The Politics of Compromise*

Alessandro Bonatti† and Heikki Rantakari‡

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Abstract

An organization must select among competing projects that differ with respect to the payoff consequences for its members. Each agent chooses a project and exerts costly effort affecting its random completion time. When one or more projects are complete, the agents must select which one to adopt. The selection rule for multiple projects that maximizes ex post welfare leads to an inefficiently high amount of polarization; rules that favor later proposals can improve upon ex post efficient selections. The optimal degree of favoritism for later proposals increases in the agents' cost of effort and discount rate.

Keywords: bargaining, compromise, conflict, consensus, free riding, standard-setting organizations.

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†MIT Sloan School of Management, 100 Main Street, Cambridge MA 02142, bonatti@mit.edu.

‡University of Rochester Simon School of Business, 252 Elmwood Avenue, Rochester NY 14627, heikki.rantakari@simon.rochester.edu.

1 Introduction

Many organizations rely on their members to develop solutions to specific problems. Universities establish search committees for hiring at the senior level or for recommending changes to the curriculum. In a very similar fashion, standards bodies routinely form working groups to define the properties of a new technological standard. In both settings, there are no readily available solutions (i.e., candidates, curricula, standards) from which to select. Instead, the members of the organization must invest time and effort developing potential solutions. Furthermore, different members may have conflicting preferences over the feasible alternatives: which candidate to hire or which courses or patents to include in the curriculum or standard, respectively. Finally, as decision rights are typically shared, members must ultimately come to an agreement over which of the proposed solutions to adopt.

The following problem is at the heart of all these examples. Because developing a proposal is costly, the first agent who presents a concrete proposal acquires considerable bargaining power. The other agents can avoid further development costs by approving his project and, hence, are willing to endorse projects that are not ideal from their perspective. When agents have conflicting preferences over the potential projects, this creates scope for rent-seeking behavior, i.e., agents exert effort to develop projects that are biased in their favor and to preempt others from presenting alternatives that they like much less.

The development of projects that are highly skewed in favor of one member or group can be detrimental to an organization if solutions that compromise among members' goals are more efficient.[1] The challenge for the organization is then to provide members with incentives to develop moderate as opposed to highly polarized projects. However, the more a member is motivated to compromise on project selection, the less interested he is in the development of his own project, which can lead to inefficient delay.

In this paper, we are interested in the design of organizational decision-making processes that strike a balance between compromise in project choices and equilibrium effort levels. We explore this trade-off in a dynamic model consisting of a *development phase* and an *adoption phase.* Loosely speaking, the development phase integrates a classic patent race framework with a choice of "research direction." Two agents continuously choose which project to pursue and how much effort to exert. Each project's completion requires a single stochastic breakthrough, and each agent affects the probability distribution of its arrival time through costly effort. Agents have conflicting interests, and compromise is efficient.

[1] In the context of a business school, examples include: senior-faculty candidates that can interact with heterogeneous groups; and core curricula for MBA students that are not dominated by one subject area. In the context of standardization, consider technological solutions that minimize the total switching costs faced by firms and consumers.

In particular, there exists a continuum of potential projects that generate different payoffs for each agent, forming a strictly concave Pareto frontier. Therefore, "intermediate" or "compromise" projects are socially desirable.

Once one or more projects are complete, agents must select which one to adopt. While projects can be ranked in terms of their payoffs for the two agents, the space of their underlying characteristics can be quite complex. Therefore, we do not allow the agents to adopt convex combinations of projects with different characteristics. Further, we do not allow agents to write contracts that condition payments or decision rights on the characteristics of the projects developed.[2]

The decision to adopt an agent's project requires the acquiescence of the other agent. For example, if a member of a hiring committee finds a given candidate sufficiently unattractive, he can delay the adoption decision and continue to search for an alternative candidate. A consensus requirement can thus limit the scope for rent-seeking and induce each agent to shift away from his ideal project to ensure to other agent's support. But a consensus requirement alone does not determine a particular level of compromise. In the hiring example, each committee member's incentives to block or to adopt the first candidate depend not only on the value of that candidate, but also on which alternative candidates he prefers and which ones he expects to generate consensus. In other words, the option value of blocking a project depends on continuation play and, thus, on the *selection rule* dictating which project is adopted when two projects have been developed. Solving backward, the selection rule influences the types of projects developed in equilibrium and their completion times.

Our main results are as follows. Under the selection rule that adopts the project with the highest social value, the agents exert efficient effort levels conditional on their chosen projects, but they pursue excessively polarized projects. In other words, we uncover a trade-off between ex post welfare and the incentives for compromise in the initial project choices. In order to improve ex ante welfare (i.e., the sum of the agents' utilities) relative to the ex post optimal criterion, the selection rule must be distorted in favor of the project developed *later*. For instance, the selection rule can allow each agent to respond to the project that is developed first with a more polarized (hence, more selfish) project. This ex post distortion "levels the playing field" by increasing the option value of blocking the first project, and it forces *both agents* to compromise more in their initial project choices.

The optimal (second-best) combination of projects and effort levels can be induced in equilibrium by adopting the project that maximizes a weighted sum of the agents' payoffs.

[2] The complexity of the projects suggests that it can be exceedingly difficult to describe them in a contract. Similarly, the existence of complementarities within a given project can make combining two distinct projects unprofitable, if not unfeasible. See Brynjolfsson and Milgrom (2013) for a discussion.

Consistent with the option-value logic, the optimal Pareto weights are skewed in favor of the agent who develops the *second* project. Furthermore, as the agents' costs of effort and discount rates increase, the option value of blocking the first project decreases, and the optimal degree of favoritism must consequently increase.

We finally consider how the model applies to standard-setting organizations, and to capture some features of their environment, we consider a slightly modified setting where voting and active agents coexist. Specifically, we introduce a continuum of voters with heterogeneous preferences over projects. We show that a simple voting procedure implements the optimal combination of projects and effort levels: projects are voted on sequentially as they are completed; a qualified majority is required for approval; and any project that fails to gain approval is removed from consideration. This procedure is closely related to those used in many standard-setting organizations, which we turn to next.

1.1 Standard Setting Organizations

We focus on the workings of voluntary standard-setting organizations (SSOs) as an application. This is a suitable application for three reasons: (i) economic relevance; (ii) the trade-off between free-riding and rent-seeking; and (iii) data availability. In particular, the inter-firm nature of SSOs facilitates finding evidence relative to intra-firm applications.[3]

Following Simcoe (2013), we define an SSO as a "multilateral organization that governs some key piece of a shared technology platform." SSOs provide a forum (with voluntary participation) for the development and establishment of broad consensus on standards prior to their adoption. Thus, the main economic advantage of SSOs is to solve the potential coordination failures that arise under unfettered market competition. In markets with network externalities, *de jure* standardization saves duplication costs, stimulates specific investments by complementary products, and avoids the risk of a standards war.

This process has been used to establish a multitude of voluntary consensus standards.[4] However, the shared interest in establishing a standard to realize the benefits of network economies often conflicts with the vested interests of each participant. Overall, the combination of free-riding, distributional conflicts and consensus requirements makes reaching an agreement quite challenging. Consistent with our approach, Simcoe (2013) and Baron, Ménière, and Pohlmann (2014) argue that the process of developing and adopting a standard

[3] From this perspective, the SSOs for the governance of the Internet are especially relevant for our model. These organizations include the Institute for Electrical and Electronics Engineers (IEEE), the Internet Engineering Task Force (IETF), and the World Wide Web Consortium (W3C).

[4] Examples of Internet-related standards adopted by the SSOs referenced above include the 802.11 standard for wireless communication in the IEEE; the HTTP protocol in the IETF; and the URL standard for the World Wide Web in the W3C.

must balance free-rider problems and rent-seeking behaviors. In Section 7, we illustrate the decision-making procedures that SSOs use to manage each element of this trade-off.

Finally, ex ante contracting may alleviate many of the inefficiencies faced by SSOs, including those examined by our model. Recent theoretical work, e.g. Lerner and Tirole (2015), suggests ex ante price commitments as a means of improving efficiency, and some SSOs have taken steps toward such commitments. However, given that price negotiations open the door to litigation, most SSOs do not encourage price commitments, and some explicitly forbid firms from negotiating licensing agreements at the standard-setting stage.[5] Consequently, we rule out ex ante transfers. In Section 6.1, we allow agents to offer payments in exchange for support for their projects. We show that policy compromise remains a crucial means of building consensus even when money is available and that ex post transfers may, in fact, be detrimental to compromise.

1.2 Related Literature

At a broad level, this paper is part of a growing literature adopting the political view of organizational decision making initiated by March (1962) and Cyert and March (1963), which is summarized by Pfeffer (1981) as follows, "to understand organizational choices using a political model, it is necessary to understand who participates in decision making, [...] what determines each actor's relative power, and how the decision process arrives at a decision." See Gibbons, Matouschek, and Roberts (2013) for a survey.

At a more detailed level, this paper is related to several strands of more recent research. First, our model can be viewed as an analysis of real authority and project choice in organizations. The most closely related papers in this field are Aghion and Tirole (1997) and Rantakari (2012) in their focus on ex ante incentives and Armstrong and Vickers (2010) in their analysis of endogenous proposals.[6]

Second, our work ties into a large literature focused on conflict resolution within a committee. For instance, Dewatripont and Tirole (1999) and Che and Kartik (2009) analyze the value of conflict for information acquisition in committees. In contrast, we focus on the roles of ex ante conflict and ex post negotiation in achieving equilibrium compromises on project choices. More closely related to our application are Farrell and Saloner (1988) and Farrell

[5] Llanes and Poblete (2014) note that in the IEEE "participants should never discuss the price at which compliant products may or will be sold, or the specific licensing fees, terms, and conditions being offered by the owner of a potential Essential Patent Claim." The European Telecommunication Standards Institute (ETSI) has similar rules in place.

[6] Other papers have examined the impact of organizational structure on information flows inside the organization. For instance, Dessein (2002), Alonso, Dessein, and Matouschek (2008) and Rantakari (2008) consider the impact of the allocation of decision rights on strategic communication and decision making.

and Simcoe (2012), who study consensus decision making in standard-setting organizations. In their setting, the organization must select one of two exogenously developed projects when information on project quality is asymmetric and the decision structure is fixed.[7] In contrast, in our model, the development phase precedes the adoption phase. The development phase is closely related to R&D and patent race models of Reinganum (1982) and Doraszelski (2008). Relative to these papers, we integrate choices over research directions and negotiations over project adoption.

Third, our paper is related to the dynamic provision of public goods, e.g. Admati and Perry (1991) and Marx and Matthews (2000). In these models, as well as in ours, each agent conditions his contributions on the type of public good provided by the other agents. An innovative feature of our framework is that it allows agents to choose which type of public good they wish to provide.[8]

Finally, our paper joins a recent political economy literature on policy contests. Callander and Harstad (2015) develop a two-period model of policy experimentation along both an horizontal dimension (e.g., ideology) and a vertical dimension (e.g., effort or quantity). In an application to federal systems, they compare decentralized decision making to a regime of progressive centralization. Hirsch and Shotts (2015) study a related (two-dimensional) static model of competing policy proposals with a fixed decision structure.

2 Model

We model an organization consisting of two agents $i = 1, 2$. There exists a continuum of feasible projects indexed by $x \in [0, 1]$. For a project to yield payoffs to the agents, it must first be *developed* and then *adopted*, as described below.

Time is continuous, and the horizon is infinite. Both agents are impatient and discount the future at rate r. To develop a project, agents exert costly effort. The development of each project is stochastic and requires the arrival of a single breakthrough that follows a Poisson process: if agent i were to choose a constant project x_i and exert a constant effort a_i over some time interval $\mathrm{d}t$, then the delay until the development of project x_i would be distributed exponentially over that time interval with parameter λa_i. Without loss of generality, we normalize λ to one. The instantaneous cost to agent i of exerting effort

[7] Simcoe (2012) estimates a complete-information, stochastic model of bargaining by exploiting variation in the nature of the projects submitted to the IETF. The decision structure is then fixed by construction.

