Essays on Network Industries: Markets, Committees, Information Revelation and Standardization

Debdatta Saha

Thesis submitted to the Indian Statistical Institute in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy

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Dedicated to my family

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“...modern mass production requires the standardization of commodities...” *-Erich Fromm*

Chapter 1

Introduction

The story of standards is as old as the story of human civilization. To a large extent, the human race has evolved over time by establishing successful standards in every sphere of human activity. As a process, standardization is the art and science of specifying and implementing technical knowledge. In itself, standards are similar to commoditized information. Rather, it often implies the contrary. The question of standardization arises in multiple contexts: politics, business and economics, science and technology, labor markets. Examples of standards, sometimes quirky and rather humorous, are ubiquitous in various spheres of human activity.

Standards are a means to achieve a desired outcome. The desired outcome in some instances are non-strategic and in others, strategic in nature. The first kind of standardization is meant to reduce transaction costs. Greater uniformity permits more economies of repitition which drive down costs of production. A large part of recorded human history is replete with attempts to establish various non-strategic standards. The creation of the Egytian 365-day calendar with year 4236 BC logged as the first year has been recorded as an advance in human civilization in their ability to establish scientific bases for agriculture. King Henry I of England standardized measurement in 1120 AD: by instituting the "ell", equivalent to the length of his arm. There are numerous examples of standards developed during the 18^{th} and 19^{th} century industrialization in Europe. For instance, the meter (as a measure of length) was established in the late 18^{th} century France post-Revolution replacing 2,50,000 units of weights and measures across provinces under the French Monarchy. The rich history of the establishment of the railroad gauge standard (specifying a uniform distance between two rails on a track) and the standards for steel rails and "double-acting" brakes for railroad transportation can be read as an attempt of the industrial revolution to establish standards to garner economies of scale. The engaging history of the first attempt of labor market standards is told through that of the protocol labor standards created for telegraph messenger boys in 19^{th} century Britain. At a later date, the usage of standardized organisms for lab experiments have led to much advances in modern science. T.H.Morgan's usage of *drosophila* (fruit fly) for breeding experiments have been at the heart of advances in genetics.

Standards of strategic variety arise most prominently in the context of network industries. Peculiar features of these industries, such as consumption externalities-direct and indirect, significant economies of scale in production, switching costs and lock-in and complementarity among components of a "system" make standardization a strategic choice for firms in such industries.

Standards ensure compatibility among technologies, which not only benefits consumers who care about such compatibility (for example compatibility between computer operating systems and computer hardware, compatibility between air interfaces for mobile communications etc.) but also for the firms producing the end-product (due to substitutability between different input components which are standardized) and those firms marketing the consequent services. However, the firms which sell the underlying technology have their own vested interests in their own technologies and lobby to ensure that their own technology becomes the chosen standard. This gives rise to a large number standard wars among firms in these industries. The range of examples straddle Betamax versus VHS in video cassette recorders in the 1980s to QWERTY versus DVORAK systems in typewriting keyboard to Schick versus Gillette among razor blades.

This does not imply that all standards in these industries are driven by strategic concerns. However, tipping effects and consumer lock-in imply that the ability of a firm to establish its technology as an industry standard is a critical determinant of its long-term competitive position and success. Hence, there is a strategic element in the process of standardization in network industries like telecommunications, computer, internet, audio and video equipment.

We now come to the process by which a standard become the operating backbone of an industry. Standards emerge as the consequence of consensus, perchance, imposition of authority, or a mixture of these. Primarily, the routes to standardization can be classified as either market-based and negotiated through institutions such as committees or associations of industry/consumer bodies (with or without governmental intervention). These institutions differ in the manner in which they achieve standards. While the latter focuses primarily on achieving a consensus among participating firms in the committee, it is well documented that it comes at the cost of large delays (Vercoulen and Wegberg (1998)). The institution of the market bandwagon, on the other hand, is more cavalier with respect to achieving standards, but the overall process can work out much faster than the committee.

What is of greater relevance is the presence of asymmetric information in the process of standardization. These industries encounter huge Schumpeterian innovation cycles and therefore, at any given point of time, there is asymmetric information among market participants about features of any product which is likely to become a potential standard. In a large number of examples, it is the case that a new technology (whose characteristics are private information to the firm developing it) challenges the incumbent to become the industry standard. The presence of one-sided private information interacts with the vested interests of the firms in the coordination game. There is limited theoretical work exploring this interaction in the context of standardization in network industries.

The essays in this thesis analyzes standardization in network industries, focusing on strategic interaction among firms in environments of incomplete information. This information structure varies in the next three chapters and is central to the results of the models in each chapter. In the next two chapters we focus on one-sided asymmetric information and the structure of information is exogenous in the sense that the firm with private information merely decides whether or not to reveal its information to the other firm. The fourth chapter, on the other hand, focuses on an endogenous information structure: where the firms do not know their own types at the beginning of the game and the committee decides whether or not to reveal types of firms which come to it.

The coordination structure in the committee, however, is homogeneous across the next three chapters. The canonical model for coordination that we consider in all three chapters of the essay involve two firms engaged in a Battle-of-the-Sexes coordination game. The canonical payoff matrix that we consider for modeling coordination in the committee game in any period is shown in table 1.1, where private benefits θ is private information for firm A and private benefit of firm B (b) and coordination benefit c, where $c > \max\ \theta, b$, are common knowledge among the firms. We assume that firm A's type is distributed with a continuous distribution function with full support.

	Wait	Insist on B
Insist on A	$\theta + c$, c	x, y
Wait	r, z	c, $b + c$

Table 1.1: Payoff matrix for the generic committee game

In the committee, if one firm waits while the other insists on its technology in any period, the standard is formed on the latter's technology. On the other hand, if they cannot agree (both insist or both wait), the game continues to the following period giving the firms another chance at reconciliation. Effectively, x, y, r and z are continuation payoffs from later subgames. In the last period, the game terminates with $x = \theta$, $y = b$ and $r = z = 0$. It is obvious that the committee structure fosters coordination by giving the firms another chance in case they cannot agree on a standard in any period.

In contrast, the canonical payoff matrix for the market game, as shown in table 1.2, does not give the firms a second chance at coordination in case they both insist on their own technologies in a particular period. The firms part ways giving rise to two incompatible standards in the market. There is only a single history leading to later subgames in a dynamic market game, with continuation payoffs r and z. This is the critical difference in terms of institutional structure aiding coordination in the committee and the market.

	Wait	Insist on B
Insist on A	$\theta + c$, c	θ, b
Wait	r,z	c, $b + c$

Table 1.2: Payoff matrix for the generic market game

The last period payoff matrix is the same for the market and the committee.

Another important aside for all the chapters of the thesis is that we model the coordination benefits as exogenous. A lot of the mechanisms for patent pooling and information sharing policies are undertaken by technical committees in network industries. These can be viewed as attempts to convince participants in the standards process that information shared in the committee impinges positively on the coordination benefits. However, the nature of the relationship between these benefits is anything but straight-forward and constant in these dynamically evolving industries. For example, in the fourth generation cellular market, there are multiple firms (Qualcomm, Nokia Siemens, Ericsson, Huawei and Samsung) that are technology drivers and all of them lay claim to large sections of the critical patent portfolio[1]. As far as each firm is concerned, the coordination benefit from a standard on its own technology is driven by the complicated combined effect of all the firms pooling their technologies and the consequent reduction in business, technical and litigation risk. Therefore, it is not unreasonable to model coordination benefits as exogenous.

1.1 One-shot committee and market games with one-sided private information

The second chapter focuses the one-shot standardization in committees and markets in the presence of one-sided asymmetric information. The structure of coordination is the same in the committee and the market. The only dif-

[1] Refer to `http://www.fiercewireless.com/story/lte-patent-pool-efforts-heat/2010-02-08`, `http://www.eetimes.com/electronics-news/4205075/Patent-pool-uncertainty-looms-over-LTE-roll-out`. Layne-Farrar and Lerner (2011) notes that participation in a modern patent pool is entirely voluntary and presents empirical evidence on participation in patent pools with technologies resulting from a standards-setting process.

ference is the institutional design for information revelation. The committee game is an extended coordination game which allows for a first round of communication, where firm A has the option of credibly revealing its private information to firm B. This communication stage is followed by the coordination game between the firms. In the market, the option of adopting its own technology reveals firm A's private information: coordination is clubbed with communiation.

The first question we address here is a comparison of the coordination efficiency of the one-shot committee and the market. In the case of firms playing pure strategies, we can show that no market equilibrium is efficient, whereas there exists at least one efficient equilibrium in the committee.

We then analyze the case where firm B plays completely mixed strategies and firm A responds with a cutoff-strategy for coordination.The mixed strategy equilibrium highlights the coordination uncertainty in the game. Additionally, the existence of a mixed strategy equilibrium requires that coordination benefits should be larger than private benefits, i.e. coordination should matter. This situation occurs most naturally for network industries, and therefore, the analysis is especially relevant in the context of these industries. However, this result is general enough to be applied in all contexts which meet the necessary conditions for mixed strategy equilibria.

We characterize the unique one-shot market equilibrium. The uniqueness result is due to the fact that the coordination benefits are greater than the private benefits. For the committee game, we show that with one-shot interaction, an equilibrium of the committee game must necessarily be characterized by no information disclosure. This result extends to the case where the coordination benefits are a function of θ. We also observe that if we allow for a correlation device and look for the correlated equilibrium of the coordination game, there is no coordination uncertainty.

These exercises bolster the underlying intuition of the non-revelation result, viz. uncertainty in coordination. The intuituion for the failure of the unraveling result is two-fold: first, information revelation does not guarantee coordination on the technology of the firm with private information in the mixed strategy equilibrium of the game, due to the the strategic uncertainty in coordination. Second, non-revelation of information makes the opponent less aggressive on its own strategy increasing the probability of coordination on the technology of the firm with private information. A high type would not want to reveal as this would make the opponent more aggressive on its own technology. As the opponent plays a purely mixed strategy, it has to choose its probability of insisting on its own technology in order to make the high type indifferent between adopting and switching. The opponent, therefore, becomes more aggressive upon information revelation. Since the high types do not want to reveal and prefers to pool with the types that do not reveal, there is no downward unraveling of information. No low type also wants to deviate from the non-revelation equilibrium, as it cannot do better than follow the strategy of non-revelation.

Coupled together, these two reasons provide the logic why unraveling fails in the case of the mixed strategy equilibrium despite the game meeting the requirements of the sufficient conditions of the information unraveling literature.

Last, we show that the non-disclosure result is unique over a very large disclosure class which allows for revelation of type over finite unions over disjoint intervals of the type-space in the communication stage.

1.2 Dynamic committee and market games with one-sided private information

We motivate the third chapter of the thesis by noting that the two common digital identifiers of modern living are a person's mobile phone number and her email address. What is interesting about the evolution of successful standards is that two different mechanisms (a technical committee and the market bandwagon) have led to the explosion of these technologies. The GSM standard in mobile telecommunication was driven by a very large technical committee, which deliberated over the features of the standard. The market driven alternative of CDMA is not as successful as the GSM. This success reflects itself in the mass accessibility of GSM based mobile phones and cheap calling rates. Even a fisherman in Kerala or a rickshawpuller in Kolkata now has access to a cellphone and enjoys the benefits of mobile communication, bridging to some extent the technological divide between the rich and the poor.

In contrast, the successful SMTP standard for email is driven by a bandwagon effect. In fact, a competing committee-based standard, X.400, never succeeded in achieving the success of the SMTP standard.

This example highlights the coexistence of different institutions which successfully deliver standards and the fact that, to a large extent, their prevalence is specific to particular industries and also varies temporally. As a network industry matures, coordination benefits increase. This impinges on the choice of the appropriate institution for standardization. The central quest of this chapter is to tease out reasons for success of committee-driven standards in one industry relative to others as well as in one industry over time. The issue of appropriate choice of ex ante mechanisms for achieving standardization has not received much attention from the theoretical literature on standardization. More importantly, the issue of one-sided asymmetric information in the context of choice of an appropriate institution for standardization is largely unexplored.

The theoretical model in this chapter compares the relative efficiency of two-period market and committee driven standards, in the presence of one-sided asymmetric information. This chapter introduces the dynamic market game. The game is such that it goes to the following subgame only if both the firms wait in one period. If the both the firms adopt their own technologies in one period, this decision is irreversible and no standard emerges in the market.

Since the exogenous coordination benefits are larger than private benefits, it then follows that if one firm adopts its technology while the other waits, then in the second period, it is a dominant strategy for the waiting firm to switch. This is how the bandwagon effect arises in this case. **The actions**

of the market game are irreversible and thus if any of the firms adopt its technology in the first period, then in the second period, that action cannot be undone.

We characterize the mixed equilibrium of an N-period market game. There is a unique information revelation cutoff, above which firm A insists and reveals its private information and below which it waits and does not reveal. The coordination cutoff is unique and determines the marginal type above which all types of firm A adopt and below which it switches to the other technology.

A feature of this equilibrium is that the firm with private information is as aggressive as firms in a setting of complete information. However, the uninformed firm is less aggressive than the probability with which a fully informed firm insists on its own technology as the standard. For a long enough market game, we observe that the only equilibrium is the bandwagon on A and the mixed strategy equilibrium does not hold.

We next characterize the mixed strategy equilibrium in the two-period committee game: where there is one first stage for communication of private information followed by two periods of coordination. Unlike the market game, there are two distinct histories leading to the last period: when both the firms wait or when both the firms insist on their own technologies. This provides an additional channel for coordination in the committee relative to the market.

A comparison of the coordination efficiency and expected payoff in the two-period market and committee games allow us to address our central question. For capturing coordination efficiency, we use the notions of comparative conditional efficiency (types I and II) and risk in coordination. For relatively small coordination benefits, we focus on what is the technology on which coordination has taken place using the concept of comparative conditional efficiency of two types. On the other hand, for higher values of coordination benefits, it makes more sense to focus on whether any coordination (either on A or on B) at all has taken place or not. The overriding concern for high values of such coordination benefits is whether any coordination happens at all, rather than choosing between technologies to coordinate on. We refer to this as the risk in coordination.

We formally define what we refer to as good ideas as opposed to bad ideas. A particular technology standard is referred to as a good (bad) idea if the private return from that technology is greater than (less than) that from the other technology, given the value of coordination benefits. Given the benefit from coordination, the market is conditionally more efficient than the committee if the probability of coordination on a good idea in the market is higher relative to the committee (CEI). An equivalent definition would be, given coordination benefits, the market is conditionally more efficient than the committee if the probability of coordinating on a bad idea is lower in the market than the committee (CEII). We further define that the market rewards good ideas if the relative payoff to firm A in the market is higher when the market is conditionally more efficient in coordinating on A compared to the committee. By a similar argument, the market kills bad ideas if the relatively payoff to firm A in the market is lower when it is conditionally less efficient in coordinating on A compared to the committee.

A summary of our results is that for $b = 0.5$ and c at some low value close to max θ:

- the market is conditionally more efficient than the committee mostly by coordinating on "good ideas", rather than not coordinating on "bad ideas".

- coordination in the market is more risky than the committee upto a certain cutoff θ. Above that cutoff, the market is either less risky or as risky as the committee. For instance, given $c = 2$, the committee risk is lower up to $\theta = 0.6$ and above it, the risk is the same in the two institutions.

For c at some high value relative to max θ ($c > 2$)and $b = 0.5$, we observe that:

- coordination risk in the market is higher than in the committee. For instance, for $c = 50$, the market is more risky than the committee for all values of θ.

- committee exhibits higher efficiency mostly by coordinating on "good ideas" rather than rejecting "bad ideas". For instance, for very high values of c, say around 50, the committee shows higher conditional efficiency than the market for almost all values of θ other than those in a narrow range.

In both the games, probability of coordination are declining in θ, indicating that for higher values of θ, relative to c, firm A becomes more aggressive reducing chances for coordination. The same holds for the behavior of firm B as well. In terms of expected payoffs to the firms, we find that for lower values of c relative to the maximum value of θ the market "rewards most good ideas" and "kills some bad ideas" more efficiently than the committee. For higher values of c, the committee outperforms the market in compensating good ideas.

Our model suggests that different network industries at a point in time can be characterized by c. Relative efficiency of the market depends on how high c is in relation to the private benefits. For very high values of c, the committee outperforms the market on all counts. However, for lower values of c in relation to private benefits, the market does seem to provide efficient standardization solutions.

1.3 Committee game revisited: Strategic information revelation and coordination in network industries

The fourth chapter posits that the committee is an intermediary in the process of standardization. Such intermediaries arise naturally in situations of imperfect information and often behave strategically. This element of strategic behavior of the committee has not been modeled in the earlier chapters. The committee is interested in the evolution of a standard, but is not biased in favor of any particular technology. The central issue is the welfare effects of the presence of the committee as an intermediary in the market and strategic revelation of information by the committee.

In the context of endogenous information structure, we focus on the information revelation role of the committee. We assume that the firms do not know their actual types at the beginning of the game. This situation arises when the firms are at the cutting edge of technological evolution and are not aware about the market potential of their own technologies. Committees, which specialize in certification and testing, have established credentials and the expertise to test these technologies and reveal how good the product is. This also gives the committee the option to strategically reveal a firm's type.

At the beginning of the game, the committee credibly announces its disclosure rule. The firms then decide whether or not to go the committee. In the last stage, both the firms play a coordination game regarding choice of technology as the standard. It should be noted that in the penultimate stage, if both the firms go to the committee then they engage in one round of cheap talk messages on intent, where firms simultaneously announce "insist on their own technologies" or "wait this round". Farrell (1987) (as well as the results from our model) has shown that such cheap talk on intent reduces the probability of coordination failure. Therefore, the committee benefits from this round of cheap talk to the extent that the probability of coordination failure is lowered raising its expected payoff. However, if one or none of the firms go to the committee, it does not get any benefit from coordination which still has a chance of evolving as a result of the direct play of the coordination game between the firms. It should also be noted that if a firm goes to the committee, its type is publicly revealed if at all (depending upon the declared the disclosure rule).

We compare the mechanisms of structured “Pareto” cheap talk on intent and strategic information revelation for achieving coordination by the committee. Cheap talk on intent, in our model, is similar to “Pareto” cheap talk on intent as described by Rabin (1994). It is more structured than “Pareto” talk, as it occurs through the offices of the committee. There are only some messages that can be sent costlessly and without any payoff-relevance by the participants in the committee to each other. In that sense, talk is cheap in our model, but not trivial. Therefore, babbling equilibria can be ruled out due to the unique construct of our model. Strategic information revelation is the other mechanisms for achieving coordination by the committee.

We consider the class of disclosure rules which allow for revelation in finite unions of disjoints intervals of the type space. Preliminary results show that disclosure rules within this class are participation compliant, i.e. both the firms go to the committee. Our first result regarding strategic information revelation is that with one round of cheap talk on intent, the committee can sustain non-disclosure of information in perfect Bayesian equilibrium of the game. In other words, non-disclosure gives rise to the lowest probability of coordination failure and highest expected payoff of the committee compared to full or partial disclosure of information.

The strength of introducing one round of cheap talk on intent shows up clearly here. With no cheap talk, the committee is indifferent between full and no disclosure. With one round of cheap talk, the equilibrium expected coordination failure is lower with no disclosure compared to full disclosure. Non-disclosure is to be interpreted as a strategic action by the committee to aid standardization, as revelation is assumed to be costless for the committee.

A second result shows that non-disclosure is unique within a very large class of disclosure rules. The equilibrium cutoff for revelation is degenerate at the corner indicating no disclosure in this game with one round of pre-play communication which is costless and non-binding. However, this result requires the fact that the firms know that the committee is strategic.

As the committee has to truthfully reveal a firm's type and commits to its disclosure rule, along the equilibrium path either firm updates their belief about their types following the optimal disclosure strategy of the committee as they know the strategic intent of the committee. This updated belief about their type is increasing monotonically in the strategy of the committee. This monotonicity of the firms' beliefs ensure that any information revealed in any interval of the type space increases the inherent vested interest and conflict between the firms in the coordination game, reducing the expected probability of coordination. Therefore, this condition is sufficient for the existence of non-disclosure as the unique equilibrium in a very large class of disclosure rules.

If the model is changed such that there is uncertainty about the efficiency of the committee's costless testing equipment, then the committee can exploit this uncertainty and we demonstrate a third result which states that there exists at least one optimal partial disclosure rule in equilibrium.

In conclusion, we discuss some reasons why we consider only one round of cheap talk prior to the coordination game as opposed to multiple rounds of cheap talk. Real life committees are finitely lived, and we show that in a mixed strategy equilibrium, finite cheap talk will never be able to achieve full coordination given any disclosure rule.

We next note that the effectiveness of cheap talk on intent, given any disclosure rule, in bringing about coordination is centrally linked to the **degree of inherent conflict** in the game. As highlighted in Farrell (1987), the problem of coordination becomes more severe the larger is the conflict of interest among the firms in the coordination game (which is of the nature of a Battle-of-the-Sexes game). The firms in the coordination game have vested interests in their own technology and prefer coordination to take place on their own respective technologies. This gives rise to an inherent conflict of interest among the firms in this game. In a context of full information among the firms, Farrell (1987) shows that the effectiveness of cheap talk on intent (even multiple rounds and in the limit as the number of rounds become very large) is reduced the higher is the extent of vested interest of the firms. We show that this result is a product of the special payoff matrix under consideration in Farrell (1987). In the more general payoff matrix that we consider, it is only if the private benefits of the firms are exactly the same in equilibrium (which is an event with measure zero), that it is possible that infinitely long cheap talk would remove coordination failure completely. Otherwise, even if the vested interest of each firm become small (but stay non-zero) relative to coordination benefits, the limiting probability of coordination failure would be bounded away from zero even with very long cheap talk on intent.

The second observation is that as number of cheap talk rounds increase, the conflict of interest between the firms and the committee increases, as the payoffs of the firms approach c in the limit for any disclosure rule in the class we consider. Therefore, the committee would find it difficult to ensure participation compliance in very long cheap talk games. Given these limitations of long cheap talk, we derive regarding strategic information disclosure with only a single round of cheap talk.

1.4 Conclusion

The theme of coordination/standardization remains unchanged in the three essays. Nonetheless, the specific information context in which the problem is couched gives different results in the three chapters. The problem of standardization is mired with issues of informational asymmetry among participating firms. A major takeaway from these essays is that the informational context as well as the specific structure of the game enabling coordination informs critically the nature of the equilibrium and efficiency outcomes in the process of standardization in network industries. The following paragraphs summarize the main lessons from all the chapters.

First, the information unraveling result does not hold in the mixed strategy equilibrium of the one-shot committee game due to the presence of coordination uncertainty, despite the conditions of monotonicity of payoffs with type, truthtelling and skeptical beliefs among opponents being present. This result requires coordination benefit from standardizing on a particular technology to be independent of the private benefit of the technology.

This result is true not only in the specific context of network industries, but also in any general coordination problem with communication which satisfies the assumptions of the model. The second observation is specific to network industries. Full revelation occurs when coordination benefit from standardizing on a particular technology is a function of the private benefit of that technology. However, the actual relationship between these benefits in these dynamically evolving industries is anything but straight-forward. For most purposes, it is a sensible assumption to take these benefits as independent of each other. In that case, our non-revelation result for the one-shot coordination game in the committee is of relevance. It informs us that the committee, which is a voluntary platform for firms to achieve standards, cannot incentivize information revelation by the firm with private information in the one-shot game with independent benefits.

For a dynamic coordination game with an explicit communication stage, as our two-period committee game, our third result shows that the non-revelation result is characterized by a relationship between the two period cutoffs that holds with certainty for negatively skewed and symmetric type distributions. In a longer committee game, information non-revelation does not yield the same benefits to the firm with private information (firm A in our model) as in the one-shot game because the opponent (firm B) can update its belief about firm A's type along the equilibrium path in conformity with firm A's optimal strategy.

The fourth observation is that the unique mixed strategy equilibrium in any period of a dynamic market game has an interior coordination (and information revelation) cutoff, in contrast with the committee game. This interior cutoff implies that in any period, some types of firm A reveal their private information and adopt their technology. This does not happen in the one-shot committee game, and is a possibility in longer coordination games in the committee.

A fifth result comes from a direct comparison of the coordination efficiency of the market and committee-based coordination. The central query motivating this exercise is the question, "Does the market kill bad ideas?", where "bad" and "ideas" are defined in the specific context of the game in chapter 3. In a general context, one would expect a market-based mechanism to achieve this role efficiently. Our answer to this question is not a straightforward yes, and is colored by the strength of coordination benefit relative to private benefits in the network industry we study. The answer is not only network industry-specific, but also specific to the time of analysis as these benefits change over time.

In chapter 4, which endogenizes the structure of information, the central query is to study strategic information revelation by an intermediary in the standardization process for very new technologies whose types are not known to the firms sponsoring them. In the one-shot game, the committee is adorned with strategic intent on achieving coordination to maximize its own benefits. We observe that the committee can be no more strategic than committing to a non-disclosure rule. However, when there is uncertainty about the ability of the intermediary (the committee) to reveal types, this can be exploited by the committee to achieve better coordination with the application of a partial disclosure rule. In the process of this investigation, we underscore the limitation of cheap talk in achieving coordiantion in our game with vested interests and an endogenous information structure.

The result of non-revelation of information resonates in the first and the last result of the chapters in this thesis. In the first result, non-revelation arises when the structure of information is not endogenized. The firm with private information does not reveal strategically in order to maximize its payoff in the one-shot coordination game. In the last result, the committee does not reveal the firms' type strategically in order to achieve the highest coordination possible in the same one-shot coordination game as in the first result. Despite different information structures and different objectives of the agents in the two cases, we get the result of non-revelation.

The correct comparator for the first finding is the information "unraveling" result as discussed earlier. The last result is comparable with strategic information revelation by intermediaries in any market with information asymmetries (Lizzieri (1999) for instance). The last result also provides an understanding of the behavior of technical committees, which have grown vastly in importance as intermediaries in process of standardization in most technology-intensive industries such as telecommunication and wireless technologies.

Laura Shavin: "British yogurt will be renamed "fermented milk pudding" if Brussels has its way..."

Steve Punt: "But Brussels won't have its way 'cuz it's not true, and, in any case, since the English call sour cream *creme fresh*, and fromage frais is nothing to do with cheese, and the French call custard English cream, while in England custard cream is a biscuit containing neither...I think a bit of standardization would help, quite frankly." *-On the Now Show, BBC Radio 4*

Chapter 2

Information revelation and coordination in committees in network industries

2.1 Motivation

Coordination or compatibility is an important issue in markets for technologically hi-end goods, such as communication equipment, video tapes, players and cassettes, computer hardware and software, airline transport, railroads, electric plugs and sockets, camera lenses to name a few.

As noted in the introduction, the main institutions for standardization in network industries are the committee and the market. Some of these industries, such as wireless telecommunications, have experienced very rapid growth in the last two decades which has resulted in increased requirements for effective standardization and compatibility in product features. Gruber and Koutroumpis (2010) note that "Since 2002 mobile subscribers have exceeded the number of fixed lines globally. The process to achieve what fixed phones have struggled for more than 120 years took less than a fifth of the time for mobile networks" with 67 per cent of the world's population with mobile phone connections. The rate of growth in developing countries is even more stunning. For instance, Chibber (2007) notes that the mobile sector in India has grown from around 10 million subscribers in the year 2002 to over 150 million at the end of February 2007 with a growth rate of nearly 6 million mobiles per month. This development has been in step with the quick proliferation of technical standards committees, relative to market-based standards.

These committees are quite diverse and can be categorized by functionalities, composition, duration, jurisdiction etc. For example, ATIS which develops standards for the information and technology (ICT) industry (in domains such as cloud services) has under its umbrella 17 different committees with different structures and functions.

Firms approach different technical committees for a variety of reasons such as product demonstration, collaboration and information sharing. Upstream firms meet their downstream counterparts to discuss issues in coordination in fora such as the CTIA (International Association for the Wireless Telecommunications Industry) which is dedicated to wireless technologies. Its sponsored event, the CTIA Wireless@2012 is the destination for all mobile companies to showcase and discuss current issues in the industry.

