EUI Working Papers

ECO 2009/20
DEPARTMENT OF ECONOMICS

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EUI Working Paper **ECO** 2009/20

ISSN 1725-6704

Printed in Italy
European University Institute
Badia Fiesolana
I – 50014 San Domenico di Fiesole (FI)
Italy
www.eui.eu
cadmus.eui.eu

Decision Making and Learning in a Globalizing World*

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May 20, 2009

Abstract

Decision-makers can benefit from the experience of others with solutions to common problems. If a best practice exists, the challenge is to recognize it and to ensure its diffusion. Information about different solutions is often dispersed, and decision-makers may be reluctant to switch for reputational reasons. We study how (i) the assignment of decision rights (who decides on the solutions' implementation?) and (ii) globalization (who knows what about solutions adopted in other places?) influence both the quality of the information on locally adopted solutions that decision-makers exchange and the quality of the solutions that are actually being used next.

Keywords: centralization, decentralization, learning, cheap talk, reputational concerns, globalization, health care consensus panels, EU Open Method of Coordination

*We thank seminar audiences at Bologna University, the European University Institute, Maastricht University, MEDS Kellogg School of Management, Tilburg University, and at the MPSA 2009 conference, and especially Michael Raith for their comments and questions. Part of this paper was written while Visser was a Fernand Braudel fellow at the EUI. Email: swank@ese.eur.nl and bvisser@ese.eur.nl

1 Introduction

Many things can be done in different ways. Managers can motivate employees in different ways. Dentists can resolve tooth root infections in different ways. Teachers can teach children arithmetic in different ways. The list is virtually endless. In many areas, it is a blessing that alternative solutions to a problem exist. It enables one to effectively match a solution with the exact problem. In other areas, matching is less of an issue. In those cases a best solution, or best practice, may exist. The challenge then is to recognize the best practice and to ensure its diffusion.

The identification and diffusion of best practices raise two main problems. First, information about different practices is often dispersed. The reason is that users (teachers, doctors, politicians) usually have experience with a limited number of practices. The implication is that the search for the best practice requires communication. Second, users may identify themselves with a particular practice. Identification is likely in situations where a user is held responsible for the selection of the proper practice. A user may then be reluctant to switch to another practice out of fear of being perceived as somebody who initially selected the wrong one. Such reputational concerns may obstruct diffusion of best practices. In the present paper we address the question how features of the learning process determine the quality of communication about the performance of locally adopted practices and the diffusion of best practices. We compare a decentralized and a centralized process. In a decentralized process, users communicate with each other (horizontal communication). Next, each user makes his own decision regarding the practice to use. In a centralized decision process, users of practices communicate with a central authority (vertical communication), and the central authority chooses the practice the users have to adopt next.

The following two examples illustrate that the above mentioned problems as to the identification and diffusion of best practices are real-world problems. First, the delivery of medical interventions varies widely from place to place.[1] This variation has been a source of worries as, most likely, some patients do not receive optimal treatment.[2] It also offers scope for learning. In response, physicians' associations and health care authorities have exerted

[1] That variation is large is a well-established fact, see Phelps (2000).

[2] See, e.g., Eddy (1990).

much effort to design learning processes in which locally gained experiences are compared, and best practices – interventions, surgical procedures, drug use – diffused. In the medical sector, expert panels are frequently used to evaluate the extant evidence on the effectiveness of rival practices in a given field. There are innumerable ways in which evidence on the effectiveness of a given practice can be manipulated. Given the close ties between experts and industry, and the long gestation period that characterizes the development of practices, experts tend to have vested interests and to identify with certain practices. The result, according to students of expert panels, is "process loss" due to status concerns and social pressure, meaning poor information exchange and aggregation in the meetings, and a low adoption rate of best practices afterwards.[3] Organizing these panels is therefore fraught with problems. An important organizational dimension is the degree of centralization of the process and, relatedly, the degree of freedom individual physicians have in following the outcomes of panel meetings.[4]

The European Union is another case in point. It has been promoting the so-called open method of coordination (OMC) to foster learning and the diffusion of best practices in many policy areas. The hope is that goals like EU competitiveness can be furthered by avoiding the grand questions about the best model for Europe and by taking instead a more pragmatic micro-orientation in which countries that face similar problems seek to learn from each other. Rather than relying on legislation by Brussels, the OMC leaves more freedom to member states to implement the lessons learned. Moreover, instead of applying formal sanctions to transgressors, the OMC turns to naming and shaming to expose a country's weak performance in public, and applies peer pressure if a country opposes adoption of superior policies.[5] In practice, the method is not considered to be very successful in guaranteeing a high quality learning process. It is generally felt that countries exaggerate the success of their current practices. The implementation of new ideas is very limited. Claudio Radaelli (2003, p. 12), a political scientist, argues that these disappointing results stem from a misguided view of policy makers among the proponents of the OMC. Rather than caring about the truth, they care about political capital and prestige.

[3] See Fink et al. (1984) and Rowe et al. (1991).

[4] Eddy (1990) distinguishes, in increasing degree of freedom, standards, guidelines, and options.

[5] See Pochet (2005) and Radaelli (2003).

Both the example of the medical sector and the example of the European Union make clear that the identification and diffusion of best practices require communication, and that learning may be hampered by reputational or career concerns. By definition, learning from others requires the ability to go beyond one's local experience. It is therefore related to globalization. In the context of the search for best practices, globalization may have two effects. First, decision makers observe what other decision makers do. Globalization therefore widens the scope for learning as more experiences can be exchanged. Second, the market receives more information about local decision-makers. By the market we mean the people in the eyes of whom a decision-maker want come across as competent. For example, the peers of a medical specialist may observe that his practice gains more adherents in other areas. Or, in line with the EU example, a citizen of a country may observe that politicians adopt policies from another country. Therefore, as a result of globalisation, the market can compare treatments or policies across places. We will argue that this aspect of globalization has important implications for how reputational concerns affect communication and final decisions.

The main objective of our analysis is to better understand the effects of (i) the structure of the learning process (decentralization versus centralization) and (ii) globalization on the quality of information exchange and, in turn, on the quality of decisions. We use an incomplete contracts approach to understand the way in which communication about the quality of locally adopted technologies is affected by the assignment of decision rights. In that sense, we follow Alonso et al. (2008) and Rantakari (2008). In particular, we do not endow some mechanism designer with the ability to first design complete contracts that prompt agents to reveal their information and next to commit to them. Clearly, a mechanism design approach would demonstrate the superiority of centralization, and would not contribute to our understanding of the effects of globalization on the decision whether or not to centralize.[6]

We present a simple two-period model of learning in which agents care both about adopt-

[6] See Mookherjee (2006) for an excellent survey on the centralization-decentralization debate from a mechanism design perspective. It is perhaps worth noting that in the context of a search for best practices a central authority does not always exist. A temporary one (e.g., a health care consensus panel) must be created. It might be hard for such a temporary central authority to commit to mechanisms.

ing the better practice and about acquiring a reputation for finding the better practice (medical intervention, policy etc.). Through learning-by-doing each agent gains information about the value of his own practice. We assume this information to be private and non-verifiable. The information exchanged then amounts to cheap talk. In the conclusion, we briefly discuss verifiable information.

We derive various sets of results that each describe the communication behaviour and the rules governing the adoption decision in the various cases. In period one, an agent adopts a practice he considers to be the better one. We start with analyzing a situation in which an agent operates in "isolation". As far as the agent is aware of there are no comparable other agents. There is a market that forms a perception of the agent's ability to choose the better practice. In this setting, the agent can only learn from his own experience. We show that a sufficiently high value of the practice leads to continuation of the initial practice, while a bad experience is followed by the adoption of another practice. When the market does not observe the quality of a practice, it will base its perception of the agent's ability on the practices the agent adopts. Continuation commands a higher reputation than change as it signals higher observed values of the practice and therefore a better initial choice. Hence, reputational concerns make the agent reluctant to change.

When the world starts to become more open, an agent can learn from others. In case of a decentralized learning process and markets that are unaware of practices used by other agents ('local markets'), we show that the quality of information exchange in the decision-making process is high. An agent can only gain by listening to others, and has nothing to loose by truthfully revealing his own experience. However, the technologies that are adopted next reflect this information poorly. Again, reputational concerns discourage agents to switch to another technology.

Our third set of results describes what happens when markets gain a better understanding of the technologies that are initially adopted in other places thanks to progressing globalization ('global markets'). Then, an agent's reputation starts to depend on what technologies he and others use. His reputation is particularly strong if others start to adopt "his" initial technology. As a result, the role of communication in the decision-making process becomes strategic. An agent wants to convince others that "his" technology is best. We show that communication breaks down completely: an agent only learns which technology has been used in other places. Decision-making in the second period is poor. This is reminiscent of the experience of the OMC, a case of decentralized learning with global markets.

Next we show how, in case of global markets, communication can be partly restored by centralization. Agents talk about their local experience in the presence of a central authority. Next this authority imposes the practice that is reportedly better. An agent now faces a trade-off. On the one hand, as the agent loses decision-making power, he wants to make sure that the center is well-informed. On the other hand, his reputational concerns imply that he wants the center to impose "his" technology at either site. As a result, each agent sends coarse information about his own practice.

We show that in case of global markets, centralization offers a clear advantage over decentralization from a social welfare perspective thanks to the restoration of communication. Such a clear advantage is absent in case of local markets: the improved decision-making that comes with concentrating decision powers in the hands of a benevolent central authority is to a large degree offset by impoverished communication about the performance of technologies.

The paper is organized as follows. The next section discusses the related literature. In Section 3, we present the model. Section 4 analyses isolated agents. In section 5 we analyse learning when markets are local, and we turn to global markets in section 6. Section 7 concludes.

2 Related Literature

Our paper contributes to the literature that studies how the quality of information exchange is determined by the features of the decision-making process. This literature takes an incomplete contracts approach to decision-making in which commitment is limited to the ex ante assignment of decision rights. As a result, communication among agents amounts to cheap talk. In their seminal paper, Crawford and Sobel (1982) show that the quality of cheap talk depends on the degree of alignment between the interests of the informed sender and the uninformed decision-maker (receiver). There is now a growing literature that explores how characteristics of decision-making processes influence the quality of communication. The literature took off in political science, perhaps because of the central role played by debate and rhetoric in the political arena. Gilligan and Krehbiel (1987) analyse how restrictions on the ability of the receiver (a parent body) to amend proposals of a sender (a committee) improve the latter's incentive to gather information. Austen-Smith (1990) discusses the role deliberation can play if an agenda is fixed or still has to be set. Coughlan (2000) analyse the role played by cheap talk communication preceding voting in a committee. He shows that, if jurors' objectives are similar enough, an equilibrium exists in which each juror reveals his signal in the deliberation stage. The implication is that in the final vote, jurors have no incentives to vote strategically. There is now a growing literature on factors that influence the quality of debate in group decision-making processes. Austen-Smith and Feddersen (2005) study situations in which each committee member has private information both about his personal bias and about the value of a term common to all members. Dessein (2007) shows how granting authority to one member rather than using majority vote improves decision-making by avoiding lengthy discussions. Visser and Swank (2007) study how reputational concerns influence the quality of debate and can explain the observed desire of committees to show a united front to the outside world. They also show how the optimal voting rule balances the quality of information exchange and the alignment of interests of the decisive voter with those of the principal.[7]

The current paper differs from the above in its focus on the possibilities for learning from the experience of others in a context where agents have reputational concerns. Moreover, whereas a committee takes a collective decision, in the current paper there is either decentralized or centralized decision-making.

The desirability of decentralization or centralization is also studied by Alonso et al. (2008) and by Rantakari (2008) in the context of a multidivisional firm. Each division benefits from adapting its decision to its own market circumstances and from coordinating its decision with those of the other divisions. Divisions are privately informed about their market circumstances. They can either exchange information and next decide independently of each other what decisions to take or they can report information to headquarters which

[7] See Gerardi and Yariv (2007) for a mechanism design approach to voting preceded by deliberation. Meirowitz (2006, 2007) compares the effectiveness of debate and transfers in inducing information revelation

then decides for both divisions. They show that even if coordination becomes of overriding concern to the firm, decentralization may still outperform centralization due to the difference in quality of communication.[8]

As Alonso et al. and Rantakari we study the effect of the assignment of decision rights on the quality of communication and of the final decisions taken. The situation we analyse, however, is quite different. In our paper, there are no local circumstances to which a decision should ideally be adapted, nor is there a need to coordinate per se. Instead, there is room for learning from each other's past experience (to identify the better technology), resistance to change (because of reputational concerns), and possibly the desire to convince the other to adopt one's technology (due to reputational concerns in case of global markets).