[8] Unlike in Bonatti and Hörner (2011) and Campbell, Ederer, and Spinnewijn (2014), deadlines for project adoption are not optimal in our model. Deadlines can, however, serve as disciplinary devices off the equilibrium path that induce the selection of compromise projects.

$a_i \in \mathbb{R}_+$ is independent of the project chosen.[9] It is given by $c_i(a_i) = c_i \cdot a_i^2/2$ for some constant $c_i > 0$.

The chosen projects and effort levels are assumed to be *non-contractible* and *unobservable* to the other player. Once a project has been developed, it can be adopted. The selection of a project is irreversible and ends the game. We analyze various procedures for selecting the project that is, in fact, adopted. In all of our settings, an outcome of the game consists of (1) the measurable functions $a_i : \mathbb{R}_+ \to \mathbb{R}_+$ and $x_i : \mathbb{R}_+ \to [0,1]$, where $a_{i,t}$ is the level of effort exerted by i at time t toward the development of project $x_{i,t}$; (2) the set of projects $x_{i,\tau}$ developed by either agent i at any time τ; and (3) at most one project $x_{i,\tau}$ adopted at time $\tau' \geq \tau$.

We also assume that each agent can freely modify his choice of project $x_{i,t}$ during the game, that each agent i can develop at most one project and that the development (or "completion") of any project is publicly observable.[10]

Adoption of project x yields a net present value of $v_i(x)$ for each agent i. As long as no project has been adopted, agents reap no benefits from any project. If project x is adopted at time τ, the discounted payoff to agent i is given by

$$V_i = e^{-r\tau} v_i(x) - \int_0^\tau e^{-rt} c_i\left(a_{i,t}\right) \mathrm{d}t. \tag{1}$$

The payoff functions $v_i\left(x\right)$ are monotone, differentiable and strictly concave. In particular, $v_1\left(x\right)$ is increasing, and $v_2\left(x\right)$ is decreasing, with $v_1\left(1\right) = v_2\left(0\right) = 1$ and $v_1\left(0\right) = v_2\left(1\right) = 0$. Thus, the sum of the agents' payoffs $v_1\left(x\right) + v_2\left(x\right)$ is strictly concave in x. In other words, agents have conflicting preferences over projects: $x = 1$ is agent 1's preferred project and $x = 0$ is agent 2's preferred project. Moreover, compromise is efficient: the agents' payoffs $(v_1(x), v_2(x))$ form a continuously differentiable and strictly concave payoff frontier. We maintain the following assumptions throughout the paper.

Assumption 1 (Symmetry)

1. *The agents' cost functions are identical, i.e.,* $c_1 = c_2 = c$.
2. *The payoff frontier is symmetric, i.e., for all* $x \in [0,1]$,

$$v_1\left(x\right) = v_2\left(1 - x\right).$$

[9] In the context of SSOs, developing a project may require combining several existing technologies into a working solution. Thus, to a first approximation, development costs do not depend on which firms hold the relevant patents.

[10] The results of our baseline model (Section 4) are robust to the relaxation of all three assumptions.

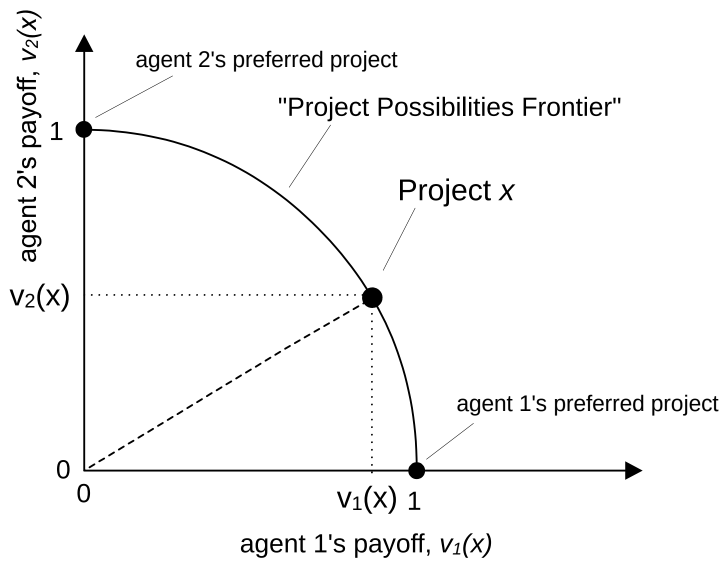
We also define the *effective discount rate* as

$$\rho \triangleq c \cdot r.$$

Intuitively, ρ combines two costs associated with developing a project, i.e., the delay itself and the cost of effort incurred during that delay.

Under Assumption 1, we denote the payoff frontier as a strictly decreasing and strictly concave function $v_j = \phi(v_i)$. Figure 1 provides an illustration.

FIGURE 1: PROJECT POSSIBILITIES FRONTIER



The *development phase* is followed by an *adoption phase.* In the adoption phase, once one or more projects have been developed, negotiations to select which one is adopted take place. Adoption decisions require consensus, i.e., both agents must agree to adopt a project that has been developed. More formally, suppose that agent 1 developed the first project x_1 at time τ. Agent 2 can choose to adopt agent 1's project at any time $t \geq \tau$. As long as no project has been adopted, agent 2 can attempt to develop a different project x_2, i.e., agent 2 can *de facto* veto agent 1's initial project by delaying its adoption until he has developed a competing project.

Naturally, the incentives to adopt or to veto a project depend on the outcome that agent 2 expects once he has developed his own project. It is then crucial to understand how negotiations unfold in the subgame that begins once two projects x_1 and x_2 have been developed. Our model seeks to capture two crucial aspects of the bargaining process: (a) agents are able to condition their play on the public history prior to the adoption phase, and (b) because developed projects are publicly observable, each agent i can anticipate the outcome of the adoption phase as a function of which project is developed at which time. We would like our approach to be insensitive to the details of the bargaining process. Thus, we do not analyze a specific extensive form game. Instead, we follow the approach to (re)negotiation introduced by Tirole (1986) in the context of procurement, i.e., we posit a *selection function*

$$\xi(\underline{x}, \underline{\tau}) \in \{x_1, x_2\} \tag{2}$$

that indicates which project is adopted if $\underline{x} = (x_1, x_2)$ were developed at $\underline{\tau} = (\tau_1, \tau_2)$.

With this formulation, we are focusing on deterministic, ex post Pareto-efficient selection functions, i.e., a project is adopted immediately with probability one. As an illustration, suppose that negotiations unfold as a complete information war of attrition in continuous time: each agent i can "concede" at any time, leading to the adoption of project x_j. Under this protocol, $\xi(\underline{x}, \underline{\tau}) = x_i$ selects the Pareto-efficient equilibrium in which agent j concedes immediately. The war of attrition and other bargaining games admit inefficient equilibria, such as those with costly delays characterized by Hendricks, Weiss, and Wilson (1988). In Section 5, we explain why allowing for stochastic or inefficient selection functions does not enlarge the equilibrium payoff set.

3 Fixed-Projects Benchmark

Before analyzing the full model, we consider a benchmark model with the following characteristics: each agent i works on an exogenously given project x_i; the first project to be developed is adopted immediately; and effort levels are chosen non-cooperatively. The goal of this section is twofold: to derive how the equilibrium effort levels depend on the project characteristics (x_1, x_2), which is instrumental to characterize *on-path* effort when the projects x_i are endogenously chosen; and to identify the *second-best* projects (x_1^*, x_2^*) that would be developed if agents could contract ex ante on project characteristics.

Throughout this section, fix a pair of projects (x_1, x_2) such that each agent prefers his own project to the other agent's, i.e. $x_1 > x_2$. Given the two projects, each agent i chooses a measurable function $a_i : \mathbb{R}_+ \to \mathbb{R}_+$ to maximize his expected discounted payoff $V_{i,0}$. Because the hazard rate of the first breakthrough is given by $a_{1,t} + a_{2,t}$, each agent's expected payoff at time t may be written as

$$V_{i,t} = \int_t^\infty e^{-\int_0^{t'} (r + a_{1,s} + a_{2,s}) \mathrm{d}s} \left(a_{i,t'} v_i(x_i) + a_{j,t'} v_i(x_j) - c(a_{i,t'}) \right) \mathrm{d}t'. \tag{3}$$

The solution concept is Nash equilibrium. Proposition 1 provides an existence and uniqueness of a stationary equilibrium, i.e., agents exert a constant effort level.[11] For any pair of symmetric projects, i.e. $x_2 = 1 - x_1$, we denote the payoff distance as

$$\Delta(x_i) \triangleq v_i(x_i) - v_i(1 - x_i).$$

Proposition 1 (Equilibrium Effort)

1. *For all (x_1, x_2) with $x_1 > x_2$, there exists a unique equilibrium, which is stationary.*

2. *For all symmetric projects, there exists a unique symmetric equilibrium, which is stationary. The (constant) effort level of agent i is given by*

$$a_i^*(x_i) = \frac{\Delta(x_i) - cr + \sqrt{(\Delta(x_i) - cr)^2 + 6crv_i(x_i)}}{3c}. \tag{4}$$

3. *The equilibrium effort levels $a_i^*(x_i)$ are decreasing in c and increasing in $\Delta(x_i)$ and r.*

In this game, each agent controls the expected development time of his own project: by exerting higher effort, agent i increases the probability of achieving a breakthrough at a constant rate. Agent i's incentives to exert effort at time t are then driven by the value of ending the game with a payoff of $v_i(x_i)$. This can be seen more clearly by rewriting agent i's value function $V_{i,t}$ recursively through the following Hamilton-Jacobi-Bellman equation:

$$rV_{i,t} = \max_{a_{i,t}} \left[a_{i,t}(v_i(x_i) - V_{i,t}) + a_{j,t}(v_i(x_j) - V_{i,t}) - c(a_{i,t}) + \dot{V}_{i,t} \right]. \tag{5}$$

This formulation of the agent's problem relates the optimal choice of effort to the gains from developing his own project over and above his continuation value. In particular, each agent i chooses an effort level $a_{i,t}^*$ that satisfies

$$c'\left(a_{i,t}^*\right) = \max\{v_i(x_i) - V_{i,t}, 0\}. \tag{6}$$

Intuitively, any variable that affects agent i's continuation payoff negatively (such as the discount rate r) also affects his incentives to exert effort positively. An increase in agent j's effort may then motivate or discourage high effort levels by agent i. Agent j's effort has two effects on agent i's payoff: on the one hand, agent j is more likely to generate positive benefits $v_i(x_j)$ for agent i; on the other hand, agent i is now less likely to realize the benefits $v_i(x_i)$ that accrue from developing his project first.

[11] If each agent prefers his opponent's project, i.e. $x_1 < x_2$, multiple stationary equilibria as well as non-stationary equilibria may exists due to the extreme free-rider problem in the provision of effort.

The formulation of the agent's problem (5) suggests that agent j's effort imposes a negative externality on agent i whenever the payoff of each agent i from *his opponent's project* $v_i(x_j)$ is lower than *his own continuation value* $V_{i,t}$. Differentiating expression (3) with respect to agent j's time-t instantaneous effort $a_{j,t}$ yields

$$\frac{\partial V_{i,t}}{\partial a_{j,t}} = \frac{v_i(x_j) - V_{i,t}}{r}. \tag{7}$$

The characteristics of the two projects x_1 and x_2 determine the nature of the externality that each player's actions impose on the other player. For example, when agents pursue their favorite projects $x_1 = 1$ and $x_2 = 0$, agent 2's effort imposes a negative externality on agent 1. Indeed, the payoff $v_1(0) = 0$ falls short of the equilibrium continuation value $V_{1,t}$, which is strictly positive because agent 1 has a positive probability of developing and adopting his own project x_1. The opposite holds when the two projects are very similar and $v_1(x_1) \approx v_1(x_2)$. In this case, the payoff $v_1(x_2)$ exceeds the continuation value $V_{1,t}$, which accounts for costly effort and delay. Consequently, the effort levels in the noncooperative solution may then be above or below the levels that would maximize the agents' joint surplus, just as in racing vs. free-riding.