An older and grander example is the GSM (Group Sociale Mobile) established in 1987 with memberships from 219 countries uniting "nearly 800 of the world's mobile operators, as well as more than 200 companies in the broader mobile ecosystem, including handset makers, software companies, equipment providers, Internet companies, and media and entertainment organisations." The GSM performs various functions such as undertaking initiatives to stimulate innovation and growth for the mobile industry, catalyse mobile and internet service convergence, represent the mobile industry to the goverment and the regulators and facilitate the expansion of the mobile broadband services through the GSM technology family.

The IEEE is more broad-based than the GSM, encompassing computing and sustainable energy systems, to aerospace, communications, robotics, healthcare, and more. It is the world's largest professional association with a focus on technological innovation. IEEE performs a number of functions, noteworthy among which are standands formation in various industries (a large number of which have network features). It also produces cited publications, conferences, professional and even educational activities.

Other organizations, such as the International Standards Organization, also focus on coordination and standardization in many network industries. ISO develops standards for firms to coordinate their technologies on and disseminate the standards for the benefit of consumers. ISO has a portfolio of over 18,500 standards, a number of which pertain to railways, shipbuilding, aircrafts, electronics and energy systems.

As the nature of emergent technologies in these industries is a function of the underlying processes and institutions which create them, an understanding of the technical committees is a pre-requisite for characterizing new technologies such as 4G and Wimax which arise through deliberations in these institutions.

The focus of this chapter is to understand the tradeoffs in the process of formal standardization through the aegis of technical committees and markets. We focus on the problem of achieving an industry-wide standard, when two participating firms have vested interests in their own technology and there is one-sided asymmetric information about private benefits among the firms. We study the one-shot coordination game in these institutions in this chapter.

For the one-shot coordination game, the coordination game (payoff matrix which is the same as the Battle-of-the-Sexes game) is the same in the market and the committee. However, the mechanism for revelation of private information is different in the committee and the market.

There is no separate stage for information revelation in the market unlike the committee. The action of "adopting" its own technology A implies that all private information is revealed by firm A in the market[1].

[1] A rationale for this assumption about the structure of information revelation in the market is that the firm has to raise external capital in the market in order to advertise and market its technology. The technology does not become the de facto standard without substantial marketing expenditure by firm A in the market bandwagon. The process of raising external capital entails that it has to reveal its private benefit information with the investors.

The committee game is the coordination game extended by one prior stage of communication, where the firm with private information about its technological type decides whether or not to reveal its private information.

The central issue is to understand the interlinkage between coordination and information facilitation roles of these institutions. We do this in the belief that analysing each function, such as coordination or information facilitation, in isolation allows for a partial understanding of the manner in which these institutions conduct their duties. In particular, it becomes evident from our analysis that information revelation is directly affected by the compulsions of coordination in the committee. This analysis is not only important from a policy perspective regarding appropriate design of technical committees but also for a relative assessment of committees vis-a-vis markets in achieving coordination, which is the focus of the next chapter of the thesis.

The structure of information in this chapter is exogenous (it is endogenized in chapter 4). Neither the market nor the committee can decide what information can be credibly be transmitted to the uninformed firm. In equilibrium, the firm with private information simply decides whether or not to reveal its private information before the coordination game.

We first analyze the pure strategy equilibria of the one-shot committee and market games. The one-shot coordination game is the same in the market and the committee. However, the information revelation is simultaneous with coordination in the former, but sequential in the latter. Therefore, we get the result that there will exist at least one efficient equilibrium in the committee game unlike the market game. This highlights the role of cheap talk making coordination possible.

We then move onto the case where the firm without private information plays a purely mixed strategy and the other firm responds with a simple cut-off strategy for coordination. We find that in this case, there exists a unique market equilibrium. The committee game also admits a unique equilibrium where there is no information revelation. We allow for revelation of private information over fintie unions of disjoint intervals of the type space in the committee game. As this is a fairly large class for information revelation, we contend that the uniqueness result for non-revelation holds in a very large class for revelation of information.

This result is also interesting from the perspective of the trade-offs between coordination and information revelation in the committee. It highlights that the compulsions of coordination prevent revelation of any private information in the one-shot committee game.

Most of the literature on information unraveling and full disclosure for instance Milgrom (1981); Grossman (1981) require three sufficient conditions: monotonicity of payoffs with type, truthtelling and skeptical beliefs among opponents and consumers.

Payoff to the firm with private information is monotonic in its type in our model. More importantly, truthtelling and skeptical beliefs are also present. Nonetheless, these conditions are not sufficient for information unraveling in the class of equilibria we investigate for the committee. Of the two possible reasons for non-revelation: conditional independence of payoffs and the tension of coordination on a technology on information revelation, we observe that it is the latter condition which leads us to the non-revelation result. Even if payoffs are conditionally independent, absent compulsions of coordination (when we allow for corner solutions in pure strategies), full revelation is an equilibrium.

The intuituion for the failure of the unraveling result is two-fold: first, information revelation does not guarantee coordination on the technology of the firm with private information in the mixed strategy equilibrium of the game, due to the the strategic uncertainty in coordination. Second, non-revelation of information makes the opponent less aggressive on its own strategy increasing the probability of coordination on the technology of the firm with private information. A high type would not want to reveal as this would make the opponent more aggressive on its own technology in the mixed strategy equilibrium. Since the high types do not want to reveal and prefers to pool with the types that do not reveal, there is no downward unraveling of information. No low type also wants to deviate from the non-revelation equilibrium, as it cannot do better than follow the strategy of non-revelation.

Coupled together, these two reasons provide the logic why unraveling fails in the case of mixed strategy equilibria of the one-shot committee game despite the game meeting the requirements of the sufficient conditions of the information unraveling literature.

The chapter is organized as follows: section 2.2 gives a brief literature review of papers on information revelation and coordianation in a variety of contexts. Section 2.3 details the model for the one-shot market and the necessary assumptions. Section 2.4 characterizes the pure strategy equilibria in the one-shot market and committee games. Section 2.5 extends the analysis to the case where the firm without private information plays mixed strategies for coordination and the firm with private information responds with a cut-off strategy for coordination. Section 2.6 concludes the chapter.

2.2 Literature review

The actual process leading to standardization is a relatively neglected issue in the vast literature analyzing the incentives of firms for standardization and its welfare implications. One early exception is Farrell and Saloner (1988), which investigates the comparative performance of formal committees, markets and hybrid mechanisms in achieving standardization. The formal committee in this paper is in a complete information setting. The model in this chapter extends the committee game in Farrell and Saloner (1988) to a one-sided asymmetric information setting.

Technical standard setting committees have also been studied by Economides and Skrzypacz (2003), but the issue dealt with is endogenous formation of standards platforms in industries with network externalities. Depending upon the strength of network effects, they find that equilibrium platform sizes vary from industry-wide single platform to multiple incompatible coalitions. In contrast, our model takes the size of the technical committee as given, as in Farrell and Saloner (1988), focusing more on the interlinkage between coordination and information revelation.

David and Greenstein (1990) is a survey of various institutional setups in standardization in network industries. The paper focuses on four kinds of institutional standards processes: market competition involving products embodying unsponsored standards, market competition among sponsored (proprietary) standards, agreements within voluntary standards-writing organizations, and direct governmental intervention. The first two are finer gradations of the market based or *de facto standards*, while the latter two arise in the context of committee-driven or *de jure standards*.

Regarding standardization in the former, Katz and Shapiro (1986) is an early paper which spells out the difficulties of standardization in the market. If a very small fraction of consumers adopt a new standard, then the overall costs of adopting the new standard outweighs the benefit emergence of the standard. There are two possibilities in equilibrium: either everyone adopts the new standard or no one adopts its. Other papers which have contributed to this line of research include Cabral (1990), Besen and Farrell (1994) and Katz and Shapiro (1985). Farrell and Saloner (1985) demonstrate a very important feature of market based standards. Under complete information and identical preferences among firms, standardization benefits in the market cannot trap the industry in an obsolete or inferior standard when a better alternative is available. However, with incomplete information, this kind of "excess inertia" can occur. They investigate how communication can mitigate this problem. Farrell and Saloner (1986b) and Farrell and Saloner (1986a) show that with heterogenous preferences, communication need not alleviate the problems of inertia.

For specific network industries, there are some empirical papers which focus on what makes standardization work. For instance, Funk and Methe (2001) highlights the role of national governments in the formation of technical standards in the mobile telecommunications industry.

There is a large literature on incomplete information (for instance, Bag and Roy (2011), Bag and Roy (2008), Bag and Dasgupta (1995), Bac and Kanti Bag (2002) and Bac and Bag (2003)). Some papers refer specifically to incomplete information in coordination games. Farrell and Simcoe (2009) incorporates two-sided private information about quality of techonology in a two player war-of-attrition game for standard formation. They observe a tradeoff between *ex ante* efficiency and delays in standard setting. In the symmetric equilibrium of their committee game, the *ex ante* efficient technology is selected at the cost of severe delay. Under some restrictions, the committee can outperform the market. As opposed to this, the one-sided asymmetric information battle-of-the-sexes game in our model eschews discounting, skirting the issue of delays to highlight the tension in information revelation and coordination probabilities itself.

Our committee game has some connections with two papers in the domain of cheap talk. Baliga and Morris (2002) discuss the role of cheap talk in a two player coordination game with spillovers with one-sided incomplete information. They observe that information non-revelation requires a breakdown of self-signalling. We similarly model the two player coordination game with one-sided information, but the information in our model is verifiable hard evidence. Thus, the requirement of self-signalling is absent. Interestingly, despite this redundancy, there is no information revelation in our committee game. Banks and Calvert (1992) models a two player battle-of-the-sexes game with two-sided incomplete information, analysing the extent to which cheap talk communication and mediation resolve the conflict between ex ante and ex post efficiency. Unmediated communication cannot achieve incentive efficiency. In our model with one-sided information and communication with verifiable hard evidence, ex ante efficiency is not achievable.

Okuno-Fujiwara et al. (1990) couch cheap talk with some non-cheap talk communication in a two stage game (a communication stage and a subsequent strategic interaction stage). They characterize sufficient conditions for information revelation (and non-revelation) in general cheap talk games with an information sharing stage and a subsequent stage. Our static committee game similarly has two stages, but the reasons driving non-revelation in the mixed strategy equilibrium of the game do not require the strong conditions of Okuno-Fujiwara et al. (1990) due to the interplay of coordination uncertainty and mixed strategy equilibrium.

The literature on voting has some discussion on optimal committee design in the presence of private information such as Persico (2004), Schulte (2006), Coughlan (2000) and Doraszelski et al. (2003). However, most of these papers are concerned about private information about a public good, whereas we focus on private information about a private variable. Further, the issue of strategic complementarity and coordination is absent, so that they are not relevant for network industries.

Our assumption of one-sided asymmetric information is appropriate for a large number of empirical examples of standardization[2]. At any given point of time, there are only a finite number of new ideas that accrue from research and development, and it is rare that many participants in the coordination game have private information. One can think of B as the incumbent and A as the new entrant with private information about its own technology benefits.

2.3 One-shot game

2.3.1 Model Assumptions: Coordination

Two firms, with two incompatible technologies A and B, are playing a simultaneous game of coordination. Firm A prefers its own technology A, which gives it a private benefit of θ, whereas firm B gets a private benefit of b from its preferred technology B. The incumbent firm B's benefit b is common knowledge, but the entrant firm A's benefit θ is not. Firm B only knows that $\theta \in \Theta = [\theta_l, \theta_h] \subset \mathbb{R}_+$. Firm B also knows that θ is drawn from a strictly monotonic continuous distribution function $F(\theta)$ over Θ.

[2]One relevant example of this is the Enhanced Data rates over GSM Evolution (EDGE) proposal by Ericsson at a GSM meeting for increasing the throughput of data over the GPRS system in mobile phones. All the committee members were aware about the features of the incumbent technology. Ericsson revealed to the GSM committee participants private information about EDGE. Simulations revealed by Ericsson portended tripling of data rates compared to the incumbent technology. Refer to `http://www.ericsson.com/res/docs/whitepapers/evolution_to_edge.pdf`.

Both firms would like to coordinate jointly on their preferred technology as the standard. This is a Battle-of-the-Sexes game with one-sided asymmetric information. Pure benefits from coordination is captured by c. As in Farrell and Saloner (1988), we assume that coordination benefits c is common knowledge and $c > b, \theta_h$. This assumption captures the fact that in network industries, the most important factor is compatibility and coordination of technology. This also ensures that all θ types play a coordination game.

Among other assumptions, firm A is assumed to present certifable hard evidence if it decides to reveal its private information. There are no side payments between the players. In the committee, membership fees are normalized to zero.

The payoffs are shown in table 2.1. The interpretation of this particular

	Switch	Adopt B
Adopt A	$\theta + c$, c	θ,b
Switch	0,0	c, $b + c$

Table 2.1: Payoff matrix for the one-shot market and committee games

payoff matrix is that if both the firm choose to adopt their own technologies in the one-shot game, no standard emerges and each firm gets only their private benefits θ and b. On the other hand, if both the firms switch to the other technology, then both get a payoff of 0. This interpretation is the same as in Farrell and Saloner (1988).

2.3.2 Model Assumptions: Information Revelation

For the market game, there is no separate stage for information revelation. The act of adoption reveals firm A's type. On the other hand, the committee game allows for a first stage for communicating private information, following by the one-shot coordination game, with payoff matrix shown in table 2.1.

2.4 Pure Strategy Equilibria

The central question that we address here is whether an efficient outcome can be supported in the committee or the market scenarios if both the firms play pure strategies.

Definition 1. *The bandwagon on A (B), where both the firms coordinate on technology A (B), is* ***efficient*** *iff* $\theta > (<) b$*, given that* $c > \theta_h$*.*

2.4.1 Pure strategy equilibria: one-shot market game

The pure strategy equilibria of the market game are either bandwagon formation on A (with firm A revealing its private information) or bandwagon formation on B (with no information revelation by firm A). Therefore, an outcome (in pure strategies) has to be inefficient since either firm will coordinate on either A or on B irrespective of the relation between θ or b.

For characterizing the pure strategy Bayesian Nash equilibria of this game, we define the following:

Definition 2. *Firm A follows simple cut-off strategies for coordination iff:*

$$\text{adopt A, if } \theta > t_\theta,$$
$$\text{switch otherwise}$$

Proposition 1. *Any market equilibrium, where the firm A follows a simple cut-off strategy for coordination, is inefficient.*

Proof. Consider the following strategy profile:
Firm A: for $\theta > t_\theta$, firm A adopts A and switches to B otherwise. Firm B would prefer to adopt B rather than switching to A iff

$$(1 - F(t_\theta))b + F(t_\theta)(b + c) \geq (1 - F(t_\theta))c \Rightarrow F(t_\theta) \geq \frac{c - b}{2c} \tag{2.1}$$

Hence, the cutoff for firm A is $t_\theta = F^{-1}(\frac{c-b}{2c})$.A cutoff of $F(t_\theta) = \frac{c-b}{2c}$ violates the definition for efficiency[3]. Therefore, the market equilibrium with the given strategy profile is inefficient. ■

Note that this result would hold in the symmetric case, where both the firms had private information about their types.

2.4.2 Pure strategy equilibria: one-shot committee game

The one shot committee game has two stages: in stage 1, firm A decides whether or not to reveal its private information. In stage 2, the coordination game is played between the two firms.

In the communication stage, only firm A acts. It sends messages from the message space $M = [\theta_l, \theta_h] \cup \{\text{not reveal } \theta\}$ as per the revelation strategy

[3]This is obvious for the uniform distribution where $F(\theta) = \theta$.

$\rho_R : \Theta \to M$, where the revelation set R is a finite union of disjoint intervals defined above.

Proposition 2. *The committee game has at least one equilibrium where efficiency is attained*[4].

Proof. Consider the following pure strategy equilibrium in the committee: In the communication stage, firm A reveals its private information. In the coordination stage, both the firms choose A if θ is revealed to be greater than b and choose B otherwise. If firm A does not reveal in the communication stage, then B chooses its own technology with probability one and the bandwagon forms on B. For this equilibrium, the standard is A if $\theta > b$ and it is B if $\theta \leq b$. This strategy, therefore, satisfies the definition for efficiency. ■

The separate communication stage in the committee for private information revelation allows for an efficient outcome. This highlights the coordinating role of cheap talk on intent, as studied in Farrell (1987).

2.5 Mixed Strategy Equilibria

The class of coordination games that we study has multiple pure strategy equilibria (either bandwagon on A or bandwagon on B). Standardization in this context means that one of the equilibria is selected ad hoc. One cannot focus on the underlying tension of strategic uncertainty in the game, as noted by Farrell and Saloner (1988). It is only through an analysis of

[4] I would like to thank my examiner, Dr. Kunal Sengupta, for suggesting the proof.

the mixed strategy equilibrium that we can highlight strategic uncertainty in coordination and the resultant impact on information revelation for firm A.

We now consider the case where firm B uses a completely mixed strategy. Let q_B denote the probability that firm B adopts B, where $0 < q_B < 1$. Therefore, $(1 - q_B)$ denotes the probability that B switches to A. Firm A's best response to it is to use a *simple cut-off strategy* for coordination, as defined below:

Definition 3. *Firm A's employs a simple cut-off $\hat{\theta}$ for coordination s.t.*

$$\begin{aligned} &\textit{adopt, if } \theta > \hat{\theta}, \\ &\textit{switch, } \quad \textit{otherwise} \end{aligned}$$

The additional insight that we glean from analyzing the mixed strategy equilibrium is that for the committee game, at most one type of firm A would be indifferent between revealing and not revealing whereas all other types would not want to reveal private information. This contrasts with the result in the pure strategy equilibrium in the committee game, where there was atleast one efficient equilibrium.

2.5.1 Mixed strategy equilibrium: one-shot market game

Proposition 3. *The market game equilibrium is unique if firm B uses a completely mixed strategy for coordination and firm A employs a cut-off strategy as its best response*[5]*.*

[5] I would like to thank my examiner, Dr. Kunal Sengupta, for suggesting the proof.

Proof. The cut-off type for firm A is determined by the equilibrium condition whereby firm B is indifferent between adopting and switching:

$$(1 - F(\hat{\theta}))c = (1 - F(\hat{\theta}))b + F(\hat{\theta})(b + c) = b + F(\hat{\theta})c \qquad (2.2)$$

Since $c > b$, equation (2.2) has a unique solution for $\hat{\theta} = F^{-1}(\frac{c-b}{2c})$. Furthermore, given the strategy of firm B, the cut-off strategy of firm A will be optimal if, at $\hat{\theta}$, we have

$$\frac{\hat{\theta} + c}{2c} = q_B \qquad (2.3)$$

■

Therefore, in the unique mixed strategy equilibrium of the one-shot market game, all types of $\theta > F^{-1}(\frac{c-b}{2c})$ reveal and adopt A. Those below this cutoff θ switch to B. The probability with which the standard forms on A is $(1-q_B)(1-F(\frac{c-b}{2c})$ and that with which the standard forms on B is $q_B F(\frac{c-b}{2c})$.

Efficiency, in this context, requires that $b = \hat{\theta} = F^{-1}(\frac{c-b}{2c})$ and that for $\theta > \hat{\theta}$, we have $q_B = 0$ and that for $\theta \leq \hat{\theta}$, $q_B = 1$. Unfortunately, in the mixed strategy equilibrium, $0 < q_B < 1$ for all values of θ and there is no guarantee that $b = \hat{\theta}$. Therefore, the mixed strategy equilibrium does not satisfy the requirement for efficiency.

2.5.2 Mixed strategy equilibrium: one-shot committee game

Under one shot interaction (and the use of completely mixed strategies by firm B), *an* equilibrium of the committee game must necessarily be characterized by no information revelation.

Let $q_R(\theta)$ denote the probability that firm B adopts B given that firm A has revealed to be of type θ. Let q_{NR} denote the probability that firm B adopts its own technology B in stage 2 of the committee game, given that firm A does not reveal any information in stage 1. Assume further that $q_R(\theta), q_{NR} \in (0, 1)$.

We can solve for $q_R(\theta)$ explicitly and it is given by

$$q_R(\theta) = \frac{\theta + c}{2c} \tag{2.4}$$

Proposition 4. *In any equilibrium where firm B uses completely mixed strategies, in stage 1, at most one type of firm A is indifferent between revealing and not revealing information. All other types prefer non-revelation to revelation*[6]*.*

Proof. Given that θ has revealed information in stage 2, there exists a unique equilibrium (in which firm B uses completely mixed strategy). In this equilibrium, firm A of type θ also mixes between adopting A and switching and its equilibrium payoff is $\frac{\theta+c}{2}$, using the fact that $q_R(\theta) = \frac{\theta+c}{2c}$.

Now, if firm A does not reveal its type, then its payoff in stage 2 is either $\theta + c - q_{NR}c$ (if firm A adopts A in stage 2) or $q_{NR}c$ (if firm A switches in stage 2). If firm A of type θ reveals, we must have

$$\frac{\theta + c}{2} \geq q_{NR}c \tag{2.5}$$

[6] I would like to thank my examiner, Dr. Kunal Sengupta, for suggesting the proof.

If the inequality in equation (2.5) is strict, then we have

$$\frac{\theta + c}{2} < \theta + c - q_{NR}c \tag{2.6}$$

However, given equation (2.6), firm A of type θ will be strictly better off not revealing and choosing to adopt. Thus, for firm A of type θ to reveal, we must have

$$\frac{\theta + c}{2} = q_{NR}c \tag{2.7}$$

But, given q_{NR}, the equality in (2.7) can only hold for at most one value of θ. ■

2.5.3 Characterization of the non-revelation equilibrium

Proposition 5. *The one-shot committee game is characterized by no information revelation, an interior coordination cutoff for firm A at* $\hat{\theta} = F^{-1}(\frac{c-b}{2c})$ *with firm B's probability of adopting its own technology being* $q_{NR} = \frac{1}{2} + \frac{\hat{\theta}}{2c} = \frac{1}{2} + \frac{F^{-1}(\frac{c-b}{2c})}{2c}$.

Figure 2.1 shows this equilibrium graphically.

The market game has the same coordination cut-off, but this also coincides with the cut-off for information revelation. All types above this cut-off reveal and adopt in the market game, whereas in the one-shot committee game, no type reveals but above (below) this coordination cutoff, all types adopt A (switch to B).

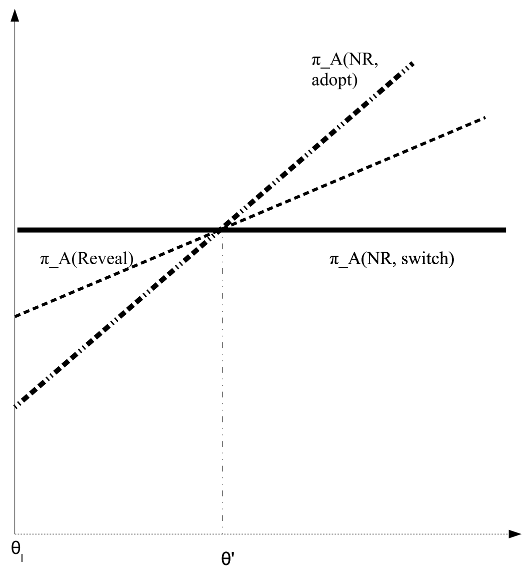


Figure 2.1: Equilibrium with no information revelation

Remark 1. Suppose there was no information revelation allowed in the market game. Then, following the steps in the previous proof, it is easy to deduce that the equilibrium payoff to the firm of type θ is at least $\frac{\theta+c}{2}$, which it can guarantee itself by revealing in the committee. Therefore, for the non-information revelation equilibrium of the one-shot market game is the same as that in the one-shot committee game, when firm B plays completely mixed strategies.

Remark 2. Following from our earlier remark and the discussion on efficiency of the mixed strategy one-shot market game, it is obvious that the mixed strategy equilibrium in the one-shot committee game does not meet the requirements for efficiency. This is unlike the pure strategy efficiency result for the one-shot committee game, where we could establish at least one efficient outcome.

Remark 3. We should also note that the above result holds even when c depends on θ. One can follow the same steps (as in the earlier proof) to deduce that if firm A, of type θ, reveals, then one must have

$$\frac{\theta + c(\theta)}{2c(\theta)} = q_{NR}$$

Consequently, as long as $\frac{\theta}{c(\theta)}$ is monotonic in θ, the earlier result must hold.

2.5.4 Uniqueness of the non-revelation equilibrium in the one-shot committee game

Given this result, we can postulate that the type indifferent between revealing and not revealing will not actually reveal any information. We now prove that this equilibrium is unique in the class of strategies where revelation is allowed over finite unions of intervals of the type space, firm B plays a completely mixed strategy and firm A responds with a simple cut-off strategy for coordination.

Lemma 1. *The completely mixed strategy of firm B, q_R (if firm A reveals) or q_{NR} (if firm A does not reveal) obeys a single crossing property in the type space of firm A, so that $q_{NR} > q_R \ \forall \ \theta < \hat{\theta}$ and $q_{NR} < q_R \ \forall \ \theta > \hat{\theta}$.*

1. *$0 < q_{NR} < 1$ is constant. q_R increases linearly with θ.*

2. *q_R intersects q_{NR} from below at the coordination cutoff point $\hat{\theta}$.*

3. *q_{NR} increases linearly in firm B's belief $\hat{\theta}$.*

Proof. 1. The result follows from

$$q_{NR} = \frac{1}{2} + \frac{\hat{\theta}}{2c} = \frac{1}{2} + \frac{F^{-1}(\frac{c-b}{2c})}{2c} \tag{2.8}$$

and from

$$q_R = \frac{1}{2} + \frac{\theta}{2c} \tag{2.9}$$

2. We know from equations (2.8) and (2.9) that $q_{\mathrm{NR}} = q_R$ at $\hat{\theta}$. As q_{NR} is constant and q_R increases with θ, for all $\theta > \hat{\theta}$, $q_{\mathrm{NR}} < q_R$. Therefore, q_R has to intersect q_{NR} from below at $\hat{\theta}$.

3. From equation (2.8), we get that $\frac{\partial q_{\mathrm{NR}}}{\partial \hat{\theta}} = \frac{1}{2c} > 0$. Thus, q_{NR} increases linearly in firm B's belief $\hat{\theta}$.

■

Figure 2.2 shows this lemma graphically, for a given $\hat{\theta}$.

Definition 4. *R is the set of types that reveal in the first stage.*

Hence, the complement set R^c is the set of types that do not reveal.

Definition 5. *R_A is the set of θ that play adopt in the coordination stage without revealing.*

Definition 6. *The revelation set R is a finite union of disjoint intervals. Therefore,*

$$R = \cup_{s=1}^{n} [\theta'_s, \theta''_s]$$

Lemma 2. *$\theta_h \in R^c$, i.e. the highest type in the type space will never reveal.*

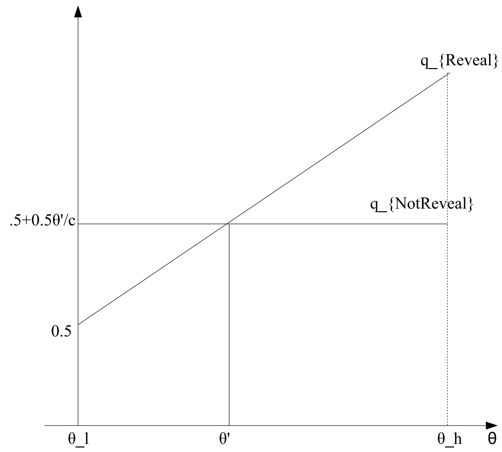


Figure 2.2: q_R vs. q_{NR}

Proof. Firm A of type θ_h will not deviate and reveal, as firm B's strategy would become $q_R = \frac{\theta_h + c}{2c}$ upon revelation. With non-revelation, firm B's belief about its type would be set at $\hat{\theta} < \theta_h$ (Lemma 1). Lemma 2 shows that q_{NR} is linearly increasing in beliefs. With a lower belief, firm B's strategy $q_{\text{NR}} < q_R$ as q_R is based on a higher $\theta = \theta_h$. Now, by not revealing and adopting its technology, firm A's payoff would be $(\theta_h + c) - q_{\text{NR}}c$ which is strictly greater than the revelation payoff of $(\theta_h + c) - q_R c = \frac{\theta_h + c}{2}$.Thus, type θ_h would not reveal. ∎

The set R^c, as noted earlier, is either a continuous interval or a finite union of disjoint intervals. We have thus shown that the non-revelation set R^c contains θ_h. Consider the subset R^h of R^c which contains θ_h. So $R^h = [\theta', \theta_h] \subset R^c$. No type in this subset reveals in their type in equilibrium. Now, suppose R^h is contiguous with a revelation range. Therefore, θ', the infimum of the set R^h, has to be indifferent between revelation and non-revelation.