Finally, our paper is related to the existing literature on learning from others. This literature is, however, methodologically quite different from ours. In the existing literature, it is *assumed* that either an agent observes the true value of the actions taken by others, whether the environment is strategic[9] or not[10], or that no such information is observed at all[11]. Furthermore, inertia is an *exogenous* factor. For example, in the literature on word-of-mouth communication, it is assumed that only a given fraction of agents updates its decisions once new information becomes available. In our paper both the quality of the information exchange and the degree of inertia are equilibrium outcomes. Were it not for the reputational

[8] Friebel and Raith (2007) study how the scope of the firm affects the quality of strategic information transmission between a division and head quarters.

[9] See the discussion of social learning in a strategic experimentation game in Bergemann and Välimäki (2006). In this literature, it is assumed that an agent perfectly observes both the technology others use and the true value they obtain. It is not clear that an agent, if he could, would not want to deviate from a strategy of truthfully revealing the value of the technology he has gained experience with. It seems that he would benefit from exaggerating the value as this would make adoption by others more likely. As a result, more (public) information would become available about this technology, and the deviator would benefit from an improved estimate of the technology's value.

[10] See Bala and Goyal (1998) for a model of learning in non-strategic networks, and Ellison and Fudenberg (1993, 1995) and Banerjee and Fudenberg (2004) for analyses of word-of-mouth communication in non-strategic environments.

[11] In the literature on informational herding, communication between decision-makers is excluded although the environment in non-strategic. See e.g. Bikhchandani, Hirshleifer and Welch (1998). See Çelen, Kariv and Schotter (2008) for a first experimental analysis of social learning from actions and advice.

concerns, the problem the agents are facing in our model, that of choosing one technology out of many, is similar to a common value bandit problem in which the bandit's arms represent the technologies of unknown, but common, value.[12] The main difference is that in a bandit problem the distribution of the value of a technology does not change with an observation of the value of *another* technology, whereas in our problem it does. This stems from the fact that in our model the initial signal an agent receives provides information about the better technology. The higher is the observed value of a technology Y, the higher is the probability that the agent identified the better technology. And this means that it becomes more likely that the value of the other technology is lower than the actual value of Y.

The fact that in our model the quality of information exchange and the degree of inertia are endogenous, and that a key assumption of the statistical bandit model is violated imply that a general analysis of the asymptotic behaviour of the decision-making processes described here is difficult and beyond the scope of this paper. Instead, we compare the behaviour of agents across various decision-making processes in a two-period setting. This comparative institutional analysis should shed light on the problems that practitioners have encountered.

3 A model of learning-by-doing and learning from others with reputational concerns.

There are two sites (hospitals, states, etc.), $i \in \{1, 2\}$, and one problem. There is an agent i at each site. Often, j will denote "the other site" or "the other agent," $j \neq i$. The problem has to be addressed at each site both in period $t = 1$ and in $t = 2$. There are two possible technologies (policies, interventions, etc.) $X \in \{Y, Z\}$, one of which has to be used to address the problem at each site in each period. The technology adopted at site i in period t is denoted by $X_{i,t}$. A priori, the value of technology X is unknown, but independent of time and site. Moreover, we assume that it is a random draw from a continuous and strictly increasing distribution function $F_X(\cdot)$ and associated density function $f_X(\cdot)$, with support

[12] See Bergemann and Välimäki (2006) for a concise survey of bandit problems.

$[0,1]$. Note that we use X both to denote a technology and its random value. We assume that the values Y and Z are iid, $F_Y = F_Z = F$. We use lower case letters, like x, to denote a possible value of technology X, such that $x \in [0,1]$. As strategies will be defined in terms of X (or x), it will be useful to let X^C (or x^C) refer to "the other technology". That is, if $X = Y$, than $X^C = Z$, etc.

The agents' diagnostic ability levels $\theta_i \in \{\underline{\theta}, \bar{\theta}\}$ and the state of the world $(y,z) \in [0,1]^2$ are exogenously given. The ability levels and the state of the world are all statistically independent, with $\pi = \Pr(\theta_i = \bar{\theta}) \in (0,1)$ for $i \in \{1,2\}$.

At the beginning of period $t = 1$, agent i at site i receives a private, non-verifiable, signal $s_i \in \{s^Y, s^Z\}$ about which technology solves the problem best. The informativeness of the signal depends on the agent's ability: $\Pr(s^X | x > x^C, \bar{\theta}) = 1$, $\Pr(s^X | x^C > x, \bar{\theta}) = 0$, $\Pr(s^X | x > x^C, \underline{\theta}) = \Pr(s^X | x^C > x, \underline{\theta}) = 1/2$, for $X \in \{Y, Z\}$. That is, if i is highly able, $\theta_i = \bar{\theta}$, the signal (diagnosis) reveals with probability one the better technology: $\Pr(x > x^C | s^X, \bar{\theta}) = 1$ for $X \in \{Y, Z\}$. Hence, conditional on s^X and $\theta = \bar{\theta}$, X is distributed as the maximum of two iid random variables, $F_X(x | s^X, \bar{\theta}) = F(x)^2$. On the other hand, if i is less able, $\theta_i = \underline{\theta}$, the signal is uninformative about the relative quality of the technology: $F_X(x | s^X, \underline{\theta}) = F(x)$. Note that an agent does not get a signal about his ability. Instead, π is the common prior.[13] Still in period 1, i next decides which technology X to adopt on the basis of his signal s_i. At the end of the period he learns the value x of the chosen technology (learning-by-doing).

At this point, it is worth emphasizing that the focus of our analysis will be on period 2. As mentioned in the introduction, we intend to understand the pros and cons of alternative decision making processes in situations where (i) agents have gained experiences with different technologies, treatments, or policies and (ii) there is scope for learning. In our model, period 1 can be interpreted as the history in which agents gained information. We model history to stress that past decisions matter for current decisions, for example, through reputational concerns.

We distinguish three decision processes p that characterize period $t = 2$. Such a process

[13] What matters for the results is that if $\theta_i = \bar{\theta}$, member i has a higher likelihood of correctly assessing the state of the economy than if $\theta_i = \underline{\theta}$.

consists of a decision-making stage, possibly preceded by a communication stage. In case there is a communication stage, agent i sends a message about the quality of the technology adopted at site i in period $t = 1$. The receiver of this message depends on the process p. We assume that agent i, if and when he sends a message, knows the technology (*not* its value) that j has used in $t = 1$ when he sends a message. This is often the relevant case, as agents may well be aware that other technologies are used, without knowing their quality. Hence, a communication strategy $\mu_i^{\mathsf{p}}(\cdot)$ is a conditional probability distribution. Let $\mu_i^{\mathsf{p}}(m_i|s_i, x_{i,1}, X_{j,1})$ be the likelihood that i sends message $m_i \in M$, where M is a message space, in case his signal equals s_i, the observed value of $X_{i,1}$ equals $x_{i,1}$, and agent j uses technology $X_{j,1}$. Next, a decision maker determines which technology $X_{i,2}$ is adopted at site i at time $t = 2$. Who this decision maker is depends on the decision process p. Let $I_i^{\mathsf{p}} \in \mathcal{I}_i^{\mathsf{p}}$ be the information this person has at the beginning of the decision-making stage. It depends on the process p. The decision strategy d_i^{p} determines the relationship between I_i^{p} and the technology adopted at site i.

(i) In case of *isolated agents* (p=ia), agents do not communicate, and therefore do not know what technology is being used at the other site. Hence, $\mathcal{I}_i^{\mathsf{ia}} = \{s^Y, s^Z\} \times [0,1]$: the information i has is a signal and the value of the technology used in $t = 1$. Agent i decides on $X_{i,2}$. Let $d_i^{\mathsf{ia}}(X_{i,1}|s_i, x_{i,1})$ denote the likelihood that i continues with his initial technology $X_{i,1}$ in $t = 2$ given his signal s_i and the observed value $x_{i,1}$.

(ii) In case of a *decentralized decision-making process* (p=dl), each agent i simultaneously sends a message m_i^{dl} to the other agent concerning the value of the technology he has adopted in $t = 1$. So, $\mathcal{I}_i^{\mathsf{dl}} = \{s^Y, s^Z\} \times [0,1] \times M \times \{Y, Z\} \times M$. That is, in addition to the information in case of p=ia, agent i now also knows the message $m_i^{\mathsf{dl}} \in M$ he sent, the technology $X_{j,1} \in \{Y, Z\}$ adopted at the other site, and a message $m_j^{\mathsf{dl}} \in M$ about the value of that technology. Agent i next decides on $X_{i,2}$. Let $d_i^{\mathsf{dl}}(X_{i,1}|s_i, x_{i,1}, m_i, X_{j,1}, m_j)$ denote the likelihood that i continues with his initial technology in $t = 2$ given I_i^{dl}.

(iii) In case of a *centralized decision-making process* (p=cl), each agent i simultaneously sends a message m_i^{cl} concerning the value of the technology he has adopted in $t = 1$ to "the center." Hence, $\mathcal{I}_C^{\mathsf{cl}} = \{Y, Z\}^2 \times M^2$ represents the center's information set: information about which technology has been adopted at each site, and a message concerning the value of each technology. Next, the center decides which technology is adopted at either site. Let $d_C^{\mathsf{cl}}(X_{1,1}, X_{2,1}|X_{1,1}, X_{2,1}, m_1, m_2)$ denote the correspondence indicating for given technologies used at either site and for given messages sent by the agents the likelihood that a technology is continued at sites 1 and 2, respectively.

As noted in the introduction, globalization has two effects: first, it allows a previously isolated agent to learn from the experience of others, and second, it offers more information about a local agent to "the market". The market at site i at time t is characterized by its information, $\Omega_{i,t}$. An agent learns about technologies and their values through learning-by-doing and by listening to others. We assume that the market knows less about technologies than an agent does: markets only know certain patterns of technology adoption. In particular, in $t = 1$, $\Omega_{i,1} = \{X_{i,1}\}$ for $i \in \{1, 2\}$. For $t = 2$, we distinguish two cases. Say that markets are *local*, if markets possess knowledge about site-specific adoption patterns only, $\Omega_{i,2} = \{X_{i,1}, X_{i,2}\}$ for $i \in \{1, 2\}$. Say that markets are *global*, if markets possess knowledge about all adoption patterns, $\Omega_{i,2} = \{X_{i,1}, X_{j,1}, X_{i,2}, X_{j,2}\}$ for $i \in \{1, 2\}$. We call $(X_{i,1}, X_{j,1}, X_{i,2}, X_{j,2})$ the *adoption vector*, indicating which technologies are adopted in $t = 1$ at sites i and j, and in $t = 2$ at sites i and j, respectively. Clearly then, we assume that learning-by-doing gives the agent an informational advantage over his market: whereas an agent learns the true value of the technology he uses, his market only observes certain adoption patterns.[14]

To analyse the effect of reputational concerns, we assume that an agent's utility depends on the value of the technology adopted at his site and on his market's assessment of his ability. The ex post belief that i is highly able conditional on the information set $\Omega_{i,t}$ equals $\hat{\pi}_{i,t}(\Omega_{i,t}) = \Pr(\theta_i = \bar{\theta}|\Omega_{i,t})$. If x is the value of the technology $X_{i,t}$ that i adopts, and the market's information set equals $\Omega_{i,t}$, then the period t utility equals $U(X_{i,t}) = x + \lambda\hat{\pi}_{i,t}(\Omega_{i,t})$, with $\lambda > 0$ the relative weight of reputational concerns. We ignore time discounting. The center's utility equals the sum of the values of the technologies adopted in

[14] What is important for the results is that agent i has an informational advantage over his market. As long as such an advantage exists, the agent will use the technology adoption decision to influence the market's view on his ability, and the communication strategies will qualitatively remain the same. For example, we could endow market i with a noisy signal about $X_{i,1}$ and $X_{i,2}$.