The nature of the *payoff externality* imposed by one agent's effort on the other agent also determines whether the game has the *strategic properties* of a patent race, where agents want to preempt each other by working harder, or of a moral hazard in teams problem, where agents have an incentive to free-ride on each other's efforts. Differentiating the first-order condition for effort (6) we obtain

$$\frac{\partial a^*_{i,t}}{\partial a_{j,t}} = -\frac{1}{c}\frac{\partial V_{i,t}}{\partial a_{j,t}}. \tag{8}$$

Combining equations (7) and (8), we conclude that effort levels at any point in time are strategic substitutes or complements depending on whether agent j's effort imposes a negative or positive externality on agent i.

$$\frac{\partial a^*_{i,t}}{\partial a_{j,t}} > 0 \iff \frac{\partial V_{i,t}}{\partial a_{j,t}} < 0 \iff v_i(x_j) < V_{i,t}. \tag{9}$$

Proposition 2 formalizes the intuition from condition (9) that inefficiently high effort levels, strategic complements, and negative payoff externalities occur simultaneously.[12] We define the *first-best* effort level for player i as the effort level $a_i^{FB}(x_1, x_2)$ that maximizes the

[12] Beath, Katsoulacos, and Ulph (1989) and Doraszelski (2008) obtain analogous results for R&D races with imperfect patent protection.

sum $V_{1,0} + V_{2,0}$ defined in (3), given the projects x_1 and x_2.

Proposition 2 (Racing vs. Free Riding)

1. *Agent i's best reply* $a_i^*(a_j)$ *is increasing in* a_j *if and only if*

$$(v(x_i) - v_i(x_j))^2 \geq 2v_i(x_j)cr. \tag{10}$$

2. *There exists a unique pair of projects* (x_1^E, x_2^E) *that induce the first-best effort levels. These projects are symmetric and satisfy (10) with equality.*

3. *For all symmetric projects, the equilibrium effort levels* $a_i^*(x_i)$ *are above (below) the first-best levels* $a_i^{FB}(x_i)$ *if* $x_1 - x_2 > (<)\, x_1^E - x_2^E$.

Consistent with intuition, equilibrium effort levels increase with the difference between the two projects' payoffs $\Delta(x_i)$, while the first best levels depend on their sum only. Thus, equilibrium effort levels are below the first best when $\Delta(x_i)$ is low and $\Sigma_j v_j(x_i)$ is consequently high. It follows from the intuition in (7) that the efficient-effort projects (x_1^E, x_2^E) satisfy

$$v_i(x_j^E) = V_i(x_1^E, x_2^E). \tag{11}$$

As the discount rate r or the cost of effort c increase, the payoff distance between the two projects x_1^E and x_2^E increases. As either c or r grows without bound, equation (10) implies $v_i(x_j^E) \to 0$, meaning $x_1^E \to 1$ and $x_2^E \to 0$. In other words, as c or r grow, agents' efforts are strategic substitutes for a wider choice of projects: if an agent is either very impatient or finds effort to be very costly, he is more likely to benefit from the other agent developing his project and hence to free ride on the other agent's effort.

The projects that elicit the efficient effort levels x_1^E and x_2^E do not maximize the agents' ex-ante payoffs. Intuitively, starting from the efficient effort levels, inducing more compromise entails a second-order loss due to reduced effort, but a first-order gain due to the increased social value of the adopted project. In Proposition 3, we characterize the *second-best* projects x_1^* and x_2^*. These are the two projects that maximize the sum of the agents' payoffs $V_{1,0}+V_{2,0}$, subject to $x_1 > x_2$, when effort levels are chosen noncooperatively.[13]

[13] Throughout the paper, we adopt the utilitarian criterion to assess welfare. Even if decisions in the model are not contractible (recall we have ruled out monetary transfers ex-post), decision structures may well be. In other words, it is sufficient that agents be able to contract on the decision structure (e.g., on process rules in an SSO) for the choice of governance structure (ex-ante) to be guided by the utilitarian criterion. Finally, maximizing the sum of the agents' utilities is a simple second-best goal for the organization. For example, Murphy and Yates (2009) note that utilitarian criterion is explicitly cited in the International Standards Organization's (ISO) mission statement "to unify the needs of industry and thus bring about the greatest good for the greatest number."

Proposition 3 (Second-Best Projects)

1. *The second-best projects x_1^* and x_2^* are symmetric.*
2. *The equilibrium effort levels $a_i^*(x_i^*)$ are lower than the first-best levels $a_i^{FB}(x_i^*)$.*
3. *The distance between the second-best projects $\Delta(x_i^*(\rho))$ is strictly increasing in ρ. Moreover, $\lim_{\rho\to 0}\Delta(x_i^*(0)) = 0$ and $\lim_{\rho\to\infty}\Delta(x_i^*(\rho)) < 1$.*

If both effort levels and project characteristics were contractible, each agent would develop project $x_i = 1/2$ and exert the first-best effort levels. In contrast, when effort levels are not contractible, pursuing these projects yields inefficiently low equilibrium effort levels.[14]

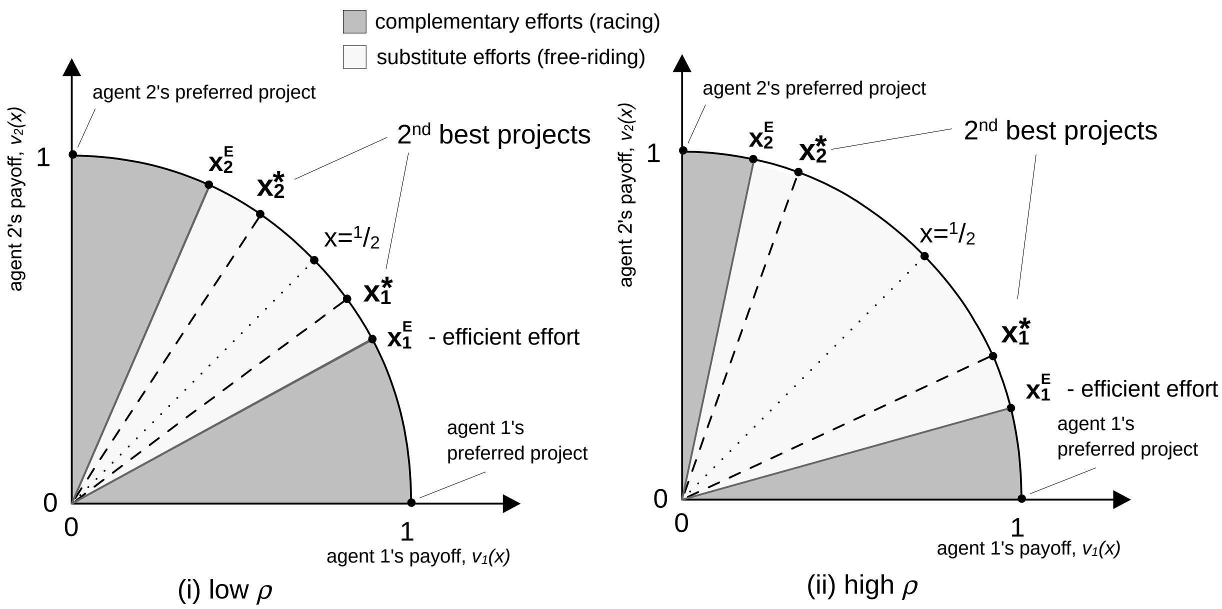
The second-best projects trade-off the expected cost of delay and the quality of the adopted projects by always inducing a game of strategic substitutes with equilibrium effort levels below the first best. In other words, $x_1^* < x_1^E$ and $x_2^* > x_2^E$, so that the distance between the second-best projects satisfies $\Delta(x_i^*) < \Delta(x_i^E)$ for any positive discount rate. As agents become arbitrarily patient (or efficient), both x_i^E and x_i^* converge to 1/2. Finally, while the second-best projects always lie in the region of strategic substitutes, the exact characteristics of the these projects depend on the discount rate and the cost of effort. As either c or r increases, the second-best projects become more distant, because a higher degree of conflict stimulates effort when the development of a project is more urgent or more costly. However, in the limit and in contrast to the efficient-effort projects, the second-best projects do not approach $(0, 1)$; even as the agents become arbitrarily impatient, it is always optimal to induce some positive amount of compromise.

To summarize, a high degree of conflict in the pursued projects is detrimental to the organization for two reasons: (a) the total value of the projects being developed is low and (b) the equilibrium effort levels are inefficiently high. By increasing the value of the projects being developed and simultaneously reducing the equilibrium effort levels, some compromise in project selection is always optimal. At the same time, too much compromise leads to free-riding and inefficiently low effort levels: a positive degree of conflict in project selection is, in fact, also optimal. Figure 2 summarizes the benchmark projects described in this section for different values of ρ.

In the remainder of the paper, we endogenize the agents' choice of project. Without loss, we restrict attention to stationary effort strategies whenever the payoff environment (i.e., the continuation or terminal values resulting from the development of any project) is stationary.

[14] Of course, this assumes that there is no value to developing and adopting two different projects. In the context of an SSO, different implications for end users and knowledge spillovers from R&D are two potential benefits of project heterogeneity. In the conclusions, we discuss how one might extend our framework in this direction.

FIGURE 2: BENCHMARK PROJECTS



4 Equilibrium Project Selection

When project choice is not contractible, agents choose which projects to pursue based on their expectations of how the game will unfold when one or both projects have been completed. The expectation over the outcome of the negotiations with two complete projects is captured by the selection function $\xi(\underline{x}, \underline{\tau})$. If only agent j has completed his project, we must compute agent i's expected value from continuing the game. In particular, agent i can choose a new project x_i' after agent j develops project x_j, even if agent i had previously been pursuing project x_i. However, developing his own project is costly for agent i in terms of both effort and time. Thus, agent i adopts project x_j immediately if and only if its value $v_i(x_j)$ exceeds his continuation value under the selection function.

We will refer to this continuation value as the *option value* of blocking the first project. The option value is crucially determined by the set of projects that agent j can expect to develop and have adopted. In particular, let $u(w)$ denote the value that an agent assigns to earning $0 \leq w \leq 1$ upon the development of his project. This value is given by

$$u(w) \triangleq \max_{a_{i,t}} \int_0^\infty e^{-\int_0^t (r+a_{i,s})\mathrm{d}s} \left(a_{i,t}w - c a_{i,t}^2/2\right) \mathrm{d}t = w + \rho - \sqrt{\rho^2 + 2w\rho}. \tag{12}$$

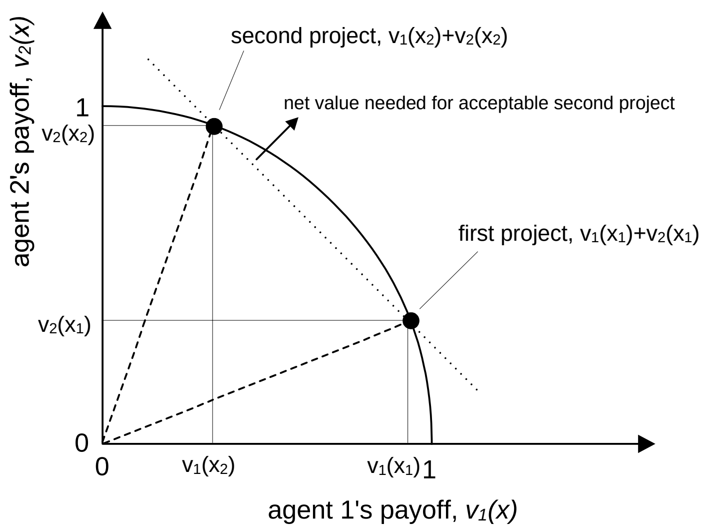
Solving backwards, both agents have an incentive to engage in preemptive compromise: by proposing a project that is sufficiently attractive to the other agent, the first agent is able to guarantee immediate adoption. This avoids a deadlock, where the second agent develops his own project and then negotiations take place over the two proposed alternatives. The rest of this section analyzes how the agents' project choice is influenced by the selection function (and thus the option value of blocking) and under what conditions it is possible to induce the agents to pursue second-best projects.