Lemma 3. *If a revelation range is contiguous with R^c, then the infimum of the set containing θ_h must coincide with $\hat{\theta}$, i.e. $\theta' = \hat{\theta}$.*

Proof. If $\theta' > \hat{\theta}$, then firm A would prefer not to reveal and adopt rather than reveal as $(\theta' + c) - q_{\text{NR}}c > (\theta' + c) - q_R c$. This is because $q_{\text{NR}} < q_R$ for all $\theta > \hat{\theta}$. If $\theta' < \hat{\theta}$, then type θ' would prefer not to reveal and switch getting a payoff of $q_{\text{NR}}c$ as opposed to $q_R c$ if it revealed, where $q_{\text{NR}} > q_R$ for all $\theta < \hat{\theta}$ from Lemma 2.

It is only for $\hat{\theta} = \theta'$ that $q_R = q_{\mathrm{NR}}$ and the payoffs from revelation and non-revelation are the same, making θ' indifferent between these strategies. ■

Lemma 4. *There cannot be a contiguous revelation range with R^h. R^c is an continuous interval with θ_h in it.*

Proof. Consider any $\tilde{\theta} = \theta' - \epsilon$, where ϵ is vanishingly small. Whereas θ' is indifferent between revealing and not revealing (it is the infimum of R^h), $\tilde{\theta}$ reveals its type as it is in the contiguous revelation range. However, Lemma 2 shows that for all $\theta < \hat{\theta} = \theta'$, $q_{\mathrm{NR}} > q_R$ ensuring that by deviating from revelation, $\tilde{\theta}$ can get a higher payoff (switching without revealing will give a payoff $q_{\mathrm{NR}}c > q_R c$). Thus, $\tilde{\theta}$ will not reveal. This proves that there cannot be any contiguous range of revelation with $R^h \subset R^c$. As we can show deviations from revelation for any $\tilde{\theta}$ contiguous with the non-revelation set which contains θ_h, the non-revelation set R^c is a continuous interval and not a finite union of disjoint intervals. ■

Proposition 6. *Non-revelation is unique in the class of equilibria where revelation is allowed over finite unions of disjoint intervals, firm B plays a completely mixed strategy and firm A responds with a simple cut-off strategy for coordination in the one-shot committee game.*

Proof. Lemma 5 proves that as long as θ_h is an element of the non-revelation interval, no type below it will reveal in equilibrium. Lemma 3 proves that θ_h will never reveal and will always belong to R^c. Hence, the only equilibrium of $\Gamma_{\tilde{c}}$ involves no information revelation. ■

2.6 Conclusion

The central question we address here is a comparison of the coordination efficiency of the one-shot committee and the market. In the case of firms playing pure strategies, we can show that no market equilibrium is efficient, whereas there exists at least one efficient equilibrium in the committee.

We then analyze the case where firm B plays completely mixed strategies and firm A responds with a cutoff-strategy for coordination.The mixed strategy equilibrium highlights the coordination uncertainty in the game. Additionally, the existence of a mixed strategy equilibrium requires that coordination benefits should be larger than private benefits, i.e. coordination should matter. This situation occurs most naturally for network industries, and therefore, the analysis is especially relevant in the context of these industries. However, this result is general enough to be applied in all contexts which meet the necessary conditions for mixed strategy equilibria.

We characterize the unique one-shot market equilibrium. The uniqueness of this equilibrium derives from the payoff matrix and the coordination benefits being greater than the private benefits. For the committee game, we show that with one-shot interaction, an equilibrium of the committee game must necessarily be characterized by no information disclosure. The mixed strategy equilibrium played if information is revealed punishes revelation with too aggressive a strategy of firm B. We know that q_R increases in θ in order to keep types of firm A indifferent between adopting and switching. Nonetheless, the mixed strategy equilibrim picks up the tension in coordination. However, it this very tension in coordination that prevents any revelation of information in the unique mixed strategy equilibrium of the one-shot committee game. Had there been no tension of coordination, then information revelation would take place. If we could design a coordinating device which reduced q_R, it would make revelation more attractive.

This non-revelation result holds for a large class of communication rules which allows for revelation over finite unions of disjoint intervals of the type space.

One possibility for information revelation is the correlated equilibrium. Hypothetically, suppose the committee could be designed such that after information revelation, an unbiased authority would flip an unbiased coin and instructs both firms to coordinate on A if heads or coordinate on B if tails. Then firm A would reveal information in the first stage. This correlated equilibrium payoff to firm A, if it reveals information, would be $\frac{1}{2}\theta + c$. The difference between the correlated equilibrium payoff and the non-revelation payoff is strictly positive. We would get the same result if the unbiased authority, instead of suggesting the probabilities $\{\frac{1}{2}, \frac{1}{2}\}$ for coordinating on A and on B, chose $\{1, 0\}$ or $\{0, 1\}$.

Most of the literature on revelation of hard evidence rely on three sufficient conditions: monotonicity of payoffs in types, truthtelling and skeptical beliefs. However, the model of the one-shot committee game shows that despite these conditions being valid, the unique mixed strategy equilibrium of the game involves no information revelation. The reason for this is uncertainty in coordination (and not conditional independence of payoffs).

Therefore, we show that the three conditions mentioned in the literature are not sufficient for information revelation in the presence of coordination uncertainty.

> “The prevailing wisdom is that markets are always right. I take the opposition position. I assume that markets are always wrong. Even if my assumption is occasionally wrong, I use it as a working hypothesis.” - *George Soros on Soros : Staying Ahead of the Curve, 1995*

Chapter 3

Market game: How does it compare with coordination in committees in network industries?

3.1 Motivation

In chapter 2, we analyzed the one-shot market and committee games in the presence of one-sided asymmetric information.This purpose of this chapter is to study information revelation and coordination efficiency in dynamic two-period market and two-period committee games.

We characterize the perfect Bayesian equilibrium of a multi-period market game along with the limiting payoffs and coordination probabilities in this game. As in chapter 2, we focus on the mixed strategy equilibrium of the game, which arises when the firm with private information plays a cutoff strategy as a best response to the completely mixed strategy of the firm without private information. A condition on the continuation payoff in any period (precisely that the continuation payoffs of each firm is less than the coordination benefit) ensures the existence of the mixed strategy equilibrium in the market game. In equilibrium, there is a unique information revelation cutoff in the market game every period if continuation payoff is less than coordination benefits.

We also prove that the firm with private information behaves similarly with the firms in the complete information environment of Farrell and Saloner (1988). In contrast, the other firm is less aggressive than the firms in the complete information environment. The lack of private information makes the limiting behavior of the firms different from that in Farrell and Saloner (1988). The probability of achieving coordination is higher in the market in an incomplete information environment compared to the complete information one in a very long market game, by reducing the vested interest of the firm without private information.

We then analyze the mixed strategy equilibrium in the dynamic committee game. Here, firm A is allowed to reveal or not reveal its private information before the firms play the coordination game for two periods. As in chapter 2, the class over which firm A reveals is finite unions of disjoint intervals of the type space. We note that the non-revelation equilibrium in the two-period committee game is characterized by a particular relationship between coordination cutoffs in the two periods. This condition is easily satisfied by symmetric distributions.

Lastly, this chapter compares the standardization outcomes in the committee and the market. Most of the theoretical literature comparing market with committee-driven standards has focused on mostly either on the market or on the committee (or a hybrid mechanism which has the institutional characteristics of both the committee and the market) relative to the market.

Casual empiricism suggests otherwise. It does appear that some network industries are more suitable for market-based standards and some for committee based standards. Vercoulen and Wegberg (1998) notes that "the Internet, the telecom and the computer industry created different institutional contexts for developing and selecting standards." Most of the successful standards in the computer industry (and the internet) mainly evolved through the market place whereas in telecommunications, standards were mostly defined or selected in official standards bodies, such as the ITU, which is a formal organization (Garud and Kumaraswamy (1993), Besen and Saloner (1989), Cargill (1989)).

Another interesting anecdotal evidence is provided by the two common identifiers of a person in the modern e-age: her email address and mobile number. Interestingly, both of these technologies are immensely successful products of two very different network industries. The successful standards that drove the tipping of the market in the favor of these technologies were formulated by very different processes. The hugely successful GSM standard, which is deployed in 82 percent of mobile phone networks worldwide[1], was the fruit of a elaborate Group Social Mobile committee involving 14 EU countries, handset companies, chip manufacturers and service providers. When it came out, it faced multiple entrenched competitors (AMPS for example had been in commercial usage in the USA, NMT was already operating in Scandinavia); yet, in a very short time, it spread like wild fire, initially in Europe and then in China and India, driving exponential growth in these markets.

On the other hand, the successful SMTP (Simple Mail Transfer Protocol) that drives 92 percent of the e-mail clients worldwide had its genesis in a bandwagon started experimentally at the University of Berkeley and then distributed for free to other universities and eventually commercial entities. A competing standard, X.400, formulated by a technical committee of the International Telecommunication Union, with the full weight of the world's leading authorities behind it, failed to take off. By the time that the first recommendations of the X.400 committee were finalized, the bandwagon had already rolled in favor of the SMTP.

Other instances of the market delivering standards is in the case of video-tapes, as shown by the recent victory of the Blu Ray standard over the HD DVD standard in 2000-03 and the success of the VHS standard over the BetaMax[2].

[1]This should be read as GSM and its successors UMTS etc

[2]Farrell and Saloner (1988) mentions that the presence of VHS and Beta standards show the failure of the market bandwagon. However, at present, the market share of the Beta standard is less than 2 per cent worldwide. The market bandwagon did allow VHS to become the successful standard.

There are other instances where the market has failed to develop a bandwagon. One is example, as pointed out by Farrell and Saloner (1988), is the presence of three incompatible standards for color television (NTSC, SECAM and PAL).

Table 3.1 summarizes some of the committees responsible for standardization in telecommunications. Infact, the importance of committee-based standards in telecommunications has increased over time as the mobile industry has matured. As illustrated, different industries can be roughly classified

	Route to standardization	Year
First generation	NMT: FDMA analog based technology (Nordic Radio/Steering Committee)	1981
Second generation	GSM: TDMA and FDMA digital and non-packet based technology (Groupe Special Mobile)	1991
Third generation	UMTS:WCDMA packet-based technology (Electronic Communications Committee of the CEPT)	2001

Table 3.1: Standardization in mobile telephony

in terms of the different routes which have led to successful standardization in these industries. There are many factors behind the success of these standard which tell a complicated story. Nonetheless, it is true on an average that successful standards in analog television and video recording and optical disc formats have been largely market driven, whereas those in mobile telephony are exclusively committee driven.

These cross-sectional variations in the success of committees relative to the market aside, there are also temporal variations within a given network industry. As an industry matures, the route to successful standards keep changing. A relatively new industry grows by introducing new standards when requirements of coordination among different firms in the industry at the time of product introduction is not too large. As an industry matures, coordination requirements increase. Therefore, it is not surprising that as networking has become more important and introduction of new products become more costly and complicated, standardization through committees or alliances are becoming more important even in the computer industry.

The model in this chapter provides a possible explanation for why committee-based standards are more successful ex ante in some network industries relative to others at a given point in time (cross-sectionally) as well as why successful standardization uses different routes as it matures (temporally). This explanantion does not depend on delays in committee based standards. Rather, the model depends on the presence of one-sided asymmetric information about private benefit from standards and that different network industries are characterized by different exogenously given coordination benefits. Depending upon the relevant strength of the exogenous coordination benefit to private benefit, the model predicts the efficiency in standardization of the committee relative to the market in different network industries.

We contrast the probability of coordination in the two period market and the committee games. For the purpose of this comparison, we assume that the firm with private information has its types distributed uniformly over the interval $[0, 1]$. We also use assume that the private benefit $b = 0.5$ of the firm without private information.

In the comparison of coordination probability of the two period committee and market games, in the specific case where types are uniformly distributed over [0, 1], we find that the relative efficiency of the market, for a given value of c and b, changes as θ changes. We also find that:
For $b = 0.5$ and c at some low value close to max θ:

- the market is conditionally more efficient than the committee mostly by coordinating on "good ideas", rather than not coordinating on "bad ideas".

- coordination in the market is more risky than the committee upto a certain cutoff θ. Above that cutoff, the market is either less risky or as risky as the committee. For instance, given $c = 2$, the committee risk is lower up to $\theta = 0.6$ and above it, the risk is the same in the two institutions.

For c at some high value relative to max θ ($c > 2$)and $b = 0.5$, we observe that:

- coordination risk in the market is higher than in the committee. For instance, for $c = 50$, the market is more risky than the committee for all values of θ.

- committee exhibits higher efficiency mostly by coordinating on "good ideas" rather than rejecting "bad ideas". For instance, for very high values of c, say around 50, the committee shows higher conditional efficiency than the market for almost all values of θ other than those in a narrow range.

In both the games, probability of coordination are declining in θ, indicating that for higher values of θ, relative to c, firm A becomes more aggressive reducing chances for coordination. The same holds for the behavior of firm B as well.

In terms of expected payoffs to the firms, we find that for lower values of c relative to the maximum value of θ the market "rewards most good ideas" and "kills some bad ideas" more efficiently than the committee. For higher values of c, the committee outperforms the market in compensating good ideas.

Our model suggests that different network industries at a point in time can be characterized by c. Relative efficiency of the market depends on how high c is in relation to the private benefits. For very high values of c, the committee outperforms the market on all counts. However, for lower values of c in relation to private benefits, the market does seem to provide efficient standardization solutions.

The nature of standardization needs some comment. Intuitively, one might expect that the market bandwagon, with very little allowances made for coordination, would punish "bad ideas" severely and commensurately reward "good ideas". However, the result of our model is that the market seems to perform the latter task better than the former, for relatively low values of c.

This chapter is organized as follows: section 3.2 provides the review of relevant literature. Section 3.3 introduces and characterizes the mixed strategy equilibrium of the N-period market game, with firm A playing a cutoff strategy to firm B's mixed strategy. Section 3.4 introduces and characterizes the mixed strategy equilibrium in the two period committee game. These results are used in section 3.5, which details the two-period coordination probabilities of the market and the committee games. It compares the information revelation results in the two period market and the committee games. Section 3.6 concludes.

3.2 Literature review

Farrell and Saloner (1988) was one of the earliest papers to analyze the comparative efficiency of the market, the committee and hybrid mechanism in achieving standardization in network industries in a game of complete information. The market game in their paper shares the same institutional structure as in our game. However, introducing one-sided asymmetric information changes some of their results.

Among other papers comparing institutional standardization capabilities, Farrell and Simcoe (2009) provides an explanation for why the market might be a preferred institution for standardization by focusing on the delays in committee-based standards in a war-of-attrition game for standard formation. These papers, however, do not tie down performance of standardizing institutions to the features of the network industries.

There is some empirical literature noting the pattern of standardization in network industries cross-sectionally and temporally. Among early examples, Besen and Johnson (1986) summarize their empirical findings from seven cases of standardization in the broadcasting industry with particular reference to the *de facto* coordination on Video-Cipher, after Home Box Office chose it as the protocol for scrambling signals and the evolution of a standard in the AM stereo market. Among other observations, they note that difference in preferences among the firms and the users hampers the process of standardization. Berg and Schumny (1990) document the failure of a market-based standard to emerge in radio. Crane (1978) observes a similar result for the TV broadcasting industry. Swann (1985) and Swann (1987) summarize standards evolution in the U.S microprocessor industry, noting that there is a lot of design variety (standardization through the market bandwagon) in the early stages of the development of the technology, but at later stages product variety gets streamlined. The requirement of coordination becomes more important in a mature network industry and this reflects in a change in the manner in which standardization occurs over time.

Breshanan and Chopra (1990) provide another explanation for why standards might successfully emerge through the market rather than consensually through a committee by contrasting the development of standards in local area networks (LANs) in the factory and in offices. Conflict between users (who prefer compatibility) and the vendors (who prefer to market non-standardized proprietary products to "lock-in" consumers) drive the results. Therefore, the initial market structure and concentration of buyers and vendors. The presence of a large vendor, such as IBM, would indicate that tipping of standards through the market bandwagon.

Our examination of why the market and not the committee does not consider conflicts of interest between the buyers and the sellers in these markets. Rather, the focus is on the presence of one-sided asymmetric information when there is conflict of interest among the sellers themselves. Brock (1989) pursues this line of reasoning in his account of the development of the COBOL and the ASCII standards for mainframe computers. The disagreement between IBM and the other firms engendered standards throught the market bandwagon.

3.3 Dynamic Market Game

3.3.1 Action sets, Payoffs, Strategies and Equilibrium

Let $\Gamma_m(k, N)$ denote the game in the kth period in a N-period market game. Thus, $\Gamma_m((N-1), N)$ and $\Gamma_m(0, N)$ are the first and the last periods respectively of an N-period market game.

The action set for firm A is A_A and for firm B, it is A_B and can be described in two stages. In **stage 1**, each firm $i \in \{A, B\}$ simultaneously takes an action from the set

$$A_i = \begin{cases} \{\text{adopt own technology, wait}\}, \ \forall k \neq 0, \\ \{\text{adopt own technology,} \\ \ \text{switch to the competing technology}\}, \ \text{if } k = 0. \end{cases}$$

In **stage 2**, if both the firms choose {wait, wait} in period k, then the game goes to the following period $(k-1)$. Else, the game terminates.

The interpretation is that if any firm adopts its own technology, it becomes committed to it. If, simultaneously, the other firm has chosen to wait, then the bandwagon forms in favor of the committed technology, terminating the game. On the other hand, if the other firm also adopts, then the game terminates with the market getting fragmented into two incompatible technologies. Since $c > \{b, \max \theta\}$, it then follows that if one firm adopts its technology while the other waits, then in the second period, it is a dominant strategy for the waiting firm to switch. This is how the bandwagon effect arises in this case. **The actions of the market game are irreversible and thus if any of the firms adopt its technology in the first period, then in the second period, that action cannot be undone.**

We consider the payoff matrix in any period k of the market game in the table 3.2. Note that $V_i(k-1)$ are continuation payoffs from the remaining subgames. For convenience, let $V_A(k-1) = w$ and $V_B(k-1) = z$. In period $k = 0$, $w = z = 0$.

Let h^k be the history of the market game upto period k. $\mathcal{M}$ is the set of behavioral strategies played by B at every information set of the market

	Wait	Adopt B
Adopt A	$\theta + c$, c	θ, b
Wait	w,z	c, $b + c$

Table 3.2: Payoff matrix for the generic market game

game. $\mathcal{C}$ is the set of cut-off strategies played by firm A, with $\mathcal{C} \subset \mathcal{M}$.

Firm A's strategy in period k is a mapping $\sigma_A^k : h^k \times \Theta \to \Delta(A_A)$.

Definition 1. *The function σ_A belongs to the cutoff class of strategies $\mathcal{C}$ if it satisfies the following property: $\forall k$, $\exists\ \theta_k$, s.t.*

$$\sigma_A = \begin{cases} \textit{adopt own technology, if } \theta \geq \theta_k, & (3.1) \\ \textit{wait (switch to the competing technology if } k = 0\textit{), otherwise} & (3.2) \end{cases}$$

Firm B's period k behavioral strategy is a mapping $\sigma_B^k : h^k \to \Delta(A_B)$. Let $\sigma = \sigma_A \times \sigma_B$. Firm B's inference function about A's types is $\beta(h^k) : M \to \mathcal{B}$, where $\mathcal{B}$ is the space of probabilities over A's types. Elements of $\mathcal{B}$ represent beliefs about A's type.

Recall from the model in chapter 2 that R is the set of types of firm A that do not reveal and that R_A is the set of types that adopt without revealing in the coordination stage. Due to the different structure of the market game, we have that in any period k of the market game:

Definition 2. *$R(k) = R_A(k)$ is the set of types of firm A that adopt and do not reveal their types in period k of the market game.*

3.3.2 Characterization of the weak PBE of the dynamic market game

We first solve for the equilibrium in the generic market game. It should be noted that payoffs are not aggregated across periods. Payoffs accrue at the end of the game. At the beginning of every period, firm A has the option to reveal its private information by adopting its own technology. The generic payoff matrix is given in table 3.2

Proposition 1. *Suppose in period k, firm B believes that $\theta \in [\theta_l, v]$, where θ is distributed according to $F(\theta)$ on $[\theta_l, \theta_h]$. Let x_{k-1} and y_{k-1} be the continuation payoffs in period k from the remaining $(N-k)$ periods for firms A and B respectively. Then, in the weak PBE of the generic market game $\exists F(\theta_k) = \frac{c-b}{2c-y_{k-1}}F(v)$ such that $\forall \theta \leq \theta_k$, type θ of firm A waits (switches if $k=0$) and $\forall \theta > \theta_k$, firm A of type θ adopts. Firm B's equilibrium behavioral strategy of adopting $q_k = \frac{F^{-1}(\frac{c-b}{2c-y_{k-1}}F(v))}{2c-x_{k-1}} + \frac{c-x_{k-1}}{2c-x_{k-1}}$. A sufficient condition for this equilibrium is $c > \delta$, $\delta = x_{k-1}, y_{k-1}$.*

Proof. Suppose the game enters period k. Then, firm B believes that $\theta \in [\theta_l, v]$, as types in $[v, \theta_h]$ have already adopted and revealed their types prior to this period. On the other hand, types in the range $[\theta_l, v]$ have chosen to wait in the earlier period. Note that $v = \theta_{k+1}$, the coordination cutoff for the previous period. The game enters period k with probability $(1 - q_{k+1})$ because firm B chooses to wait in period $(k+1)$ with this probability.

Suppose θ_k is the coordination cutoff in period k. At θ_k, firm A is indifferent between adopting and waiting.

$$\pi_{A;\theta}(k) = x_k = \begin{cases} (1-q_k)(\theta_k + c) + q_k\theta_k \;\forall\; \theta \in (\theta_k, v] \\ (1-q_k)x_{k-1} + q_k c \;\forall\; \theta \in [\theta_l, \theta_k] \end{cases} \tag{3.3}$$

Firm A's payoff, as given in (3.3), yields θ_k in (3.4).

$$\theta_k = (2q_k - 1)c + (1-q_k)x_{k-1} \tag{3.4}$$

Note that $\theta_l < \theta_k < \theta_h$ implies that $\theta_l < cq_k - (1-q_k)(c - x_{k-1}) < \theta_h$. A sufficient condition for this to hold is that $c > x_{k-1}$. Any such type above θ_k gets a lower payoff by deviating and waiting. Similarly, any θ_k below the cutoff gets a lower payoff by deviating from the action of waiting.

Given firm A's strategy, firm B's belief that firm A will adopt, given that firm A waited in the previous period, is:

$$\beta_k = \frac{F(v) - F(\theta_k)}{F(v) - F(\theta_l)} = \frac{F(v) - F(\theta_k)}{F(v)} \tag{3.5}$$

Given this belief, firm B maximizes its payoff given in (3.6).

$$E(\pi_B(k)) = y_k = q_k(\beta_k b + (1-\beta_k)(b+c)) + (1-q_k)(\beta_k c + (1-\beta_k)y_{k-1}) \tag{3.6}$$

Maximizing (3.6) with respect to q_k yields:

$$\beta_k = \frac{b + c - y_{k-1}}{2c - y_{k-1}} \tag{3.7}$$

Note that a sufficient condition for $0 < \beta < 1$ is that $c > y_{k-1}$. On simplification, we get the relation between θ_k and $v = \theta_{k+1}$ from equation (3.5):

$$F(\theta_k) = (1-\beta_k)F(v) + \beta_k F(\theta_l)) = (1-\beta_k)F(v) = \frac{c - b}{2c - y_{k-1}}F(v) \tag{3.8}$$

In equilibrium, equating θ_k from (3.4) and (3.8), we get:

$$q_k = \frac{F^{-1}(\frac{c-b}{2c-y_{k-1}}F(v))}{2c - x_{k-1}} + \frac{c - x_{k-1}}{2c - x_{k-1}} \tag{3.9}$$

It should be noted that for $0 < q_k < 1$ it is sufficient that $c > v$, which holds as $c >$max(θ). ■

Proposition 1 characterizes the equilibrium in any period k of the market game. In the last period, we know that that continuation payoffs are zero. Using the results from proposition 1, we can find out the equilibrium cutoff, firm B's strategy and payoffs in the last period.

Corollary 1. *In the last period of the game with zero continuation payoffs, the equilibrium coordination cutoff is* $\theta_0 = F^{-1}(\frac{c-b}{2c})$ *and firm B's strategy of adopting is* $q_0 = \frac{1}{2} + \theta_0 = \frac{1}{2} + F^{-1}(\frac{c-b}{2c})$*. Firm A's equilibrium payoff is:*

$$\pi_{A;\theta}(0) = x_0 = \begin{cases} \theta + (1 - q_0)c \; \forall \; \theta \in [\theta_0, \theta_h] \\ q_0 c \; \forall \; \theta \in [\theta_l, \theta_0] \end{cases}$$

Firm B's equilibrium payoff is: $E(\pi_B(0)) = y_0 = \frac{b+c}{2}$.

Proof. In the last period, firm A of types $[\theta_0, \theta_h]$ adopt and reveal and those in the range $[\theta_l, \theta_0]$ wait without revealing their type. From equation (3.5), we observe that in the last period, $\beta_0 = \frac{F(\theta_h)-F(\theta_0)}{F(\theta_h)-F(\theta_l)} = 1 - F(\theta_0)$. From equation (3.7), the conditional probability that firm A will adopt given that it waited in the previous period is $\beta_0 = 1 - F(\theta_0) = \frac{b+c-y_0}{2c-y_0} = \frac{b+c}{2c}$. On simplification, the equilibrium cutoff θ_0 is given by:

$$\theta_0 = F^{-1}\left(\frac{c-b}{2c}\right) \tag{3.10}$$

From equation (3.9), the equilibrium strategy of firm B is given by:

$$q_0 = \frac{F^{-1}((1-\beta)F(\theta_h))}{2c-0} + \frac{c-0}{2c-0} = \frac{\theta_0}{2c} + \frac{1}{2}$$

As the continuation payoff is zero, from equation (3.3), we get the equilibrium payoff of firm A as:

$$x_0 = \begin{cases} \theta + (1-q_0)c \; \forall \; \theta \in [\theta_0, \theta_h] \\ q_0 c \; \forall \; \theta \in [\theta_l, \theta_0] \end{cases}$$

Equation (3.6) and the equilibrium cutoff θ_0 as given in equation (3.10) indicate that firm B's equilibrium payoff is:

$$y_0 = \beta_0 c = (1 - F(\theta_0))c = (1 - \frac{c-b}{2c})c = \frac{c+b}{2} \tag{3.11}$$

■

The following proposition reflects on the uniqueness of the equilibrium.