$t = 2$, $W(X_{1,2}, X_{2,2}) = x_{1,2} + x_{2,2}$. We use the expected value of W, from now on "expected welfare," evaluated before signals are received, to compare the value of decision processes.

Different decision processes cause differences in behaviour in the second period, but not in the first. This will be readily apparent from the analysis in the following sections. Independent of the decision process, period $t = 1$ behaviour that maximizes agent i's utility is to follow his signal: $X_{i,1} = Y$ if and only if $s_i = s^Y$. This maximizes the expected value of the technology and minimizes the probability of changing (or having to change) technology in period 2.

An equilibrium consists of a communication strategy $\mu_i(\cdot)$ for each agent, a belief function $f_i(\cdot)$ for each decision maker, a decision strategy $d_i(\cdot)$ for each decision maker, and ex post assessments $\hat{\pi}_{i,t}(\Omega_{i,t})$ for each market. In case of a decentralized decision-making process, let $f_i\left(x_{j,1}|I_i^{\mathsf{dl}}\right)$ denote the density of $x_{j,1}$ conditional on information I_i^{dl}. Analogously, let $f_i\left(x_{i,1}|I_C^{\mathsf{dl}}\right)$ denote the density of $x_{i,1}$ conditional on I_C^{dl}. We use the concept of Perfect Bayesian Equilibrium (from now on, equilibrium) to characterize behaviour.

4 Isolated agents

Once agent i has followed his signal $s_i = s^X$ in period 1 and observed value x, he has to decide in $t = 2$ whether to continue with his technology. Note that having received s^X and next observing x allows an agent to update the expected value of the other technology,

$$E\left[X^C|s^X, x\right] = \Pr\left(\bar{\theta}|s^X, x\right) E\left[X^C|s^X, x, \bar{\theta}\right] + \Pr\left(\underline{\theta}|s^X, x\right) E\left[X^C\right], \tag{1}$$

as $E\left[X^C|s^X, x, \underline{\theta}\right] = E\left[X^C\right]$. Two effects of x can be distinguished. First, the larger is x, the more likely it is that the agent is highly able and correctly identified the more valuable technology. This is the $\Pr\left(\bar{\theta}|s^X, x\right)$ term. Second, conditional on the agent being highly able, a higher value of x increases the expected value of X^C. This is the $E\left[X^C|s^X, x, \bar{\theta}\right]$ term. Of course, $E\left[X^C|s^X, x, \bar{\theta}\right] \leq E\left[X^C\right]$. The following lemma summarizes some characteristics of $E\left[X^C|s^X, x\right]$.

Lemma 1 *The expected value of technology X^C given that i has received $s_i = s^X$ and observed x satisfies: (a)* $E\left[X^C|s^X, 0\right] = E\left[X^C|s^X, 1\right] = E\left[X^C\right] \in (0, 1)$, *and* $E\left[X^C|s^X, x\right] <$

$E\left[X^C\right]$ for $x \in (0,1)$; (b) $E\left[X^C|s^X, x\right]$ is decreasing in x for $x < E\left[X^C|s^X, x\right]$, increasing for $x > E\left[X^C|s^X, x\right]$, and $x = E\left[X^C|s^X, x\right]$ has a unique solution.

This lemma is illustrated in Figure 1. The dashed horizontal line represents the unconditional expectation $E\left[X^C\right]$, and the conditional expectation $E\left[X^C|s^X, x\right]$ is a convex function of x.

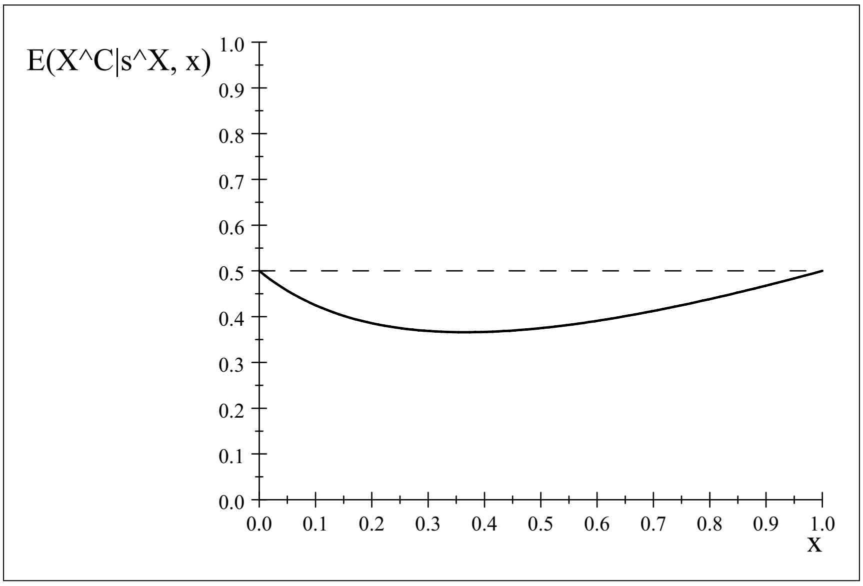

Figure 1: Graphical representation of Lemma 1 for the case that X is uniformly distributed on $[0,1]$, and $\pi = 1/2$.

Ignore reputational concerns for the moment. Given $I_i^{\mathsf{ia}} = \left\{s^X, x\right\}$, the decision strategy that maximizes the expected value of the technology adopted at site i in the second period, the first-best strategy, is to stick to the existing technology $X_{i,1} = X$ if and only if $x \geq E\left[X^C|s^X, x\right]$. It follows from lemma 1, part (b), and it is clear from Figure 1, that the first-best decision strategy is a (one-dimensional) threshold strategy,

$$d_i^{\mathsf{ia}}\left(X_{i,1}|I_i^{\mathsf{ia}}; \bar{t}\right) = \begin{cases} 1 & \text{if } x_{i,1} \geq \bar{t} \\ 0 & \text{otherwise,} \end{cases}$$

with $\bar{t} = \bar{x}_{\mathsf{ia}}^{FB}$ and where $\bar{x}_{\mathsf{ia}}^{FB}$ solves $\bar{x}_{\mathsf{ia}}^{FB} = E\left[X_{i,1}^C|s^X, \bar{x}_{\mathsf{ia}}^{FB}\right]$.

Besides being interested in picking the most valuable technology, an agent is also interested in his reputation. Consider a threshold decision strategy and any threshold value $\bar{t} \in (0,1)$. Recall that in case of isolated agents, markets only have local knowledge. Let

$\hat{\pi}(X, X'; \bar{t})$ denote the reputation, obtained using Bayes' rule, if $X_{i,1} = X$ and $X_{i,2} = X' \in \{Y, Z\}$, and the agent uses the threshold $\bar{t}$. Then,[15]

$$\hat{\pi}(X, X; \bar{t}) = \frac{1 + F(\bar{t})}{1 + F(\bar{t})\pi}\pi > \pi > \hat{\pi}\left(X, X^C; \bar{t}\right) = \frac{F(\bar{t})}{F(\bar{t})\pi + (1-\pi)}\pi. \tag{2}$$

Irrespective of $\bar{t}$, continuation commands a higher reputation than switching to the other technology. Continuation suggests having observed a sufficiently high value of $x_{i,1}$. A highly able agent is more likely to have implemented a technology that generates a high value than a less able agent. Hence, as an agent cares about his reputation, he wants to deviate from the first-best decision rule by lowering the hurdle that his initial technology should pass for its continuation. The agent wants to give up technological adequacy for reputational benefits. We will call the difference $\hat{\pi}_i(X, X; \bar{t}) - \hat{\pi}_i\left(X, X^C; \bar{t}\right)$ the reputational gap. It is the source of the distortion. Proposition 1 describes equilibrium behaviour of isolated agents.

Proposition 1 *In case of isolated agents, and for $\lambda < \bar{\lambda}_{\mathsf{ia}} = E\left[X^C\right]/\pi$, the equilibrium decision strategy is a threshold strategy with threshold value $\bar{x}_{\mathsf{ia}}$ that satisfies*

$$\lambda\left[\hat{\pi}_i(X, X; \bar{x}_{\mathsf{ia}}) - \hat{\pi}_i\left(X, X^C; \bar{x}_{\mathsf{ia}}\right)\right] = E\left[X^C|\bar{x}_{\mathsf{ia}}\right] - \bar{x}_{\mathsf{ia}}, \tag{3}$$

with $\bar{x}_{\mathsf{ia}} \in \left(0, \bar{x}_{\mathsf{ia}}^{FB}\right)$. The higher is λ, the lower is the threshold value $\bar{x}_{\mathsf{ia}}$, and the larger is the reputational gap $\hat{\pi}_i(X, X; \bar{x}_{\mathsf{ia}}) - \hat{\pi}_i\left(X, X^C; \bar{x}_{\mathsf{ia}}\right)$. For $\lambda \geq \bar{\lambda}_{\mathsf{ia}}$, $\bar{x}_{\mathsf{ia}} = 0$, i.e., agent i always continues his initial technology, and $\hat{\pi}_i(X, X; 0) = \pi$ and $\hat{\pi}_i\left(X, X^C; 0\right) = 0$.

Eq. (3) can be written as $\bar{x}_{\mathsf{ia}} + \lambda\hat{\pi}_i(X, X; \bar{x}_{\mathsf{ia}}) = E\left[X^C|s^X, \bar{x}_{\mathsf{ia}}\right] + \lambda\hat{\pi}_i\left(X, X^C; \bar{x}_{\mathsf{ia}}\right)$. The left-hand side equals the value of continuing with X if its observed value equals $\bar{x}_{\mathsf{ia}}$, whereas the left-hand side equals the value of switching technology for the same observed value of X. At the threshold value $\bar{x}_{\mathsf{ia}}$, the agent is indifferent between sticking to X and switching to X^C.

The stronger are reputational concerns, the lower is $\bar{x}_{\mathsf{ia}}$. It follows from (2) that the lower $\bar{x}_{\mathsf{ia}}$ is, the lower is the reputation the agent commands in case of sticking to the original technology *and* in case of switching technologies. If the hurdle for continuation is lowered, passing the hurdle becomes a less convincing signal of diagnostic ability. At the same time,

[15] Deriviations can be found in the Appendix.

not passing a lower hurdle becomes a stronger signal of incompetence. As the reputational gap is still strictly positive for a threshold value equal to zero, it follows from (3) that for $\lambda \geq \bar{\lambda}_{\mathsf{ia}}$ $\bar{x}_{\mathsf{ia}} = 0$: the agent will continue with his initial choice of technology irrespective of the true value of his technology.

Figure 2 illustrates Proposition 1 for the case that $x \in \{y, z\}$ is uniformly distributed on $[0, 1]$. The bold line depicts $E\left[X^C | s^X, x\right]$. For $x = \bar{x}_{\mathsf{ia}}^{FB}$, the dashed 45º line intersects this bold line. The influence of reputational concerns can be represented by an upward shift of the 45º line, for instance to the dotted line. Due to reputational concerns, the threshold value the agent actually uses equals $\bar{x}_{\mathsf{ia}} < \bar{x}_{\mathsf{ia}}^{FB}$. The more important are reputational concerns, the more the 45º line shift upwards. The difference $E\left[X^C | s^X, \bar{x}_{\mathsf{ia}}\right] - \bar{x}_{\mathsf{ia}}$ equals the value of the reputational gap $\lambda\left[\hat{\pi}_i\left(X, X; \bar{x}_{\mathsf{ia}}\right) - \hat{\pi}_i\left(X, X^C; \bar{x}_{\mathsf{ia}}\right)\right]$.