4.1 Efficient Continuation

To illustrate how the possibility to veto projects and the observability of project developments drive the initial choice of projects, consider an intuitive selection function $\xi(\underline{x}, \underline{\tau})$. We define the (utilitarian) *efficient-continuation selection function* as follows: let $\xi(\underline{x}, \underline{\tau}) = x_1$ if $\Sigma_i v_i(x_1) > \Sigma_i v_i(x_2)$ or $\Sigma_i v_i(x_1) = \Sigma_i v_i(x_2)$ and $\tau_1 > \tau_2$. In other words, agents select the more socially valuable project whenever two projects have been developed, and they break ties in favor of the project developed second.[15]

Suppose project $x_1 > 1/2$ has been developed. In order to prevail in the adoption phase, agent 2 must develop a project x_2 that gives the sum of the agents at least as much as under the standing project x_1. With this continuation play, the best project agent 2 can develop and adopt is $x_2 = 1 - x_1$, i.e. a project that yields the same level of total surplus as x_1 and grants agent 2 exactly as much as agent 1 would receive under the original project x_1. Figure 3 illustrates the equilibrium outcome under the efficient-continuation selection function.

FIGURE 3: EQUILIBRIUM PROJECTS UNDER EFFICIENT CONTINUATION



However, agent 2 knows that developing a second project is costly. More generally, each

[15] In Section 6.2, we introduce a continuum of small potential "users" with heterogeneous preferences over projects. This selection function corresponds to resolving any *deadlock* through a binary vote.

agent i adopts immediately any project x_j that satisfies

$$v_i(x_j) \geq u(v_i(1 - x_j)), \tag{13}$$

where the value of the single-agent problem $u(\cdot)$ is defined in (12). Proceeding backwards, each agent j initially chooses to pursue a project that makes agent i's acceptance constraint (13) bind. On the equilibrium path, each agent i receives from agent j's project a payoff equal to his option value of "matching" project x_j, and the first project to be developed is adopted immediately. Let v denote the value of each agent's own project. By the symmetry of the payoff frontier $v_j = \phi(v_i)$, the equilibrium projects (x_1, x_2) yield a payoff $v_i(x_i) = v$ that satisfies

$$\phi(v) = u(v).$$

Proposition 4 characterizes the projects developed in equilibrium.

Proposition 4 (Efficient Continuation)
The efficient-continuation selection function yields a unique equilibrium outcome. Agents develop the efficient-effort projects (x_1^E, x_2^E), and the first project is immediately adopted.

To understand why the efficient-effort projects are developed in equilibrium, recall condition (11) for the game with exogenous projects: if agents develop (x_1^E, x_2^E), each agent i receives a payoff from project x_j^E equal to his equilibrium continuation value $V_i(x_1^E, x_2^E)$. Therefore, agent j's effort imposes no payoff externalities on agent i. In particular, agent j could stop working, while agent i continues working on his current project, without affecting agent i's continuation value.

Now consider the game under the efficient-continuation selection function: on the equilibrium path, agent i receives a payoff $v_i(x_j)$ from project x_j equal to the option value $u(v_i(x_i))$ of working alone *on his current project* x_i. It then follows that the two equilibrium projects induce the efficient effort levels, and hence suboptimal levels of compromise.

Therefore, Proposition 4 establishes that efficient continuation play off the equilibrium path generates insufficient incentives for compromise on the equilibrium path. In other words, inducing efficient compromise requires *dissipation* off the equilibrium path, through the selection of the socially least valuable project, or other forms of "burning money."

4.2 Equilibrium Projects Set

Because the option value of blocking depends on the selection function once both projects are completed, unanimity requirement alone does not uniquely determine the type of projects developed by the agents. Instead, each selection function $\xi(\underline{x}, \underline{\tau})$ is associated with its own continuation values and hence initial project choices, leading to a very rich set of potential equilibrium outcomes.

Intuitively, the more an agent expects to earn from the adoption phase with two projects on the table, the more the other agent's project must generate compromise in order to be adopted immediately. In particular, suppose that agent 2 can "counter" any initial project x_1 with his favorite project $x_2 = 0$ (worth $v_2(0) = 1$) and have it adopted. Then, in order to be adopted by agent 2, the initial project x_1 must then yield a payoff of at least $u(1)$, as defined in (12).

We define agent i's *maximum-compromise* project $\bar{x}_i$ as the project satisfying $v_j(\bar{x}_i) = u(1)$. Recall from (12) that the value of the single-agent problem $u(1)$ is strictly decreasing in ρ and vanishes as $\rho \to \infty$. Consequently, the distance between the maximum-compromise projects $\bar{x}_1(\rho) - \bar{x}_2(\rho)$ is strictly increasing in ρ and goes to 1 in the limit.

We refer to a pair of projects (x_1, x_2) as *developed in equilibrium* if there exists a selection function $\xi(\underline{x}, \underline{\tau})$ that induces agents to develop projects (x_1, x_2) on the equilibrium path. In Proposition 5, we characterize the set of equilibrium projects; we identify conditions under which the second-best projects (x_1^*, x_2^*) are developed in equilibrium; and we characterize the equilibrium that maximizes the sum of the agents' payoffs when they are not. We define the threshold $\bar{\rho} > 0$ as the (unique) discount rate for which the second-best and maximum-compromise projects coincide, i.e.

$$x_i^*(\bar{\rho}) = \bar{x}_i(\bar{\rho}). \tag{14}$$

Proposition 5 (Equilibrium Projects Set)

1. *Any pair of projects* $(x_1, x_2) \in [\bar{x}_1, 1] \times [0, \bar{x}_2]$ *is developed in equilibrium.*

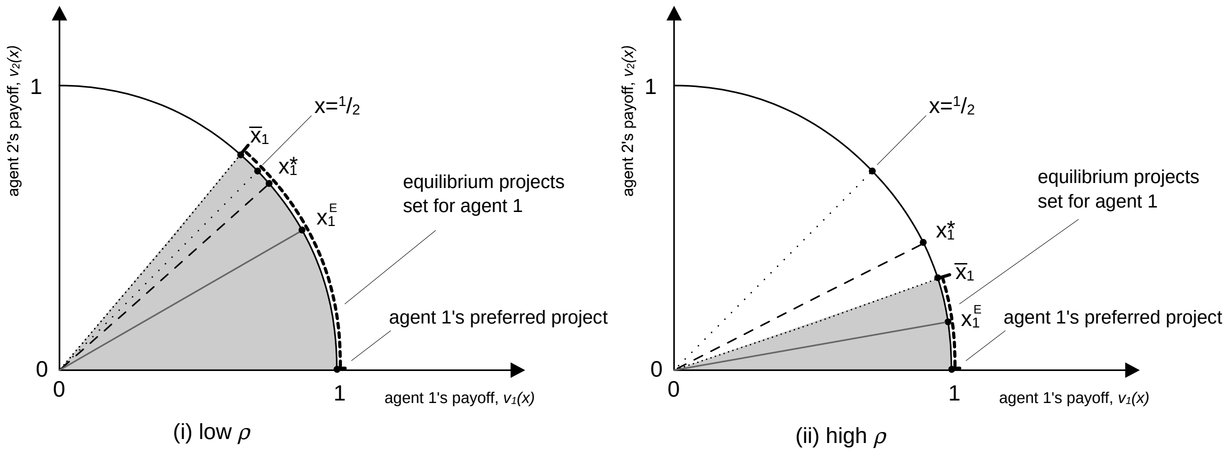
2. *If* $\rho \leq \bar{\rho}$*, the second-best projects* (x_1^*, x_2^*) *are developed in the best equilibrium.*

3. *If* $\rho > \bar{\rho}$*, the maximum-compromise projects* $(\bar{x}_1, \bar{x}_2)$ *are developed in the best equilibrium.*

Proposition 5 shows that any project ranging from an agent's favorite project to his maximum-compromise project is, in fact, developed in equilibrium. Figure 4 illustrates the equilibrium projects set for agent 1.

Simple selection functions can be used to construct equilibria where any pair of projects in the equilibrium set is developed and immediately adopted. In particular, for any pair $(\hat{x}_1, \hat{x}_2)$, we can choose a function $\xi(\underline{x}, \underline{\tau})$ that selects the first project developed (x_i) if $x_i = \hat{x}_i$ and the second project developed otherwise. This type of selection function implements any desired $(\hat{x}_1, \hat{x}_2)$ as long as $v_j(\hat{x}_i) \leq u(1)$. Because $u(1)$ is a tight upper bound on agent j's option

Figure 4: Equilibrium Projects



value, if $v_j(\hat{x}_i) > u(1)$, then agent i could deviate to a more favorable project x_i' that agent j would adopt immediately.[16]

The equilibrium projects set is bounded by the (aptly named) maximum-compromise projects, and hence it is sensitive to the discount rate ρ. In particular, a lower discount rate increases the option value of the agent who does not develop the first project, and hence increases the maximum degree of equilibrium compromise. Consequently, when agents are sufficiently patient or the cost of effort sufficiently low, there exists a selection function in the adoption phase that induces the choice of the second-best projects $x_1^*(\rho)$ and $x_2^*(\rho)$. As ρ grows, however, the bargaining power of the agent without a developed project becomes too low, even if he is granted unconditional authority from then on. Therefore, for high values of ρ, no selection function in the adoption phase can induce the optimal degree of compromise on the equilibrium path.[17] The highest equilibrium payoff is then obtained by effectively giving all the bargaining power to the agent who does not develop the first project. Figure 5 illustrates the best equilibrium projects as a function of ρ.

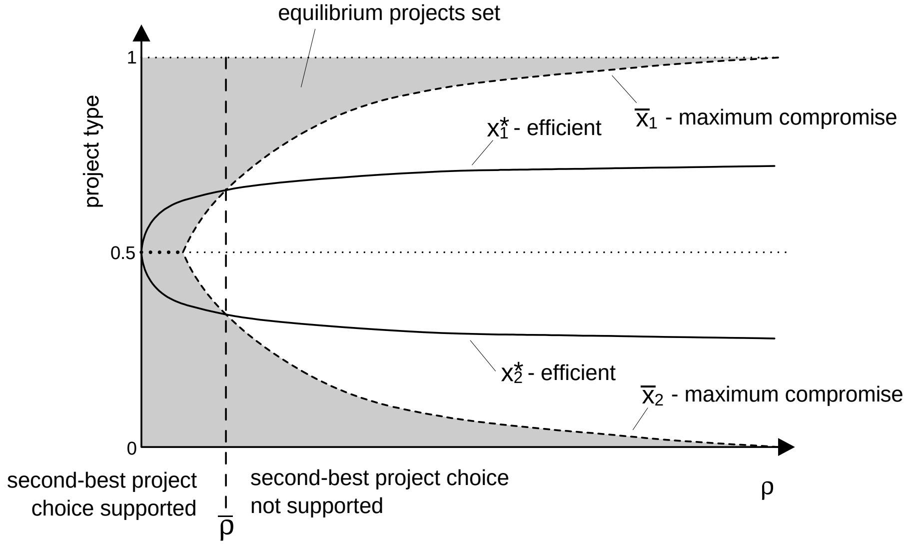
Our entire analysis has focused on a stationary *payoff environment*. However, the logic of option values can be applied more broadly to characterize the equilibrium projects set. In particular, if the payoff environment is not stationary, the set of equilibrium projects changes over time.[18] Finally, our characterization of the equilibrium projects set does not rely on our assumption that, once two projects have been developed, one of them is adopted

[16]Under these equilibrium strategies, agents would immediately reveal a breakthrough even if they privately observed their project's development. Thus, the results in Proposition 5 do not rely on the assumption of publicly observable project development.