Proposition 2. *If the weak Perfect Bayesian equilibrium in the generic market game exists, then it is unique.*

Proof. The payoff of firm A is:

$$\pi_{A;\theta}(k) = x_k = \begin{cases} (1-q_k)(\theta + c) + q_k\theta \; \forall \; \theta \in (\theta_k, v] \\ (1-q_k)x_{k-1} + q_k c \; \forall \; \theta \in [\theta_l, \theta_k] \end{cases}$$

The expression for the payoff of firm A is linear in θ. If a type $\hat{\theta}$ wants to adopt A, then all types higher than $\hat{\theta}$ would also want to adopt A. ■

3.3.3 Dynamic Market Game: Limiting properties of payoffs

Given the form of expected payoff of firm B in any general period k and that in the last period from corollary 1, we can find the following relationship between the expected payoff of firm B in period k, the coordination cutoff in period k and that in the last period 0.

Corollary 2. *The expected payoff of firm B in any period k can be expressed as:*

$$y_k = \left(1 - \frac{F(\theta_k)}{2F(\theta_0)}\right) c + \frac{F(\theta_k)}{2F(\theta_0)} b \tag{3.12}$$

Proof. In the last period, the expected equilibrium payoff of firm B from equation (3.11) is $y_0 = \frac{c+b}{2}$. Therefore, from the form of the expected payoff in period k in equation (3.6) and noting that $\beta_1 = \frac{F(\theta_0)-F(\theta_1)}{F(\theta_0)}$ in the penultimate period, the equilibrium expected payoff of firm B in the penultimate period is:

$$y_1 = \beta_1 c + (1-\beta_1) y_0 = c - \left(\frac{F(\theta_1)}{F(\theta_0)}\right) \frac{c-b}{2} \tag{3.13}$$

Similarly, in period 2, with $\beta_2 = \frac{F(\theta_1)-F(\theta_2)}{F(\theta_1)}$ and y_1 given by the equation above, we get:

$$y_2 = \beta_2 c + (1-\beta_2) y_1 = c - \left(\frac{F(\theta_2)}{F(\theta_0)}\right) \frac{c-b}{2} \tag{3.14}$$

Therefore, by induction, in period k, the expected equilibrium payoff of firm B is:

$$y_k = c - \left(\frac{F(\theta_k)}{F(\theta_0)}\right) \frac{c-b}{2} = \left(1 - \frac{F(\theta_k)}{2F(\theta_0)}\right) c + \frac{F(\theta_k)}{2F(\theta_0)} b \tag{3.15}$$

■

The corollary above can now be used to characterize the equilibrium payoffs of the firms in any general period k of the market game.

Proposition 3. *In any period k, the equilibrium payoffs for firms A and B are such that:*

$$\theta < x_k < c + \theta \ \forall \ \theta, k$$

$$b < y_k < c \ \forall k$$

Proof. For firm A, from equation (3.3), we observe that the equilibrium payoff in period k is:

$$\pi_{A;\theta}(k) = x_k = \begin{cases} (1 - q_k)(\theta_k + c) + q_k\theta_k \ \forall \ \theta \in [\theta_k, v] \\ (1 - q_k)x_{k-1} + q_k c \ \forall \ \theta \in [\theta_l, \theta_k] \end{cases}$$

For all $\theta > \theta_k$, it is obvious that $\theta < x_k < \theta + c$. For all $\theta \leq \theta_k$, we can prove by induction that $\theta < x_k < c$. To see that, observe that in the last period for all $\theta \leq \theta_0$, $x_0 = q_0 c = \frac{\theta_0 + c}{2}$. As $c >$maxθ, $\theta_0 < x_0 < c$. As $\theta \leq \theta_0$ for this payoff of x_0, it must be the case that in the last period, $\theta < x_0 < c$.

In the penultimate period,

$$x_1 = (1 - q_1)x_0 + q_1 c \ \forall \ \theta \in [\theta_l, \theta_1] \tag{3.16}$$

As $\theta < x_0 < c$, it must be the case that $\theta < x_1 < c \ \forall \ \theta \leq \theta_1$. By induction, we get that for any period k, $\theta < x_k < c \ \forall \ \theta \in [\theta_l, \theta_k$. Therefore, for all θ, in any period k, it must be the case that $\theta < x_k\theta + c$.

Further, from equation (3.12), observe that:

$$y_k = \left(1 - \frac{F(\theta_k)}{2F(\theta_0)}\right)c + \frac{F(\theta_k)}{2F(\theta_0)}b \tag{3.17}$$

The right hand side of this equation is a weighted average of c and $b < c$. Therefore, $b < y_k < c$. ∎

The following propositions 4 and 5 characterize the limiting payoffs to either firm and the equilibrium coordination (and information revelation) cutoff respectively.

Proposition 4. *The limiting value of the payoff to either firm tends to c as the number of periods k tend to infinity if all continuation payoffs x_{k-1}, y_{k-1} are less than c.*

Proof. From equation (3.3), we find the equilibrium relation between the payoffs in periods k and the continuation payoffs from the remaining $(N-k)$ periods, x_{k-1} for firm A is:

$$x_k = (1 - q_k)x_{k-1} + q_k c \tag{3.18}$$

If $c > x_k$ in all periods k, $x^* \to c$ as k tends to infinity. The equilibrium payoffs in periods k and the continuation payoffs from the remaining $(N-k)$ periods, for firm B is given by equation (3.6):

$$y_k = \beta_k c + (1 - \beta_k)y_{k-1} \tag{3.19}$$

As $0 < \beta_k < 1$, we get that $y^* \to c$ as k tends to infinity if $c > y_k$ for all k. ∎

We observe from equations (3.18) and (3.19) that $x_k - x_{k-1} = q_k(c - x_{k-1}) > 0$ and $y_k - y_{k-1} = \beta_k(c - y_{k-1}) > 0$. As k increases, it is true that $c > y_{k-1}$ and therefore, the limiting behavior of firm B's payoff is unaffected. However, as $\theta < x_k < \theta + c \,\forall\, \theta$ (from Proposition 3), and $x_k > x_{k-1}$, there exists some $k = \hat{k}$ above which $c < x_k$. Beyond $\hat{k}$, the limiting payoff of firm A exceeds c. However, this indicates that firm A no longer waits, as its payoff from waiting is bounded above by c (from equation (3.18)). Therefore, firm A simply adopts revealing its type ensuring that firm B switches[3] to firm A's technology for the market game with $k \geq \hat{k}$. The mixed strategy equilibrium no longer holds for such a long market game and a pure bandwagon forms in favor of A's technology. The mixed strategy equilibrium holds for all market games with periods $k < \hat{k}$.

This observation is further bolstered by the following Proposition 5, which shows the behavior of the limiting coordination cutoff.

Proposition 5. *The limiting value of the coordination (and information revelation) cutoff* θ^* *tends to* θ_l *as the number of periods* k *tend to infinity.*

Proof. We first note that the coordination cutoff of an earlier period becomes the upper bound of the type space that firm B believes types to be distributed in in a particular period. If the game enters period k, then from equation (3.8) we find the relationship between coordination cutoffs θ_k and $\theta_{k-1} = v$

[3]Firm B's equilibrium mixed strategy in period k, $0 < q_k < 1$ requires that $c > v$ as shown in Proposition 1. For $k \geq \hat{k}$, this condition does not hold and the equilibrium strategy degenerates to the pure strategy $q_k = 0 \;\forall\; k \geq \hat{k}$.

as:

$$F(\theta_k) = (1 - \beta_k)F(v) + \beta_k F(\theta_l)) = (1 - \beta_k)F(\theta_{k-1}) \tag{3.20}$$

As F(.) is monotonic, $0 < \beta_k < 1$, the equation (3.20) shows that:

$$\frac{F(\theta_k)}{F(\theta_{k-1})} = 1 - \beta_k < 1 \tag{3.21}$$

This proves that the relation between the equilibrium cutoffs are: $\theta_k < \theta_{k-1} \ \forall \ k$. It also indicates that as k tends to infinity, $F(\theta^*)$ tends to zero, which in turn implies that θ^* tends to θ_l. ■

Proposition 5 shows that the equilibrium coordination cutoff is more to the left for an earlier stage compared to a later stage in the market game, indicating that firm A is more aggressive towards the beginning of the game. The range for adopting A is higher in the early stages of play. In Farrell and Saloner's model, in an environment of complete information, a similar result obtains proving that there is very little coordination in the early stages of the game. In this model, firm A with private information behaves similarly as the firms in Farrell and Saloner (1988). It is very aggressive in the initial periods of coordination in the game.

The following proposition characterizes the limiting probability of adopting for firm B.

Proposition 6. *The limiting value of the probability of adopting for firm B, q^* tends to $\frac{\theta_l}{c}$ if the continuation payoffs are less than c.*

Proof. Proposition 1 proves that in any period k, as long as the continuation payoffs x_{k-1} and y_{k-1} are less than the coordination benefits c, the probability of adopting B is given by:

$$q_k = \frac{F^{-1}\left(\frac{c-b}{2c-y_{k-1}}F(\theta_{k+1})\right)}{2c-x_{k-1}} + \frac{c-x_{k-1}}{2c-x_{k-1}}$$

Proposition 4 proves that the limiting values of the payoffs of both the firms tend to c (with the restriction on continuation payoffs). Proposition 5 proves that the coordination cutoff, in the limit, tends to θ_l. Therefore, as k tends to infinity,

$$q^* = \frac{F^{-1}\left(\frac{c-b}{c}F(\theta_l)\right)}{c} + 0 = \frac{F^{-1}(0)}{c} = \frac{\theta_l}{c}$$

■

In contrast with the behavior of firm A, firm B is not as aggressive as in the complete information setup (Farrell and Saloner (1988)) in a very long market game. In the limit, firm B's strategy of adopting its own technology is strictly less than 1. This result demonstrates the impact of one-sided asymmetric information in the market game. It makes firm B less aggressive than in the case where it does not have imperfect information about A's type.

The second point to note is that as θ_l (the lower bound of the type space of firm A's types) falls, the limiting value of the probability of adopting by firm B falls. This stems from the feature of the completely mixed strategy of firm B: q^* is an increasing function of θ. The purpose of firm B's mixed strategy is to keep a type θ indifferent between adopting and waiting. The higher is firm A's type, the higher has to be q^* in order to make this higher type indifferent between adopting and waiting.

3.4 Dynamic Committee Game

The timing of the dynamic committee game is: in the first stage, firm A decides whether or not to reveal its private information. In the second stage, the firms play the coordination game for two periods. There difference from the market game, in the coordination game, is that there are two distinct paths {insist, insist} and {wait, wait} leading to the last period. The last period of the coordination game is the same as that of the one-shot game[4].

The unique mixed strategy equilibrium in the one-shot game is driven by the relation between q_R and q_{NR}. Non-revelation allows firm A to insist when $q_R > q_{\mathrm{NR}}$ and to switch when $q_R < q_{\mathrm{NR}}$. The dynamic committee game is structurally different from the one-shot game because in the former, it is not only the dynamics of q_R and q_{NR} but also that of the continuation payoffs x_R and x_{NR} for firm A that determine the equilibrium disclosure strategy. There is a tradeoff between making firm B less aggressive (reducing q_{NR}) and reducing the continuation payoff x_{NR} relative to x_R through non-revelation. The strength of this trade-off is determined by the relation between the cutoffs in the different periods.

We explicitly solve the two-period committee game to characterize this tradeoff. We first investigate the conditions under which non-revelation is an

[4]We model the dynamic committee where the firm A gets to reveal its information only at the beginning of the two period coordination game and not prior to each period of the coordination game. The reason is that most technical committees arrange for a round of discussions before finalizing the standard. An alternative formulation would allow for communication of private information prior to every period of coordination.

equilibrium in the mixed strategy equilibrium of this game.

The payoff matrix in the first period is the same as shown in table 3.3, where x, y and w, z are the continuation payoffs corresponding to the two distinct histories leading to the last period. In the last period, the payoff matrix is the same as that in the one-shot game, with $x = \theta$, $y = b$, and $w = z = 0$.

	Wait	Adopt B
Adopt A	$\theta + c$, c	x, y
Wait	w,z	c, $b + c$

Table 3.3: Payoff matrix for the generic market game

The cutoff coordination strategy for firm A in the two period game is:

1. insist in period 1 and adopt in period 2 if $\theta \in [\theta_1^2, \theta_h]$
2. insist in period 1 and switch in period 2 if $\theta \in [\theta_1, \theta_1^2]$
3. wait in period 1 and adopt in period 2 if $\theta \in [\theta_2^2, \theta_1]$
4. wait in period 1 and switch in period 2 if $\theta \in [\theta_l, \theta_2^2]$.

As noted in chapter 2, for each of the two paths, there exist coordination cutoffs for firm A θ_i^2, $i = 1, 2$ (as in the one-shot game). With non-revelation in equilibrium, the continuation payoffs for firm A are $x_i = \frac{c}{2} + \frac{\theta_i^2}{2}\ \forall\ i = 1, 2$. The payoff to type θ with full revelation in the single period game is $\frac{c}{2} + \frac{\theta}{2}\ \forall\ \theta$ which becomes the continuation payoff $x_R(\theta)$ in the two period game.

Let q_{NR} be firm B's probability of insisting on B in period 1 and let $q_{\text{NR}}(h_i^2)$ be firm B's probability of adopting B in period 2 following each of the histories $h_i^2, i = 1, 2$.

Corollary 3. *If no type reveals in equilibrium, then the coordination stage requires a cutoff strategy for firm A in the two period game.*

Proof. Suppose no type reveals in equilibrium in the two period game. Then,

$$\pi_A(\text{NR, insist}) = (1 - q_{\text{NR}})(\theta + c) + q_{\text{NR}} x(h_1^2) \quad (3.22)$$

$$\pi_A(\text{NR, wait}) = (1 - q_{\text{NR}}) x(h_2^2) + q_{\text{NR}} c \quad (3.23)$$

The payoff from not revealing and insisting increases linearly with θ, whereas the payoff from not revealing and waiting is a constant. Hence, if there exists for some $\theta' \in [\theta_l, \theta_h]$ where firm A of type θ' prefers insisting to waiting, then for all $\theta > \theta'$ the payoff from not revealing and insisting will dominate the payoff from not revealing and waiting. Therefore, there will exist a cutoff θ_1 in period such that all θ above it will insist and all θ below it will wait.

For all $\theta > \theta_1$, the game goes to the last period with probability $q_{\text{NR}}(h_1^2)$ following the path along the history h_1^2. Similarly for all $\theta < \theta_1$, the game goes to the last period with probability $q_{\text{NR}}(h_2^2)$ following history h_2^2. Since the last period game has the same structure as the single period game described in the last section, we get from Lemma 1 that there will exist cutoffs θ_i^2 for each history $h_i^2, i = 1, 2$ in the last period of the two period game. ■

Note that h_1^2 arises from the action profile {insist on A, insist on B}, whereas h_2^2 arises from the action profile {wait, wait}. Hence, by the definition of firm A's cutoff strategy, $\theta_1^2 > \theta_2^2$, where $\theta_l < \theta_i^2 < \theta_h$, $i = 1, 2$.

Definition 3. $\Delta = \theta_1 - \frac{(\theta_1^2 + \theta_2^2)}{2}$

The sign of Δ depends on the nature of the distribution function $F(\theta)$ and the parameters of the model c, b, θ_l and θ_h. For symmetric or negatively skewed distributions, $\Delta \leq 0$. For positively skewed distributions, $\Delta > 0$.

Proposition 7. *Suppose the two-period committee game involves* $\Delta \leq 0$. *Then, no other equilibrium other than full non-revelation exists.*

Proof. Suppose that no type reveals in equilibrium. Now consider any path along the history h_i^2 leading to the last period 2, $i = 1, 2$.

Step 1. Firm A's expected payoff maximization when it does not reveal its type: coordination cutoffs in the last period 2

In the last period, firm A of type θ adopts A if $\theta > \theta_i^2$ and waits if $\theta < \theta_i^2, i = 1, 2$. Type θ_i^2, $i = 1, 2$ must be indifferent between adopting A and switching in a mixed strategy equilibrium. This leads to the first order condition for $i = 1, 2$:

$$\theta_i^2 = \left(2q_{\text{NR}}(h_i^2) - 1\right) c \tag{3.24}$$

Step 2. Firm B's expected payoff maximization in period 2 when firm A does not reveal its type

In this period, firm B maximizes its expected payoff with respect to $q_{\text{NR}}(h_i^2)$, $i = 1, 2$.

$$\pi_B = q_{\text{NR}}(h_i^2)(\beta_i^2 b + (1 - \beta_i^2)(b + c)) + (1 - q_{\text{NR}}(h_i^2))(\beta_i^2 c + (1 - \beta_i^2)0) \tag{3.25}$$

where β_i^2 is the conditional probability that firm B will adopt given that it insisted without revealing in period 1. This maximization gives us:

$$\theta_1^2 = \theta_1^2(\theta_1) = F^{-1}\left(\frac{c-b}{2c} + F(\theta_1)\frac{b+c}{2c}\right) \tag{3.26}$$

$$\theta_2^2 = \theta_2^2(\theta_1) = F^{-1}\left(F(\theta_1)\frac{c-b}{2c}\right) \tag{3.27}$$

Both the last period cutoffs are monotonic functions of the first period cutoff, as F(.) is a monotonic function.

Step 3. Calculating the non-revelation equilibrium strategies $\hat{\theta}$ and $q_{\mathbf{NR}}$ in the last period of the two-period game

Equating the coordination cutoffs θ_i^2 for all i from A's and B's maximizations, we get the expressions for firm B's strategy, $q_{\mathrm{NR}}(h_i^2)$, in a mixed strategy equilibrium as functions of c and θ_1.

$$q_{\mathrm{NR}}(h_1^2) = \frac{1}{2} + \frac{\theta_1^2(\theta_1)}{2c} \tag{3.28}$$

$$q_{\mathrm{NR}}(h_2^2) = \frac{1}{2} + \frac{\theta_2^2(\theta_1)}{2c} \tag{3.29}$$

As $c >$max(θ), $0 < q_{\mathrm{NR}}(h_i^2) < 1 \ \forall i = 1, 2$.

Step 4. Calculating the continuation payoffs x_i and y_i, $i = 1, 2$, for firms A and B respectively

The continuation payoffs from the last period feeding into period 1 by the two different paths are:

$$x_1 = \frac{c}{2} + \frac{\theta_1^2(\theta_1)}{2} = f_1(c, \theta_1) < c$$
$$x_2 = \frac{c}{2} + \frac{\theta_2^2(\theta_1)}{2} = f_2(c, \theta_1) < c$$
$$y_1 = (\theta_h - \theta_1^2(\theta_1))(q_{\text{NR}}(h_1^2)b + (1 - q_{\text{NR}}(h_1^2))c) + (\theta_1^2(\theta_1) - \theta_1)q_{\text{NR}}(h_1^2)(b + c) < c$$
$$y_2 = (\theta_1 - \theta_2^2(\theta_1))(q_{\text{NR}}(h_2^2)b + (1 - q_{\text{NR}}(h_2^2))c) + (\theta_2^2(\theta_1) - \theta_l)q_{\text{NR}}(h_2^2)(b + c) < c$$

Note that all the continuation payoffs are less than c because $c > \max(\theta)$. More importantly, the continuation payoffs for firm A of type θ, $x_i,\ i = 1, 2$ are not only independent of θ, but also ordered such that $x_1 > x_2$ for all θ.

We can represent the continuation payoffs for firm B directly as functions of θ_1 and the other parameters of the model i.e., $y_1 = g_1(\theta_1, \theta_h, b, c)$ and $y_2 = g_2(\theta_1, \theta_l, b, c)$, due to the monotonicity of the distribution function F(.).

Step 5. Firm B's expected payoff maximization in the first period 1 when firm A does not reveal its type: calculating the first period coordination cutoff θ_1

Firm B maximizes π_B^1 with respect to q_{NR}.

$$\pi_B^1 = q_{\text{NR}}(\beta y(h_1^2) + (1 - \beta)(b + c)) + (1 - q_{\text{NR}})(\beta c + (1 - \beta)y(h_2^2)) \quad (3.30)$$

where β is the conditional probability that firm A will insist given that it has not revealed its type. The first order condition yields

$$\beta = \frac{F(\theta_h) - F(\theta_1)}{F(\theta_h) - F(\theta_l)} = \frac{b + c - y(h_2^2)}{2c + b - y(h_2^1) - y(h_2^2)} < 1 \quad (3.31)$$

Equation (3.31) very neatly allows the following condition on θ_1:

$$F(\theta_1) = (1-\beta)F(\theta_h) + \beta F(\theta_l) \tag{3.32}$$

As $0 < \beta < 1$ and as F(.) is a monotonic function, we get that $\theta_l < \theta_1 < \theta_h$. This condition, along with equations (3.26) and (2.18) further ensure that $\theta_l < \theta_2^2 < \theta_1 < \theta_1^2 < \theta_h$.

Upon simplifying equation (3.31), we get the solution for $\theta_1 = \theta^*$ uniquely determined in terms of the underlying parameters of the model θ_h, θ_l, b and c.

Step 6. Firm A's expected payoff maximization when it does not reveal its type: calculating firm B's period 1 strategy $q_{\mathbf{NR}}$

In a mixed strategy equilibrium, firm A of type $\theta_1 = \theta^*$ is indifferent between insisting and waiting.

$$(1-q_{\text{NR}})(\theta^* + c) + q_{\text{NR}} f_1(c, \theta_1) = (1-q_{\text{NR}}) f_2(c, \theta^*) + q_{\text{NR}} c \tag{3.33}$$

Therefore, the equilibrium strategy

$$q_{\text{NR}} = \frac{\theta^* + \frac{c-\theta_2^2}{2}}{c + \theta^* - \frac{\theta_1^2 + \theta_2^2}{2}} \tag{3.34}$$

As we have shown that all the continuation payoffs of firm A, $f_j(c, \theta^*) = \frac{c}{2} + \frac{\theta_i^2(\theta_1)}{2} < c; i, j = 1, 2$, we know that $0 < q_{\text{NR}} < 1$.

Step 7. Revelation payoff for firm A

If a type deviates and reveals, then its payoff in the two period game is: $\pi_A(\text{reveal}) = (1-q_R)(\theta + c) + q_R x_R = (1-q_R)x_R + q_R c = \frac{(3c-\theta)(\theta+c)}{4c}$. where $q_R = \frac{\theta + c}{2c}$ is the same as the that in the last period.

Step 8. Comparing the revelation and non-revelation payoff in the two period game

The slope of the payoff from revelation for type θ is slope $(1-q_R) = \frac{1}{2} - \frac{\theta}{2c}$. Hence, the slopes of the payoffs from revealing and not revealing are the same when $(1-q_{\text{NR}}) = (1-q_R)$. Suppose this occurs at $\theta = \theta'$, with $q_{\text{NR}} = q_R = q(say)$.

For all $\theta > \theta'$, the slope of the not reveal and insist payoff is greater than that of revealing implying that $q_{\text{NR}} < q_R$[5]. For all $\theta < \theta'$, $q_{\text{NR}} > q_R$ by similar reasoning.

Using the expression for q_{NR} from equation (3.34), θ' is given by:

$$\theta' = \frac{c(\theta_1^2 + \Delta)}{(c+\Delta)} \tag{3.35}$$

where, $\Delta = \theta^* - \frac{(\theta_1^2+\theta_2^2)}{2}$.

If one of these two conditions do not hold, then there is revelation of type in equilibrium. The first of these conditions is demonstrated to hold for $k=2$, if the coordination cutoffs in the two periods (θ_1 in period 1 and θ_i^2, $i=1,2$ in the last period 2) are such that: $\Delta = \theta_1 - \frac{\theta_1^2+\theta_2^2}{2} = 0$.

The second condition holds for N=2 if $\Delta = \theta_1 - \frac{\theta_1^2+\theta_2^2}{2} < 0$ If $\Delta = 0$, then $\theta' = \theta_1^2$. At θ_1^2, $x_1 = \frac{c}{2} + \frac{\theta_1^2}{2} = x_R(\theta_1^2) = x$. Therefore, π_A(NR, insist) and π_A(reveal) are tangent at θ_1^2. As the payoff from revealing increases at a decreasing rate, whereas the payoff from not revealing and insisting increases linearly with θ, π_A(NR, insist) $> \pi_A$(reveal) for all $\theta \in (\theta_1^2, \theta_h]$ and vice versa

[5] As the reveal payoff increases at a decreasing rate with θ, whereas the not reveal and insist payoff increases linearly with θ.

for all $\theta \in [\theta_l, \theta_1^2)$.

If $\Delta < 0$, then $\theta' < \theta_1^2$. At θ',

$$\pi_A(\text{NR, insist}) - \pi_A(\text{reveal}) = q(x_1 - x_R(\theta')) > 0 \tag{3.36}$$

For all $\theta \in (\theta', \theta_h]$ and for all $\theta \in [\theta_l, \theta')$, the revelation payoff is below the non-revelation but insist payoff as the latter increases linearly with θ and the former increases at a decreasing rate with θ.

At θ^*, $\pi_A(\text{NR, insist}) = \pi_A(\text{NR, wait}) > \pi_A(\text{reveal})$. At θ_l, $q_{\text{NR}} \geq q_R$ (as $\theta_l \leq \theta'$) and $x_2 > x_R(\theta_l)$.

$$c - \pi_A(\text{NR, wait}) = (1 - q_{\text{NR}})(c - x_2) < (1 - q_R)(c - x_R(\theta_l)) = c - \pi_A(\text{reveal}) \tag{3.37}$$

Therefore, in the interval $\theta \in [\theta_l, \theta^*]$, the payoff from not revealing and waiting is higher than the revelation payoff. Non-revelation is an equilibrium with no tangency of the reveal and not reveal and insist payoffs. ■

If $\Delta = 0$, then θ_h will never reveal and will belong to the non-reveal set R^c, where R^c is the set of all types which does not reveal. Let R^h be the subset of R^c that contains θ_h. If a revelation range is contiguous with R^h, then the infimum of the set R^h (where a type is indifferent between revealing and not revealing) has to be at θ_1^2. However, for any type $\theta_1^2 - \epsilon$, where ϵ is vanishingly small, the payoff from not revealing and insisting dominates the revelation payoff (as the two payoffs are tangent only at θ_1^2). Therefore, there cannot be any revelation range contiguous with a non-revelation range. Therefore, no type in the type-space will reveal compared to not revealing in equilibrium.

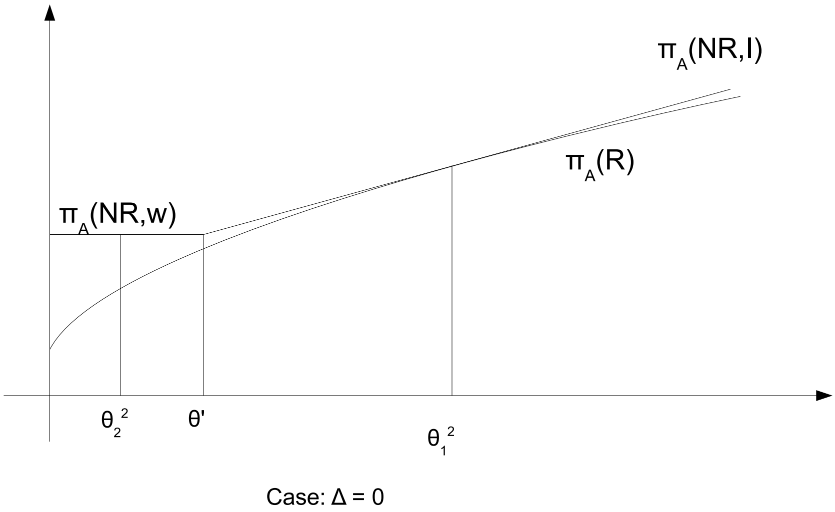


Figure 3.1: $\Delta = 0$

Similarly, if $\Delta < 0$, θ_h will never reveal and will belong to the non-reveal set R^c. There is no θ such that it is indifferent between revealing and not revealing now. Therefore, revelation and non-revelation intervals cannot alternate.

With $\Delta = 0$ and $\Delta < 0$, the non-revelation equilibria are shown in figures 2.4 and 2.5.