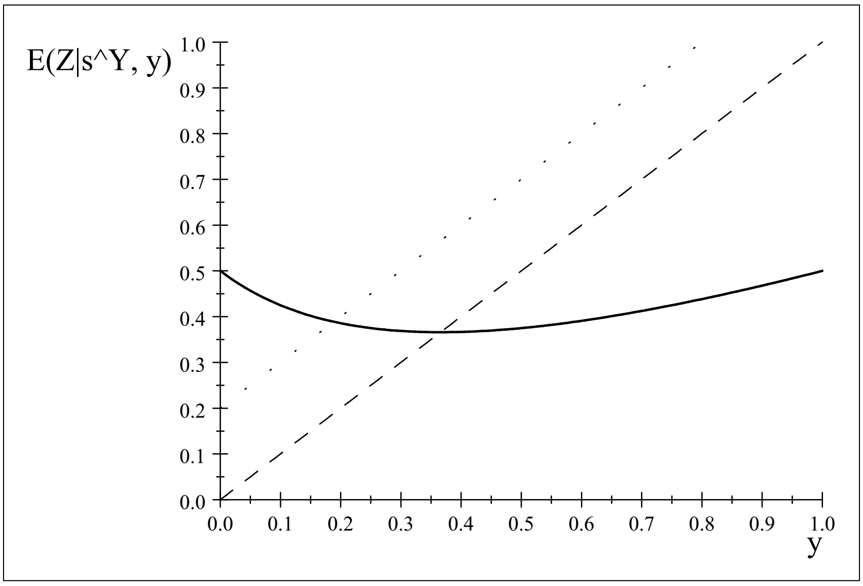

Figure 2: Illustration of Proposition 1 for $\pi = 1/2$, $\lambda = 1/2$ and $X \in \{Y, Z\}$ uniformly distributed on $[0, 1]$.

5 Local markets

By definition, local markets only know the technology that is adopted locally.

5.1 Decentralized process

We begin by describing first-best behaviour in a decentralized process. In the communication stage each agent truthfully reveals his private information. Say that i *truthfully reveals* his private information if, for all $s_i \in \{s^Y, s^Z\}$, all $x_{i,1} \in [0,1]$, and all $X_{j,1} \in \{Y, Z\}$, $\mu_i^{\mathsf{p}}(m_i|s_i, x_{i,1}, X_{j,1}) = 1$ if $m_i = x_{i,1}$ and $\mu_i^{\mathsf{p}}(m_i|s_i, x_{i,1}, X_{j,1}) = 0$ otherwise. Next, the first-best decision strategy equals

$$d_i^{\mathsf{dl}}\left(X_{i,1}|I_i^{\mathsf{dl}}; \bar{x}_{\mathsf{S}}^{FB}\right) = \begin{cases} 1 & \text{if } X_{j,1} = X_{i,1} \text{ and } x_{i,1} \geq \bar{x}_{\mathsf{S}}^{FB} \\ 1 & \text{if } X_{j,1} = X_{i,1}^C \text{ and } x_{i,1} \geq m_j \\ 0 & \text{otherwise,} \end{cases}$$

where $\bar{x}_{\mathsf{S}}^{FB}$ satisfies $\bar{x}_{\mathsf{S}}^{FB} = E\left[X_{i,1}^C|\bar{x}_{\mathsf{S}}^{FB}, s^X, s^X\right]$, and where m_j denotes the message that j sends about $x_{j,1}$. That is, if both agents adopted the *same* technology, each agent should continue this technology if its value is larger than $\bar{x}_{\mathsf{S}}^{FB}$.[16] If instead agents adopted different technologies, they should next choose the one with superior performance.

Can truthful revelation be part of an equilibrium? With agent i's reputation independent of what the other agent decides, and with agent i being free to choose what technology to adopt in $t = 2$, truthful revelation of the technology's value is a weakly dominant communication strategy for each agent. Absent any motive to influence the other agent, the quality of the information exchange is high.

Once communication has taken place, each agent independently decides whether to continue with his original technology or to switch to the other technology. Let a two-dimensional threshold strategy $d_i^{\mathsf{dl}}\left(X_{i,1}|I_i^{\mathsf{dl}}; \bar{t}_S, \bar{t}_D\right)$ with thresholds $(\bar{t}_S, \bar{t}_D) \geqq 0$ be defined as

$$d_i^{\mathsf{dl}}\left(X_{i,1}|I_i^{\mathsf{dl}}; \bar{t}_S, \bar{t}_D\right) = \begin{cases} 1 & \text{if } X_{j,1} = X_{i,1} \text{ and } x_{i,1} \geq \bar{t}_S \\ 1 & \text{if } X_{j,1} \neq X_{i,1} \text{ and } x_{i,1} \geq m_j - \bar{t}_D \\ 0 & \text{otherwise.} \end{cases}$$

That is, agent i continues with his original technology $X_{i,1}$ (i) if both agents used the same technology and its value exceeds $\bar{t}_S$; or (ii) if the agents used different technologies, but the

[16] Of course, the fact that both experts used the same technology in the first period bodes well for the superiority of this technology, and so the first-best standard for continued adoption is lower than in case of isolated experts, $\bar{x}_{\mathsf{S}}^{FB} < \bar{x}_{\mathsf{ia}}^{FB}$.

other technology is either less valuable or its superior performance does not exceed by a margin larger than $\bar{t}_D$ the value of the current technology. Let $\hat{\pi}_i(X, X'; \bar{t}_S, \bar{t}_D)$ denote i's reputation if he uses $d_i^{\mathsf{dl}}(\cdot)$, and adopts technologies $X_{i,1} = X$ and $X_{i,2} = X'$ in periods 1 and 2, respectively, with $X, X' \in \{Y, Z\}$.

To see that an agent wants to distort the decision on $X_{i,2}$, suppose i were to use the first-best threshold values, $(\bar{t}_S, \bar{t}_D) = \left(\bar{x}_{\mathsf{dl}}^{FB}, 0\right)$. If i continues with his initial technology, his market would deduce that either the same technology was used at the other site and its observed value exceeded $\bar{x}_{\mathsf{dl}}^{FB}$, or that the other site used the other technology which proved to be of inferior quality. Either event strengthens i's reputation. Analogously, discontinuing a technology hurts a reputation. As a result, reputational concerns induce an agent to distort the decision in $t = 2$. If both agents adopted the same technology X in $t = 1$, then agent i sticks to this technology if and only if $x + \lambda\hat{\pi}_i(X, X; \bar{t}_S, \bar{t}_D) \geq E\left[X^C | x, X, X\right] + \lambda\hat{\pi}_i\left(X, X^C; \bar{t}_S, \bar{t}_D\right)$. Similarly, in case agents applied different technologies, agent i wants to continue with X iff $x + \lambda\hat{\pi}_i(X, X; \bar{t}_S, \bar{t}_D) \geq x^C + \lambda\hat{\pi}_i\left(X, X^C; \bar{t}_S, \bar{t}_D\right)$. Proposition 2 describes equilibrium behaviour.

Proposition 2 *Define* $\underline{\lambda}_{\mathsf{dl}}^{\mathsf{lo}} = E\left[X^C\right] / \hat{\pi}_i\left(X, X; 0, E\left[X^C\right]\right)$ *and* $\bar{\lambda}_{\mathsf{dl}}^{\mathsf{lo}} = 1/\pi$. *In case of a decentralized process with local markets, an equilibrium exists in which*
(i) it is a weakly dominant equilibrium communication strategy for each agent to truthfully reveal the value $x_{i,1}$ *to the other agent;*
(ii) the equilibrium belief functions are $f_i\left(x_{j,1} | I_i^{\mathsf{dl}}\right) = f_i\left(x_{j,1} | m_j\right) = 1$ *(0) for* $x_{j,1} = m_j$ *(*$x_{j,1} \neq m_j$*);*
(iii) the equilibrium decision strategy is a two-dimensional threshold strategy. For $\lambda < \underline{\lambda}_{\mathsf{dl}}^{\mathsf{lo}}$, *equilibrium threshold values* $(\bar{t}_S^*, \bar{t}_D^*)$ *satisfy*

$$\lambda\left[\hat{\pi}_i(X, X; \bar{t}_S^*, \bar{t}_D^*) - \hat{\pi}_i\left(X, X^C; \bar{t}_S^*, \bar{t}_D^*\right)\right] = E\left[X^C | \bar{t}_S^*, s^X, s^X\right] - \bar{t}_S^* \quad (4)$$

$$\lambda\left[\hat{\pi}_i(X, X; \bar{t}_S^*, \bar{t}_D^*) - \hat{\pi}_i\left(X, X^C; \bar{t}_S^*, \bar{t}_D^*\right)\right] = \bar{t}_D^*, \quad (5)$$

with $\bar{t}_S^* \in \left(0, \bar{x}_{\mathsf{S}}^{FB}\right)$ *and* $\bar{t}_D^* \in (0, 1)$. *The larger is* λ, *the smaller is* $\bar{t}_S^*$ *and the larger is* $\bar{t}_D^*$. *For* $\lambda \in [\underline{\lambda}_{\mathsf{dl}}^{\mathsf{lo}}, \bar{\lambda}_{\mathsf{dl}}^{\mathsf{lo}})$, *threshold values are* $(0, \bar{t}_D^*)$ *and* $\bar{t}_D^*$ *solves* $\lambda\hat{\pi}_i(X, X; 0, \bar{t}_D^*) = \bar{t}_D^*$. *The larger is* λ, *the larger is* $\bar{t}_D^*$. *Finally, for* $\lambda \geq \bar{\lambda}_{\mathsf{dl}}^{\mathsf{lo}}$, *threshold values equal* $(0, 1)$.

Note that if $\lambda \geq \underline{\lambda}_{\mathsf{dl}}^{\mathsf{lo}}$ $\left(\lambda \geq \bar{\lambda}_{\mathsf{dl}}^{\mathsf{lo}}\right)$ and agents adopted the same technology (different technologies) in period 1, agents adhere to their technology in period 2, no matter the value of $x_{i,1}$ $(x_{i,1}, m_j)$. Thus, $\underline{\lambda}_{\mathsf{dl}}^{\mathsf{lo}}$ and $\bar{\lambda}_{\mathsf{dl}}^{\mathsf{lo}}$ denote the upperbounds of λ for which agents are responsive to information on the technologies.

The structure of the equilibrium can best be understood by looking at Eqs (4) and (5). The loss in technological value should be compensated by a boost in reputation. As the market is local and thus does not know the technology adopted at the other site in $t = 1$, the reputation is based only on agent i's decision to continue or discontinue his initial technology. Clearly, in equilibrium the size of distortions, $E\left[X^C | \bar{t}_S^*, s^X, s^X\right] - \bar{t}_S^*$ and $\bar{t}_D^*$, and the value of the reputational gap, $\lambda\left[\hat{\pi}_i\left(X, X; \bar{t}_S^*, \bar{t}_D^*\right) - \hat{\pi}_i\left(X, X^C; \bar{t}_S^*, \bar{t}_D^*\right)\right]$, are the same. The loss in technological value due to the distortion should in either case be compensated by the same boost in reputation.

At $\lambda = \underline{\lambda}_{\mathsf{dl}}^{\mathsf{lo}}$, $\bar{t}_S^* = 0$, and $\bar{t}_D^* = E\left[X^C\right]$. Then, the market deduces from $\left(X, X^C\right)$ that $x < x^C$, and so i initially picked the inferior technology, $\hat{\pi}_i\left(X, X^C; 0, E\left[X^C\right]\right) = 0$. It follows from (4) that $\underline{\lambda}_{\mathsf{dl}}^{\mathsf{lo}} = E\left[X^C\right] / \hat{\pi}_i\left(X, X; 0, E\left[X^C\right]\right)$. For $\lambda \in [\underline{\lambda}_{\mathsf{dl}}^{\mathsf{lo}}, \bar{\lambda}_{\mathsf{dl}}^{\mathsf{lo}})$, if i learns that j used the *same* technology, he continues his initial technology irrespective of its value x. The distortion in case of *different* technologies is growing in λ. For $\lambda \geq \bar{\lambda}_{\mathsf{dl}}^{\mathsf{lo}}$, i sticks to his initial technology $X_{i,1}$, irrespective of its value $x_{i,1}$, and regardless of what j reports, $(\bar{t}_S^*, \bar{t}_D^*) = (0, 1)$. Then $\hat{\pi}_i\left(X, X; 0, 1\right) = \pi$, while $\hat{\pi}_i\left(X, X^C; 0, 1\right) = 0$ is a plausible out-of-equilibrium belief. Hence, $\bar{\lambda}_{\mathsf{dl}}^{\mathsf{lo}} = 1/\pi$.