[17]Recall that the distance between the second-best projects is uniformly bounded away from one.

[18]Under learning by doing (decreasing marginal cost of effort), the option value of the agent without a project increases over time, and the equilibrium projects set expands. Conversely, if agents face a fixed deadline for adopting a project, the equilibrium projects set shrinks.

Figure 5: Best Equilibrium Projects



immediately. Inefficient continuation equilibria (i.e., selection functions) tend to reduce the degree of compromise on path, but do not expand the equilibrium projects set.[19]

To conclude, the agents' option to develop and adopt a competing project going forward emerges as the key driver of equilibrium compromise under a unanimity rule. In Section 5, we introduce (commitment to) a decision-making procedure to overcome the multiplicity of equilibria.

5 Decision-Making Procedures

As we have seen, the emergence of compromise relies on each agent's power to reject the other agent's project in favor of continuing to develop his own. In the case of unanimity, the value of this option depends on the agents' implicit understanding of how negotiations would unfold after two projects have been developed. In this section, we examine an environment in which agents can commit ex ante to a decision-making procedure. We search for procedures that guarantee a good outcome when project characteristics are not contractible.

More formally, we shall refer to a *mechanism* as a procedure that dynamically assigns authority (i.e., decision rights over projects) as a function of project development times

[19] Suppose, for instance, that negotiations with two developed projects unfold as in the mixed-strategy equilibrium of a war of attrition. Then each agent's option value of developing the second project is equal to the value of adopting the first project (less the costs of additional effort and delay). This leads to the immediate adoption of any project, and therefore to the development of each agent's favorite project on the equilibrium path, i.e., $x_1 = 1$ and $x_2 = 0$. However, this outcome can already be achieved with the simple (Pareto-efficient) selection functions described above.

(τ_1, τ_2) and calendar time. In particular, let τ_i denote the development time of agent i's project, and let $h^t = (\tau_1, \tau_2, t)$ denote a history of project developments up to time t. Let H^t denote the set of time-t histories. We define a mechanism as a vector-valued function

$$A : H^t \to \{0, 1, 2\} \times 2^{\{x_1, x_2\}}.$$

Thus, $A(h^t)$ indicates which agent (if any) has the right at time t to adopt (a subset of) the projects developed so far. For tractability, we focus on symmetric mechanisms. Thus, a mechanism does not describe a general procedure for decision-making. Instead, we are focusing on the role of time- and project-specific authority to quantify the value of a flexible allocation of decision rights, and of the commitment power necessary to enforce it.

5.1 Single-Agent Authority

A simple decision-making procedure consists of assigning the irrevocable right to adopt any project to just one agent (e.g., agent 2). This procedure leads to a unique equilibrium outcome, in which agent 1 must obtain agent 2's "approval." Because project choices are not observable, it is a dominant strategy for agent 2 to pursue her most preferred project, $x_2 = 0$. However, because developing a project requires time and effort, agent 2 is willing to implement immediately any project x_1 that yields a sufficiently high payoff to her. Therefore, agent 1 develops his maximum-compromise project $\bar{x}_1$, and the first project developed is adopted. We now compare the welfare properties of this procedure to the case of unanimity.

Proposition 6 (Authority)
For all $\rho \geq 0$, the total equilibrium payoff under unilateral authority is higher than in the worst and lower than in the best symmetric equilibrium under unanimity.

Allocating authority to a single agent is able to induce one of the agents to compromise because the bargaining power is now firmly in the hands of the other agent. Indeed, agent 2 has both the incentive and the authority to veto the adoption of agent 1's project whenever it does not generate a sufficiently high payoff $v_2(x_1)$. Proposition 6 shows that an organization stuck in a "bad" equilibrium under unanimity, namely the one in which each agent develops his favorite project, would be better off choosing authority. At the same time, the best outcomes require unanimity. In particular, in order to achieve the best payoff under unanimity as the unique equilibrium outcome, an organization cannot rely on the unconditional allocation of authority. This provides a motivation to study more complex mechanisms that assign ex-post decision rights to agents.

5.2 Optimal Procedures

We now consider procedures that (i) condition the assignment of authority on the timing of project developments, and (ii) introduce the potential for money-burning. Of particular interest for our application to SSOs is a deadline for presenting a competing project. This mechanism works as follows: suppose agent i develops project x_i at time τ. *At time τ only,* agent j can adopt project x_i or eliminate it. If agent j eliminates project x_i, he can adopt any project he develops before time $\tau + T$. If agent j does not develop any competing project by that date, no agent is assigned authority thereafter, and all projects are abandoned.

We now show that the optimal deadline induces a unique equilibrium outcome, in which agents develop the same projects and exert the same effort levels as in the best equilibrium under unanimity. Let $\bar{\rho}$ denote the threshold discount rate defined in (14).

Proposition 7 (Deadline for Competing Projects)

1. *The optimal deadline induces the best equilibrium outcome under unanimity.*
2. *The optimal deadline is finite if and only if $\rho < \bar{\rho}$.*
3. *The optimal deadline is increasing in the cost of effort c and (if any are present) in the value of the agents' outside options $\bar{v}$.*

A deadline for developing a competing project replicates the distribution of bargaining power under unanimity. In principle, this is a challenging task: unlike continuation equilibria, a mechanism cannot condition on the characteristics of the developed projects. Therefore, incentives for compromise must rely on the dynamic allocation of authority. Under this mechanism, developing the first project entails the loss of all future authority, and forces each agent to seek a compromise.

However, assigning unconditional authority to the second agent may induce degrees of equilibrium compromise that exceed the second-best. In other words, it can be necessary to limit the second agent's bargaining power. A finite deadline allows the mechanism to fine-tune this agent's option value.

Therefore, the optimal deadline is sensitive to the preference environment. In particular, as the cost of effort c increases, developing a competing project becomes less attractive. In order to discourage extreme projects, the agent without a project must then be given more time to respond. Furthermore, for $\rho > \bar{\rho}$, the optimal deadline is infinite.

Likewise, a high outside option reduces the value of the most attractive competing project that any agent can develop and adopt. Thus, the optimal procedure must react to outside options, despite the fact that the second-best projects are constant in $\bar{v}$. In other words, it is incorrect to assume that outside options are substitutes for decision-making procedures that induce equilibrium compromise.

A similar intuition applies to the case of preference alignment. As preferences become more aligned, the decision structure must grant more power to the agent without a project in order to ensure he vetoes extreme projects.[20] Finally, the logic of our results extend to any mechanism that empowers the agent who does not develop the first project.

The probabilistic abandonment of all projects is only one means of limiting the second agent's option value. For instance, imposing a deterministic delay in the adoption of any competing project is an outcome-equivalent procedure. A general picture then emerges where an optimal mechanism must introduce *dissipation* off the equilibrium path. Procedures that induce dissipation are not unreasonable in many settings.[21] However, one may wonder whether other mechanisms (including ones that dispense with off-path inefficiency) can induce higher expected payoffs for the two agents. In Proposition 8, we establish that the best equilibrium outcome under unanimity provides a tight upper bound on the equilibrium payoffs under any mechanism. Moreover, dissipation off the equilibrium path is necessary for achieving the best outcome when agents are patient.

Proposition 8 (Optimal Mechanisms)

1. *Any optimal symmetric mechanism induces the constrained-efficient compromise.*
2. *For sufficiently low ρ, any optimal symmetric mechanism requires dissipation off the equilibrium path.*

Recall that the equilibrium effort associated with the second-best projects is below the first-best level. In principle, a mechanism could then boost equilibrium effort (e.g., through on-path deadlines or other time incentives) and achieve a higher payoff than unanimity. However, in the proof of Proposition 8, we show that any optimal mechanism induces stationary choices of projects and effort levels, and avoids dissipation along the equilibrium path. Thus, while higher effort levels are attainable over a finite period, they are, in fact, suboptimal.

To gain some intuition for why dissipation is necessary *off path*, contrast the optimal deadline described above with an intuitive mechanism that allows agents to "save" the first project, and to adopt it at the deadline. Under this mechanism, the agent (say, agent 2)

[20] The result is less clear-cut, however, because the second-best projects and the agents' preferences are changing simultaneously as α varies. Consequently, we have not been able to prove the result formally. However, we are yet to find a counter-example.

[21] A hiring committee may require additional costly screening or external evaluation of any candidate unless a consensus is built around the first candidate. Similarly, a committee may "lose the hiring slot," e.g., in favor of another department, if a member vetoes a candidate and fails to suggest an alternative candidate in a reasonable time.

who does not develop the first project never adopts x_1 immediately. Instead, agent 2 exerts effort towards his favorite project until the deadline. When agents are very patient or very efficient, the flow cost of waiting is given by $rv_2(x_1)$, but agent 2 can generate a much higher expected flow return by working on his favorite project $x_2 = 0$. This mechanism does generate a positive degree of compromise, because a more favorable first project reduces agent 2's incentives to exert effort towards a competing project. However, it fails to induce the development of the second-best projects because (a) any project will be adopted with delay, and (b) the originator of the first project assigns positive probability to his alternative being adopted at the deadline. The latter effect limits the incentives to compromise in the first place, relative to the case where the other agent permanently vetoes the project.

5.3 Static vs. Dynamic Decision Making

The optimal procedure described above creates *potential* competition by allowing each agent to respond to a first developed project with a competing one of his own. One may wonder whether a static procedure that creates actual competition between projects would be more conducive to compromise. One way of probabilistically inducing a "horse race" is to postpone decisions until a given date. This creates a contest-like environment where agents trade-off the "probability of winning" with the value of having their project adopted in the absence of a competing proposal.

More formally, suppose that a project (if any) must be adopted at a fixed, non-renegotiable date T. If two projects have been developed by that date, the one yielding the higher total payoff is adopted. If symmetric projects are developed, each one is adopted with equal probability. Players observe nothing until the deadline.[22]

It is not hard to see that there cannot be a pure-strategy equilibrium in project selection: each agent has an incentive to either (a) undercut the other one by choosing a socially more valuable project that is adopted with probability one, or (b) to deviate to his favorite project. By a similar logic, each player's distribution cannot have atoms, and its support must include each agent's most preferred project.

Thus, each agent is pursuing potentially different projects in equilibrium and must be indifferent among all of them, implying that the payoff for developing each project v in the support of $F(\cdot)$ must be constant. In turn, this means each agent's effort level does not depend on the realization of his mixed strategy. It does, however, depend on calendar time, and it increases as the deadline T approaches. Proposition 9 summarizes our results.

[22] This allows for the best comparison of our model with a static game. While this violates our earlier assumption of observable project developments, it makes for the most interesting comparison with a static decision criterion. In particular, the only dynamics at play in this game will concern the equilibrium effort.

Proposition 9 (Fixed-Date Decisions)
There exists a symmetric equilibrium with the following properties.

1. *Each agent i randomizes over all projects x_i such that $v_i(x_i) \in [v_L, 1]$ according to a positive and continuous distribution.*
2. *The lower bound of the support v_L is increasing in r and c, and decreasing in T.*
3. *Each agent i's effort level $a_{i,t}$ is deterministic and strictly increasing over time.*

The equilibrium is essentially unique in the sense that it pins down the distribution of each agent's project choice at any time t. However, since nothing is observed until T, agents have no reason to change their project over time. Randomization over projects can then occur at time 0, with each agent pursuing a fixed project throughout (this is certainly the case with switching costs).

