0,2$ and $0,2$). Since receivers are expected to take the action that lies in the middle of the indicated partitions, the partitions must in the case of $b_1 = 0$ be of equal length for the sender to be indifferent. The larger b_1 gets[5], the larger the relative length of

[4]Please remember that the utility function of the sender shows that he wants the receiver to take action $\theta + b_1$. In this case that is $x_1 + 0$.

[5]By larger, I mean larger in absolute terms, i.e. larger positive or larger negative values.

the second partition is[6]. When b_1 gets larger than $\frac{1}{4}$ (or smaller than $-\frac{1}{4}$), x_1 lies outside $[0, 1]$. Within $[0, 1]$, there is only one partition. The result of this is that the sender must always send the same message, irrespective of what the value of θ is. Consequently, this message does not learn the receiver anything about θ. When b_1 gets too large, communication can no longer take place.

4.1.2 Two receivers

A two-step equilibrium for two receivers can be solved in the same way. The expected responses to the messages "low" ($\frac{x_1}{2}$) and "high" ($\frac{x_1+1}{2}$) are inserted into the utility function of the sender and the results of this are set equal. θ is replaced by x_1. This leads to equation 4.

$$-(\frac{x_1}{2} - x_1 - b_1)^2 - (\frac{x_1}{2} - x_1 - b_2)^2 = -(\frac{x_1+1}{2} - x_1 - b_1)^2 - (\frac{x_1+1}{2} - x_1 - b_2)^2 \quad (4)$$

From equation 4 it can be derived that $x_1 = \frac{1}{2} - b_2 - b_1$. This outcome should be interpreted the same as the outcome of equation 3. The only difference is that the length of the partitions is now determined by the sum of b_1 and b_2. This is interesting, because consequently, it could be that although the values of b_1 and b_2 are both too large for communication[7], they sum up to 0 or any other number below $\frac{1}{2}$[8], resulting in more than one partition and thus possible communication. Please note that the reverse is not true. When public communication is not possible, there could be communication with one of the receivers, but not with both of them.

4.1.3 m receivers

A two-step equilibrium for m receivers is derived in the same way. It follows that $x_1 = \frac{1}{2} - \sum_{j=1}^{m} \frac{2}{m} b_j$. Also here, communication that is not possible privately, could take place publicly, depending on the values of b_j.

[6] Why this is the case, will be further explained under equation 6.

[7] Again, in absolute terms (say, -10 and 10).

[8] Please note that the earlier mentioned treshold value of $\frac{1}{4}$ is doubled here, since the b's of the two receivers are also added up.

4.2 n partitions

Now I characterize an equilibrium with more than two partitions.

4.2.1 One receiver

Let's take a look at the two partitions that surround state x_i, namely $[x_{i-1}, x_i)$ and $[x_i, x_{i+1})$. Suppose that the sender can either send a message that indicates the former partition, or one that indicates the latter partition. In that case, in line with the two-step equilibrium, receivers will respond with the action that lies in the middle of the indicated partition. A message indicating $[x_{i-1}, x_i)$ leads to action $\frac{x_{i-1}+x_i}{2}$ and a message indicating $[x_i, x_{i+1})$ leads to action $\frac{x_i+x_{i+1}}{2}$. For an n-step equilibrium to exist, the expected utility of the sender observing state x_i must be equal in the case of both actions. Therefore, the best responses of the receivers to both messages are inserted into the utility function of the sender and the results are set equal to each other in equation 5. Here, θ is replaced by x_i, which is the state of the world in which case the sender must be indifferent.

$$-(\frac{x_{i-1}+x_i}{2} - x_i - b_1)^2 = -(\frac{x_i + x_{i+1}}{2} - x_i - b_1)^2 \tag{5}$$

Solving and simplifying equation 5 gives equation 6.