We can now examine the welfare consequences of the first effect of globalization: the opportunity to share experiences. A decentralized decision process with a local market yields better results in period 2 than a world of isolated agents. Sharing experiences has two effects. First, in the second period the decision on X is based on more information. Second, the decision on X has a larger impact on the agent's reputation. Note that the second effect is a consequence of the first. If agents exhibit first-best behaviour, the reputational gap is wider when agents share information than when they do not. With better informed agents in period 2, switching to another technology becomes a clearer indication that the technology initially adopted was the inferior one. Agents' incentives to distort are therefore stronger. As the second effect is a consequence of the first, the first effect dominates the second. Sharing information improves decision-making. If the second effect were to dominate the first, the decision on X would be based on less information. But this would mean that the reputational gap would shrink, a contradiction.

5.2 Centralized process

First-best behaviour in the case of a centralized learning process is for each agent to truthfully reveal his private information, and for the center next to pick the technology with the higher, reported or expected, value:

$$d_C^{\mathsf{cl}}\left(X_{1,1}, X_{2,1} | I_C^{\mathsf{cl}}; \bar{x}_{\mathsf{S}}^{FB}\right) = \begin{cases} 1,1 & \text{if } X_{1,1} = X_{2,1} \text{ and } m_{1,1} \geq \bar{x}_{\mathsf{S}}^{FB} \\ 1,0 & \text{if } X_{1,1} \neq X_{2,1} \text{ and } m_{1,1} > m_{2,1} \\ 0,1 & \text{otherwise.} \end{cases}$$

What does equilibrium behaviour look like? Suppose agents adopted the *same* technology X in $t = 1$. If the center bases her decision on the information she deduces from the lower message, and if j truthfully reveals the value of X, then exaggeration by i is to no avail.[17] If agents initially use technologies that differ, it is not part of an equilibrium for an agent to truthfully reveal his private information.

Lemma 2 *Under a centralized process with local markets, first-best communication behaviour is not equilibrium behaviour in case agents use different technologies in period $t = 1$.*

It suffices to show that agent i has an incentive to slightly exaggerate the value of $X_{i,1}$. If agents and center were to stick to first-best behaviour, then being allowed to continue with one's technology commands a higher reputation than being forced to change, $\hat{\pi}_i(X, X) > \hat{\pi}_i\left(X, X^C\right)$. Assume i deviates by communicating $x + \varepsilon > x$ instead of x. If this exaggeration changes the center's decision i.e., for $x^C \in (x, x + \varepsilon)$, the reputational boost equals $\lambda\left[\hat{\pi}_i(X, X) - \hat{\pi}_i\left(X, X^C\right)\right] > 0$ and is independent of ε, whereas the costs to an agent (in terms of the choice of an inferior technology) can be made arbitrarily small by reducing the value of ε. This shows that a profitable deviation from first-best behaviour exists.

[17] This presumes that agents do not collude and jointly exaggerate the true value of the initial technology. We come back to this in the conclusion.

Of course, in equilibrium an agent cannot "systematically exaggerate" as then the center could simply undo the exaggeration through inversion. Instead, as in Crawford and Sobel (1982), in equilibrium information is lost as the agent adds noise to his message: he partitions the space of possible technology values $[0,1]$ into intervals, and reports only to which interval the value of his technology belongs. That is, he ranks its value, and the number of intervals equals the number of possible ranks. Roughly put, the stronger are reputational concerns λ, the fewer ranks are used in equilibrium.

Let $a(N) \equiv (a_0(N), \ldots, a_N(N))$ denote a partition of $[0,1]$ in N intervals, with $0 = a_0(N) < a_1(N) < \cdots < a_N(N) = 1$. Agent i is said to use a *partition strategy* to communicate if there exists a tuple $(N, a(N))$, such that for all s^i and $X_{j,1}$, $\mu_i^{\mathsf{p}}(m_i|s_i, x_{i,1}, X_{j,1})$ is uniform, supported on $[a_r(N), a_{r+1}(N)]$ if $x_{i,1} \in (a_r(N), a_{r+1}(N))$ for $r = 0, \ldots, N-1$.[18] As in Crawford and Sobel (1982), if a partition in $N > 1$ intervals exists, there also exists one in $n < N$. We focus on the the highest value of N consistent with incentives.

Let the center choose the technology that is the better one given the messages of the agents. In case they rank different technologies the same, the center is indifferent and tosses a coin. Even if both agents report on the same technology, the center may still decide to make them switch to the other technology. Formally,

$$d_C^{\mathsf{cl}}\left(X_{1,1}, X_{2,1}|I_C^{\mathsf{cl}}\right) = \begin{cases} 1,1 & \text{if } X_{1,1} = X_{2,1} \quad \text{and } E\left[X_{1,1}|m_{\min}^{X_1}\right] \geq E\left[X_{1,1}^C|m_{\min}^{X_1}\right] \\ 1,0 & \text{if } X_{1,1} \neq X_{2,1} \quad \text{and } E\left[X_{1,1}|I_C^{\mathsf{cl}}\right] > E\left[X_{2,1}|I_C^{\mathsf{cl}}\right] \\ 1,0 & \text{if } X_{1,1} \neq X_{2,1} \quad \text{and } E\left[X_{1,1}|I_C^{\mathsf{cl}}\right] = E\left[X_{2,1}|I_C^{\mathsf{cl}}\right] \text{ and } \mathsf{coin} = X_{1,1} \\ 0,1 & \text{otherwise,} \end{cases} \tag{6}$$

where "$\mathsf{coin}= X_{1,1}$" means that the center flips a fair coin with faces $X_{1,1}$ and $X_{2,1}$, and $X_{1,1}$ comes up, and where $m_{\min}^{X_1} := \min\left[m_1^{\mathsf{cl}}, m_2^{\mathsf{cl}}\right]$ is the lower valued message sent concerning the same technology. The contents of these messages – what they imply concerning the expected value of the technology – are the same if $m_1^{\mathsf{cl}}, m_2^{\mathsf{cl}} \in [a_{r-1}, a_r)$ and they differ if $m_i < a_r \leq m_j$

[18] Note that between any two partitions the expert uses a random strategy. This guarantees that in equilibrium any possible message is sent with strictly positive probability. A discussion of out-of-equilibrium beliefs (what should the planner think about the value of a technology if he were to observe a non-equilibrium message?) can thus be avoided.

for some r.[19] The next proposition characterizes equilibrium behaviour.

Proposition 3 *In case of a centralized process with local markets, there exists an equilibrium in which*
(i) the equilibrium communication strategy is (a) a partition strategy $(N, a(N))$*, with* $N \geq 1$*, if initial technologies differ, and (b) truthful revelation if initial technologies are the same;*
(ii) the center's belief function (a) $f_i\left(x_{i,1}|I_C^{\mathsf{cl}}\right)$ *is uniform, supported on* $[a_r(N), a_{r+1}(N)]$ *if* $m_i \in (a_r(N), a_{r+1}(N))$ *for* $r = 0, \ldots, N-1$ *if initial technologies differ, and (b)* $f_i\left(x_{i,1}|I_C^{\mathsf{cl}}\right) = f_i(x_{i,1}|m_i) = 1\ (0)$ *for* $x_{i,1} = m_i$ $(x_{i,1} \neq m_i)$ *if initial technologies are the same;*
(iii) the partition $a(N)$ *satisfies* $a_0(N) = 0$*,* $a_N(N) = 1$*, and*

$$\begin{aligned} & \lambda\left[\hat{\pi}_i(X, X; a(N)) - \hat{\pi}_i\left(X, X^C; a(N)\right)\right] \\ = \;& E\left[X^C|a_{r-1}(N) \leq x^C \leq a_{r+1}(N), x = a_r(N), s^X, s^{X^C}\right] - a_r(N) \end{aligned} \tag{7}$$

for $r = 1, \ldots, N-1$*, and* N *is the highest integer for which* $a(N)$ *satisfies (7);*
(iv) the center's equilibrium decision strategy is defined in (6).
(v) for $\lambda < \bar{\lambda}_{\mathsf{le}}^{\mathsf{cl}} = E\left[X^C\right] / \left(\hat{\pi}_i(X, X; a(1)) - \hat{\pi}_i\left(X, X^C; a(1)\right)\right)$*,* $N(\lambda) \geq 2$*, whereas for* $\lambda \geq \bar{\lambda}_{\mathsf{le}}^{\mathsf{cl}}$*,* $N(\lambda) = 1$*. That is, no information is transmitted for* $\lambda \geq \bar{\lambda}_{\mathsf{le}}^{\mathsf{cl}}$*.*

In case both agents use the same technology in $t = 1$, truthfully revelation is an equilibrium outcome. In case they used different technologies, the communication strategy is a partition strategy. Eq (7) determines the partitioning. If agent i observes a value x he has to decide how to rank his technology X. The higher the rank is, the more likely it becomes that the center chooses his technology. This suggests that his technology is the better one. As a result, agent i enjoys a reputational benefit. Ranking it highly also has a cost. If $x^C > x$ but agent j does not rank X^C as highly as i ranks X, the center chooses X, the inferior technology in period 2. This possibility stops the agent from ranking his technology too highly. Eq (7) determines the values of x (the a_r's) for which i is indifferent

[19] Note that we assume that the planner tosses a coin in case of $X_{1,1} \neq X_{2,1}$ and $E\left[X_{1,1}|I_C^{\mathsf{cl}}\right] = E\left[X_{2,1}|I_C^{\mathsf{cl}}\right]$. This ensures harmonisation - sites adopt the same technology in $t = 2$. In a companion paper we analyse the case where both sites can continue with their initial technologies. This has interesting consequences for the nature and quality of communication.

between using two adjacent ranks (messages) to describe the value of technology X. The lengths of the partitions and the number of the partitions depend on how much agents are concerned with their reputation. The higher is λ, the noisier is the communication between the agents and the center. For $\lambda \geq \bar{\lambda}^{\mathsf{cl}}_{\mathsf{le}}$, no communication occurs in case the agents use different technologies in period 1. To see this, consider a situation in which agent 1 uses 2 ranks, such that the partition is fully characterized by $a_1(2)$. The larger is λ, the lower $a_1(2)$ is. However small $a_1(2)$ is, continuation continues to command a strictly higher reputation than being forced to switch technology. For $\lambda = \bar{\lambda}^{\mathsf{cl}}_{\mathsf{le}}$, $a_1(2) = 0$, and agent 1 uses only one rank. As a result, the center decides by tossing a coin. Nevertheless, if the center decides for X rather than X^C in period 2, agent 1's reputation is strengthened: agent 1's market does not know whether the center chooses X through flipping a coin, or because both agents used technology X in period 1. The latter makes it more likely that the agents received a correct signal. Hence, for $\lambda \geq \bar{\lambda}^{\mathsf{cl}}_{\mathsf{le}}$, the reputational gap continues to exist and communication is uninformative.

5.3 What type of learning is best if markets are local?

The above discussion raises the question as to which decision process performs better with local markets. On the basis of the above analysis two main conclusions can be drawn. First, with respect to communication, decentralization performs better. Irrespective of whether the agents used different or the same technologies in period 1, they are willing to share information. The reason is that with local markets agents do not have an interest in affecting each others decisions. As a result, by providing information an agent does not affect his own payoff. Under centralization and with both agents using different technologies in period 1, communication is distorted. The reason is that both agents want to influence the center's decision. This gives them an incentive to paint too rosy a picture of their technology. Under centralization perfect communication is an equilibrium in case both agents used the same technology in period 1.

The second conclusion that can be drawn is that centralization performs better in the decision stage. By assumption, conditional on the available information, the center chooses the better technology. Under decentralization, by contrast, the agents are biased towards keeping their technology.

Together the first two conclusions imply a trade-off between, on the one hand, better decision-making by the center conditional on the information received, and less informative communication about differences in technologies when learning is centralized. Centralization shifts the distortion from the decision stage to the communication stage. Numerical simulations show that the difference in expected welfare is typically small. As centralization works better than decentralization in case agents used the same technologies in $t = 1$, the relevant situation to analyse is the one in which technologies initially differed. Then, our simulations show that for large values of λ, decentralization yields a higher expected value of the technology than centralization. One reason is that under decentralization learning occurs for a wider range of λ than under centralization. Moreover, the smaller is π–the a priori likelihood of an agent being highly able–the better is the relative performance of decentralization for high values of λ. Of course, the smaller is π, the more likely it becomes that in fact agents start out with different technologies.