The distribution function can be solved in closed form, and it is given by

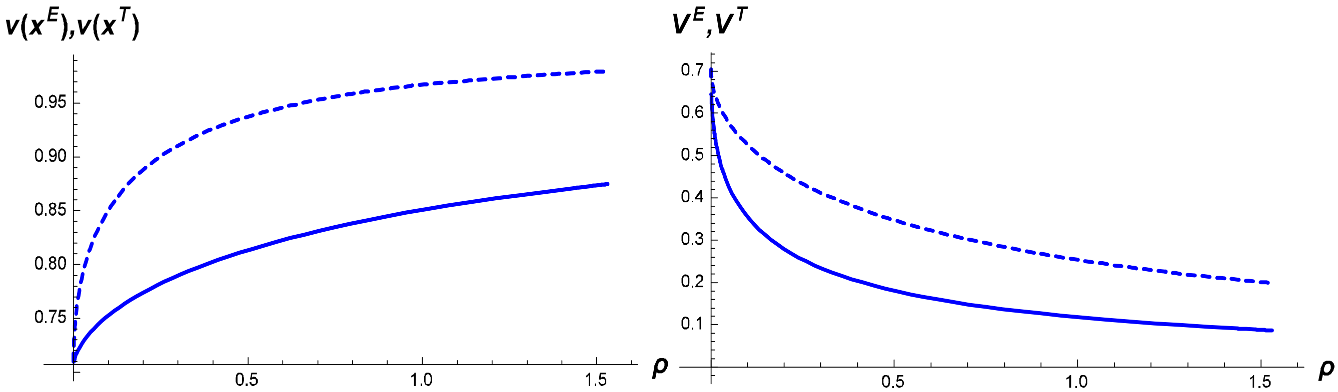
$$F(v) = \frac{1 - e^{-\int_{v_L}^{v} \frac{1}{w - \phi(w)} \mathrm{d}w}}{1 - e^{-\int_{v_L}^{1} \frac{1}{w - \phi(w)} \mathrm{d}w}}.$$

Random (inefficient) project choice is also a feature of the static model of competing policy proposals in Hirsch and Shotts (2015). Here, we can contrast static-decision making with its dynamic counterpart in Section 4.1. While the ex-post efficient selection function yields the development of projects x_i^E from each i, setting a fixed date for (efficient) adoption decisions does not guarantee any positive level of compromise. Consistent with intuition, numerical examples suggest the optimal deadline is decreasing in ρ. In Figure 6, we compare the project choices and equilibrium values in the dynamic and static decision-making environments.[23]

Depending on the length of the deadline, the lower bound v_L may be above or below v^E. In this example, the equilibrium payoff is lower, for any T, than in the efficient-continuation selection function characterized in Proposition 4 that yields the efficient-effort projects. Overall, our analysis suggests that the power to generate alternatives and to commit to *dynamic* (vs. fixed-date) decision-making is a necessary condition for generating efficient compromise through delegation. In other words, the threat of a competing project may be more effective than the (probabilistic) development of an actual alternative.

[23] For any payoff frontier $\phi(v)$, the discount rate, the optimal deadline, and the equilibrium payoff can be solved for in closed form as a function of v_L. Figure 6 parametrically plots $\rho(v_L)$ (left) and V_L (right). The frontier is given by $\phi(v) = \sqrt{1 - v^2}$.

Figure 6: Optimal Decision Date (solid) vs. Dynamic Procedure (dashed)



Equilibrium Projects (agent 1) | Equilibrium Payoffs

6 Extensions

We address two extensions that are particularly relevant for our application to SSOs. In the first one, we discuss the role of monetary payments (e.g., licensing fees for standard-essential patents). In the second one, we introduce not actively participating, yet voting, members of the organization. The main message of this analysis is that agents' choice of projects in order to "stop the game" remains the key driver of equilibrium compromise.

6.1 Bargaining and Monetary Transfers

In practice, the agents may have access to various forms of side payments, over and above policy compromise, to gain the approval of other members. These payments can vary from direct monetary transfers to relational transfers as a part of a repeated-game equilibrium. In the context of SSOs, monetary transfers may correspond to concessions in terms of licensing fees, or more generally to different continuation equilibria in the ensuing industry competition. Our setting cannot account for the full richness of real-world interactions, but we can shed some light on the implications of such transfers by considering direct monetary transfers between the agents. Quite simply, we allow the agents to use payments to buy each other's approval.

With monetary transfers, consensus (and thus stopping of the game) can now be achieved through the combination of policy proposals and side payments. The challenge for complete analysis is that the exact equilibrium outcome may be sensitive to the bargaining protocol considered. However, our analysis suggests that policy compromise remains a crucial means of building consensus even when money is available. The simple reason for this result is that policy compromise, unlike monetary transfers, affects the total surplus level. In other words, it is typically cheaper to compensate the other agent by expanding the pie instead of simply giving away a slice of the existing pie.

At the same time, the choice of project is by no means trivial, in that the agents do not simply pursue the surplus-maximizing project $x = 1/2$ independent of the decision-making process and the bargaining process. Put differently, even "closing the model" with the Nash bargaining solution does not make process rules irrelevant. The intuition for this result is deeply tied to the dynamics of our model. In particular, bargaining over transfers can occur at two stages: with one and with two developed projects. Now, if substantive compromise weakens the proposing agent's bargaining position when two projects have been developed, agents prefer to compromise less and use (more) money to induce adoption of the first project.

To formalize this intuition, we investigate the role of transfers on the projects chosen on and off the equilibrium path. We impose the following assumptions: (a) adoption of a project requires unanimous support; (b) support for a project is contractible; and (c) an agent cannot threaten to withdraw support for his own project to extort payments. For clarity of exposition, we further assume that, in each phase of the negotiations, the option to leave the relationship is worthless. In other words, each agent's outside option is to adopt the other agent's project or to delay the adoption of any project.[24] We uncover three results that highlight the *qualitative* effect of allowing side payments: (i) side transfers and substantive compromise can be used jointly to buy support; (ii) transfers may introduce an additional rent-seeking channel that is detrimental to compromise; and (iii) the welfare effect of allowing monetary transfers is ambiguous.

To illustrate these results, consider the subgame starting with the development of (the first) project x, say by agent 1. Adopting that project yields payoffs $(v_1(x), v_2(x))$ to the two agents. In contrast, if agent 2 develops his own project, let the continuation payoffs be given by $V_1(x)$ and $V_2(x)$. Agent 1 is then willing to pay at most $v_1(x) - V_1(x)$ to have his project adopted, while agent 2 requires at least $V_2(x) - v_2(x)$ to accept immediate implementation. Suppose for now that *at this stage only*, the agent with the first proposal x has all the bargaining power. Consequently, agent 1 chooses project x in order to maximize

$$W_1(x) \triangleq v_1(x) - t(x) = v_1(x) + \min\{0, v_2(x) - V_2(x)\},$$

where $t(x)$ is the transfer necessary to induce approval of project x. We first introduce a technical result that examines the case where the continuation value is not sensitive to the type of the first project developed.

[24] All our results below are robust to a small outside option for leaving the relationship $\beta_i(x_1, x_2) > 0$.

Proposition 10 (Fixed Continuation Value)
Suppose the continuation value of each agent i is given by $V_i(x) \equiv V$.

1. *The first project x_i^* developed by each agent i satisfies $v_j(x_i^*) = \min\{V, v_j(1/2)\}$.*
2. *Agent i uses monetary transfers for the adoption of x_i^* if and only if $V > v_j(1/2)$.*

This result follows directly from the basic idea that as long as the payoff frontier is concave, policy compromise is more economical than monetary transfers as long as the current level of compromise is below the value-maximizing level $x = 1/2$ (as then \$1 worth of policy compromise yields more than \$1 to the other agent), while monetary transfers dominate otherwise. When continuation payoffs do not depend on the first project developed, this is the only trade-off that matters. Thus, the first agent will use only policy compromise to induce acceptance as long as $V \leq v_j(1/2)$, so that the acceptance threshold is satisfied for a weakly selfish project, while he will use a combination of the value-maximizing project $v_j(1/2)$ and money if $V > v_j(1/2)$, because the acceptance threshold would require excessive compromise in that case.

An example of a bargaining protocol that induces project-independent continuation values is one in which the agent who most recently developed a project can make a take-it-or-leave-it offer to the other agent. Thus, if the game proceeds to the second stage, the second agent develops his favorite project. Given this expectation, agents will at first pursue projects that are just enough to preempt the other agent from continuing. To achieve this, the first agent must deliver a value of $u(1)$ (defined in Section 4) to the second agent.

In the absence of transfers, this expectation induces the agents to pursue their maximum compromise projects, $\bar{x}_i$. As long as $\bar{x}_2 < 1/2 < \bar{x}_1$, acceptance is more efficiently achieved through policy compromise alone, and thus the equilibrium with transfers is equivalent to the case of no transfers. If, however, the threat of continuation is able to induce excessive compromise with $\bar{x}_1 < 1/2 < \bar{x}_2$, then transfers allow the agents to lower their initial compromise to $x = 1/2$ and use a monetary transfer to provide the additional compensation required for adoption.

This benchmark case ignores the facts that, under most bargaining protocols, the continuation values and thus the future bargaining position of the first agent depend on the first proposal, which affects the current bargaining position as well. In the next result, we consider two familiar bargaining protocols with equal bargaining power, to contrast with the previous case.[25] In the first one, the total surplus is divided equally unless the outside option

[25] Equal bargaining power is a realistic assumption in licensing negotiations within SSOs. For instance, Llanes and Poblete (2014) describe the ex-post *equalizing transformation* that occurs because all patents included in a standard become essential.

binds for one of the agents. This corresponds to bargaining à la Rubinstein with frequent offers in the adoption phase. In the second protocol, agents engage in Nash-style bargaining, where the surplus over the agents' outside options is divided equally between them. In both cases, each agent's disagreement payoff (outside option) is given by $v_i(x_j)$, i.e. the payoff from adopting the other agent's project. This corresponds, for example, to the payoffs in the mixed-strategy equilibrium of a complete-information war of attrition.

Proposition 11 (Symmetric Bargaining Power)

1. *Under Rubinstein bargaining, each agent i pursues project $x_i = 1/2$, and no transfers take place in equilibrium.*
2. *Under Nash bargaining, each agent i pursues project x_i with $v_i(x_i) = \min\{\hat{v}, 1\}$ and*

$$\hat{v} + 2\phi(\hat{v}) - \rho(\phi'(\hat{v})^2 - 1) = 0.$$

Monetary transfers are used to induce immediate adoption of the first project developed.

Under the Rubinstein bargaining protocol, if the game reaches the stage where two projects have been developed, the socially more valuable one is adopted, yielding each agent half the total surplus. As a result, the second agent to develop a project will pursue the total value-maximizing project $x = 1/2$. In the first stage, as long as an agent pursues a project that is adopted immediately, he will receive half the total surplus, since the outside option of the other agent will not bind. As a result, both agents pursue value-maximizing projects in the first stage as well. Thus, access to monetary transfers leads to an increased level of compromise, even if actual monetary transfers do not take place in equilibrium (since the project payoffs generate the equilibrium allocation directly).

We have already established that this level of compromise is excessive in relation to the second-best projects, because it induces too strong free-riding incentives. More generally, whether this increase in compromise increases or decreases the sum of payoffs relative to no transfers depends on both the equilibrium selection and the concavity of the payoff frontier. When the frontier is sufficiently flat, compromise creates limited value, and the equilibrium with monetary transfers yields the *worst* symmetric equilibrium outcome without transfers.[26] On the other hand, if the frontier is sufficiently concave (compromise is sufficiently valuable) then total performance can improve with the introduction of transfers.