$$x_{i+1} - x_i = x_i - x_{i-1} + 4b_1 \tag{6}$$

Equation 6 leads to an important finding of Gibbons (1992): each partition is $4b_1$ longer than the former. This is intuitive. Based on the utility function of the sender, he wants receivers to choose action $x_i + b_j$. Receivers, however, choose either action $\frac{x_{i-1}+x_i}{2}$ or $\frac{x_i+x_{i+1}}{2}$. For the sender to be indifferent between sending a message about the former or the latter interval, these actions have to yield him equal utility. The midpoints of the partitions thus have to be of equal distance to the sender's preferred action $x_i + b_j$[9]. For this to be the case, $[x_i, x_{i+1})$ must be longer than $[x_{i-1}, x_i)$. The steps by which the partitions grow[10], are however limited (in this

[9] Please remember that the utility of the sender declines in positive as well as negative variations from the action he prefers from a sender.

[10] Please note that b_j could also be negative. In that case the partitions grow with a negative number and thus actually are shorter in stead of longer than the former.

case to $4b_1$). The reason for this is that if they get too long, the best response of the receiver to the former partition would become closer to the preferred action of the sender than the best response to the latter. As a result, the sender would no longer be indifferent between sending a message about the former or the latter partition; he would prefer indicating the former.

4.2.2 Two receivers

In order to solve the n-step equilibrium for two receivers, we take a look at the two partitions that surround state x_i, namely $[x_{i-1}, x_i)$ and $[x_i, x_{i+1})$. The expected responses from the receivers to a message that indicates these intervals, are $\frac{x_{i-1}+x_i}{2}$ and $\frac{x_i+x_{i+1}}{2}$, respectively. In order for an n-step equilibrium to exist, the sender who observes state x_i must be indifferent between indicating the former and the latter partition. This is expressed by equation 7.

$$-(\frac{x_{i-1}+x_i}{2}-x_i-b_1)^2-(\frac{x_{i-1}+x_i}{2}-x_i-b_2)^2 = -(\frac{x_i+x_{i+1}}{2}-x_i-b_1)^2-(\frac{x_i+x_{i+1}}{2}-x_i-b_2)^2 \tag{7}$$

Solving and rewriting gives the following.

$$x_{i+1} - x_i = x_i - x_{i-1} + 2b_1 + 2b_2 \tag{8}$$

From equation 8 it follows that each partition is $2b_1 + 2b_2$ longer than the former partition. As explained before, when $b \succ 0$, each partition must be longer than the former for the sender to be indifferent between sending a message about either of them.

4.2.3 m receivers

In the case of m receivers, something interesting happens. Whether the same mathematics are applied to three, five or any other number of receivers, the length of the partitions can be described systematically the same. It follows that $x_{i+1} - x_i = x_i - x_{i-1} + \sum_{j=1}^{m} \frac{4}{m} b_j$. Each partition is thus $\sum_{j=1}^{m} \frac{4}{m} b_j$ longer than the former.

4.3 $n^*(b)$ partitions

From the length of the partitions the maximum number of partitions can be derived. This can be interpreted as the maximum richness of the language in which the sender and receiver(s) communicate. We call this maximum number $n^*(b)$ and derive it in the rest of this subsection for one, two and m receivers.

4.3.1 One receiver

As shown earlier, in the case of one receiver, each partition is $4b_1$ longer than the former. In order to find the maximum number of partitions, Gibbons (1992) reasons as follows. All partitions together sum up to 1 and let us call the first partition d; this gives equation 9.

$$d + (d + 4b) + ... + [d + (n - 1)4b] = 1 \tag{9}$$

Using the fact that $1 + 2 + ... + (n - 1) = n(n - 1)/2$, we rewrite equation 9 into equation 10.

$$n \cdot d + n(n - 1) \cdot 2b = 1 \tag{10}$$

Given that $n \cdot d$ can not be zero or negative, the largest possible n - we call that $n^*(b)$ - is the largest value of n such that $n(n - 1) \cdot 2b < 1$. Applying the quadratic formula shows that $n^*(b)$ is the largest integer less than $\frac{1}{2}(1 + \sqrt{1 + \frac{2}{b}})$.