6 Global markets

Global markets *do* know the technologies adopted at different sites. This fundamentally changes the quality of communication in case sites initially use different technologies. Meaningful communication becomes impossible under decentralized learning. Under centralized learning, the communication strategy is a partition strategy. But contrary to what happens in local markets, communication remains feasible for any degree of reputational concerns. As a result, if reputational concerns are very strong, centralization is uniquivocally better than decentralization.

6.1 Decentralized learning

We start by showing that first-best behaviour, described on page 17, is not equilibrium behaviour. Suppose imputed equilibrium behaviour is first-best behaviour. Then, if agents initially adopted different technologies, the only adoption vectors possible are $\left(X, X^C, X, X\right)$ and $\left(X, X^C, X^C, X^C\right)$. The inference the market draws from the first (resp. second) vector is that X (resp. X^C) is the superior technology, and that i made the correct (resp. wrong) choice. The correct choice can be thanks to skill, or due to low ability and luck. The wrong choice, by contrast, *must* be due to low ability. Hence, $\hat{\pi}_i\left(X, X^C, X, X\right) = \frac{2\pi}{1+\pi} > \pi$ and $\hat{\pi}_i\left(X, X^C, X^C, X^C\right) = 0$. Clearly, from a reputational point of view, the former is the best and the latter is the worst that could happen to agent i. Could i convince j to adopt "his" technology? Rather than truthful revelation, consider the following deviation strategy in case of different initial technologies: "send $m_i = 1$ independent of x, and in the decision stage stick to X if and only if $x \geq m_j$." The effect of this deviation strategy is that i convinces j to adopt X in $t = 2$. Whether i continues with X depends on the reported value m_j and x. For $x \geq m_j$, the adoption vector in $t = 2$ becomes $\left(X, X^C, X, X\right)$, the same as it would have been had i stuck to truthful revelation. If $x < m_j$, the adoption vector in case of the deviation strategy equals $\left(X, X^C, X^C, X\right)$, whereas in case of truthful revelation it would have been $\left(X, X^C, X^C, X^C\right)$. The reputation implied by such a deviation is not determined by the imputed equilibrium behaviour. However, it is consistent with the model to assume that, given any adoption vector, any increase in the use at $t = 2$ of the technology i adopted in $t = 1$ increases the reputation of i.

Assumption 1 *Consider any adoption vector with $X_{i,1} = X$. The reputation of i increases if i (resp. j) changes from $X_{i,2} = X^C$ to $X_{i,2} = X$ (resp. from $X_{j,2} = X^C$ to $X_{j,2} = X$).*

With this assumption, the deviation is advantageous in terms of reputation, and costless in terms of technical adequacy. We have proved the next Lemma.

Lemma 3 *First-best behaviour is not equilibrium behaviour in case of a decentralized process with global markets.*

The above line of reasoning can be applied to *any* imputed equilibrium in which, in case agents started by adopting *different* technologies, j's decision regarding $X_{j,2}$ depends on the message m_i of i. The profitable deviation is then for i to send the message that induces j to adopt $X_{i,1}$, and to continue to base his own decision for $t = 2$ on a comparison of x and the expected value of X^C given m_j. This shows that the unique equilibrium communication strategy in case $X_{i,1} \neq X_{j,1}$ is a pooling strategy.[20] The interest an agent has to convince the other to agent to switch technology destroys all meaningful communication. This is in line with one of the concerns expressed about the OMC in the EU, a case of a decentralized learning process with global markets.

In case agents initially adopted the *same* technology, it is easy to see that truthful revelation is an equilibrium strategy. Communication is also irrelevant.[21] Proposition 4 below establishes that in this case an agent wants to deviate from first-best behaviour in the *decision* stage.

As communication breaks down in case of different initial technologies, and is irrelevant in case of the same initial technology, the equilibrium decision strategy of i amounts to a comparison of $x_{i,1}$ with a cut-off value that depends on the number of agents that used the same technology in $t = 1$. Let a two dimensional cut-off strategy with cut-offs $(\bar{c}_S, \bar{c}_D) \geqq 0$ be defined as

$$d_i^{\mathsf{dl}}\left(X_{i,1}|I_i^{\mathsf{dl}}; \bar{c}_S, \bar{c}_D\right) = \begin{cases} 1 & \text{if } X_{j,1} = X_{i,1} \text{ and } x_{i,1} \geq \bar{c}_S \\ 1 & \text{if } X_{j,1} \neq X_{i,1} \text{ and } x_{i,1} \geq \bar{c}_D \\ 0 & \text{otherwise.} \end{cases}$$

Of course, conditional on the information exchanged, the values of $\bar{c}_S$ and $\bar{c}_D$ that would maximize the technological value are $\bar{c}_S = \bar{x}_{\mathsf{S}}^{FB}$, and $\bar{c}_D = \bar{x}_{\mathsf{D}}^{FB}$, where $\bar{x}_{\mathsf{D}}^{FB}$ satisfies $\bar{x}_{\mathsf{D}}^{FB} = E\left[X^C|\bar{x}_{\mathsf{D}}^{FB}, s^X, s^{X^C}\right]$. The next Proposition describes equilibrium behaviour.

Proposition 4 *Define* $\bar{\lambda}_{\mathsf{dl,S}}^{\mathsf{go}} = E\left[X^C\right] / \left(\hat{\pi}_i\left(X, X, X, X; 0\right) - \hat{\pi}_i\left(X, X, X^C, X\right)\right)$ *and* $\bar{\lambda}_{\mathsf{dl,D}}^{\mathsf{go}} = E\left[X^C\right](1+\pi)/\pi$. *In case of a* **decentralized process** *with* **global markets**, *there exists an equilibrium in which*

(i) the equilibrium communication strategy is (a) a pooling strategy if initial technologies differ, and (b) truthful revelation if initial technologies are the same;

[20] To avoid a discussion of out-of-equilibrium beliefs, we assume that each agent uses a probability distribution over the full support $[0, 1]$ that is independent of the value $x_{i,1}$ he observed. This strategy is pay-off equivalent to any other pooling strategy. We refer to this equilibrium communication strategy simply by "pooling strategy".

[21] This is so as in our model solutions have a common value that is learned before agents communicate in $t = 2$.

(ii) the equilibrium belief function is (a) $f_i\left(x_{j,1}|I_i^{\mathsf{dl}}\right) = f\left(x_{j,1}\right)$ *in case* $X_{i,1} \neq X_{j,1}$ *for all* $x_{j,1}$ *and* m_j*; and (b) equals* $f_i\left(x_{j,1}|I_i^{\mathsf{dl}}\right) = f_i\left(x_{j,1}|m_j\right) = 1$ *(0) for* $x_{j,1} = m_j$ *(*$x_{j,1} \neq m_j$*) in case* $X_{i,1} = X_{j,1}$*;*

(iii) the equilibrium decision strategy is a two-dimensional cut-off strategy. The equilibrium cut-off value in case initial technologies are the same, $\bar{c}_S^*$*, satisfies*

$$\lambda\left[\hat{\pi}_i\left(X, X, X, X; \bar{c}_S^*\right) - \hat{\pi}_i\left(X, X, X^C, X\right)\right] = E\left[X^C|\bar{c}_S^*, s^X, s^X\right] - \bar{c}_S^*, \tag{8}$$

with $\bar{c}_S^* \in \left(0, \bar{x}_{\mathsf{S}}^{FB}\right)$ *for* $\lambda < \bar{\lambda}_{\mathsf{dl,S}}^{\mathsf{go}}$*. The larger is* λ*, the smaller is* $\bar{c}_S^*$*. For* $\lambda \geq \bar{\lambda}_{\mathsf{dl,S}}^{\mathsf{go}}$*,* $\bar{c}_S^* = 0$*. The equilibrium cut-off value in case initial technologies differ,* $\bar{c}_D^*$*, satisfies*

$$\lambda\frac{\pi}{1+\pi} = E\left[X^C|\bar{c}_D^*, s^X, s^{X^C}\right] - \bar{c}_D^*, \tag{9}$$

with $\bar{c}_D^* \in \left(0, \bar{x}_{\mathsf{D}}^{FB}\right)$ *for* $\lambda < \bar{\lambda}_{\mathsf{dl,D}}^{\mathsf{go}}$*. The larger is* λ*, the smaller is* $\bar{c}_D^*$*. For* $\lambda \geq \bar{\lambda}_{\mathsf{dl,D}}^{\mathsf{go}}$*,* $\bar{c}_D^* = 0$*.*

Global markets, by definition, know the technologies adopted at both sites. Hence, (8) is based on agents who initially used the same technology, whereas (9) is based on agents who adopted different technologies in $t = 1$. This gives rise to different reputational gaps, and therefore to distortions in the decision stage that differ in size. This contrasts with what happens in local markets. Reputation in local markets is based on past and present technology adoption at a given site. Hence, the left-hand sides of (4) and (5) in Proposition (2) are the same. As a result, for $\lambda < \underline{\lambda}_{\mathsf{dl}}^{\mathsf{lo}}$ in local markets the distortions are of equal size.

In Section 5.1 we have argued that from a welfare point of view a decentralized decision process performs better than isolated agents. We can now examine how the second aspect of globalization (global rather than local markets) affects welfare. Under a decentralized decision process, the main effect of globalization of the public is that communication between the agents breaks down. This aspect of globalization is therefore bad from a social point of view. However, a decentralized decision process performs still better than isolated agents. The reason is that decisions in period 2 are still based on more information, as agents observe what other decision makers do.

6.2 Centralized learning

We start by showing that first-best behaviour is not equilibrium behaviour in case of centralized learning in the presence of global markets.

Lemma 4 *Under a centralized process with global markets, first-best behaviour is not equilibrium behaviour.*

It suffices to show that agent i has an incentive to slightly exaggerate the value of $X_{i,1}$ in case j adopted a different technology. If agents and center were to stick to first-best behaviour, then being allowed to continue with one's technology commands a higher reputation than being forced to change. With global markets $\hat{\pi}_i(X, X, X, X) > \hat{\pi}_i\left(X, X^C, X^C, X^C\right)$. Assume i deviates by communicating $x + \varepsilon > x$ instead of x. Conditional on this exaggeration changing the center's decision i.e., for $x^C \in (x, x + \varepsilon)$, the reputational boost equals $\lambda\left[\hat{\pi}_i(X, X, X, X) - \hat{\pi}_i\left(X, X^C, X^C, X^C\right)\right] > 0$ and is independent of ε, whereas the costs (in terms of the choice of an inferior technology) can be made arbitrarily small by reducing the value of ε. This shows that a profitable deviation from first-best behaviour exists.

The center can guarantee first-best behaviour if both agents adopted the *same* technology X in $t = 1$ by basing her decision on the information she deduces from the lower message. Then, if j truthfully reveals the value of X, exaggeration by i is to no avail. Proposition 5 establishes that when initial technologies differ, an equilibrium exists in which communication strategies are partition strategies.

Proposition 5 *In case of a centralized process with global markets, there exists an equilibrium in which*
(i) the equilibrium communication strategy is (a) a partition strategy $(N, a(N))$, with $N \geq 2$, if initial technologies differ, and (b) truthful revelation if initial technologies are the same;
(ii) the center's belief function (a) $f_i\left(x_{i,1}|I_C^{\mathsf{cl}}\right)$ is uniform, supported on $[a_r(N), a_{r+1}(N)]$ if $m_i \in (a_r(N), a_{r+1}(N))$ for $r = 0, \ldots, N-1$ if initial technologies differ, and (b) $f_i\left(x_{i,1}|I_C^{\mathsf{cl}}\right) = f_i(x_{i,1}|m_i) = 1$ (0) for $x_{i,1} = m_i$ $(x_{i,1} \neq m_i)$ if initial technologies are the same;

(iii) the partitioning $a(N)$ satisfies $a_0(N) = 0$, $a_N(N) = 1$, and

$$\lambda \left[\hat{\pi}_i \left(X, X^C, X, X; a(N)\right) - \hat{\pi}_i \left(X, X^C, X^C, X^C; a(N)\right)\right] \tag{10}$$

$$= E\left[X^C | a_{r-1} \leq x^C \leq a_{r+1}, x = a_r, s^X, s^{X^C}\right] - a_r \tag{11}$$

for $r = 1, \ldots, N-1$, and where N is the largest integer such that $a(N)$ satisfies (10);
(iv) the center's equilibrium decision strategy is defined in (6);
(v) for all λ, $N \geq 2$. That is, communication between agents and center remains possible for all λ.