Finally, under Nash bargaining, each agent receives half of the surplus in excess of the two outside options. In this case, the mere access to monetary transfers invites rent-seeking

[26] This is the case if $v_i(1/2) < 1/\sqrt{3}$, irrespective of other parameter values.

activities in the form of hold-up: under the threat of a war of attrition, each agent can reduce his partner's disagreement payoff by developing a more selfish project to begin with.

In other words, the fear of hold-up makes the members of the organization more hesitant to compromise in terms of policy proposals, and leads them to use monetary transfers to build consensus. Indeed, Proposition 11 shows that the agents may begin to choose fully selfish projects of zero compromise, unless compromise is significantly more efficient in providing value than a direct monetary transfer.

The main takeaways of this extension are three-fold. First, inducing compromise remains an essential issue in creating value and remains relevant even once monetary transfers between the parties are allowed. Second, monetary transfers may actually be damaging to the organization, as they may invite rent-seeking behavior and thus self-protective choice of initial projects or, conversely, excessive compromise and free-riding.[27] Thus, organizations may want to forbid monetary transfers between its members. Third, the outcome can be very sensitive to the details of the bargaining protocol. Thus, the organization needs to take great care in designing the rules for the use of the transfers, if possible. These rules are as important as the decision-making procedure in ensuring that ex-ante conflict between the parties is best harnessed to yield both effort and compromise.

The results derived in this section provide some rationale for rules that ban at least monetary side payments, if not log rolling. While these results are based on specific bargaining procedures, the more general picture that emerges is one where policy proposals as well as transfers will be made to buy the support of the other agent. The logic of continuation payoffs determining the value required for "stopping the game" remains valid, though the equilibrium level of such option values depends in a more subtle way on the rules of the game. Overall, our message resonates well with the observation by Cyert and March (1963) that "side payments, far from being the incidental distribution of a fixed, transferable booty, represent the central process of goal specification. That is, a significant number of these payments are in the form of policy commitments. Policy commitments have (one is tempted to say always) been an important part of the method by which coalitions are formed."

6.2 Voting Procedures

If agents can commit to decision-making procedures, they can implement the optimal decision rule in several ways. In Section 5, we have explored a protocol wherein either agent can eliminate the first complete project, but then faces an exogenous deadline to complete his

[27] Under the protocols described above, if the agents' outside options are tied to the projects they developed, allowing monetary transfers may also invite developing a selfish project that will not be adopted, just in the hope of getting "bought off."

own. This protocol uniquely implements the optimal mechanism. Moreover, it is a reasonable procedure for settings with a small number of relevant participants, such as university hiring committees or research joint ventures.[28]

Instead, SSOs encourage broad participation, and proposals are voted on by participants who are not linked to a specific project. With this context in mind, we describe a setting in which actively participating agents ("firms") and simply voting agents ("users") coexist and how voting rules influence the equilibrium project choices.

Consider a continuum of users of mass one, whose types θ are distributed on $[0,1]$ according to some continuous and symmetric density $f(\theta)$. A user of type θ derives value $w(\Delta(\theta,x))$ if project x is adopted, where $\Delta(\theta,x) \triangleq |\theta - x|$ is the distance of the project from the user's ideal project and w is a strictly decreasing and concave function. The two firms have identical preferences to those of the potential users. Their types are given by $\theta_2 = 0$ and $\theta_1 = 1$, representing the two extremes of the preference spectrum.[29]

The timing of the game is similar to that of the baseline model: each firm chooses a project to work on; upon completion of the first project, the second firm can decide whether to "endorse" the project, ending the game with its adoption;[30] if the second firm does not endorse, the first firm calls a vote on whether its project should be adopted, and the voting rule requires that a qualified majority $\gamma \geq 1/2$ vote in favor for it to be adopted.

If the first complete project is rejected by the voters, we consider two alternative procedures that are especially relevant for our application to SSOs. In the first, the rejected project is removed from further consideration. The second firm can continue its development efforts until its project is complete, at which point a binary vote is held between the second project and the status quo (worth zero to all agents). In the second, the rejected project is set aside until the second project is complete, after which a binary "runoff" vote determines which alternative is adopted. Proposition 12 summarizes the key properties of the equilibrium outcome, restricting attention to the case $\rho \leq \bar{\rho}$.

[28] In the hiring example, it prescribes that the committee loses the hiring slot if a member vetoes a candidate and fails to suggest an alternative candidate in a reasonable time.

[29] The logic of our results generalizes to both interior preferences for the developing firms and to the case in which the firms are partly (or fully) profit driven, with the profits being generated through the collection of licensing fees from the users.

[30] More generally, a binary vote is held between the newly developed project and the status quo, with the knowledge that if the second firm endorsed the first project, it also terminated its development efforts.

Proposition 12 (Voting and Equilibrium Compromise)

1. *Any supermajority requirement* $\gamma \geq 1/2$ *induces a unique equilibrium outcome in which the first project developed is immediately adopted.*

2. *If* $\gamma \in [1/2, \underline{\gamma}(\rho)]$*, each firm develops its favorite project. The threshold* $\underline{\gamma}(\rho)$ *is increasing in* ρ *with* $\underline{\gamma}(0) = 1/2$ *and* $\lim_{\rho\to\infty} \underline{\gamma}(\rho) = 1$.

3. *If* $\gamma > \underline{\gamma}(\rho)$*, the equilibrium degree of compromise is strictly positive and weakly increasing in* γ *and in* ρ.

4. *If the first project is removed from consideration upon a negative vote, there exists a unique* $\gamma^*(\rho) \in (\underline{\gamma}(\rho), 1)$ *that induces the second-best projects.*

5. *If the first project is set aside until the runoff vote, the highest degree of equilibrium compromise is given by the efficient-effort projects.*

Strikingly, small supermajority requirements are unable to induce any compromise. The pivotal voter knows that if the first project developed is rejected, the second project will be either fully selfish (if the former is eliminated), or only incrementally better than the first from her perspective (if a runoff is held). Hence, she votes in favor of the first project developed to avoid the costs of delay. This allows firms to pursue their favorite projects.[31] Inversely, under the ex post welfare maximizing selection function ($\alpha = 1/2$), the first project must satisfy an agent (i.e. the other firm) who stands to gain from waiting for a competing project, leading to a positive degree of compromise.

Thus, while simple majority is effective at selecting among pre-existing alternatives, it performs considerably worse in inducing the development of attractive projects. Indeed, the only ways to induce compromise under majority voting are to delay decisions until both projects are complete or to use a predetermined date on which all complete projects are put to a vote.[32]

As we increase the supermajority requirement γ above $\underline{\gamma}(\rho)$, the pivotal voter becomes increasingly aligned with the firm without the first project. She is thus more willing to bear the cost of delay and both firms must offer a positive degree of compromise to induce immediate adoption. However, for sufficiently high γ, the second firm becomes willing to

[31] A simple majority rule is unable to induce *mutual* compromise even when the distribution of user types is asymmetric: if the median voter falls in an intermediate range, both firms pursue fully selfish projects; and if the median voter's preferences are highly skewed, only the favored firm does.

[32] This two-stage procedure is reminiscent of the policy contests in the models of Callander and Harstad (2015) and Hirsch and Shotts (2015). See Section 5.3.

halt its development efforts and to endorse the first project. This may occur even if a voter, who bears no cost of development, might prefer to wait for the second project.[33]

The voting procedure following rejection of the first project faces a similar trade-off to the one identified in Proposition 4. If the first project is removed from further consideration, a negative vote gives the second firm free reign to develop and adopt its preferred project. The second firm is thus willing to stop its development efforts if offered the maximum-compromise project described in Section 4.1. Additionally, because the level of compromise is monotonically increasing in γ up to the maximum compromise project, there exists an interior supermajority requirement that induces the second–best projects.

If the first project is not eliminated, the second firm must develop a project preferred by the majority of the voters in order to win the runoff vote. Thus, firm j develops project $x_j = 1 - x_i$ as a *competing* project. Turning to the *initial* project choice, the equilibrium degree of compromise is increasing in γ. However, for sufficiently high γ, the second firm becomes willing to endorse the same projects as under the efficient selection function. Both firms then pursue the efficient-effort projects x_i^E and the second-best projects are not attainable.

Therefore, inducing the second-best level of compromise requires both a supermajority requirement and the threat of inefficient continuation if the first project is rejected. The analysis highlighted one source of dissipation, i.e., the inability to resurrect projects that have previously been voted down. Another avenue consists of biasing the second-stage vote in favor of the later project. In practice, both these avenues run the risk of somehow circumventing the rules because the parties may want to revisit rejected projects after the fact, and firms may be able to develop multiple projects over time.

Finally, an actual voting rule must account for the event that two projects are on the table, even if that does not occur in equilibrium in the present model. Delays in calling a vote, private information and other elements outside our model can cause such situations to arise. In these cases, the choice of rules must balance the difficulty of achieving agreement with multiple projects and the ability to induce compromise in the first place.

This logic suggests the simple prediction that settings in which multiple projects will likely be available at the time of the vote should rely on simple majority to avoid deadlock and delay, while settings in which voting will likely take place on a single project should rely on a supermajority rule to guarantee adequate selection of the pursued projects. We now discuss voting rules and their practical consequences in the context of SSOs.

[33] The threshold $\bar{\gamma}(\rho)$ for which this occurs depends on the procedure following rejection of the first project.

6.3 Observable Projects

In many team settings, it may be more reasonable to assume each agent knows what his teammates are working on. We therefore consider the case of observable projects. Observability of projects introduces a continuous-time repeated game (with many details to be spelled out). Intuitively, players can support more cooperative outcomes when project choices are observable, because deviations (i.e., unsuccessful development of off-path projects) can now be punished by reverting to a worse stationary equilibrium (for example, the one in which each agent develops his most selfish proposal).

To be more formal, consider a discrete-time version of a game with the following rules: each agent can freely choose which project to work on at any point in time, but the first developed project is immediately adopted. Let Δ denote the period length. The public signal reveals the projects researched by the two agents and the outcome of their efforts. Suppose for simplicity that agents punish deviations by switching to the stationary equilibrium where each agents pursues his favorite project (worth zero to the other agent) at all times. Let V_L denote the punishment equilibrium payoff. As $\Delta \to 0$, agents can support the stationary choice of any pair of symmetric projects (x_1, x_2) because any deviation (say, to $x_1' = 1$) yields a benefit of at most $(1 - v_1(x_1))\, a_1\Delta$, and a cost of $(1 - a_1\Delta)(V_L - V^*)$ in terms of continuation payoffs. Conversely, if project choices are not observable and $\Delta \to 0$, the unique equilibrium involves each agent pursuing his favorite project at all times.

A similar trade-off characterizes the analysis under unanimity. In that case, agents can condition their actions on all past projects (developed and not developed ones). Therefore, our analysis with unobservable projects is robust in the following sense: equilibria under unobservable projects remain such when projects are observable, because they correspond to the case where agents ignore unsuccessful deviations. That being said, the agents can clearly do better. For instance, in the unanimity case, we conjecture it is possible to sustain the development of the second-best projects for any discount rate as $\Delta \to 0$.

7 Application

The trade-offs described in our model resonate well with the challenges faced by SSOs. A fundamental problem of standards-setting is the public good nature of a technological standard. Crafting proposed standards and participating in SSO processes can be quite costly, creating incentives to free-ride.[34] To counter free-riding, SSOs rely on participating

[34] Formulating a proposal may require research and development of a new technology and combining multiple existing technologies (not all of which are proprietary) into a well-functioning solution. The administrative costs of participating in the standardization process can also be substantial. Updegrove (2003)

firms' vested interests. Indeed, the value of a standard to a firm depends on its provisions: which patents it includes, what the licensing conditions are, and how compatible it is with each firm's own systems, to name of few. However, this approach poses the challenge of inducing firms to generate solutions that are attractive to the market as a whole. In other words, solutions that disproportionately favor one firm are typically less effective (from a utilitarian perspective) than more integrated compromise solutions.[35] Thus, compromise is efficient and desired by the SSO, but may be challenging to achieve due to the conflicting interests of the participants.