4.3.2 Two receivers

The same can be done in the case of two receivers. We found that each partition is in this case $2b_1 + 2b_2$ longer than the former. All partitions together sum up to 1 and let us again call the first partition d; this gives us equation 11.

$$d + (d + 2b_1 + 2b_2) + ... + [d + (n - 1)(2b_1 + 2b_2)] = 1 \tag{11}$$

Using the fact that $1 + 2 + ... + (n - 1) = n(n - 1)/2$, we rewrite equation 11 into equation 12.

$$n \cdot d + n(n - 1) \cdot (b_1 + b_2) = 1 \tag{12}$$

Given that $n \cdot d$ can not be zero or negative, $n^*(b)$ is the largest value of n such that $n(n-1) \cdot (b_1 + b_2) < 1$. Applying the quadratic formula shows that $n^*(b)$ is the largest integer less than $\frac{1}{2}(1 + \sqrt{1 + \frac{4}{b_1+b_2}})$.

4.3.3 m receivers

In the case of m receivers - just as was the case by the length of the partitions - there happens to be a systematic formula for $n^*(b)$. This is expressed in equation 13.

$$n^*(b) = \text{the largest integer less than } \frac{1}{2}(1 + \sqrt{1 + \frac{2m}{\sum_{j=1}^{m} b_j}}) \tag{13}$$

Please note that the fraction $\frac{2m}{\sum_{j=1}^{m} b_j}$ can also be written as $\frac{2}{\frac{\sum_{j=1}^{m} b_j}{m}}$. Now n^* looks just the same as in the case of one receiver; though it is now a function of the average of all b's. Let's call this b_{av}.

4.4 Analysis: summary

The mathematical results that were derived in this section are summarized in the following table.

	n partitions	$n^*(b)$ = largest integer less than:
1 receiver	$x_{i+1} - x_i = x_i - x_{i-1} + 4b_1$	$\frac{1}{2}(1 + \sqrt{1 + \frac{2}{b}})$
2 receivers	$x_{i+1} - x_i = x_i - x_{i-1} + 2b_1 + 2b_2$	$\frac{1}{2}(1 + \sqrt{1 + \frac{4}{b_1+b_2}})$
m receivers	$x_{i+1} - x_i = x_i - x_{i-1} + \sum_{j=1}^{m} \frac{4}{m} b_j$	$\frac{1}{2}(1 + \sqrt{1 + \frac{2m}{\sum_{j=1}^{m} b_j}})$ or: $\frac{1}{2}(1 + \sqrt{1 + \frac{2}{b_{av}}})$

These results lead to the following proposition.

Proposition 1 *There exist partially pooling perfect Bayesian equilibria of the extended cheap-talkgame in which every partition is* $\sum_{j=1}^{m} \frac{4}{m} b_j$ *longer than the former and* $n^*(b)$ *is the largest integer less than* $\frac{1}{2}(1 + \sqrt{1 + \frac{2}{b_{av}}})$.

5 Interpretation

We knew already from Crawford and Sobel (1982) that the expected welfare of the sender and receiver is higher when their interests are more aligned. Furthermore, they found that when b is zero, the sender is induced to tell the truth[11]. On the other hand, communication possibilities are limited or even non-existent when b gets too large. The CEO thus already knew that the board of directors might not believe him when he tells them how good the company is doing. The reason for this is that their interests are too far apart: the board of directors wants to give him a very small reward, while the CEO wants to be granted a big one. The same goes for the real estate agent and the job applicant: when they brag about their house for sale or their fluency in German, they probably won't be believed.

What can we and the CEO learn from proposition 1 with respect to communicating with different receivers? From solving the extended cheap-talkmodel, we learned that in the case of m receivers, the maximum number of partitions is determined by b_{av}. Keeping the earlier findings of Crawford and Sobel in mind, this has huge implications for the CEO and all others who have to choose how to communicate with more than one receiver. When the interests of the receivers are not at all aligned with those of the sender, communication could still take place. For this it is only required that the *average* interests of the group aren't too far apart from those of the sender. It is thus possible for a CEO to communicate with a group of receivers who wouldn't have believed him in separate conversations.