Note that $q_{\text{NR}} = q_{\text{NR}}(h_1^2) > q_{\text{NR}}(h_2^2)$ with $\Delta = 0$. The uniform distribution along with any type compact type space $[\theta_l, \theta_h] \subset \mathbb{R}_+$ satisfies $\Delta = 0$.

Proposition 8. *If $\Delta > 0$, then non-revelation is not an equilibrium of the two period committee game.*

Proof. If $\Delta > 0$, then $\theta' > \theta_1^2$. At θ', the revelation payoff exceeds the

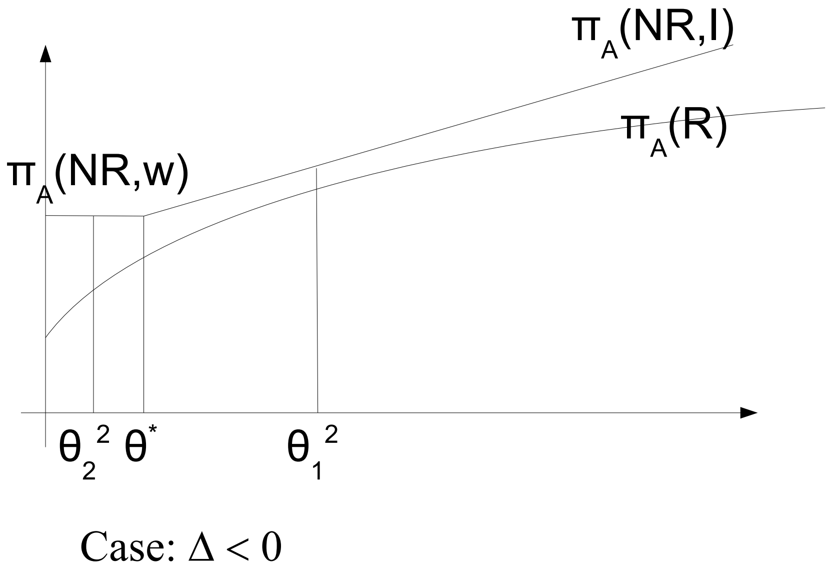


Figure 3.2: $\Delta < 0$

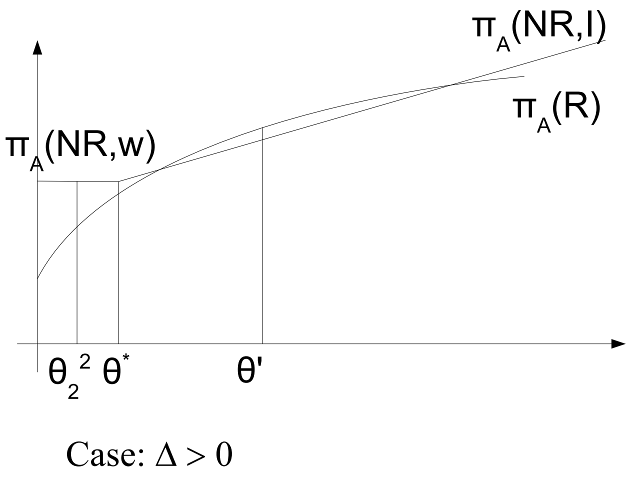


Figure 3.3: Case 1:$\Delta > 0$

non-revelation payoff.

$$\pi_A(\text{NR, insist}) - \pi_A(\text{reveal}) = q(x_1 - x_R(\theta')) < 0 \tag{3.38}$$

■

Possible equilibria if $\Delta > 0$ are shown in figures 2.6 and 2.7.

3.4.1 Coordination and Information Revelation: Discussion

What is most striking in the move from a single period game to a two period game is that the payoff from revelation is a non-linear function of θ in the two period game, unlike the linear function in the single period game. The

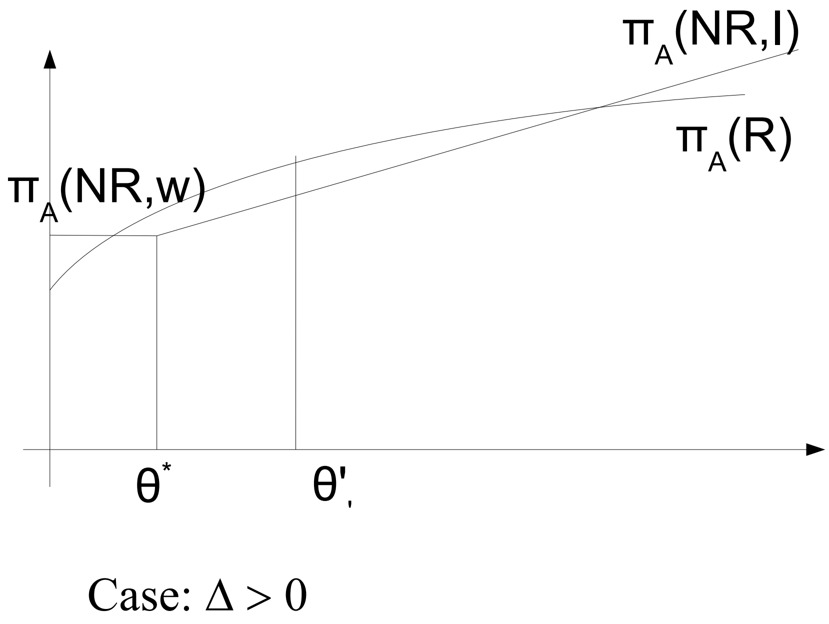


Figure 3.4: Case 2:$\Delta > 0$

revelation payoff reaches a maximum of $c > \max\theta$ and hence, this payoff increases at a decreasing rate in the type space Θ. The payoffs from non-revelation are of the same nature as in the single period game.

This change in the nature of the revelation payoff function results from the different continuation payoffs with revelation and non-revelation. These continuation payoffs are absent in the single period game. Absent continuation payoffs in the single period game, it is solely the relationship between q_{NR} and q_R that determine the existence of the coordination cutoff.

The relation between q_{NR} and q_R alone does determine the existence of a coordination cutoff in the two period game, unlike the single period game. The continuation payoffs $x(h_i^2)$, $i = 1, 2$ in conjunction with q_{NR} presents a more complicated story for the existence of the coordination cutoff in the first period.

3.5 Comparing the Market and Committee Games with Two Periods

We want to compare the coordination probabilities and equilibrium payoffs in the committee and the market games. We now work out the equilibrium strategies and coordination probabilities for a particular distribution of types for two period committee and market games.

Assumption about type space:

We assume that it is common knowledge that firm A's type is uniformly distributed in $[0,1]$. This simplifies the calculations significantly. We fix $b = 0.5$ for the coordination comparison of the committee and the market. We want to identify what advantages in information revelation and coordination the committee game (with additional structure) has relative to the market game.

3.5.1 Coordination probability in the two period market game

Proposition 9. *The two period market game has a unique mixed strategy equilibrium in which firm A has an interior cutoff above which it adopts and below which it waits in any period. The equilibrium cutoff strategies in the market game are:*

$$\theta_1^m = \frac{2(c-b)}{3c-b} \qquad \theta_0^m = \frac{(c-b)}{2c} \cdot \theta_1^m$$
$$q_1 = 0.5 + \frac{(c-b)}{4c^2} \cdot \theta_1^m \quad q_0 = \frac{c+\theta_1^m}{2(c-\theta_2^m)} + c + \theta_1^m$$

Proof. Given the payoff structure in table 3.2, we observe that the continuation payoff in period 1 from period 0, $x_0, y_0 < c$ for the two period market game. Therefore, it follows from Propositions 1 and 2 that there will be a unique interior cutoff in every period of the two period market game. Solving for the actual values of the cutoffs, we get the expressions for the cutoffs θ_0^m and θ_1^m respectively. The same applies for firm B's equilibrium strategy $\{q_0, q_1\}$. ■

For the this particular type space (uniform over [0, 1]), we observe that the first period coordination cutoff tends to $\frac{2}{3}$ as $c \to \infty$. In other words, as the size of the coordination benefits becomes infinitely large in relation to the private benefits θ and b, the first period coordination cutoff tends to $\frac{2}{3}$. All types above $\frac{2}{3}$ adopt in period 1 and types below $\frac{2}{3}$ wait in period 1. With probability q_1, the game goes to period 0 (the last period) and all types above θ_0^m adopt in the last period.

The interesting point to note here is that even when coordination benefits are infinitely larger than private benefits, a fraction $\frac{1}{3}$ of high types adopt in period 1 itself. Therefore, even with very high coordination benefits, there remains a positive probability of coordination failure in the market game. In fact, the equilibrium probability of coordination in the two period market game is:

$$\Psi_A^m = \begin{cases} 1 - q_0 & \theta \in (\theta_1^m, 1] \\ (1 - q_0)(1 - q_1) & \theta \in (\theta_0^m, \theta_1^m] \\ 0 & \theta \in [0, \theta_0^m] \end{cases}$$

$$\Psi_B^m = \begin{cases} 0 & \theta \in (\theta_1^m, 1] \\ q_0 & \theta \in (\theta_0^m, \theta_1^m] \\ q_0 + (1 - q_0)q_1 \text{ if} & \theta \in [0, \theta_0^m] \end{cases}$$

The equilibrium payoffs of the firms in the two period market game are:

$$\begin{aligned}\pi_1 &= \chi_{\{\theta \in [0,\theta_0^m)\}}[(1-q_0)cq_1 + cq_0] \\ &+\chi_{\{\theta \in [\theta_0^m,\theta_1^m\}}[(1-q_0)(\theta+(1-q_1)c)+cq_0] \\ &+\chi_{\{\theta \in [\theta_1^m,1]\}}[\theta+(1-q_0)c]\end{aligned}$$

$$\begin{aligned}\pi_2 &= (1-\theta_1^m)c + (\theta_1^m - \theta_0^m)[(1-q_0)(1-q_1)c \\ &+(1-q_0)q_1\cdot b + q_0(c+b)] + \theta_0^m(b+c)\end{aligned}$$

3.5.2 Coordination probability in the two period committee game

Proposition 10. *Non-revelation of private information by firm A is a mixed strategy equilibrium of the committee game. The equilibrium cutoff strategies are:*

$\theta_1 = \frac{c-b}{2c}$ $\qquad \theta_0^1 = \frac{(c-b)(3c+b)}{4c^2}$ $\qquad \theta_0^2 = \frac{(c-b)^2}{4c^2}$

$q_{NR}(1) = \frac{\frac{c}{2}+\theta_1\cdot(1-\frac{c-b}{2c^2})}{\frac{b+c}{4c}+c-\frac{1}{2}+\theta_1\cdot(1-\frac{c-b}{2c^2}-\frac{b+c}{4c})}$ $\qquad q_{NR}(0)^1 = \frac{1}{2}+\frac{(c-b)(3c+b)}{8c^3}$ $\qquad q_{NR}(0)^2 = \frac{1}{2}+\frac{(c-b)^2}{8c^3}$

Proof. Recall that $\{x_1, y_1\}$ and $\{x_2, y_2\}$ are the continuation payoffs to the first period from the last period in the two period committee game. We can work out that the sufficent conditions for the existence of the mixed strategy equilibrium:

$c > x_1 = \frac{c}{2}+\frac{(c-b)(3c+b)}{8c^2}$, $c > x_2 = \frac{c}{2}+\frac{(c-b)^2}{8c^3}$, $c > y_1 = \frac{(c+b)^2}{4c}$ and $c > y_2 = \frac{c^2-b^2}{4c}$ holds in the first period.

We also note that the non-revelation equilibrium in the two period committee game for $c \geq \max\ \theta$ and $b = 0.5$ with types distributed uniformly over [0,1] satisfies

$$\Delta = \theta_1 - \frac{\theta_0^1 + \theta_0^2}{2} = 0$$

as the uniform distribution is symmetric. ■

For the uniform distribution of types in the space [0, 1], the equilibrium payoffs of the firms in the committee game are:

$$\begin{aligned}
\pi_A &= I_{\{\theta \in [0,\theta_1\}} \left[(1 - q_{\mathrm{NR}}(1)x_2 + q_{\mathrm{NR}}(1)c\right] \\
&+ I_{\{\theta \in [\theta_1,1]\}} \left[(1 - q_{\mathrm{NR}}(1))(\theta + c) + q_{\mathrm{NR}}(1)x_1\right] \\
\pi_B &= (\theta_0^2 - 0)\left(q_{\mathrm{NR}}(1)(b+c) + (1 - q_{\mathrm{NR}}(1))q_{\mathrm{NR}}(0)^2(b+c)\right) \\
&+ (\theta_1 - \theta_0^2)\left(q_{\mathrm{NR}}(1)(b+c) + (1 - q_{\mathrm{NR}}(1))(q_{\mathrm{NR}}(0)^2 b + (1 - q_{\mathrm{NR}}(0)^2)c)\right) \\
&+ (\theta_0^1 - \theta_1)\left(q_{\mathrm{NR}}(1)q_{\mathrm{NR}}(0)^1(b+c) + (1 - q_{\mathrm{NR}}(1)c\right) \\
&+ (1 - \theta_0^1)(q_{\mathrm{NR}}(1)\left(q_{\mathrm{NR}}(0)^1 b + (1 - q_{\mathrm{NR}}(0)^1)c\right) + (1 - q_{\mathrm{NR}}(1)c\right)
\end{aligned}$$

where $x_1 = \frac{\theta_0^1 + c}{c}$ and $x_2 = \frac{\theta_0^2 + c}{c}$.

The equilibrium coordination probabilities on A and B in the committee game are:

$$\Psi_A^c = \begin{cases} 0, & \text{for } \theta \in [0, \theta_0^2], \\ (1 - q_{\text{NR}}(1))(1 - q_{\text{NR}}(0)^2), & \text{for } \theta \in (\theta_0^2, \theta_1], \\ (1 - q_{\text{NR}}(1)), & \text{for } \theta \in (\theta_1, \theta_0^1], \\ q_{\text{NR}}(1)(1 - q_{\text{NR}}(0)^1) + (1 - q_{\text{NR}}(1)), & \text{for } \theta \in (\theta_0^1, 1]. \end{cases}$$

$$\Psi_B^c = \begin{cases} q_{\text{NR}}(1) + (1 - q_{\text{NR}}(1))q_{\text{NR}}(0)^2, & \text{for } \theta \in [0, \theta_0^2], \\ q_{\text{NR}}(1), & \text{for } \theta \in (\theta_0^2, \theta_1], \\ q_{\text{NR}}(1)q_{\text{NR}}(0)^1, & \text{for } \theta \in (\theta_1, \theta_0^1], \\ 0, & \text{for } \theta \in (\theta_0^1, 1]. \end{cases}$$

3.5.3 Information Revelation Comparison

The market game is the benchmark for comparing information revelation in the committee, which has a separate stage for information revelation whereas the market has no explicit platform for firm A to reveal its private information. An interesting result in this context is that non-revelation is a mixed strategy equilibrium of the two period committee game, whereas in the market game, firm A reveals and adopts its own technology above a certain cutoff type . Therefore, there is some information revelation in the market game which is absent in the equilibrium we investigate in the committee game.

The tradeoff between coordination and information revelation in the mixed strategy equilibrium of the committee game results in no revelation of private information. On the other hand, the market is much less careful about coordination than the committee and some information is revealed through firm A's action of adoption of its technology itself in any period.

3.5.4 Coordination Comparison

First, we define "good ideas" as opposed to "bad ideas" and efficiency in coordination (conditional efficiency and risk in coordination).

Definition 4. ***Good (bad) idea:*** *For a given value of* c*, a particular value of* θ *is referred to as a "good (bad) idea" if* $\theta > (\leq) b$.

Definition 5. ***Conditional efficiency:*** *Given* c*, the market is* conditionally more efficient *than the committee if the probability of coordination on a "good idea" in the market is higher relative to the committee. Equivalently, given* c*, the market is* conditionally more efficient *than the committee if the probability of coordinating on a "bad idea" is lower in the market than the committee.*

Given the closeness of these two definitions to the notions of Type I and Type II errors in statistical hypothesis testing, we define the following:

Definition 6. ***Conditional Efficiency type I (CEI):*** *The market is conditionally more efficient of the type I nature if the probability of coordinating on a "good idea" in it is higher relative to the committee.*

Definition 7. ***Conditional Efficiency type II (CEII):*** *The market is conditionally more efficient than the market if the probability of coordinating on a "bad idea" is lower in it relative to the committee.*

Definition 8. ***Coordination risk:*** *The probability of no coordination on either A or B in any institution (committee or market).*

For our simulations, we have assumed $\theta \sim U[0,1]$, $b = 0.5$ and that $c >$max $\theta = 1$. For relatively low values of c close to 1 (the maximum possible value of θ), the important question to address is the technology on which coordination has taken place. The notions of CEI and CEII address this issue. On the other hand, for higher values of $c >> 1$, the relevant question is to check whether any coordination (either on A or on B) at all has taken place or not. The overriding concern for high values of c is whether any coordination happens, rather than choosing between technologies to coordinate on. In this case, we focus more on coordination risk rather than on CEI and CEII.

Comparative conditional efficiency is summarized by figure 3.5.4.
Fix $b = 0.5$ and c at some low value close to max θ. The relative efficiency of the market, for a given value of c, changes as θ changes. We observe that:

- the market exhibits higher CEI relative to the committee: it is conditionally more efficient than the committee mostly by coordinating on "good ideas", rather than not coordinating on "bad ideas".

- coordination in the market is more risky than the committee upto a certain cutoff θ. Above that cutoff, the market is either less risky or as risky as the committee. For instance, given $c = 2$, the committee risk is lower up to $\theta = 0.6$ and above it, the risk is the same in the two institutions.

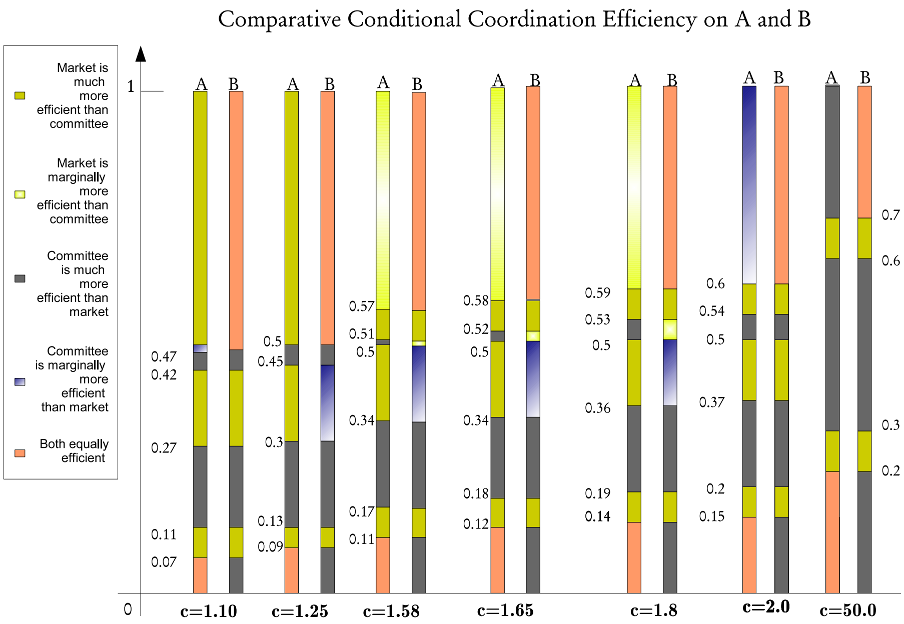


Figure 3.5: Comparison of conditional coordination probabilities

Fix c at some high value relative to θ ($c > 2$) and $b = 0.5$. We observe that:

- coordination risk in the market is higher than in the committee. For instance, for $c = 50$, the market is more risky than the committee for all values of θ.

- committee exhibits higher CEI relative to the market: conditional efficiency in the committee rises as c rises mostly by coordinating on "good ideas" rather than rejecting "bad ideas". For instance, for very high values of c, say around 50, the committee shows higher conditional efficiency than the market for almost all values of θ other than those in a narrow range.

In both the games, probability of coordination Ψ_c and Ψ_m are declining in θ, indicating that for higher values of θ, relative to c, firm A becomes more aggressive reducing chances for coordination. The same holds for the behavior of firm B as well.

3.5.5 Expected Payoff Comparison

We compare the two period expected payoffs in the committee and market games in figure 3.5.5 for $c = 2$ and $b = 0.5$. Firm B gets a higher expected payoff in the committee than the market. This is not driven by the information uncertainty, which is the same in the two period committee and market games. This difference is due to lower coordination uncertainty in the com-

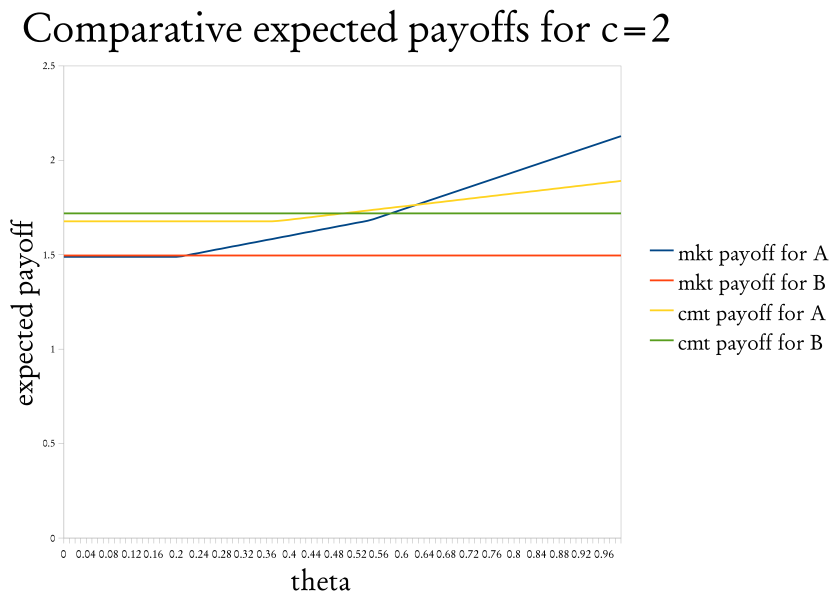


Figure 3.6: Two period committee vs market expected payoff comparison

mittee compared to the market. For higher values of c, this difference is larger due to better coordination in the committee relative to the market.

The expected payoff comparison of firm A is more complex. Given a value of c, expected payoff in the committee in the market and the committee varies with θ. In fact, for a given value of c and $b = 0.5$, there is a cutoff θ above which the market payoff outperforms the committee payoff and below which it is lower[6]. This cutoff θ shifts to the right as the value of c rises. For very large values of c (say $c = 50$), the expected payoff from the committee dominates that from the market for all values of θ.

Definition 9. ***Rewarding good ideas:*** *If the payoff to A relative to B in the market is higher than in the committee when the market has higher CEI relative to the committee, i.e. when the market coordinates more efficiently on A compared to the committee for* $\theta > b = 0.5$.

Definition 10. ***Killing bad ideas:*** *If the payoff to A relative to B in the market is lower than in the committee when the market has lower CEII relative to the committee i.e. when the market is conditionally more efficient in* not coordinating *on A for* $\theta \leq b = 0.5$ *compared to the committee.*

Figure 3.5.5 clearly demonstrates that for any c and $b = 0.5$, the market "rewards good ideas" rather than "killing bad ideas" for most values of θ. As c rises, the market's to either "reward good ideas" or "kill bad ideas"

[6]This cutoff θ does not coincide with that above which the coordination risk in the market is the same or lower than the committee.

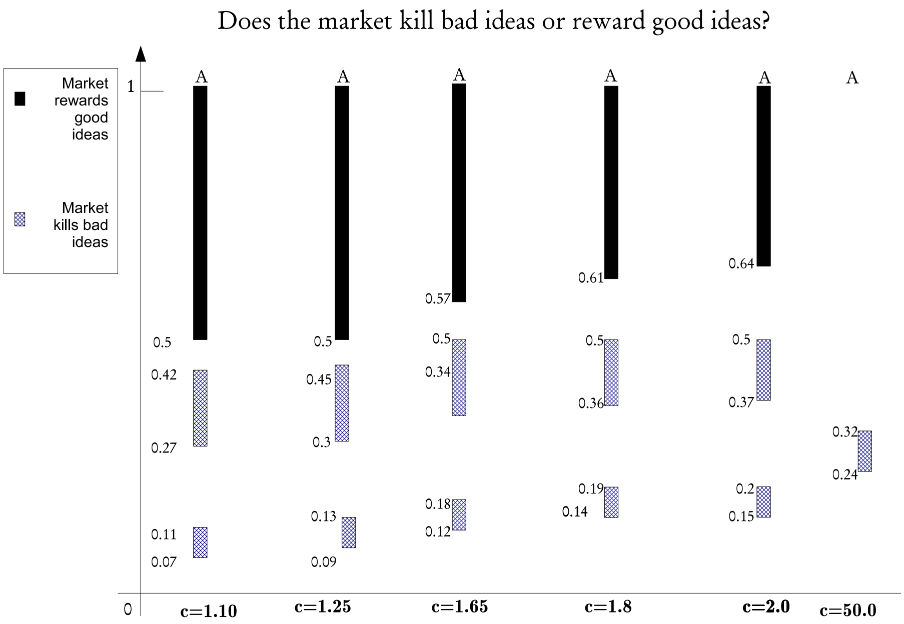


Figure 3.7: Payoff performance of the market for technology A

diminish. For instance, given $c = 2$, $b = 0.5$ and $\theta \geq 0.6$, the market is as risky as the committee, but conditionally more efficient. It also payoff dominates the committee for values of $\theta \geq 0.64$. Thus, the market in the range $[0.64, 1]$ not only is more efficient (conditionally), it also "rewards good ideas" better than the committee.

On the other hand, for values of $\theta < 0.64$, the market generates a lower payoff for some values of θ relative to the committee and thus "kills some bad ideas" over certain ranges for values of $\theta < 0.64$. This pattern is more pronounced for lower values of c, closer to 1. The market, in all these cases, generates a lower payoff (and thereby punishes or "kills") for some "bad ideas" (for which the market is also less risky than the committee) and a higher payoff ("rewards") for most "good ideas" relative to the committee.

3.6 Conclusion

The market, as an institution facilitating information revelation and coordination, has some limitations compared to a committee designed to achieve the very same objectives. The requirement that the player with private information can reveal it only through adopting its own technology prohibits the market's ability to achieve higher coordination through information revelation. Furthermore, unlike the committee, the market has no innate mechanism to facilitate coordination through fiat. If both the players, in any period, "adopt", then the market game terminates whereas the committee game goes on to the following period giving the players another chance for coordination.

Despite this limitation, this chapter points out two interesting results that highlight the efficiency of markets and the importance of institutional design of committees. First is regarding the question about which institution achieves better coordination. For the uniform distribution of types over $[0, 1]$, for $c >> 1$, efficiency in coordination in the committee is better than the market, as it has lower risk of coordination failure. For lower values of c, relative to the maximum value of θ, we have shown that the market "rewards most good ideas" and "kills some bad ideas" more efficiently than the committee. For higher values of c, the committee outperforms the market in compensating good ideas.

Depending upon the strength of c in the network industry (the range in which θ/c lies), the market route might be preferred to "reward good ideas" or "killing bad ideas" or the committee might be used to achieve coordination with lower risk. This result validates the empirical evidence that institutions for standardization are industry-specific (for a cross-sectional comparison) or for a given industry, the route to successful standardization changes as c changes. For more mature industries, c rises and hence, there is a proliferation of technical committees aiding standardization rather than the market bandwagon.

In a more general context, the central result of this chapter sheds light on how the specifics of the industry determine whether the market or the committee is a more efficient institution for standardization. Intuitively, one might expect that the market bandwagon, with very little allowances made for coordination, would punish "bad ideas" severely and commensurately reward "good ideas". However, the result of our model is that the market seems to perform the latter task better than the former, for relatively low values of c. As coordination benefits increase, the committee does better than the market in both coordinating on the better idea and compensating it.