The nature of equilibrium behaviour is very similar to that in case of local markets. There are, however, two important differences. First, in case of global markets, when agents adopted different technologies in period 1 agents continue to transmit information even for very high values of λ, see part (v) of Proposition 5. Recall that in a centralized process with local markets, agents stop communicating information for large values of λ, see part (v) of Proposition 3. This difference stems from the fact that global markets know the strategies adopted at different sites, whereas local markets do not. This causes differences in the reputational gap. If with global markets no information were transmitted, the center would always flip a coin to make a decision on which technology should be adopted in $t = 2$. As a result, reputations would not depend anymore on the technology decision in $t = 2$, but only on the fact that the agents adopted different technologies in $t = 1$. Hence, if no information were transmitted, the reputational gap would vanish. But this, in turn, would mean that the reason *not* to transmit information would disappear, a contradiction. In fact, in the Appendix we derive that the reputation in case of centralization with two ranks or words equals $\hat{\pi}_i \left(X, X^C, X, X; a(2)\right) = \frac{\pi}{1+\pi}\left(1 + 2F(a_1) - 2F(a_1)^2\right)$ and $\hat{\pi}_i \left(X, X^C, X^C, X^C; a(2)\right) = \frac{\pi}{1+\pi}\left(1 - 2F(a_1) + 2F(a_1)^2\right)$. Hence, the reputational gap equals $\frac{\pi}{1+\pi} 4F(a_1)(1 - F(a_1))$, which does indeed vanish for $a_1 = 0$. As we explained on page 23, in case of local markets a decision for X rather than X^C in period 2 always boosts agent 1's reputation, even if i were not to transmit any information about x. Hence, the reputational gap continues to exist.

A second difference between the equilibrium described by Proposition 3 and Proposition 5 is the impact of reputational concerns. Under centralization, whether markets are local or global matters most when the agents initially adopted different technologies. In that situation, the size of the reputational gap depends heavily on whether the market is local or global. In case of a local market, an agent severely damages his reputation by switching technology. The reason is that the market does not know whether agents initially used different technologies. With global markets, the agents' reputations are already damaged by the fact that they initially used different technologies. As a result, the cost of switching are relatively modest. An implication is that under global markets agents have a weaker incentive to exaggerate the value of their technology than under local markets.

6.3 What type of learning is best if markets are global?

The preceding two subsections allow us to compare the performance of decentralization and centralization from a welfare point of view.

Proposition 6 *In case of global markets, expected welfare is higher in case of centralization than in case of decentralization.*

The proof is straightforward if agents start with the same technology in $t = 1$. Center and local agents have the same information when they make their decisions, and the first makes undistorted decisions, whereas the latter are also led by reputational concerns. The proof is somewhat more complicated in case agents started with different technologies for two reasons. First, the quality of communication in case of centralization depends on the number of ranks the agents use. The more ranks they use, the higher the expected welfare is. Hence, we are done with the proof if we can show that the proposition is true if communication under centralization is limited to two ranks. Proposition 5 *(v)* shows that an equilibrium with two ranks exists for all parameter values. Second, although there is no communication in case of decentralization, a local agent knows the exact value of his own technology, whereas the center can only rely on the messages she receives. However, this difference is immaterial when calculating ex ante expected welfare.

So, in case of centralization with two ranks, if agents rank their technologies differently, the center picks the higher ranked technology. Given the communication strategies of the agents this technology is indeed the better one. However, for $(y, z) \in [0, a_1]^2$ and $(y, z) \in$

$[a_1, 1]^2$, both technologies are ranked in the same way (say, "low" and "high," respectively). Hence, the center tosses a fair coin. The inferior technology is chosen half of the time at both sites. In case of decentralization, for $y < \bar{c}_D^* \leq z$, the Y-user switches to Z, and the Z-user continues his technology. Both agents use the superior technology in $t = 2$. The same holds, mutatis mutandis, for $z < \bar{c}_D^* \leq y$. However, for $(y, z) \in [0, \bar{c}_D^*]^2$, both agents switch, while if $(y, z) \in [\bar{c}_D^*, 1]^2$, both agents continue. In either case, the inferior technology is used at one site with probability one.

Clearly, if $a_1 = \bar{c}_D^*$, then either process would yield the same expected welfare. From the proof of Proposition 5, we know that a_1 satisfies $\lambda \frac{\pi}{1+\pi} 4F(a_1)(1 - F(a_1)) = E[Z|a_1, s^Y, s^Z] - a_1$ in case of two ranks. From Proposition 4 we know that $\bar{c}_D^*$ satisfies $\lambda \frac{\pi}{1+\pi} = E[Z|\bar{c}_D^*, s^Y, s^Z] - \bar{c}_D^*$. As $4F(a_1)(1 - F(a_1)) < 1$ for all a_1, the reputational gap in case of centralization is smaller than that gap in case of decentralization. As the reputational gap equals the size of the distortion from what would have been the first-best value given the information available[22], centralization yields a higher expected welfare than decentralization. In particular, note that for $\lambda > \bar{\lambda}_{\mathsf{dl,D}}^{\mathsf{go}}$, the adoption decision of a decentralized agent is to continue with his technology *irrespective* of its observed value, see Proposition 4, while two ranks keep on being used in case of decentralization.

For global markets the welfare analysis leads to stronger statements than for local markets. If markets are global, centralization is unequivocally better than decentralization. The fact that centralization is already superior to decentralization if agents can use two words to rank their technology suggests that the welfare difference can be substantial if λ allows for richer communication. For local markets our results are more subtle in two respects. First, decentralization may actually be superior to centralization. Second, the quantitative effects are much smaller. The reason is that for local markets the choice between decentralization and centralization involves a clear trade-off. Decentralization leads to perfect communication, but distorted decisions. By contrast, centralization leads to imperfect communication, but given information, optimal decisions. To a large extent, both effects cancel each other out.

[22] Of course, this value would have been $\bar{y}$ satisfying $E[Z|\bar{y}, s^Y, s^Z] - \bar{y} = 0$ for a Y-user (and analogously for a Z-user).

7 Concluding Remarks

An important objective of this paper was to gain insight into the effects of alternative decision-making processes on the quality of decisions in situations where information is dispersed among agents, and agents are concerned about their reputations. Our analysis focuses on two broad features of decision-making processes: the extent of centralization and whether decision-makers operate in a local or global world. We believe that our focus enabled us to derive a couple of interesting results. By focusing on these two broad features, we have abstracted from more subtle features of decision-making processes. Here we would like to elaborate on some of the specific assumptions we have made.

Centralization. One important assumption is that in a centralized process the center always acts in the general interest. In reality, there is little reason to put so much confidence in central bodies. For example, a center may be biased towards one of the technologies because of favoritism. Alternatively, a center may be biased because somehow his name is connected to one of the technologies. Of course, our assumption of a "benevolent" center provides too favourable a picture of centralized processes.

There is a second reason to be less optimistic about centralization. We have shown that truthful revelation is an equilibrium communication strategy in case agents have used the same technology in period 1. This is so as the planner bases his decision on the information provided by the agent who reports the lower value. A plausible alternative equilibrium is one in which both agents send highly positive information on technology X if they want the center to choose X, and to send less positive information if they want the center to choose X^C. Experts have incentives to coordinate on such a strategy as it may boost their reputation. Because an agent knows the technology adopted at the other site, such (tacit) collusive behaviour is feasible. As this strategy implies a distortion, it makes a centralized process less attractive from a normative point of view.

Information. We have described the private information that agents have as non-verifiable, and communication as cheap talk. Although this may well reflect an important part of information agents have gained locally, they may also have verifiable information. Such information can be checked by other agents. If it is unknown whether an agent actually possesses information that is decision-relevant to another agent, the former may have an incentive to selectively withhold his private information from the latter, see e.g. Milgrom and Roberts (1986). How does the presence of verifiable information change our findings? Although the nature of information manipulation changes, the incentives to manipulate continue to be determined by the interplay of the decision rights and the knowledge the markets have. As a result, the quality of information exchange depends in essentially the same way on these same two factors. Consider decentralized decision-making with local markets. The fact that an agent's reputation is independent of what the other agent does and that an agent can decide himself what technology he uses next makes that revealing all positive and negative pieces of information is a weakly dominant strategy. With global markets (and decentralised decision-making), it is important from a reputational perspective to convince the other agent to switch to "your" technology. As a result, any negative information will be withheld. The introduction of centralised decision-making in the presence of global markets gives rise to the selective revelation of negative information. On the one hand, as the agent at a site loses decision-making power, he wants to make sure that the center is well-informed. On the other hand, his reputational concerns imply that he wants the center to impose "his" technology at either site. Ceteris paribus, the more damaging negative information is for the technological value, the more likely it is that the information is revealed. Similarly, the more damaging negative information is for his reputation, the less likely it becomes that this information is revealed.

In our model, signals are for free. However, one can easily imagine situations where agents can increase the probability of receiving an informative signal by putting more effort in investigating technologies. We consider modeling agents' effort decisions as a promising extension of our model. We expect that reputational concerns do not only lead to distortions in communication and decisions, but that they may also induce agents to put more effort in investigating technologies, see e.g. Suurmond, Swank and Visser (2004).

Decision rights. We have limited attention to centralization and decentralization. A possible third organizational structure is a committee consisting of the two agents that makes a collective decision in period 2 on the basis of some voting rule. Visser and Swank (2007) analyze communication and voting in committees in the presence of reputational concerns.

Our approach is particularly relevant for situations where agents independently gained experiences that are worth sharing. In our model, period 1 represents history. However, in other situations experience still has to be gained. Then, some planner could opt for ignoring signals and assign one technology to agent 1 and the other technology to agent 2. Such a procedure is likely to weaken reputational concerns as the technology decisions are no longer linked to signals. Moreover, it allows for learning in period 2. It is easy to show that assigning technologies in period 1 is optimal if signals are not very informative. The first-period costs of ignoring signals are then small.

8 Appendix

Proof of lemma 1: Consider (1) in the text. (a) As $\Pr\left(\bar{\theta}|s^X,0\right)=0$, $E\left[X^C|s^X,0\right]=E\left[X^C\right]$. Similarly, as $\Pr\left(\bar{\theta}|s^X,1\right)=1$, then $E\left[X^C|s^X,1,\bar{\theta}\right]=E\left[X^C\right]$, and therefore $E\left[X^C|s^X,1\right]=E\left[X^C\right]$. Moreover, $E\left[X^C|s^X,x,\bar{\theta}\right]<E\left[X^C\right]$ for $x\in(0,1)$, as the term on the LHS is the expected value of the truncated distribution on $[0,x)$. (b) To determine the derivative, use Bayes' rule to write $\Pr\left(\bar{\theta}|s^X,x\right)=2F(x)\pi/(2F(x)\pi+(1-\pi))$. Also, $E\left[X^C|s^X,x,\bar{\theta}\right]=\int_0^x tf(t)\,dt/F(x)$. One can verify that $\partial\Pr\left(\bar{\theta}|s^X,x\right)/\partial x=\Pr\left(\bar{\theta}|s^X,x\right)\left(1-\Pr\left(\bar{\theta}|s^X,x\right)\right.$ 0, and $\partial E\left[X^C|s^X,x,\bar{\theta}\right]/\partial x=\left(x-E\left[X^C|s^X,x,\bar{\theta}\right]\right)\frac{f(x)}{F(x)}$. Hence, $\partial E\left[X^C|s^X,x\right]/\partial x=\Pr\left(\bar{\theta}|s^X,x\right)\frac{f(x)}{F(x)}\left(x-E\left[X^C|s^X,x\right]\right)$, from which it follows immediately that $E\left[X^C|s^X,x\right]$ is decreasing for $x<E\left[X^C|s^X,x\right]$ and increasing for $x>E\left[X^C|s^X,x\right]$. That $x=E\left[X^C|s^X,x\right]$ has a unique solution is then immediate. ■