This finding could be seen as a sharpening of, and an addition to Crawford and Sobel's conclusions. It shows that (very) different interests among individuals don't always rule out communication through cheap talk. Furthermore, my research shows that Crawford and Sobel's model is not only fit for describing private communication, but also for public communication.

What does the CEO practically learn from this? He might be able to communicate with people of whom it never seemed plausible that they would believe him. Within a group, the individual interests of the receivers could "block each other out" and the group could become sufficiently aligned to his interests to be willing to believe him. When their average b is zero, it is even in his and their best interest to tell the truth.

You might ask whether an average b of zero is likely to be the case in the CEO example. It probably isn't. The reason for this is that there isn't enough negative

[11] The sender is induced to tell the truth because his preferred action of the receiver is $\theta + b$. When b becomes zero, the sender wants the receiver to choose action θ. Since the receiver sets his action equal to θ, the sender honestly tells what the value of θ is.

variation among his audience. In other words, there is nobody whom he wants to believe that the value of the company is lower than it actually is. Maybe, however, he could combine talking to the internal managers and the investors. Their average b could be sufficiently low for communication to arise. Maybe companies should invite investors to internal meetings in order to make their statements about the company value credible.

The second question to be answered with this research is how senders decide whether to communicate publicly or privately. In line with the findings of Goltsman and Pavlov (who investigated communication with two different receivers) it follows from my analysis that the choice between private and public communication depends on the different values of b_j. Keeping in mind Crawford and Sobel's conclusion that more communication is better for the sender and the receiver, the sender in my extended model will reason as follows. Imagine that he wants to talk to a group with members A, B, C, D, E, F and G, with respective b's of $0, 1, 2, 3, 4, 5$ and 6. Let's say that 2 is the treshold value[12] for communication to take place. In this situation, the sender will not choose to talk to all seven receivers at the same time. The reason for this is that b_{av} would be larger than the treshold value of 2, and no communication would take place. With A, B, and C, the sender could talk privately, since their b's are ≤ 2. It would however be possible for the sender to also talk to D, if he would combine B, C and D into a group. In that case b_{av} would be 2 and communication could take place. Receiver A could also be added to this group, thereby lowering b_{av}, but the sender might not decide so. The reason for this, is that in private talk, he could be completely honest with receiver A, while in public talk, he couldn't. After all, the sender decides how to combine his receivers into a group and whom to talk to privately based on what yields him the highest expected utility.

What about the Facebook example? You want your boss to think you are serious and you want your friends to think you are wild. You are in fact an average, sociable person. When you know they are both going to read your message, there is no other option for you than to tell the truth. The question is, whether that is interesting for

[12] The concept of a treshold value for communication to take place, is clearly explained by Gibbons (1992). When b gets higher than this value, communication is no longer possible. In my extended model, this treshold value is $\frac{1}{4}$, as was derived from equation 3 and equation 4. In the example with receivers A, B, C, D, E, F and G, we take 2 as the treshold value.

you. Talking publicly, you are more credible, but also limited to sending a message you might not want to send. In the Facebook example, you might find it optimal to talk privately, and be able to customize your message at the cost of a declined (but maybe still existent) credibility. This example shows that there could be a trade off between being believed and telling what you want to tell. As said before, it depends on the utility functions of the sender and the receivers whether the sender decides to communicate publicly or privately. In some situations however, as was shown, this is already clear from the b's: in the case of a treshold value of x and respective b's of $-1, 5x$, $-3x$ and $4x$, a sender will always choose to communicate publicly, since no private communication can take place.

We can conclude that talking to a group can make communication happen that would not have arisen between the sender and the individual receivers. It seems intuitive that a message must in that case be targeted at the average person. The analysis of this thesis can however not be used to prove that. It would be very interesting for future research.

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