Infact, neither institution seem to be very efficient in terms of CEII or in "killing bad ideas". This explains why there are notable examples of inferior standards being delivered by either institution. The QWERTY keyboard is a product of the market bandwagon, which survived the more efficient DVORAK system. The GSM standard had a lower spectral efficiency compared to narrow-band CDMA, but was the standard chosen by a technical committee.

Second, the results from the two period comparison of the committee and market games show that there is some information revelation in the market game, rather than in the committee game. The committee game has a separate stage for information revelation which the market lacks. However, as shown in chapter, the compulsions of coordination in the mixed strategy equilibrium of the two period committee game with $\Delta = 0$ imply non-revelation is an equilibrium. The market, institutionally, puts a lower premium on coordination and therefore permits some revelation of private information through the very act of adoption of firm A's technology.

... Morgan Everett: “All through proper intermediaries of course.”

JC Denton: “Intermediaries?”

Morgan Everett: “We have a great number of agencies, who in turn operate other agencies. Boxes stacked one in another. They’ll need to be reactivated, but we never touch anything directly. We only influence. Suggest. Insinuate.” ... *-In the **Illuminati Ending**, a Deux Ex video game released in 2000*

Chapter 4

Committee game revisited: Strategic information revelation and coordination in network industries

4.1 Motivation

In the earlier chapters, we have studied the roles of coordination and facilitation of private information revelation in committees. The primary focus was to understand the impact of coordination requirements on the revelation of hard evidence.The committee, as an institution, was non-strategic and facilitated coordination and dissemination of private information passively.

In a more general setting, technical committees are intermediaries in the process of standardization and intermediaries often behave strategically, as in Lizzieri (1999) and Albano and Lizzieri (2001). In this chapter, we assume that the committee itself stands to benefit from standardization. In this context, we compare mechanisms of cheap talk on intent and strategic information revelation which the committee can use in order to increase coordination on a single technology by the firms.

In terms of the structure of information, there is a substantial difference between the models in chapters 2 and 3. In chapter 2, the structure of information was exogenous, whereas it is endogenous in this chapter. In chapter 2, the choice of the informed agent was whether or not to reveal its private information. In contrast, hard evidence about private information that can be credibly transmitted is a choice variable for the committee in this chapter. Therefore, much along the lines of Lizzieri (1999) and Albano and Lizzieri (2001), this chapter contributes to the literature on information revelation by endogenizing the information structure.

The central issue with exogenous information structure is whether there is unraveling of private information, as discussed in Milgrom (1981) and Grossman (1981). Chapter 2 shows that unraveling will not hold in a special class ("natural" equilibria) due to strategic uncertainty arising out of coordination requirements. With endogenous information structures, unraveling is not the relevant question. The central issue is the welfare effects of the presence of the committee as an intermediary in the market and strategic revelation of information by the committee.

In the context of endogenous information structure, we focus on the information revelation role of the committee. We assume that the firms do not know their actual types at the beginning of the game. This situation arises when the firms are at the cutting edge of technological evolution and are not aware about the market potential of their own technologies. Committees, which specialize in certification and testing, have established credentials and the expertise to test these technologies and reveal how good the product is. This also gives the committee the option to strategically reveal a firm's type.

We consider a situation where the agents in the process of standardization are two firms and one technical committee. The firms have vested interest in seeing their own technologies as the industry standard, but are also interested the establishment of a single standard. The results of chapter 3 prove the effectiveness of the committee as an intermediary in achieving coordination relative to a careless market bandwagon when coordination really matters. Therefore, we restrict attention to committee-mediated standardization. Note that the committee possesses a costless technology to test and reveal information[1].

At the beginning of the game, the committee credibly announces its disclosure rule. The firms then decide whether or not to go the committee.

[1]This is a simplification in order to highlight the impact of coordination compulsions and the ineffectiveness of cheap talk on intent on the information revelation motives of the committee, which is interested in the emergence of a single technological standard. The results go through even with a positive cost of testing or certifying the technologies which is less than the discounted value of the income that the committee expects to generate from certification of the standard emerging out of successful coordination.

In the last stage, both the firms play a coordination game regarding choice of technology as the standard. It should be noted that in the penultimate stage, if both the firms go to the committee then they engage in one round of cheap talk messages on intent. The committee benefits to the extent that the probability of coordination failure is lowered which raises its expected payoff. However, if one or none of the firms go to the committee, it does not get any benefit from coordination which still has a chance of evolving as a result of the direct play of the coordination game between the firms. Note also that the committee's announcements are public: if a firm approaches the committee, its type gets revealed to the other firm as well.

We compare the mechanisms of structured "Pareto" cheap talk on intent and strategic information revelation for achieving coordination by the committee. Cheap talk on intent, in our model, is similar to "Pareto" cheap talk on intent as described by Rabin (1994). It is more structured than "Pareto" talk, as it occurs through the offices of the committee. There are only some messages that can be sent costlessly and without any payoff-relevance by the participants in the committee to each other. In that sense, talk is cheap in our model, but not trivial. Therefore, babbling equilibria can be ruled out due to the unique construct of our model. Strategic information revelation is the other mechanisms for achieving coordination by the committee[2].

We consider the class Ψ of disclosure rules which allow for revelation in finite unions of disjoints intervals of the type space. Preliminary results show that disclosure rules within this class are participation compliant, i.e. both

[2]We do not consider correlated equilibrium.

the firms go to the committee. Our first result regarding strategic information revelation is that with one round of cheap talk on intent, the committee can sustain non-disclosure of information in perfect Bayesian equilibrium of the game. In other words, non-disclosure gives rise to the lowest probability of coordination failure and highest expected payoff of the committee compared to full or partial disclosure of information.

Non-disclosure is to be interpreted as a strategic action by the committee to aid standardization, as revelation is assumed to be costless for the committee. A second result shows that non-disclosure is unique within a very large class of disclosure rules. The equilibrium cutoff for revelation is degenerate at the corner indicating no disclosure in this game with one round of pre-play communication which is costless and non-binding. However, this result requires the fact that the firms know that the committee is strategic. This provides the intuition for the optimal disclosure being at a corner which implies non-revelation in the entire type space.

As the committee has to truthfully reveal a firm's type and commits to its disclosure rule, along the equilibrium path either firm updates their belief about their types following the optimal disclosure strategy of the committee as they know the strategic intent of the committee. This updated belief about their type is increasing monotonically in the strategy of the committee. This monotonicity of the firms' beliefs ensure that any information revealed in any interval of the type space increases the inherent vested interest and conflict between the firms in the coordination game, reducing the expected probability of coordination. Therefore, this condition is sufficient for the existence of non-disclosure as the unique equilibrium in a very large class of disclosure rules Ψ.

If the model is changed such that there is uncertainty about the committee's ability to infer a firm's type using its testing equipment, then the committee can exploit this uncertainty and we demonstrate a third result which states that there exists at least one optimal partial disclosure rule in equilibrium.

In the Appendix, we discuss some reasons why we consider only one round of cheap talk prior to the coordination game as opposed to multiple rounds of cheap talk. Real life committees are finitely lived, and we show that in a mixed strategy equilibrium, finite cheap talk will never be able to achieve full coordination given any disclosure rule.

We next note that the effectiveness of cheap talk on intent, given any disclosure rule, in bringing about coordination is centrally linked to the **degree of inherent conflict** in the game. As highlighted in Farrell (1987), the problem of coordination becomes more severe the larger is the conflict of interest among the firms in the coordination game (which is of the nature of a Battle-of-the-Sexes game). The firms in the coordination game have vested interests in their own technology and prefer coordination to take place on their own respective technologies. This gives rise to an inherent conflict of interest among the firms in this game. In a context of full information among the firms, Farrell (1987) shows that the effectiveness of cheap talk on intent (even multiple rounds and in the limit as the number of rounds become very large) is reduced the higher is the extent of vested interest of the firms. We show that this result is a product of the special payoff matrix under consideration in Farrell (1987). In the more general payoff matrix that we consider, it is only if the private benefits of the firms are exactly the same in equilibrium (which is an event with measure zero), that it is possible that infinitely long cheap talk would remove coordination failure completely. Otherwise, even if the vested interest of each firm become small (but stay non-zero) relative to coordination benefits, the limiting probability of coordination failure would be bounded away from zero even with very long cheap talk on intent.

The second observation is that as number of cheap talk rounds increase, the conflict of interest between the firms and the committee increases, as the payoffs of the firms approach c in the limit for any disclosure rule in the class Ψ. Therefore, the committee would find it difficult to ensure participation compliance in very long cheap talk games. Given these limitations of long cheap talk, we derive our results with only a single round of cheap talk.

The chapter layout is as follows: section 4.2 follows with the literature review, section 4.3 introduces the theoretical model with the necessary assumptions, section 4.4 discusses the perfect Bayesian equilibrium of the game with preliminary results, section 4.5 discusses all aspects of strategic disclosure of information in the committee and section 4.6 concludes. The Appendix is at the end of the chapter in section 4.7.

4.2 Literature Review

Farrell (1987) analyzes the extent to which cheap talk can achieve coordination among potential entrants into a natural-monopoly industry, where payoffs are qualitatively like the "battle-of-the-sexes". The same analysis applies a variety of situations, as pointed out by Farrell (1987), such as bargaining under complete information or choosing compatibility standards.

Farrell (1987) observes that cheap talk helps achieve asymmetric coordination in a symmetric mixed-strategy equilibrium. However, the extent of success of cheap talk in achieving coordination depends on the amount of conflict in the game. With even a small amount of conflict, complete coordination cannot be achieved.

This chapter integrates cheap talk on intent in the coordination game of choosing a standard, but not in an environment of complete information. We assume that, at the beginning of the coordination game, the firms do not know the precise quality (or type) of their technologies. They have the option of approaching a technical committee, which has a costless device to test their quality and report it to them.

There are some relevant papers incorporating cheap talk in different economic applications (for instance, refer to Agastya et al. (2007), Sanyal and Sengupta (2005) and Sengupta and Sanyal (2004)). Our incorporation of the cheap talk on intent is closest to Farrell (1987).

A complication lies in the fact that the committee is strategic (as opposed to the committee in chapter 2) and reveals information suited to its own interests. The committee is modeled as an institution that is interested in getting the firms to agree to a standard (either of the firms' technologies on which it can later carry out certification activities). For this purpose, it allows a round of cheap talk on intent before the coordination game. This

The strategic revelation of information by intermediaries like the technical committee in this chapter has been studied in other contexts. For instance, Lizzieri (1999) analyzes strategic information revelation by intermediaries in the context of one seller and two buyers. The role of the certification intermediary, in this case, is to test the quality of the good of the seller about which the latter has private information. The intermediary moves first by setting a price for certification and committing to a disclosure rule that specifies how much information is going to be revealed to buyers.

With a monopoly intermediary and an assumption about the distribution of quality t distributed over the compact type space $[a, b]$ the unique equilibrium outcome involves no information revelation and the intermediary extracting all the informational surplus in the market. Without allocative distortion, this result shows purely redistributive distortion, with high-quality sellers getting less profits than they would in perfect information environments.

The intermediary, in this instance, is parasitic in nature and provides no informational role in the market. It merely extracts all the informational rents. However, in markets where information asymmetries cause allocative distortions, the intermediary solves the distortion by revealing the minimum amount of information. In the process, all the surplus goes to the intermediary. The intermediary might also use the certifying ability to enhance sellers' market power and reduce that of the buyer. This is because the intermediary is paid by the seller and the part of the overall surplus going to the buyer in a trade cannot be captured by the intermediary.

With competition among intermediaries, information revelation becomes a possibility. Lizzieri (1999) finds that with oligopolistic intermediaries, there is always an equilibrium where the latter makes no profits and reveals all information. In the limit, as the number of intermediaries go to infinity, this is the only equilibrium.

In contrast to Lizzieri (1999), the committee in our model uses the strategic revelation of information to achieve coordination, in which the firms themselves have significant interest (as the benefit of coordination is higher than private benefits from individual technologies).Therefore, in terms of welfare, the committee is not as parasitic as that in Lizzieri (1999).

Our model contributes to the literature on strategic information revelation by demonstrating that in an extended coordination game (with one round of non-binding pre-play communication) with beliefs of the uninformed agents (the firms) increasing monotonically in the strategy of the informed agent (the committee), the unique equilibrium within a very large class of disclosure rules (revelation over finite union of disjoint intervals) is that of no disclosure. We show that in the perfect Bayesian equilibrium of the game, the committee cannot be more strategic than not revealing any information. Revealing information partially is not an equilibrium if the firms know the strategic intent of the committee. Partial revelation is possible in equilibrium if this sufficient condition does not hold. One possibility we demonstrate here is that there is uncertainty about the ability of the committee to find out the firm's true type with its testing equipment. This line of investigation is similar to that of Shin (1994), which allows for uncertainty about the information with the informed agent. Full disclosure of information fails in Shin (1994), as the expert is able to hide some of its information. In our case, the committee is able to exploit this asymmetry of information to increase its expected payoff and increase the possibility of standardization. Among other relevant papers on persuasion games with unbiased experts, Seidmann and Winter (1997) allow some uncertainty over the experts preferences in a game with verifiable messages and focus on the condition under which there is an equilibrium with full disclosure.

4.3 Model

Two firms {i, j} are engaged in a coordination game over two new and incompatible technologies denoted by their quality θ_k for firm k, $k = i, j, i \neq j$. Both firms want a single technology to become the standard, but have a vested interest in their own technology, even though they do not know the true types of their own technologies at the beginning of the coordination game. Ex ante, the firms know that their types are i.i.d. with a continuous and differentiable distribution function $F(.)$ and density function $f(.)$ with a compact support $\mathbb{T} = [\theta_l, \theta_h] \subset \mathbb{R}_+$. The benefit from coordination, c, is given exogenously and it is common knowledge that $c > \theta_h$.

The firms can approach a technical committee to find out their type before playing the coordination game. The technical committee can costlessly test the technology of the firm and inform the firm its type in accordance with a publicly pre-announced disclosure rule belonging to the class Ψ. This class does not allow untruthful reporting or noisy reports.

Any disclosure rule is identified by the set $\Delta \subset \mathbb{T}$ over which the committee discloses information. Ψ allows Δ to be finite unions of disjoint intervals of the type space[3].

For any disclosure rule, the message space is $\mu = M \times M$ where $M = \{\theta \cup \text{“not reveal”}\}$. A disclosure rule $D \in \Psi$ maps from the type space to the message space, $D : \mathbb{T} \to \mu$.

$$D_\Delta(\theta) = \begin{cases} \{\theta, \theta\} & \text{if } \theta \in \Delta, \\ \{\text{“not reveal”}, \text{“not reveal”}\} & \text{otherwise} \end{cases}$$

where

$$\Delta = \cup_{s=1}^{n} [\theta'_s, \theta''_s]. \tag{4.1}$$

By definition, a full disclosure rule implies $D_\Delta = D_\mathbb{T}$. For no disclosure, $\Delta = \Phi$, the null set [4].

The committee is interested in the formation of a standard, as it can sell certification services once the standard is established. It is not biased towards any technology.Therefore, not only does it not charge any fees for verification of type for the firms, it also allows one round of mediated communication of cheap talk messages on intent if both the firms approach the committee in

[3] We assume that the same Δ applies for both the firms.

[4] The revelation set in this class can be extended for the sake of completeness (without changing any of the results) to the form $\hat{\Delta} = \cup_{s=1}^{n} [\theta'_s, \theta''_s] \cup z_q$, where z_q is the set of all possible sets of measure zero. We use the form in (4.1).

order to facilitate coordination. Note that if a firm approaches the committee, its type is known to all firms.

4.3.1 Timing of the game

The game proceeds in the following stages:

- **Stage 1.** The committee announces a disclosure rule.
- **Stage 2.** Firms decide whether or not to go to the committee simultaneously.
- **Stage 3.** The disclosure rule is applied by the committee. If the committee discloses any information, it does so publicly.
- **Stage 4.** If both the firms go to the committee, then they engage in one round of cheap talk on intent[5]. If only one firm goes to the committee, the game goes to the last stage.
- **Stage 5.** The firms engage in a coordination game for selecting the standard, with actions and payoff matrix described below.

4.3.2 Actions, Strategies and Payoffs

Either firm decides whether or not to go to the committee ($d_i = 1$ if firm i goes to the committee and $d_i = 0$ otherwise), the probability with which to insist on one's own technology in the cheap talk stage ($0 < q_i < 1$ for

[5]The committee rules out all other messages, which helps rule out babbling equilibria.

firm i) and the probability with which to adopt one's own technology in the coordination stage ($0 < p_i < 1$ for firm i).

The payoff matrix of firm i in the coordination round is given in the Table 4.1 below.

	Switch	Adopt
Adopt	$\theta_i + c$, c	θ_i,θ_j
Switch	0,0	c, $\theta_j + c$

Table 4.1: Payoff matrix for the firms in the coordination stage

For a given disclosure rule D_Δ, the payoff of the committee π_c is given by:

$$\pi_c(D, r_i, r_j) \ = \begin{cases} 1, \text{if } d_i = d_j = 1, \text{ and coordination takes place on either A or B} \\ 0, \text{if } (d_i = d_j = 0), (d_i = 0, d_j = 1), (d_i = 1, d_j = 0) \end{cases}$$

The expected payoff of the committee is $E(\pi_c) = (1 - \psi)$, where ψ is the probability of coordination failure. We restrict attention to mixed strategy Perfect Bayesian equilibria of the extended game.

4.3.3 Definitions

- The mean of the distribution $F(\theta)$ distributed over $\mathbb{T}$ is $\bar{\theta} = \int_\theta \theta f(\theta) d(\theta)$.
- Recall that a disclosure rule is characterized by Δ, a finite union of disjoint intervals over which the committee reveals information. Therefore, if a type $t \in \Delta$, the committee reveals its type. Else, for $t \in \Delta^C$, the committee does not reveal any information.

- Let $\pi_i(\text{go}|\text{go})$ denote the payoff to firm i from going to the committee conditional on firm j also going to the committee.

- Let $\pi_i(\text{go}|\text{not go})$ denote the payoff to firm i from going to the committee conditional on firm j not going to the committee.

4.3.4 Preliminary Results

We first report the results of the subgames following different disclosure rules.

First consider full disclosure. We check for conditions for when both the firms go to the committee using the following corollaries.

Corollary 1. *If both the firms go to the committee, the payoff to firm k is $\pi_k(go|go) = \frac{(\theta_k+c)(3c-\theta_k)}{4c}$ $\forall$ $k = i, j$ when the committee discloses all information, given that $c > \theta_h$.*

Proof. From table 4.1, we can see that the mixed strategy equilibrium payoff for either firm k is $v = \frac{\theta_k+c}{2}$ $\forall$ $k = i, j$, with the equilibrium mixed strategy of adopting preferred technology being $p_k = \frac{\theta_k+c}{2c}$ $\forall$ $k = i, j$, given that $c > \theta_h$.

If both the firms go to the committee, then mixed strategy payoff of firm i from the cheap talk stage is:

$$\pi_i(\text{go}|\text{go}) = q_j v + (1 - q_j)(\theta_i + c) = q_j c + (1 - q_j)v \quad i \neq j \tag{4.2}$$

where v is the continuation payoff from the last coordination stage. The same applies for firm j.

Substituting v in equation (4.2), we get the equilibrium payoff of firm k as: $\pi_k(\text{go}|\text{go}) = \frac{(\theta_k+c)(3c-\theta_k)}{4c}$, where

$$q_i = p_i = \frac{\theta_j + c}{2c} \quad (4.3)$$

$$q_j = p_j = \frac{\theta_i + c}{2c} \quad (4.4)$$

■

Corollary 2. *If the committee discloses all information and only firm k goes to the committee, its payoff is $\pi_k(go|not\ go) = \frac{\theta_k+c}{2}$ $\forall$ $k = i, j$, given that $c > \theta_h$.*

Proof. If firm i alone goes to the committee, then there is no round of cheap talk. The mixed strategy equilibrium payoff for firm k can be directly computed from table 4.1.

$$\pi_i(\text{go}|\text{not go}) = p_j\theta_i + (1-p_j)(\theta_i+c) = p_jc + (1-p_j)0 = \frac{\theta_i + c}{2} \quad i \neq j \quad (4.5)$$

where $p_j = \frac{\theta_i+c}{2c}$. The same analysis applies for firm j. ■

Corollary 3. *If a firm k does not go to the committee, then its payoff is $\pi_k(not\ go|.) = \frac{\bar{\theta}+c}{2}$ $\forall$ $k = i, j$ irrespective of whether the other firm goes to the committee or not when the committee discloses all information, given that $c > \theta_h$.*

Proof. If firm i does not go to the committee, it does not know its own type. It goes on to play the final coordination stage bypassing the cheap talk stage, after taking an average of all possible types in its type space. Suppose that firm j has gone to the committee. Firm i knows j's type. However, due to conditional independence of payoffs in the payoff matrix in table 4.1, firm i's strategy p_i is not a function of the other firm's type. The optimization problem for firm i now is:

$$\text{Max}_{p_i} \int_{\theta_i} (p_i p_j \theta_i + (1-p_i)p_j c + (1-p_j)p_i(\theta_i + c) + (1-p_i)(1-p_j)0)\, dF(\theta_i) \tag{4.6}$$

which on simplification yields $\pi_k(\text{not go}|.) = \frac{\bar{\theta}+c}{2}$ $\forall\ k = i, j$, provided $c > \theta_h$. Now suppose that none of the firms go to the committee. The optimization problem of firm i is given by:

$$\text{Max}_{p_i} \int_{\theta_i} \int_{\theta_j} (p_i p_j \theta_i + (1-p_i)p_j c + (1-p_j)p_i(\theta_i + c))\, f(\theta_i) f(\theta_j) d(\theta_i) d(\theta_j) \tag{4.7}$$

which yields $\pi_k(\text{not go}|.) = \frac{\bar{\theta}+c}{2}$ $\forall\ k = i, j$ given that $c > \theta_h$. Therefore, the equilibrium payoff of any firm k not going to the committee is $\frac{\bar{\theta}+c}{2}$ and $p_k = \frac{\bar{\theta}+c}{2c}$ irrespective of whether the other firm goes to the committee or not. ∎

Using these corollaries, we conclude that both the firms will go to the committee if the latter commits to a full disclosure rule.

Proposition 1. *Suppose the committee discloses all information.Then, a firm will go to the committee ($d_i = 1\ \forall i$) irrespective of the other firm's strategy of going to the committee.*

Proof. Suppose only one firm k goes to the committee. If the committee discloses all information, then corollary 2 says that:

$$\pi_k(\text{go}|\text{not go}) = \frac{\theta_k + c}{2} \ \forall k = i, j \tag{4.8}$$

On the other hand, if firm k does not go to the committee, corollary 3 implies that:

$$\pi_k(\text{not go—.}) = \frac{\bar{\theta} + c}{2} \tag{4.9}$$

Now, on an average, going to the committee and not going to the committee for firm k yields the same payoff with a full disclosure rule[6].

$$E(\pi_k(\text{go}|\text{go})) - E(\pi_k(\text{not go}|\text{go})) = \int_{\theta_k} \left(\frac{\theta_k + c}{2} - \frac{\bar{\theta} + c}{2} \right) dF(\theta_k) = 0 \ \forall \ k = i, j \tag{4.11}$$

If both the firms go to the committee, then mixed strategy payoff from the cheap talk stage is:

$$\pi_i(\text{go}|\text{go}) = q_j v(\theta_i) + (1 - q_j)(\theta_i + c) = q_j c + (1 - q_j) v(\theta_i) \tag{4.12}$$

where $v(\theta_i)$ is the continuation payoff from the last coordination stage and is given by $v(\theta_i) = \frac{\theta_i + c}{2}$ when both firms go to the committee.

---

[6] A more conservative way of checking whether a firm k should go to the committee or not is to compare the payoff from going and not going for each possible θ_k.

$$\pi_k(\text{go}|\text{go})) - \pi_k(\text{not go}|\text{go}) > 0 \iff (\Pr(\theta_k \geq \bar{\theta}) - \Pr(\theta_k < \bar{\theta}))\frac{\theta_i - \bar{\theta}}{2} > 0 \forall \ \theta_k, k = i, j \tag{4.10}$$

This conservative method implies that a necessary and sufficient condition for going to the committee under a full disclosure policy is $L(\bar{\theta}) = \Pr(\{\theta_k \geq \bar{\theta}\}) - \Pr(\{\theta_k < \bar{\theta}\}) > 0$, which can be interpreted as a measure of skewness of the distribution of types.

Therefore, $\pi_i(\text{go}|\text{go}) = \frac{(\theta_i+c)(3c-\theta_i)}{4c}$, where $q_j = p_j = \frac{\theta_i+c}{2c}, j \neq i$. The same analysis holds for firm j.

It is easy to verify that $E(\pi_i(\text{go}|\text{go})) - E(\pi_i(\text{not go}|\text{go})) = \frac{c^2-h(\theta_i)}{4c} > 0$ for all $\theta_i < c$. Therefore, with full disclosure, going to the committee is a weakly dominant strategy for any firm and it goes to the committee irrespective of the strategy of other firm. ∎

Next, we consider no disclosure.

Corollary 4. *With no disclosure, the payoff of firm k is given by $\pi_k(.|.) = \frac{\bar{\theta}+c}{2}\ \forall\ k = i, j$ irrespective of whether it or the other firm goes to the committee or not, given that $c > \theta_h$.*

Proof. Suppose firm k goes to the committee. If the committee applies a no disclosure rule, then the firm's information set about its type (or that of the other firm) does not change from its prior belief of its type: that it is distributed according to $F(\theta_k)$ in $[\theta_l, \theta_h]$. This implies that the results are the same as that from corollary 3. Irrespective of whether the firm goes to the committee, its maximization problem is:

$$\max_{p_i} \int_{\theta_i} \int_{\theta_j} \left(p_i p_j \theta_i + (1-p_i)p_j c + (1-p_j)p_i(\theta_i + c)\right) f(\theta_i) f(\theta_j) d\theta_i) d(\theta_j) \tag{4.13}$$

which yields $\pi_k(\text{not go}|.) = \frac{\bar{\theta}+c}{2}\ \forall\ k = i, j$ given that $c > \theta_h$. Therefore, the equilibrium payoff of any firm k not going to the committee is $\frac{\bar{\theta}+c}{2}$ and $p_k = \frac{\bar{\theta}+c}{2c}$ irrespective of whether the other firm goes to the committee or not. ∎

We now prove that firms will go to the committee if the latter commits to a no disclosure rule.

Proposition 2. *Suppose the committee discloses no information.Then, a firm will go to the committee ($d_i = 1 \ \forall i$) irrespective of the strategy of the other firm.*

Proof. The only advantage of going to the committee now is the cheap talk mediation that is not available without the committee.

$$\pi_i(\text{not go}|\text{go}) = \pi_i(\text{not go}|\text{not go}) = \pi_i(\text{go}|\text{not go}) = \frac{\bar{\theta} + c}{2} \tag{4.14}$$

whereas,

$$\pi_i(\text{go}|(\text{go}) = \frac{(\bar{\theta} + c)(3c - \bar{\theta})}{4c} \tag{4.15}$$

Therefore, going to the committee is a weakly dominant strategy for either firm. ∎

Expected payoffs with disclosure rules with revelation sets of the nature $\Delta = \cup_{s=1}^{n}[\theta'_s, \theta''_s]$ are affine combinations of expected payoffs in revelation and non-revelation intervals. Corollaries 1, 2, 3 and 4 and the results from propositions 1 and 2 indicate:

Proposition 3. *Committing to any disclosure rule $D_\Delta \in \Psi : \{\Delta = \cup_{s=1}^{n}[\theta'_s, \theta''_s]$ ensures that both the firms go to the committee.*

4.3.5 Asymmetric firms and strategic committee

Using the results of the subgames noted above, we can comment on the incentives of the firms to go to the committee, had there been one-sided asymmetric information as in the previous chapters. We assume that the type of one of the firms is common knowledge to all. We also assume that it is common knowledge that the other firm does not know its own type and that the committee to which it can go to find out its type is strategic.