Derivation of $\hat{\pi}(X,X;\bar{t})$ in (2) (derivation of $\hat{\pi}\left(X,X^C;\bar{t}\right)$ analogously): $\hat{\pi}(X,X;\bar{t})=$

$$\frac{\Pr\left(X,X|\bar{\theta}\right)\Pr\left(\bar{\theta}\right)}{\Pr\left(X,X|\bar{\theta}\right)\Pr\left(\bar{\theta}\right)+\Pr\left(X,X|\underline{\theta}\right)\Pr\left(\underline{\theta}\right)}=\frac{\Pr\left(x\geq\bar{t}|\bar{\theta}\right)\Pr\left(\bar{\theta}\right)}{\Pr\left(x\geq\bar{t}|\bar{\theta}\right)\Pr\left(\bar{\theta}\right)+\Pr\left(x\geq\bar{t}|\underline{\theta}\right)\Pr\left(\underline{\theta}\right)}=$$

$$\frac{\left(1-F(\bar{t})^2\right)\pi}{\left(1-F(\bar{t})^2\right)\pi+\left(1-F(\bar{t})\right)(1-\pi)}=\frac{1+F(\bar{t})}{1+F(\bar{t})\pi}\pi.$$

Proof of Proposition 1: It is straightforward to check that (i) for $\bar{x}_{\mathsf{ia}}$ satisfying (3) an agent is indifferent between continuation and switching; (ii) $\hat{\pi}(X,X;\bar{x}_{\mathsf{ia}})-\hat{\pi}\left(X,X^C;\bar{x}_{\mathsf{ia}}\right)$

decreases in $\bar{x}_{\text{ia}}$, see (2); (iii) for $\lambda \geq \bar{\lambda}_{\text{ia}}$, $\bar{x}_{\text{ia}} = 0$. To see that $\bar{x}_{\text{ia}}$ is a decreasing function of λ, note that for every $\bar{x}_{\text{ia}} \in \left[0, \bar{x}_{\text{ia}}^{FB}\right]$, there is a unique value of λ such that (3) holds. As for $\bar{x}_{\text{ia}} = \bar{x}_{\text{ia}}^{FB}$, $\lambda = 0$ and for $\bar{x}_{\text{ia}} = 0$, $\lambda = \bar{\lambda}_{\text{ia}} > 0$, this implies that $\bar{x}_{\text{ia}}$ is a decreasing function of λ.■

Proof of Proposition 2: The equilibrium belief functions follow immediately from the equilibrium message strategies. The rest was shown in the text.■

Proof of Proposition 3: Assume that the center uses (6) and that agent j uses the partition strategy with partitions $a(N)$ to communicate about X^C. We show that it is then a best-reply for agent i to use a partition strategy with the same partitions to communicate about X. Let $x = a_r$, where we have suppressed reference to the number of partitions N. At this value of x, i should be indifferent between sending some $m_{r+1} \in [a_r, a_{r+1})$ or some $m_r \in [a_{r-1}, a_r)$. If $x^C < a_{r-1}$ or $x^C \geq a_{r+1}$, whether i sends m_r or m_{r+1} does not affect the decision of the center. Hence, one can limit attention to $x^C \in [a_{r-1}, a_r) \cup [a_r, a_{r+1})$. Define for any (α, β) such that $0 \leq \alpha < \beta \leq 1$, $p(\alpha, \beta) := \Pr\left(\alpha \leq x^C \leq \beta | x = a_r, s^X, s^{X^C}\right)$ and $X^C(\alpha, \beta) := E\left[X^C | \alpha \leq x^C \leq \beta, x = a_r, s^X, s^{X^C}\right]$. Then, for any γ such that $\beta < \gamma \leq 1$,

$$p(\alpha, \beta) X^C(\alpha, \beta) + p(\beta, \gamma) X^C(\beta, \gamma) = p(\alpha, \gamma) X^C(\alpha, \gamma). \tag{12}$$

Sending m_{r+1} yields i

$$\begin{aligned} &p(a_{r-1}, a_r)\left[a_r + \lambda \hat{\pi}_1(X, X)\right] + \frac{1}{2} p(a_r, a_{r+1})\left[a_r + \lambda \hat{\pi}_1(X, X)\right] + \\ &\frac{1}{2} p(a_r, a_{r+1})\left[X^C(a_r, a_{r+1}) + \lambda \hat{\pi}_1\left(X, X^C\right)\right], \end{aligned} \tag{13}$$

whereas m_r yields

$$\begin{aligned} &\frac{1}{2} p(a_{r-1}, a_r)\left[a_r + \lambda \hat{\pi}_1(X, X)\right] + \frac{1}{2} p(a_{r-1}, a_r)\left[X^C(a_{r-1}, a_r) + \lambda \hat{\pi}_1\left(X, X^C\right)\right] \\ &+ p(a_r, a_{r+1})\left[X^C(a_r, a_{r+1}) + \lambda \hat{\pi}_1\left(X, X^C\right)\right]. \end{aligned} \tag{14}$$

Agent i is indifferent between sending m_{r+1} and m_r for $x = a_r$ if sending m_r or m_{r+1} yields the same payoff. It is easy to check, with the help of (12), to see that this is the case if (7) in the statement of proposition 3 holds.

To complete the proof, it remains to be shown (i) that the belief function follows from applying Bayes' rule to the communication strategies of the agents, (ii) that the center's decision strategy is a best reply given the belief function, and (iii) that truthful revelation is an equilibrium strategy given the center's strategy. This is straightforward to establish. ■

Proof of Lemma 3: Suppose $X_{i,1} = X$ and $X_{j,1} = X^C$, and suppose both agents stick to first-best behaviour. Then, if $x \geq x^C$, i's payoff in $t = 2$ equals $x + \lambda\hat{\pi}_i\left(X, X^C, X, X\right)$. If instead $x < x^C$, his payoff in $t = 2$ is $x^C + \lambda\hat{\pi}_i\left(X, X^C, X^C, X^C\right)$. Now suppose i deviates from first-best behaviour only in the communication stage: instead of $m_i = x_{i,1}$, he sends message $m_i = 1$. As $1 > x^C$ with probability one, sending $m_i = 1$ guarantees $X_{j,2} = X$. If $x \geq x^C$, i's payoff in $t = 2$ equals $x + \lambda\hat{\pi}_i\left(X, X^C, X, X\right)$, the same as without the deviation. If instead $x < x^C$, his payoff in $t = 2$ is $x^C + \lambda\hat{\pi}_i\left(X, X^C, X^C, X\right) > x^C + \lambda\hat{\pi}_i\left(X, X^C, X^C, X^C\right)$, and i benefits from the deviation by Assumption 1.■

Proof of Proposition 4: To see that a cut-off strategy with $\bar{c}^*_S$ is an equilibrium strategy assume agents initially use the same technology; that j uses a cut-off strategy with $\bar{c}^*_S$; that $x = \bar{c}^*_S$; and that reputations are given. Agent i now has to choose whether to continue X, yielding $\bar{c}^*_S + \lambda\hat{\pi}_i\left(X, X, X, X; \bar{c}^*_S\right)$, or to switch to X^C, yielding $E\left[X^C|\bar{c}^*_S, s^X, s^X\right] + \lambda\hat{\pi}_i\left(X, X, X^C, X\right)$. The latter expression involves an out-of-equilibrium belief as j continues with X. Equating these two expressions shows that i is indifferent for $x = \bar{c}^*_S$. As before, for $x < \bar{c}^*_S$ (resp. $x > \bar{c}^*_S$) i strictly prefers to continue (resp. to switch). A similar analysis holds for the case of initially different technologies. As far as ex post assessments are concerned, for given strategies, (i) $\hat{\pi}_i\left(X, X^C, X^C, X^C\right) = 0$, as this reveals $x < \bar{c}^*_D \leq x^C$, which implies that i chose the inferior technology; (ii) $\hat{\pi}_i\left(X, X^C, X, X\right) = 2\pi/\left(1+\pi\right)$, as this reveals $x^C < \bar{c}^*_D \leq x$; (iii) $\hat{\pi}_i\left(X, X^C, X, X^C\right) = \hat{\pi}_i\left(X, X^C, X^C, X\right) = \pi/\left(1+\pi\right)$, as the market can deduce nothing about the relative value of X and X^C, only that not both are highly able. Hence, if $x = \bar{c}^*_D$, and if i continues X he gets

$$\begin{aligned}&\bar{c}^*_D + \lambda\Pr\left(x^C < \bar{c}^*_D|x = \bar{c}^*_D, s^X, s^{X^C}\right)2\pi/\left(1+\pi\right) + \\ &\lambda\Pr\left(x^C \geq \bar{c}^*_D|x = \bar{c}^*_D, s^X, s^{X^C}\right)\pi/\left(1+\pi\right),\end{aligned} \quad (15)$$

whereas switching to X^C yields

$$E\left[X^C|\bar{c}^*_D, s^X, s^{X^C}\right] + \lambda\Pr\left(x^C < \bar{c}^*_D|x = \bar{c}^*_D, s^X, s^{X^C}\right)\pi/\left(1+\pi\right). \quad (16)$$

Equating these expressions, one obtains (9). Again, for $x < \bar{c}^*_D$ (resp. $x > \bar{c}^*_D$) i strictly prefers to continue (resp. to switch). The values of $\lambda^{\mathsf{go}}_{\mathsf{dl,S}}$ and $\bar{\lambda}^{\mathsf{go}}_{\mathsf{dl,D}}$ can be found by substituting

$\vec{c}_S^* = 0$ (resp. $\vec{c}_D^* = 0$) in (8) (resp. (9)). The belief functions follow trivially from the communication strategies.■

Proof of Proposition 5: The proof is by and large similar to that of Proposition 3. Here, we prove *(v)*. Suppose to the contrary that for some parameter values agents would use only one word, hence $N = 1$. Then, whether the market observes $(X_{1,1}, X_{1,2}, X_{2,1}, X_{2,2}) = (X, X^C, X, X)$ or (X, X^C, X^C, X^C), it would deduce that technologies in the second period are the result of a coin toss, and so $\hat{\pi}_1 (X, X^C, X, X) = \hat{\pi}_1 (X, X^C, X^C, X^C)$. But then the LHS of (10) would equal zero, whereas its RHS would equal $E[X^C]$, a contradiction. We also derive here $\hat{\pi}_i (X, X^C, X, X)$ in case of $a(2)$ (two ranks). Write $a = a_1$. The posterior equals

$$\Pr\left(\bar{\theta}_i | X, X^C, X, X\right) = \frac{\Pr\left(X, X^C, X, X | \bar{\theta}_i\right) \Pr\left(\bar{\theta}_i\right)}{\Pr\left(X, X^C, X, X | \bar{\theta}_i\right) \Pr\left(\bar{\theta}_i\right) + \Pr\left(X, X^C, X, X | \underline{\theta}_i\right) \Pr\left(\underline{\theta}_i\right)}.$$

Consider $\Pr\left(X, X^C, X, X | \bar{\theta}_i\right)$. Given $\bar{\theta}_i$, observing $\{X, X^C, X, X\}$ requires: (i) X to be the better technology; (ii) $\theta_j = \underline{\theta}_j$ (a high ability j would have chosen X in $t = 1$); and (iii) in case $x > x^C > a$ or $a > x > x^C$ (such that both agents use the same word to describe their respective technologies), the center chooses X with probability 1/2. Of course, if instead of (iii), it is the case that $x > a > x^C$, which happens with probability $F(a)(1 - F(a))$, then the center chooses with probability one technology X as this is the technology he receives the more favourable message about. Given these observations, it follows that $\Pr\left(X, X^C, X, X | \bar{\theta}_i\right) = \frac{1-\pi}{4}\left(\frac{1}{2} + F(a)(1 - F(a))\right)$. Similarly, $\Pr\left(X, X^C, X, X | \underline{\theta}_i\right) = \frac{1}{8} - \frac{\pi}{4} F(a)(1 - F(a))$. Hence, $\hat{\pi}_i (X, X^C, X, X) = \frac{\pi}{1+\pi}\left(1 + 2F(a) - 2F(a)^2\right)$. Analogously, one can show that $\hat{\pi}_i (X, X^C, X^C, X^C) = \frac{\pi}{1+\pi}\left(1 - 2F(a) + 2F(a)^2\right)$. As a result, the reputational gap becomes $4\frac{\pi}{1+\pi} F(a)(1 - F(a))$.■

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