Proposition 4. *If only one of the firm's type is known, the firm which does not know its know its own type would go to the committee.*

Proof. Case 1: Full disclosure: Corollary 3 shows that expected π_i (not go—go)= $(\bar{\theta}+c)/2$, whereas from Corollary 1, $\pi_i(\text{go}|(\text{go}) = (\theta_i+c)(3c-\theta_i)/2$. Hence, expected $\pi_i(\text{go}|(\text{go}) - \pi_i(\text{not go}|(\text{go}) = \frac{1}{4c}\int(\theta_i+c)(c-\theta_i)f(\theta_i)d\theta_i > 0$ as long as $c > \theta_h$. Therefore, the firm with no information about its type will approach the committee.

Case 2: No disclosure policy of the committee: Similarly, Corollary 4 shows that expected $\pi_i(\text{go}|(\text{go}) - \pi_i(\text{not go}|(\text{go}) > 0$ with this disclosure policy. So, the firm with no information about its type will go to the committee.

■

Therefore, this result is the same whether or not the firms are symmetric (as in this chapter) or asymmetric (as in the earlier chapters).

4.4 Strategic disclosure of information with single round of cheap talk: optimal disclosure policy

This section summarizes the results regarding different disclosure rules, given that there is only one round of cheap talk on intent. If the committee possesses a perfect equipment for testing the firms' technologies and its objective function is known to the firms, then we show that committee can be strategic up to the extent of revealing no information, even though information revelation is costless for the committee. We prove that non-revelation is unique within class of strategies Ψ for information disclosure. If, on the other hand, if there is uncertainty about the effectiveness of the testing equipment of the committee, the committee can exploit this information asymmetry and improve upon no revelation by revealing information partially.

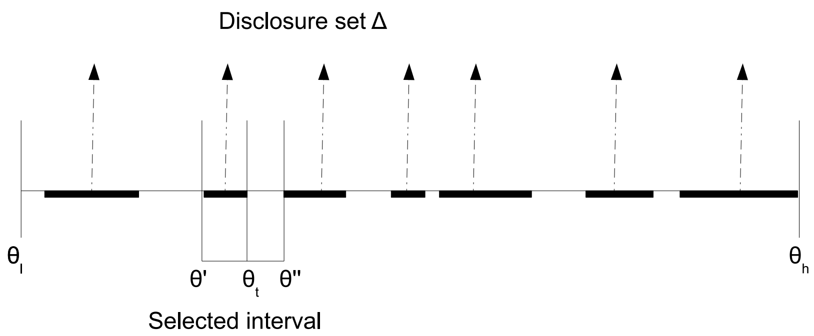
4.4.1 Committee has a perfect equipment for testing a firm's technology

We show here that the committee exhibits strategic disclosure by not disclosing any information, even though revelation is costless in the extended coordination game with one round of cheap talk on intent. Without this single round of cheap talk on intent, the committee's equilibrium expected payoff (arising from the expected probability of coordination) is the same for full disclosure and no disclosure. Therefore, we can assume that the committee discloses information fully (as it is indifferent between the two strategies). Including a single round of cheap talk on intent makes the equilibrium expected payoff for the committee with no disclosure strictly greater than that with disclosure, thereby allowing for non-disclosure in equilibrium.

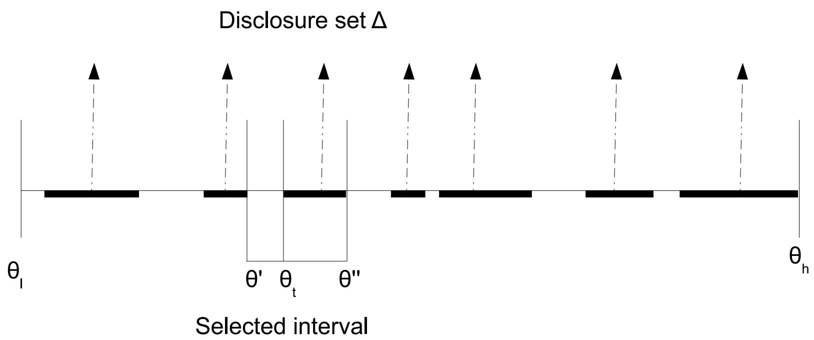
We also prove that non-revelation is unique in the class of disclosure rules which allow for revelation in finite unions of disjoint intervals of the compact type space. The existence and uniqueness of the no disclosure result requires the assumption that the firms know the strategic intent of the committees. Due to this knowledge, the firms update their beliefs in keeping with the optimum disclosure strategy of the committee. For instance, if the committee announces revelation over some interval $[\theta_l, \theta_t]$, then the firms know that the committee will not reveal any type in the interval $[\theta_t, \theta_h]$. Therefore, the firms will update their prior beliefs $\bar{\theta} = E(\theta)$ to $x(\theta) = E(\theta | \theta \in [\theta_t, \theta_h]$.

This updated belief about types is shown to be increasing in any candidate cutoff (θ_t) disclosure rule of the committee. It is this monotonicity of the firms' beliefs with the disclosure strategy of the committee that results in the optimal value of the cutoff θ_t to be at the corner θ_l which implies non-revelation in the entire type space. In fact, a sufficient condition for non-revelation to be the optimal strategy is that in equilibrium, the beliefs are monotonically increasing in the disclosure strategy of the committee.

Step 1. Consider a candidate disclosure rule $\tilde{D_\Delta} \in \Psi : \{\Delta = \bigcup_i [\theta'_i, \theta''_i]\}$, with a cutoff at θ_t such that one particular revelation interval is $[\theta', \theta_t] \subset \Delta$ and an adjoining non-revelation interval is $[\theta_t, \theta''] \subset \Delta^C$ (if possible).



(a) Revelation followed by non-revelation interval



(b) Non-Revelation followed by revelation interval

Figure 4.1: Disclosure rules and selected intervals

Additionally, we define the following

$$
\begin{array}{rcl}
\tilde{\Delta} & = & \Delta - [\theta', \theta_t] \\
\tilde{\Delta}^C & = & \Delta^C - [\theta_t, \theta''] \\
F(S \subset [\theta_l, \theta_h]) & = & \int_S f(t)d(t) \\
x(S \subset [\theta_l, \theta_h]) & = & \frac{\int_S tf(t)dt}{\int_S f(t)dt} \\
g(S \subset [\theta_l, \theta_h]) & = & \int_S tf(t)dt \\
h(S \subset [\theta_l, \theta_h]) & = & \int_S t^2 f(t)dt
\end{array}
$$

With one round of cheap talk prior to the coordination game, the expected probability of coordination failure is defined as: $E(\psi) = E(q_i q_j + (1-q_i)(1-q_j))(p_i p_j + (1-p_i)(1-p_j))$. Substitution of the equilibrium values of the probabilities $p_i = q_i = \frac{\theta_j + c}{2c}$ and $p_j = q_j = \frac{\theta_i + c}{2c}$ from (4.3) yields:

$$
\begin{aligned}
4c^4\psi = {} & \mathbb{E}_{\theta_i, \theta_j \in \Delta}(c^2 + \theta_i\theta_j)^2 + \mathbb{E}_{\theta_i \in \Delta, \theta_j \in \Delta^C}(c^2 + x(\Delta^C)\theta_j)^2 + \\
& \mathbb{E}_{\theta_i \in \Delta^C, \theta_j \in \Delta}(c^2 + \theta_i x(\Delta^C))^2 + \mathbb{E}_{\theta_i \in \Delta^C, \theta_j \in \Delta^C}(c^2 + x(\Delta^C)^2)^2 \qquad (4.16)
\end{aligned}
$$

Corollary 5. *The candidate disclosure rule can be improved by* eliminating the revelation interval $[\theta', \theta_t]$ *and extending the adjacent higher non-revelation interval to cover* $[\theta', \theta'']$*, i.e., the optimal value of* θ_t *is at* θ'*.*

Proof. If we consider the first term in equation (4.16), we can write it as

$$
\mathbb{E}_{\theta_i \in \Delta, \theta_j \in \Delta}(c^2 + \theta_i\theta_j)^2 = c^4 F^2(\Delta) + 2g^2(\Delta)c^2 + h^2(\Delta) \qquad (4.17)
$$

The second and third terms are symmetric, since θ_i and θ_j are i.i.d. and can be summed and written similarly as

$$
\begin{aligned}
& \mathbb{E}_{\theta_i \in \Delta, \theta_j \in \Delta^C}(c^2 + \theta_i x(\Delta^C))^2 + \mathbb{E}_{\theta_i \in \Delta^C, \theta_j \in \Delta}(c^2 + x(\Delta^C)\theta_j)^2 = \\
& 2c^4 F(\Delta)F(\Delta^C) + 4c^2 g(\Delta)x(\Delta^C)F(\Delta^C) + 2h(\Delta)x(\Delta^C)F(\Delta^C) \qquad (4.18)
\end{aligned}
$$

Finally, the last term becomes

$$\begin{aligned}\mathbb{E}_{\theta_i\in\Delta^C,\theta_j\in\Delta^C}(c^2+x(\Delta^C)^2)^2 &= \\ c^4F^2(\Delta^C)+2c^2x^2(\Delta^C)F^2(\Delta^C) &+ x^4(\Delta^C)F^2(\Delta^C) \qquad (4.19)\end{aligned}$$

Summing up, we get:

$$\begin{aligned}4c^4\psi &= c^4+2c^2\left[g(\Delta)+x(\Delta^C)F(\Delta^C)\right]^2+\left[h(\Delta)+x^2(\Delta^C)F(\Delta^C)\right]^2 \\ &= c^4+2c^2\bar{\theta}^2+\left[h(\Delta)+x(\Delta^C)^2F(\Delta^C)\right]^2 \\ &= c^4+2c^2\bar{\theta}^2+\left[h(\Delta)+x(\Delta^C)\left(\bar{\theta}-g(\Delta)\right)\right]^2 \qquad (4.20) \\ &= (c^2+\bar{\theta})^2+\left[h(\Delta)+x(\Delta^C)\left(\bar{\theta}-g(\Delta)\right)\right]^2-\bar{\theta}^4 \qquad (4.21)\end{aligned}$$

noting that $g(\Delta)+x(\Delta^C)F(\Delta^C)=\int_{t\in\Delta}tf(t)dt+\int_{t\in\Delta^C}tf(t)dt=\bar{\theta}$.

The optimization problem of the committee is:

$$Min_{\theta_t}4c^4E\psi=Min_{\theta_t}(c^2+\bar{\theta})^2+\left[h(\Delta)+x(\Delta^C)\left(\bar{\theta}-g(\Delta)\right)\right]^2-\bar{\theta}^4$$

The derivative of $4c^4E\psi$ w.r.t θ_t yields:

$$\frac{\partial\psi}{\partial\theta_t}=2\left(h+x^2F\right)\left(\frac{\partial h}{\partial\theta_t}+\frac{\partial x^2F}{\partial\theta_t}\right) \qquad (4.22)$$

We further note that:

$$\frac{\partial F(\Delta^C)}{\partial\theta_t}=\frac{\partial}{\partial\theta_t}\left[\int_{\theta_t}^{\theta''}f(t)d(t)+\int_{\tilde{\Delta^C}}f(t)d(t)\right]=-f(\theta_t)<0 \qquad (4.23)$$

$$\frac{\partial g(\Delta)}{\partial\theta_t}=\frac{\partial}{\partial\theta_t}\left[\int_{\theta'}^{\theta_t}tf(t)d(t)+\int_{\tilde{\Delta}}tf(t)d(t)\right]=\theta_tf(\theta_t)>0 \qquad (4.24)$$

$$\frac{\partial h(\Delta^C)}{\partial\theta_t}=\frac{\partial}{\partial\theta_t}\left[\int_{\theta'}^{\theta_t}t^2f(t)d(t)+\int_{\tilde{\Delta}}t^2f(t)d(t)\right]=\theta_t^2f(\theta_t)>0 \qquad (4.25)$$

$$\frac{\partial(xF)(\Delta^C)}{\partial\theta_t}=\frac{\partial}{\partial\theta_t}\left[\int_{\theta_t}^{\theta''}tf(t)d(t)+\int_{\tilde{\Delta^C}}tf(t)d(t)\right]=-\theta_tf(\theta_t)<0 \qquad (4.26)$$

$$\frac{\partial(x^2F)(\Delta^C)}{\partial\theta_t}=\frac{\partial x}{\partial\theta_t}xF-\theta_tf(\theta_t)x \qquad (4.27)$$

Also,

$$\begin{aligned}
& x(\Delta^C) = \frac{g(\Delta^C)}{F(\Delta^C)} \\
\Rightarrow\ & x(\Delta^C)F(\Delta^C) = g(\Delta^C) \\
\Rightarrow\ & \frac{\partial\{x(\Delta^C)F(\Delta^C)\}}{\partial\theta_t} = \frac{\partial x}{\partial\theta_t}(\Delta^C)F(\Delta^C) - x(\Delta^C)f(\theta_t) = -\theta_t f(\theta_t) \\
\Rightarrow\ & \frac{\partial x}{\partial\theta_t} = \frac{(x(\Delta^C)-\theta_t)f(\theta_t)}{F(\Delta^C)} > 0 \qquad (4.28)
\end{aligned}$$

Substituting in equation (4.22) and using equation (4.28), we get

$$\begin{aligned}
\frac{\partial\psi}{\partial\theta_t} &= 2\left(h + x^2(\Delta^C)F(\Delta^C)\right)\left(\theta^2 f(\theta_t) + \frac{\partial x}{\partial\theta_t}(\Delta^C)x(\Delta^C)F(\Delta^C) - x(\Delta^C)\theta_t f(\theta_t)\right) \\
&= 2\left(h + x^2(\Delta^C)F(\Delta^C)\right) f(\theta_t)\left\{\theta_t^2 + x(\Delta^C)(x(\Delta^C)-\theta_t) - x(\Delta^C)\theta_t\right\} \\
&= 2\left(h + x^2(\Delta^C)F(\Delta^C)\right) f(\theta_t)\left\{\theta_t - x(\Delta^C)\right\}^2
\end{aligned} \qquad (4.29)$$

This implies that the probability of coordination failure is positively sloped $\forall\theta_t$ and reaches its minimum value at $\theta_t = \theta'$. In other words, the probability of coordination failure is minimized if *the combination of a revelation interval* $[\theta', \theta_t]$ *and the adjacent non-revelation interval* $[\theta', \theta_t]$ *is replaced by a single non-revelation interval* $[\theta', \theta'']$ ■

A disclosure rule of full revelation $D_{\mathbb{T}}$ would yield:

$$4c^4\psi_F = c^4 + 2c^2\left[g(\mathbb{T}) + 0\right]^2 + \left[h(\mathbb{T}) + 0\right]^2 = (c^2 + \bar{\theta})^2 + h^2(\mathbb{T}) - \bar{\theta}^4 \qquad (4.30)$$

A disclosure rule of no revelation D_ϕ would yield:

$$4c^4\psi_N = c^4 + 2c^2\left(0 + \bar{\theta}\right)^2 + \bar{\theta}^4 = (c^2 + \bar{\theta}^2)^2 \qquad (4.31)$$

Now, $4c^4\psi_F - 4c^4\Psi_N = h^2(\mathbb{T}) - \bar{\theta}^4 = \text{var}(\theta)(E(\theta^2) + \bar{\theta}^2) > 0$ implying that non-revelation yields a lower expected probability of coordination failure for the committee compared to full revelation.

As $[\theta', \theta'']$ is an arbitrary subset of the type space $\mathbb{T} = [\theta_l, \theta_h]$, we see that no disclosure over $\mathbb{T}$ is an equilibrium disclosure rule (with appropriate adjustments in the definitions of $x(.)$, $g(.)$ and $h(.)$).

The intuition for this result is that along the equilibrium path, the firms update their beliefs given their knowledge of the optimal disclosure rule and this belief is monotonically increasing in the committee's strategy. A study of the necessary condition for finding an interior optimal θ_t in the equation below clearly shows this to be the case.

$$\begin{aligned} \frac{\partial \psi}{\partial \theta_t} &= 2\left(h + x^2 F\right)\left(\frac{\partial h}{\partial \theta_t} + \frac{\partial x^2 F}{\partial \theta_t}\right) = 0 \\ &\Rightarrow \frac{\partial h}{\partial \theta_t} + \frac{\partial xg}{\partial \theta_t} = 0 \end{aligned}$$

This necessary condition is violated in this case as all the derivatives in the right hand side of the previous equation are positive. In other words, expected probability of coordination failure on both sides of the cutoff θ_t are increasing (decreasing) as θ_t shifts to the right (left). Therefore, the lowest probability of coordination failure is achieved at the corner $\theta_t = \theta'$ indicating no disclosure.

Had $x(\Delta^C)$ not increased monotonically with θ_t, this necessary condition would have been satisfied (the increase in h would have been balanced by the decrease in xF, which falls with θ_t). Rephrasing, the belief of the firms $x(\Delta^C)$ not monotonically increasing in the strategy of the committee θ_t is sufficient to ensure the existence of a partial revelation rule in equilibrium.

Step 2. We now show that the above holds for a mirror-image of the above case, where we have a revelation interval $[\theta_t, \theta'']$ adjacent to a lower interval $[\theta', \theta_t]$. See figure 4.1.

Corollary 6. *The optimal value of θ_t is at θ'' for a participation compliant disclosure rule with a cutoff at θ_t and revelation interval $[\theta_t, \theta''] \subset \Delta$.*

The proof is along similar lines as the one for the previous proposition. Note that the definitions of $x(.)$, $g(.)$ and $h(.)$ change, in keeping with the change in the revelation interval. The expression for the derivative of expected coordination failure probability changes from (4.29) to:

$$\frac{\partial \psi}{\partial \theta_t} = -2\left(h + x^2(\Delta^C)F(\Delta^C)\right) f(\theta_t)\left\{\theta_t - x(\Delta^C)\right\}^2 \tag{4.32}$$

which is negative in the entire type space.

The result follows the same intuition as the earlier proposition. Decreasing θ_t decreases $h(\Delta)$ and $g(\Delta)$. For an interior cutoff to exist, this decrease in $h(\Delta)$ should be counterbalanced by a decrease in $g(\Delta)$. However, this counterbalancing effect cannot work if $x(\theta_t)$ also decreases and dominates the change in $g(\Delta)$. Therefore, in equilibrium disclosure rule has a corner cutoff indicating no disclosure over the entire set of types.

This leads us to the following proposition:

Proposition 5. *No disclosure is an equilibrium disclosure rule (maximizes the expected payoff of the committee by minizing the probability of expected coordination failure in the coordination game with one round of pre-play cheap talk).*

Step 3. Corollaries 5 and 6 together imply that there cannot be two contiguous revelation and non-revelation set anywhere in the type space for any optimal disclosure rule. In conjunction, they prove that for a completely arbitrary interval $[\theta', \theta'']$ of the type space, expected coordination failure is minimized if contiguous revelation and non-revelation intervals are replaced by no revelation in the entire set $[\theta', \theta'']$. Repeated application of these corollaries for any candidate disclosure rule with contiguous revelation and non-revelation intervals proves that the committee can always improve its expected equilibrium payoff (achieve minimum expected probability of coordination failure) by replacing these intervals by a no-disclosure rule in the entire type space. For instance, consider the disclosure rule with disjoint disclosure intervals $[\theta_l, \theta_{t_1}]$ and $[\theta_{t_2}, \theta_h]$, with non-disclosure in the interval $[\theta_{t_1}, \theta_{t_2}]$. Application of corollary 5 shows that the expected probability of coordination failure will decrease if θ_{t_1} coincides with θ_l, i.e. the contiguous revelation and non-revelation intervals are replaced by non-revelation in the $[\theta_l, \theta_{t_2}]$. Now, applying corollary 6, the committee achieves the lowest probability of coordination failure by setting $\theta_{t_2} = \theta_h$.

Therefore, we can conclude the following result:

Proposition 6. *No disclosure is unique in the class of disclosure strategies Ψ which allows for revelation in finite unions of disjoint intervals in the type space.*

As noted earlier, this class of disclosure rules covers nearly all measurable sets in the type space and is therefore very broad in its scope.

Significance of the single communication stage

If the communication stage is dropped, then the firms are indifferent about going or not going to the committee under any disclosure rule. If we make the additional assumption that they will go to the committee in this case, then the result is the same as when there is a communication stage sandwiched between the information revelation and coordination stages. This helps us address the question of how the results in this game tie up with the earlier chapters, particularly in the market scenario with symmetric firms.

In the market game, there is no separate communication stage. If the firms are symmetric (and do not know their own types), and there is a strategic committee which can reveal their types to them, we can state that the firms will go to the committee irrespective of its disclosure rule (as they are indifferent about going or not going to the committee).

The strength of introducing one round of cheap talk on intent is that both the firms are unambiguously incentivized to go to the committee. In terms of the incentives of the committee to reveal information, inclusion or non-inclusion of the communication stage makes no difference.

Proposition 7. *Without the communication stage, non-disclosure is still the optimal policy for the committee.*

Proof. Substitution of the equilibrium values of the probabilities $p_i = \frac{\theta_j + c}{2c}$ and $p_j = \frac{\theta_i + c}{2c}$ from (4.3) yields:

$$2c^2\psi = \mathbb{E}_{\theta_i,\theta_j \in \Delta}(c^2 + \theta_i\theta_j) + \mathbb{E}_{\theta_i \in \Delta, \theta_j \in \Delta^C}(c^2 + x(\Delta^C)\theta_j) + \mathbb{E}_{\theta_i \in \Delta^C, \theta_j \in \Delta}(c^2 + \theta_i x(\Delta^C)) + \mathbb{E}_{\theta_i \in \Delta^C, \theta_j \in \Delta^C}(c^2 + x(\Delta^C)^2) \quad (4.33)$$

On simplification, we get:

$$2c^2\psi = c^2 + [g(\Delta) + x(\Delta)]^2 - x(\Delta^C)^2 \left[1 - F^2(\Delta^C)\right] \tag{4.34}$$

The slope of the equilibrium probability of coordination failure is:

$$\frac{2c^2\partial\psi}{\partial\theta_t} = 2\left(g(\Delta) + x(\Delta)\right)\left(\theta_t + \frac{x(\Delta) - \theta_t}{F(\Delta)}\right) f(\theta_t) + \frac{2x(\Delta^C)\theta_t}{F(\Delta^C)}\left(\theta_t(1 - F^2(\Delta^C)\right) > 0 \tag{4.35}$$

implying that the optimal disclosure cutoff should be at $\theta_t = \theta_l$. ■

4.4.2 Committee does not have a perfect equipment for testing a firm's technology

We now allow for the possibility that the testing equipment of the committee is imperfect. The motivation for this assumption is that for very new technologies, tests conducted by the committee might not be informative. If the committee discloses no information, it might be due to a failure of its testing equipment rather than strategic intent. If the firms believe this to be the case, a partial disclosure rule from the cutoff class outperforms no disclosure. This result is similar to that of Shin (1994), who shows that manipulative disclosure is possible if there is uncertainty regarding the information of the informed agent's information.

The timing of the game is the same as in the previous section. The difference between this game and the previous one is that here the committee announces that for all firms coming to the committee, their types will be tested. If the committee can find out the firm's type, then the firm will be informed truthfully about its type. This leads to the result that the firm's do not know the optimal cutoff θ_t that the committee decides for revealing information. Hence, the firms do not update their beliefs to $x(\theta_t)$ over the non-revelation set. Rather, they believe that non-revelation is a result of the committee's failure to find out their true type.

In this case, non-revelation results in the firms assuming that their types are at $\bar{\theta}$. As with the case of no disclosure in the previous section, the expected payoff to firm k from going to the committee alone $\frac{\bar{\theta}+c}{2}$ is the same as that from not going. Both the firms going results in a higher payoff due to the single round of cheap talk on coordination. Therefore, going to the committee weakly dominates not going to the committee.

This exercise demonstrates that monotonically increasing beliefs in the committee's strategy is a sufficient condition for non-disclosure to be the unique equilibrium in the class of disclosure rules Ψ. With a violation of this condition, we now show that a participation compliant partial disclosure can be sustained in equilibrium.

Given that both the firms go to the committee, suppose that the committee employs a cutoff rule such that it reveals all types below θ_t and does not reveal any type above θ_t, so that $\Delta = [\theta_l, \theta_t]$ and $\Delta^C = [\theta_t, \theta_h]$. The firms are not aware of θ_t in this case and the optimization exercise of the committee becomes:

$$\begin{aligned}\min_{\theta_t} 4c^4 E\psi &= \min_{\theta_t} EI_{\theta_i,\theta_j<\theta_t}(c^2+\theta_i\theta_j)^2 \\ &+EI_{\theta_i<\theta_t<\theta_j}(c^2+\theta_i\bar{\theta})^2 \\ &+EI_{\theta_j<\theta_t<\theta_i}(c^2+\theta_j\bar{\theta})^2 \\ &+EI_{\theta_i,\theta_j>\theta_t}(c^2+\bar{\theta}^2)^2\end{aligned} \tag{4.36}$$

Recall that:

- $g(\Delta) = \int_{\theta_l}^{\theta_t} \theta_k dF(\theta_k)\ \forall k = i, j$
- $h(\Delta) = \int_{\theta_l}^{\theta_t} \theta_k^2 dF(\theta_k)\ \forall k = i, j$
- $x(\Delta^c) = \frac{\int_{\theta_t}^{\theta_h} \theta_k dF(\theta_k)}{1-F(\theta_t)} = \frac{\hat{\theta}-g(\Delta)}{1-F(\theta_t)}\ \forall k = i, j$

Note also the following derivatives:

- $\frac{\partial g(\Delta)}{\partial \theta_t} = g' = \theta_t f(\theta_t) > 0$
- $\frac{\partial x(\theta_t)}{\partial \theta_t} = x' = \frac{x(\theta_t)f(\theta_t)}{1-F(\theta_t)} - \frac{g'}{1-F(\theta_t)} > 0$
- $\frac{\partial h(\Delta)}{\partial \theta_t} = h' = \theta_t^2 f(\theta_t) > 0$

Proposition 8. *There is at least one interior cutoff θ_t such that the committee reveals all types below it and does not reveal any type above it.*

Proof. The slope of $4c^4E\psi$ in equation (4.36) is given by:

$$\begin{aligned}\frac{\partial 4c^4\psi}{\partial \theta_t} &= 4c^2gg' + 2(h+\bar{\theta}^2(1-F)^2)(h' - 2\bar{\theta}^2(1-F)f(\theta_t)) \\ &+ 2c^2\bar{\theta}g'(1-F) + 2c^2\bar{\theta}gf - 4c^2\bar{\theta}^2(1-F)f\end{aligned}$$

At $\theta_t = \theta_l$, the value of the slope, after substituting for g, g', h and h' is:

$$2\bar{\theta}^2(\theta_l^2 - 2\bar{\theta}^2)f + 2c^2\bar{\theta}(\theta_l - 2\bar{\theta})f < 0$$

where the inequality follows from the fact that $\theta_l < \bar{\theta}$. At $\theta_t = \theta_h$, the value of the slope, after substituting for $g, g', handh'$, is:

$$(4c^2\bar{\theta}\theta_h +^2 h\theta_h^2 + 2c^2\bar{\theta}^2)f > 0$$

Therefore, there has to be at least one interior minimum. ■

For the uniform distribution in the compact type space [0, 1], we present the simulated graph for expected probability of coordination failure when the strategic intent of the committee is not known to the firms for the disclosure rule, with the revelation interval $[0, \theta_t]$ and non-revelation in the interval $[\theta_t, 1]$. The graph shows that there is a interior revelation cutoff at $\theta_t = 0.5$ with the lowest expected probability of coordination failure at 0.268.

4.5 Conclusion

In this chapter, we investigate the mechanisms for achieving coordination by an external agent (committee) when such coordination/standardization on a single technology matters to the committee as well as the firms. We endogenize the structure of information and investigate the role of information revelation (hard evidence) by the strategic committee. The problem of coordination is non-trivial because the firms have vested interest in their

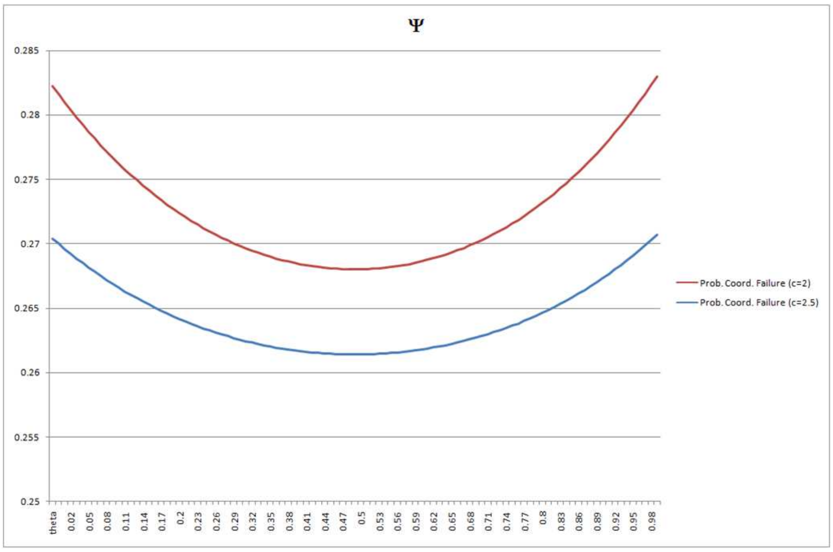


Figure 4.2: Expected probability of coordination failure with uncertainty about committee's testing efficiency

own technologies and want the standard to form on their own technologies. Conflict of interest in this game has two dimensions.

First is the clear conflict of interest among the firms as in Farrell (1987), which shows up in the coordination game with one round of pre-play cheap talk on intent. There is also the possibility of conflict between the firms (who want a standard on their own technologies) and the committee (which only wants a standard). However, as long as $c > \theta_h$, this conflict does not arise. This condition holds for one round of cheap talk for which we discuss our results. If the number of periods of cheap talk increased, then there would be different effects on the two kinds of conflict. The results in the Appendix show that for any disclosure rule, the payoff of the firms increase towards c

as the number of rounds of cheap talk become very large. While this would not affect the inherent conflict of interest between the firms, the conflict of interest between the committee and the firm would increase. This would make the firms recalcitrant about staying with a committee with a very high number of rounds of cheap talk. We also show that with inherent conflict of interest in a game of incomplete information, even an infinitely long cheap talk will not be able to achieve full coordination, extending Farrell (1987)'s result in a complete information framework.

More importantly, the power of cheap talk to achieve full coordination was restored if the conflict of interest was absent in Farrell (1987). We show that this is a result of the special payoff matrix in the entry game discussed in Farrell (1987) and need not hold with a different payoff matrix as in our model.

Given this ineffectiveness of cheap talk, we investigate strategic information revelation to achieve coordination with only one stage of cheap talk on intent. We consider the class Ψ of disclosure rules which allows for revelation in finite unions of disjoint intervals of the type space. A first interesting result is that in an extended coordination game (with one round of non-binding pre-play communication) with beliefs of the uninformed agents (the firms) increasing in the strategy of the informed agent (the committee), the unique equilibrium within this very large class of disclosure rules is that of no disclosure.An interesting result is that even with only one round of cheap talk communication, we can sustain non-disclosure of information in equilibrium.

The monotonicity of firms' beliefs in the committee's disclosure strategy is sufficient for this result. We demonstrate this by allowing for the possibility that the testing equipment is not perfect. The committee can hide its strategic intent by justifying the occasional disclosure as a failure of its testing method or apparatus - when the technologies are very new, this is a plausible excuse. This allows the committee to exercise its disclosure rule without revealing it to the firms.

In this case, the beliefs of the firms are no longer monotonic with the committee's strategy. Now it is possible for technical committees to employ a partial disclosure rule in equilibrium and improve upon the payoff with no disclosure. For general distributions, we show that there exist at least one such equilibrium. Simulations for the uniform distribution indicate that there will exist a partial disclosure in equilibrium. Therefore, the committee can strategically exploit the information uncertainty about its ability and improve upon the no disclosure result as the sufficient condition for no disclosure does not hold here.

Another point which needs highlighting is that in the entire discussion, a crucial assumption is the commitment by the committee to its disclosure rule. In the absence of such commitment, it is possible for the firms to influence the revelation decisions of the committee. Since these considerations are separate from those of understanding strategic revelation under commitment, we retain our assumption throughout the analysis. The focus is more squarely on the effectiveness of cheap talk on intent, strategic information revelation and certification and a public correlation device in order to achieve standardization, rather than issues of commitment in this chapter.

4.6 Appendix

4.6.1 Cheap talk as a coordinating device

Farrell (1987) shows that an infinitely long cheap talk can achieve full coordination if there is no conflict of interest in the game, which involves two firms' entry decisions in a market with sunk costs (such as markets for computer software, telephone switching equipment etc.) which can accomodate the profitable entry of at most one firm. The payoff matrix considered for this game is as shown in table 4.2.

	In	Out
In	$-L$, $-L$	B,M
Out	M,B	0, 0

Table 4.2: Payoff matrix in Farrell (1987)

If both firms enter each makes a loss of $-L$, whereas if only one firm enters it makes a monopoly profit of M and the firm staying out gets B. In this context,Farrell (1987) characterizes the inherent conflict in the game as $\beta = \frac{B}{M}$. For infinitely long cheap talk on coordination prior to entry, Farrell (1987) proves that the probability of coordination failure in the symmetric mixed strategy equilibrium of the game vanishes Farrell (1987) if $\beta = \frac{B}{M} \to 1$. The lower is this ratio, the larger is the probability of coordination failure, even in an extended game with cheap talk prior to entry. The analysis is done in an environment of complete information.

We show that this result extends in a modified fashion, even in the presence of incomplete information in our model, which is structurally very similar to the coordination game considered by Farrell (1987).

We first note that a finite length of cheap talk rounds cannot achieve full coordination, as in Farrell (1987). Let the payoff of firm k in period r of an extended game with K periods (of which the first $K-1$ periods are cheap talk rounds be $\pi_k^K(K-r)$ $\forall k = i, j$. Let $q_k^K(K-r)$ be the probability with which firm k insists on its own technology in period r of the cheap talk game of length K. By definition, the probability of coordination failure in a game with K periods of cheap talk is:

$$
\begin{aligned}
\psi_D^K &= [(1-q_i^K(K-1))(1-q_j^K(K-1)) + q_i^K(K-1)q_j^K(K-1)] \\
&* \ [(1-q_i^K(K-2))(1-q_j^K(K-2)) + q_i^K(K-2)q_j^K(K-2)]... \\
&* \ [(1-q_i^K(1))(1-q_j^K(1)) + q_i^K(1)q_j^K(1)] \\
&* \ [(1-p_i^K(0))(1-p_j^K(0)) + p_i^K(0)p_j^K(0)] \qquad (4.37)
\end{aligned}
$$

. For any disclosure rule $D \in \Psi$, ex ante there remains a positive probability of coordination failure even for multiple but finite number of rounds of cheap talk.

Ex ante, the minimum probability of coordination failure ψ_D^K is bounded away from zero for a K period cheap talk game in equilibrium with mixed strategies, given any disclosure rule D_Δ.

We now show that for any disclosure rule (and not only full disclosure), that it is the probability of coordination failure will not to go to zero with infinite rounds of cheap talk if there is inherent conflict in the game, as in Farrell (1987). We also find that even if there is no conflict of interest in the game, we cannot directly conclude that there will be no coordination failure even with infinite rounds of cheap talk.

In our model, inherent conflict is different for the two firms, unlike in Farrell (1987). Conforming with the terminology in Farrell (1987), inherent conflict for firm i is $\beta_i = \frac{c}{\theta_i + c}$. This ratio measures the strength of firm i's vested interest. Similarly, for firm j, $\beta_j = \frac{c}{\theta_j + c}$. Lack of inherent conflict in this game implies that $\beta_i = \beta_j = 1$ which happens only when $\theta_i = \theta_j = 0$. If either of $\beta_k \neq 1 \ \forall k = 1, 2$, then we can show that even an infinitely long cheap talk will be unable to achieve complete coordination. There is no reason for either firm to stop insisting on its own technology.

Corollary 7. *Under any general disclosure rule D_Δ, the equilibrium expected payoffs of the firms form an increasing sequence i.e. $\pi_k^K(K-r+1) > pi_k^K(K-r) \ \forall k = i, j, \ \forall r \in \mathbb{R}$.*

Proof. Consider a game with K periods, where the last stage is the coordination game and the earlier stages are the cheap talk rounds. For any general disclosure rule D_δ, the equilibrium expected payoff of firm k in the last coordination stage (after the cheap talk rounds) from table 4.1 are:

$$\pi_k^K(0) \ = \begin{cases} \frac{x(\Delta^C)+c}{2} < c, \text{if } \theta_k \in \Delta^C \\ \frac{\theta_j + c}{2} < c, \text{otherwise} \end{cases}$$

where the first inequality $\frac{x(\Delta^C)+c}{2} < c$ follows from the fact that $c > \theta_h$. In any earlier cheap talk period r, the payoff of firm i is:

$$\begin{aligned} \pi_i^K(K-r) &= q_j^K(K-r)\pi_i^K(K-(r-1)) + (1 - q_j^K(K-r))(\theta_i + c) \\ &= q_j^K(K-r)c + (1 - q_j^K(K-r))\pi_i^K(K-(r-1)) \qquad (4.38) \end{aligned}$$

As the last period payoffs are less than c, and the payoff in any period is a weighted averaged between that in a later period and c, by induction it is true that $\pi_k^K(K-r) \leq c \;\forall k = i, j$ for all r. Further equation (4.38) reveals that for all r:

$$\pi_i^K(K-r) - \pi_i^K(K-(r-1)) = q_j^K(K-r)(c - \pi_i^K(K-(r-1))) > 0 \quad (4.39)$$

A similar relation holds for firm j's equilibrium expected payoff. This proves that the sequence of equilibrium expected payoffs of the firms form an increasing sequence. ■

Therefore, we have shown that this result in Farrell (1987) holds for general disclosure rules and not only for full disclosure. Next we prove that the limiting equilibrium expected payoffs of the firms tend to c for general disclosure rules, which Farrell (1987) proves in the case of full disclosure.

Corollary 8. *With a general disclosure rule D_Δ, the expected equilibrium payoff of firm k follows:*

$$\pi_k^K(K-2) = \pi_k^{K-1}(K-2)$$

Proof. Consider a general disclosure D_Δ. For full revelation, it is obvious that if the game goes from the first to the second period of a K period game, the remaining subgame is played as though the previous stage game never happened. With non-disclosure, no type ever gets to know their types and therefore, cannot infer anything about their types from actions in later subgames. Therefore, in both these cases the subgame starting from the first period of a $(K-1)$ period game and the subgame starting from the second period of a K period game look exactly the same. With partial revelation, the firms update their beliefs about their and their opponent's types at the first period of the extended game. No further updation of types is possible as actions in later subgames are not informative about a firm's type. Therefore, for a K period and $(K-1)$ period game:

$$\pi_k^K(K-2) = \pi_k^{K-1}(K-2)$$

■

Proposition 9. *The limiting equilibrium expected payoffs of the firms tend to c for any general disclosure rule.*

Proof. Consider the equilibrium payoff of firm k. Corollary 7 proves that the sequence of payoffs of firm k increases from below under any general disclosure rule, i.e the first period payoff is higher than that in the second period. Now suppose that this sequence does not converge to c. Let each firm's payoff converge to some $\bar{\pi} < c$. This implies that for any $\epsilon > 0$, there would exist a $K(\epsilon)$ such that $|\pi_k^K(K-1) - \bar{\pi}| < \epsilon \forall K \geq K(\epsilon)$. We will show a contradiction in this case.

For a K period game in period $r = 1$, we get from equation (4.39) that:

$$\pi_k^K(K-1) - \pi_k^K(K-2) = q_k^K(K-1)(c - \pi_k^K(K-2)) > 0 \tag{4.40}$$

Therefore, replacing $\pi_k^K(K-2)$ by $\bar{\pi}$, we get

$$q_k^K(K-1)(c-\bar{\pi}) = |\pi_k^K(K-1) - \bar{\pi}| \leq |\pi_k^K(K-1) - \pi_k^K(K-2)| \tag{4.41}$$

By triangle inequality,

$$|\pi_k^K(K-1) - \pi_k^K(K-2)| \le |\pi_k^K(K-1) - \bar{\pi}| + |\pi_k^K(K-2) - \bar{\pi}| \quad (4.42)$$

Convergence of the sequence of payoffs of firm k implies that for any $\epsilon > 0$, there would exist a $K(\epsilon)$ such that:

$$|\pi_k^K(K-1) - \bar{\pi}| \;<\; \epsilon \quad (4.43)$$

$$|\pi_k^{K-1}(K-2) - \bar{\pi}| \;<\; \epsilon \quad (4.44)$$

which in turn implies that

$$|\pi_k^K(K-1) - \bar{\pi}| + |\pi_k^{K-1}(K-2) - \bar{\pi}| < 2\epsilon \quad (4.45)$$

Corollory 8 shows that:

$$|\pi_k^K(K-2) - \bar{\pi}| = |\pi_k^{K-1}(K-2) - \bar{\pi}| \quad (4.46)$$

Using this relation in equations (4.42) and (4.45) and , we get that:

$$|\pi_k^K(K-1) - \pi_k^K(K-2)| \le |\pi_k^K(K-1) - \bar{\pi}| + |\pi_k^K(K-2) - \bar{\pi}| < 2\epsilon \quad (4.47)$$

Equations (4.41) and (4.47) together imply

$$\begin{aligned} q_k^K(K-1)(c-\bar{\pi}) &= |\pi_k^K(K-1) - \bar{\pi}| \le \pi_k^K(K-1) - \pi_k^K(K-2)| \\ &\le |\pi_k^K(K-1) - \bar{\pi}| + |\pi_k^K(K-2) - \bar{\pi}| < 2\epsilon \quad (4.48) \end{aligned}$$

From equation (4.38), the equilibrium payoff of firm i is:

$$\pi_i^K(K-1) = q_j^K(K-1)\pi_i^K(K-2) + (1 - q_j^K(K-1))(\theta_i + c)$$

As $\epsilon \to 0$, equation (4.48) implies that $q_j^K(K-1) \to 0$ as $c > \bar{\pi}$ by assumption. Therefore, firm i's equilibrium payoff $\pi_i^K(K-1) \to \theta_i + c > c$ which is a contradiction of the fact that $\bar{\pi} < c$. ■

As Rabin (1994) points out, the limiting payoff from an infinitely long cheap talk guarantees each player the payoff from its worst Pareto-ranked Nash equilibrium. In this case, this translates to the coordination benefit c, which a firm gets if the standard forms on the opponent's technology.

In contrast with Farrell (1987), we show that the probability of coordination failure need not vanish even if there is no inherent conflict in the game.

Proposition 10. *Given full disclosure and participation by the firms in the committee, the probability of coordination failure in the limit is bounded away from zero even if $\theta_i = \theta_j = 0$.*

Proof. We note that in a K period cheap talk game, the probability of successful coordination $(1 - \psi^K)$ is divided equally into two outcomes {adopt, swich} and {switch, adopt}. With probability $\psi^K/[(1-p_i)(1-p_j)+p_ip_j]$, the firms go through all K rounds of cheap talk without reaching any agreement; finally with probability p_ip_j both adopt and with probability $(1-p_i)(1-p_j)$ both switch.

Therefore, the payoff to firm i is:

$$\begin{aligned}\pi_i^K = \quad & \frac{1}{2}(1-\psi^K)(\theta_i + c) + \frac{1}{2}(1-\psi^K)c \\ + \quad & \frac{\psi^K}{[(1-p_i)(1-p_j)+p_ip_j]}[p_ip_j\theta_i + (1-p_i)(1-p_j)0]\end{aligned} \quad (4.49)$$

By symmetry we have a similar expression for π_j^K. As shown in the previous corollary, π_i^K and π_j^K tend to c as $K \to \infty$. Therefore, in the limit,

$$\pi_i - \pi_j = 0 = \frac{1}{2}(1-\psi)(\theta_i - \theta_j) + \frac{\psi}{[(1-p_i)(1-p_j)+p_ip_j]}[p_ip_j(\theta_i - \theta_j)] \quad (4.50)$$

Upon simplification, we get that:

$$(\theta_i - \theta_j)[\frac{1}{2}(1-\psi) + \frac{\psi p_i p_j}{[(1-p_i)(1-p_j)+p_i p_j]}] = 0 \tag{4.51}$$

whereby, we get $\psi = \frac{(1-p_i)(1-p_j)+p_i p_j}{3p_i p_j+(1-p_i)(1-p_j)+p_i p_j} = \frac{1}{2} > 0$ even if $\theta_i = \theta_j = 0$. The last expression follows from the corollary showing that under full disclosure and participation in the committee by both the firms, $p_i = \frac{\theta_j + c}{2c}$ for firm i and a similar expression for firm j. ∎

This proves that in our payoff matrix, an infinite length of cheap talk might fail reduce the probability of coordination failure to zero even if an individual firm's private benefit (and the source of conflict of interest with the other firm) goes to zero. If both the private benefits go to zero, then it is possible (though not certain) there there will be full coordination. However, the measure of such an event in the type space that we have considered is zero.

This result is in contrast with Farrell (1987). The reason for this difference in result is that the payoff matrix in Farrell (1987) is a special case. In the table 4.2, if we allow for B_1 and B_2 as the payoffs to the firms when they stay out of the industry when the other firm enters, we will not get the limiting result that in the absence of conflict of interest in the game, there is coordination in the limit. If B_1 and B_2 are close to each other but their difference is non-zero, then even if an individual B_i is zero, there remains conflict in the game despite the number of cheap talk rounds going to infinity.

As the payoffs of the firms increase in the limit to c, the conflict of interest between the firms and the committee increases as the number of periods of cheap talk round increase. The committee would find it extremely difficult to keep the firms engaged in a game with infinitely long periods of cheap talk. Given the ineffectiveness of cheap talk, we have focused on strategic information disclosure with only a single round of cheap talk in this chapter.

Chapter 5

Conclusion

We sum up the conclusions of the results in the thesis in the following sections. All of them revolve around a game of coordination between two firms. The structure of information is different in the models of these chapters and therefore, the questions and results we get are different.

5.1 Lessons from chapter 2

The central question we address here is a comparison of the coordination efficiency of the one-shot committee and the market. In the case of firms playing pure strategies, we can show that no market equilibrium is efficient, whereas there exists at least one efficient equilibrium in the committee.

We then analyze the case where firm B plays completely mixed strategies and firm A responds with a cutoff-strategy for coordination.The mixed strategy equilibrium highlights the coordination uncertainty in the game.

Additionally, the existence of a mixed strategy equilibrium requires that coordination benefits should be larger than private benefits, i.e. coordination should matter. This situation occurs most naturally for network industries, and therefore, the analysis is especially relevant in the context of these industries. However, this result is general enough to be applied in all contexts which meet the necessary conditions for mixed strategy equilibria.

We characterize the unique one-shot market equilibrium. The uniqueness of this equilibrium derives from the payoff matrix and the coordination benefits being greater than the private benefits. For the committee game, we show that with one-shot interaction, an equilibrium of the committee game must necessarily be characterized by no information disclosure.

This non-revelation result holds for a large class of communication rules which allows for revelation over finite unions of disjoint intervals of the type space.

Most of the literature on revelation of hard evidence rely on three sufficient conditions: monotonicity of payoffs in types, truthtelling and skeptical beliefs. However, the model of the one-shot committee game shows that despite these conditions being valid, the unique natural equilibrium of the game involves no information revelation. Non-revelation is also an equilibrium for some type distributions for the two-period game. The reason for this is uncertainty in coordination (and not conditional independence of payoffs) in the natural equilibria of either game. Therefore, we show that the three conditions mentioned in the literature are not sufficient in the presence of coordination uncertainty.

5.2 Lessons from chapter 3

The market, as an institution facilitating information revelation and coordination, has some limitations compared to a committee designed to achieve the very same objectives. The requirement that the player with private information can reveal it only through adopting its own technology prohibits the market's ability to achieve higher coordination through information revelation. Furthermore, unlike the committee, the market has no innate mechanism to facilitate coordination through fiat. If both the players, in any period, "adopt", then the market game terminates whereas the committee game goes on to the following period giving the players another chance for coordination.

Despite this limitation, this chapter points out two interesting results that highlight the efficiency of markets and the importance of institutional design of committees. First is regarding the question about which institution achieves better coordination. For the uniform distribution of types over $[0, 1]$, for $c >> 1$, efficiency in coordination in the committee is better than the market, as it has lower risk in coordination. For lower values of c, relative to the maximum value of θ, we have shown that the market "rewards most good ideas" and "kills some bad ideas" more efficiently than the committee. For higher values of c, the committee outperforms the market in compensating good ideas.

Depending upon the strength of c in the network industry (the range in which θ/c lies), the market route might be preferred to "reward good ideas" or "killing bad ideas" or the committee might be used to achieve coordination with lower risk. This result validates the empirical evidence that institutions for standardization are industry-specific (for a cross-sectional comparison) or for a given industry, the route to successful standardization changes as c changes. For more mature industries, c rises and hence, there is a proliferation of technical committees aiding standardization rather than the market bandwagon.

In a more general context, the central result of this chapter sheds light on how the specifics of the industry determine whether the market or the committee is a more efficient institution for standardization. Intuitively, one might expect that the market bandwagon, with very little allowances made for coordination, would punish "bad ideas" severely and commensurately reward "good ideas". However, the result of our model is that the market seems to perform the latter task better than the former, for relatively low values of c. As coordination benefits increase, the committee does better than the market in both coordinating on the better idea and compensating it.

Infact, neither institution seem to be very efficient in terms of CEII or in "killing bad ideas". This explains why there are notable examples of inferior standards being delivered by either institution. The QWERTY keyboard is a product of the market bandwagon, which survived the more efficient DVORAK system. The GSM standard had a lower spectral efficiency compared to narrow-band CDMA, but was the standard chosen by a technical committee.

Second, the results from the two period comparison of the committee and market games show that there is some information revelation in the market game, rather than in the committee game. The committee game has a separate stage for information revelation which the market lacks. However, as shown in chapter, the compulsions of coordination in the natural equilibrium of the two period committee game with $\Delta = 0$ imply non-revelation is an equilibrium. The market, institutionally, puts a lower premium on coordination and therefore permits some revelation of private information through the very act of adoption of firm A's technology.

5.3 Lessons from chapter 4

In this chapter, we investigate the mechanisms for achieving coordination by an external agent (committee) when such coordination/standardization on a single technology matters to the committee as well as the firms. We endogenize the structure of information and investigate the role of information revelation (hard evidence) by the strategic committee. The problem of coordination is non-trivial because the firms have vested interest in their own technologies and want the standard to form on their own technologies. Conflict of interest in this game has two dimensions.

First is the clear conflict of interest among the firms as in Farrell (1987), which shows up in the coordination game with one round of pre-play cheap talk on intent. There is also the possibility of conflict between the firms (who want a standard on their own technologies) and the committee (which only wants a standard). However, as long as $c > \theta_h$, this conflict does not arise.

This condition holds for one round of cheap talk for which we discuss our results. If the number of periods of cheap talk increased, then there would be different effects on the two kinds of conflict. The results in the Appendix show that for any disclosure rule, the payoff of the firms increase towards c as the number of rounds of cheap talk become very large. While this would not affect the inherent conflict of interest between the firms, the conflict of interest between the committee and the firm would increase. This would make the firms recalcitrant about staying with a committee with a very high number of rounds of cheap talk. We also show that with inherent conflict of interest in a game of incomplete information, even an infinitely long cheap talk will not be able to achieve full coordination, extending Farrell (1987)'s result in a complete information framework.

More importantly, the power of cheap talk to achieve full coordination was restored if the conflict of interest was absent in Farrell (1987). We show that this is a result of the special payoff matrix in the entry game discussed in Farrell (1987) and need not hold with a different payoff matrix as in our model.

Given this ineffectiveness of cheap talk, we investigate strategic information revelation to achieve coordination with only one stage of cheap talk on intent. We consider the class Ψ of disclosure rules which allows for revelation in finite unions of disjoint intervals of the type space. A first interesting result is that in an extended coordination game (with one round of non-binding pre-play communication) with beliefs of the uninformed agents (the firms) increasing in the strategy of the informed agent (the committee), the unique equilibrium within this very large class of disclosure rules is that of no disclosure.An interesting result is that even with only one round of cheap talk communication, we can sustain non-disclosure of information in equilibrium.

The monotonicity of firms' beliefs in the committee's disclosure strategy is sufficient for this result. We demonstrate this by allowing for the possibility that the testing equipment is not perfect. The committee can hide its strategic intent by justifying the occasional disclosure as a failure of its testing method or apparatus - when the technologies are very new, this is a plausible excuse. This allows the committee to exercise its disclosure rule without revealing it to the firms.

In this case, the beliefs of the firms are no longer monotonic with the committee's strategy. Now it is possible for technical committees to employ a partial disclosure rule in equilibrium and improve upon the payoff with no disclosure. For general distributions, we show that there exist at least one such equilibrium. Simulations for the uniform distribution indicate that there will exist a partial disclosure in equilibrium. Therefore, the committee can strategically exploit the information uncertainty about its ability and improve upon the no disclosure result as the sufficient condition for no disclosure does not hold here.

Another point which needs highlighting is that in the entire discussion, a crucial assumption is the commitment by the committee to its disclosure rule. In the absence of such commitment, it is possible for the firms to influence the revelation decisions of the committee. Since these considerations are separate from those of understanding strategic revelation under commitment, we retain our assumption throughout the analysis. The focus is more squarely on the effectiveness of cheap talk on intent, strategic information revelation and certification and a public correlation device in order to achieve standardization, rather than issues of commitment in this chapter.

5.4 Future Research

There are some extensions and comparative static exercises using the framework of chapters 2, 3 and 4 that are part of ongoing and future research agenda. In chapters 2 and 3, it would be interesting to look at the question of what happens when the knowledge of coordination benefits c is not common to all the firms. In particular, an empirical estimation of this coordination benefit for telecommunication is an integral part of future research initiative. The model can also be extended to break the assumption of conditional independence of payoffs (between θ and b).

We intend to extend the analysis to to explore if the comparison of the market and committee coordination are robust to noisy observations of θ by firm A along the line of global games. Extending the result to multiple firms in a standardization game is also part of future research agenda. For this purpose, we are thinking of modeling the committee as a multi-sided platform and use recent results from two-sided markets (Rochet and Tirole (2003), Rochet and Tirole (2006) and Jullien (2001)) to see how the results change from the case of two firms.

Incorporating the antitrust implications of standardization through committees is an important extension for the model in chapter 2. We would have to incorporate strategic committees in order to address the issue whether this kind standardization can raise antitrust concerns as discussed in Anton and Yao (1995).

We intend to also analyze noisy disclosure rules in the model in chapter 4, apart from revelation over finite unions of disjoint intervals. Introducing commitment issues in the model in chapter 4 would give us further understanding of strategic behaviour of intermediaries in network industries. This would allow us to investigate what happens when the committee can manipulate the information it reveals to the committee. The interaction between formulation of rules for patent pooling and those for coordination are intended to be studied in that environment (without commitment).

We would also like to study committees with explicit bias towards a particular technology and study the notion of correlated equilibria therein. This latter equilibrium works in contexts such as our model, where the intermdiary is unbiased, and there is very little in the literature studying correlated equilibria in the presence of biased experts such as our technical committee.

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