SSO Processes. SSOs vary significantly in their size, focus and rules for participation and voting. However, the basic features of the process used to balance these tensions are fairly common. First, a need for a standard is identified. Second, the relevant SSO forms a working group composed of member firm and organization representatives. Working groups then review the existing technology and develop new solutions "with individual members often proposing specific alternatives based on their firm's proprietary intellectual property" (Layne-Farrar and Padilla, 2011). Finally, the members vote on the proposed options per the rules of the particular SSO.

Most working groups use Robert's Rules of Order to govern the procedures, with special provisions added according to the circumstances. Most important, the votes on proposals are based on motions and are therefore taken sequentially. After a proposal has been discussed, there is a motion to put that proposal to a vote. If the motion passes (generally requiring a vote in itself), the vote for endorsement takes place. Nearly every SSO requires a supermajority to qualify for "consensus" and, thus, for endorsement of the standard.[36] Finally, proposals that repeatedly (i.e., after further debate) fail to reach the supermajority requirement are supposed to be removed from further consideration. Thus, the process used by SSOs is quite similar to the second-best voting mechanism discussed in Proposition 12.

While the basic process and the related challenges are relatively homogeneous, the SSOs differ significantly in their particular rules and requirements that need to be met for the acceptance of a standard. These differences lie in the supermajority requirements, in the appeal and arbitration procedures, in the specifics of tiered membership and allocation of

reports that Sun Microsystems and HP have participated in over 150 SSO processes. Relatedly, Weiss and Toyofuku (1996) study free-rider problems in the development of the 10BaseT Ethernet standard in the IEEE, uncovering a large number of non-contributing members.

[35] Consistent with this view, Lehr (1992) notes that "a firm may find it profitable to promote a standard which promises to increase its market share even if total surplus declines. Those who benefit from standards do not always bear the full costs of adoption. For example, new component manufacturers who may benefit from lower entry costs may fail to share the switching costs faced by incumbent firms and their customers."

[36] The American National Standards Institute (ANSI) defines consensus as "general agreement, but not necessarily unanimity, [with] a process for attempting to resolve objections by interested parties."

voting rights, and how deadlocks and proposals that have failed to reach the supermajority requirement are treated. All of these dimensions can be viewed as influencing what projects will be eventually endorsed by the SSO.

The data in Baron and Spulber (2015) provide an overview of some of the dimensions.[37] In particular, in the 36 SSOs they surveyed, 11 operate under majority and 10 under unanimity; "interior" supermajority requirements range from 66% to 75%, including or excluding abstentions. All SSOs attempt to induce consensus by requiring negative votes to be accompanied by detailed motivations. Approximately half of the surveyed organizations allow for members to appeal decisions. Finally, some SSOs have specific rules for participation that limit the number of representatives (or votes) from any given firm or interest group.[38]

SSO Experiences. The experiences of SSOs demonstrate the ability of supermajority requirements to induce compromise through the preemption motive. In particular, the supermajority requirement appears to work well when competing parties do not yet have working and ready-to-market solutions. In that case, a proposal with sufficient substantive compromise can receive support from other members and lead to the relatively rapid adoption of a standard. Shapiro and Varian (1999) emphasize the importance of the political process of alliance building and offer several examples of such "preemptive compromise."

The case of Local Area Networks (LAN) provides a good example. IEEE began to standardize LANs in 1980. Xerox offered an open networking standard to convince computer manufacturers to adopt the Ethernet interface for their printers. The support of 3Com, Digital and Intel convinced IEEE working group 802 to adopt Ethernet as an open standard in 1982 (Shapiro and Varian, 1999). Similarly, the Wireless Ethernet Compatibility Alliance (an industry association including Lucent and Intersil) made a compromise proposal for the first-generation wireless networks (WLAN) in 1999. This was quickly adopted by IEEE as standard 802.11b. In both examples, the initiator offered enough compromise to gain sufficient support and preempt alternatives.

Conversely, when the technology is mature and firms have developed their proprietary solutions to a more advanced stage, preemptive compromise becomes difficult. Negotiating over multiple competing proposals is then more likely, and supermajority requirements may stall the process. The next-generation WLAN standards provide an illustration. In 2001, the negotiations over the 802.11g standard witnessed a standoff between two proposals by

[37] To our knowledge, the only studies to systematically examine the variation across SSO rules are Chiao, Lerner, and Tirole (2007) and Baron and Spulber (2015). The latter provides more details on the standard adoption process.

[38] Yates and Murphy (2015) point out that achieving balance between competing interests has long been a contentious issue for standards bodies, where most SSOs favor balance, though few make explicit provisions. One exception is the European Telecommunications Standards Institute (ETSI) that uses a weighted voting rule favoring European manufacturers.

Texas Instruments and Intersil. Neither proposal was able to gain the 75% majority required for acceptance. The resulting stalemate led to a de facto adoption of multiple standards, and a low-quality compromise emerged only later.

The potential for dysfunctional SSO behavior can also create perverse incentives whereby parties exploit the fear of deadlock (i.e., low option values) and are able to pursue more selfish projects. For instance, during the negotiations for the 802.11n standard in 2006, the process stalled again. In this case, DeLacey, Herman, Kiron, and Lerner (2006) describe how "a group of influential semiconductor companies formed a third group, taking on the name Enhanced Wireless Consortium (EWC) [...] they banded together and began promoting their own specifications for the standard, working outside IEEE approval." Given this pressure, IEEE adopted the EWC's draft specification in 2007 with very few concessions.[39]

In addition to technological factors, the details of an SSO's operations can have a significant impact on the nature of proposals and on the timing of their approval. For instance, the rules governing a motion to vote on a project affect the ability of SSO members to block or delay the approval of a standard, which in turn impacts the option value of a group receiving a proposal. Lehr (1996) considers the procedural elements that facilitate or hinder blocking in two rival SSOs developing network technology standards. In the ANSI-accredited X3 committee (now INCITS), a simple majority was required to discuss and vote on a working document. Instead, the IEEE 802 working group on wireless communication standards has always maintained that the supermajority required to approve a proposal is identical to that required to put one up for a vote (75%).

Lehr (1996) summarizes these and other differences and finds that it is harder and costlier to delay a standard in the IEEE than in the X3 committee. In 1987, these differences allowed IBM to delay the proceedings on the Fiber Distributed Data Interface (FDDI) under X3 by repeatedly submitting alternative proposals that contained minor design differences from the leading project. After 18 months of discussion, the committee eventually approved the leading proposal and modified its rules by introducing a 2/3-supermajority requirement to reopen a discussion.[40] In contrast, the first proposal for Distributed Queue Dual Bus (DQDB) made to the IEEE was viewed as heavily skewed in favor of certain members, but thanks to the less strict procedural controls, its sponsors were able to quickly call a vote, and the standard was adopted in the next meeting.

Resolving Deadlock. Unlike our frictionless model, SSOs must confront the fact that multiple proposals are likely to be on the table at the same time prior to any vote. In this case,

[39] Layne-Farrar and Padilla (2011) describe how "this outside group, a sort of hybrid de facto/cooperative alliance, forced IEEE's hand and a consensus standard that combined the breakout group's proposal with elements of the proposal that had bogged down in IEEE committee finally emerged through the SSO."

[40] This is the same threshold required for approval of a proposal, as per the current INCITS procedures.

an intuitive solution consists of turning to an impartial mediator to break a deadlock. For example, in the IETF, the Working Group chair is charged with establishing whether "rough consensus" has been achieved. Further, because there are no formal votes in the IETF, this is almost always the relevant case. Similar provisions are in place in the W3C, where the chair has the power to call a majority vote to break deadlock. While this procedure avoids a deadlock, the SSO faces the trade-off between ex post efficiency and ex ante compromise. In particular, we know from Proposition 12 that a runoff vote generates insufficient compromise. Indeed, achieving efficiency requires that even good proposals are sometimes eliminated from consideration following the failure to garner sufficient support.

An alternative is to introduce a specific voting rule for resolving deadlock. These rules are often the objects of contentious negotiations prior to commencing work on a given standard. For instance, during the negotiations over the IEEE 802.11g standard, the chair formulated detailed selection criteria, including a "down vote," to eliminate multiple proposals: "Rounds of voting will be held that successively eliminate one candidate proposal at a time. On each round of voting, the candidate proposal that receive the least number of votes shall be eliminated from consideration." These criteria face the challenge of (credibly) eliminating failed projects from consideration, which we turn to next.

Eliminating Proposals. Consistent with our model's findings, proposed standards that are voted down are often, in fact, eliminated from consideration. For example, in the W3C's Tracking Protection Group, the Digital Advertising Alliance (an online advertisers' industry association) formulated a proposal for a "Do Not Track" standard. The proposal was mostly silent on data collection, only regulating its use for targeted advertising. Due to the opposition of consumer protection groups and Mozilla, the proposal was voted down in 2013, which forced the group to look for a new solution. The most recent proposal is based on a different principle (Tracking Preference Expression) and limits data collection efforts.[41]

If no proposal is approved, the SSO may abandon the project altogether, as in the case of Ultra Wide Band standards in the IEEE. In 2006, the working group could not reach consensus to break the deadlock between two proposals, leading the IEEE to disband the group. As noted by a participant, "[one industry alliance] was willing to move forward with a joint proposal the other was not and had sufficient votes to block forward progress. The task group finally agreed to duke it out in the market place."[42]

Despite these examples, there are several reasons why it is difficult to eliminate a proposal that has been previously voted down, in the absence of a clearly superior alternative. First, not approving a standard is rarely a realistic outcome: once all existing proposals have been

[41] The most recent draft and the timeline are available at http://www.w3.org/2011/tracking-protection/.
[42] See http://standards.ieee.org/about/sasb/nescom/projects/802-15-3a.pdf.

voted down, the SSO will re-initiate discussions if it still believes there is potential for and value in formulating a standard. Earlier proposals might be re-introduced in this stage.

Second, the interpretation of the rules for resolving deadlock is often contentious. For example, consider the "down vote" elimination criteria the standoff between Texas Instruments and Intersil in the 802.11g negotiations. Intersil argued that the last vote should be between the last remaining proposal (theirs) and "doing nothing." Instead, the group chair (who sided with Texas Instruments) claimed that the rules mandated the elimination of the last project if it failed to meet the 75% requirement. The resulting appeals and discussion led to the impasse described above. The working group for the next-generation 802.11n standard spent over a year discussing the procedure, arguably attempting to avoid such deadlocks, only to adopt a convoluted scheme whereby "If the last remaining proposal fails to receive 75% majority on the second roll call voting round, the process shall return to the point where there were three proposals remaining." Clearly, this scheme did not allow eliminating proposals in the absence of consensus. The process, not surprisingly, fully stalled.

Third, a better technology can be reintroduced by other means, whether in another SSO ("forum shopping") or into the market directly. For example, as the process for 802.11n stalled, Eisenmann and Barley (2006) suggest that the trade association Wi-Fi alliance emerged as a competing de facto standards body, marketing partial solutions such as 802.11i and 802.11e prior to the approval of an IEEE standard. Similarly, in June 2004, a web standards proposal by Mozilla and Opera was turned down by the W3C. They subsequently broke off from the W3C and formed the Web Hypertext Application Technology Working Group (WHATWG). In April 2007, they successfully proposed that the W3C adopt WHATWG's Web Forms 2.0 as the "forms chapter" of the HTML standard.

Discussion. There are, of course, several aspects of SSOs that our model does not capture. Even if projects are not contractible, ex post payments are realistic in SSOs for at least two reasons. Quite literally, the payoff from any technological proposal can be amended by bargaining over the licensing terms. More important, many SSO members interact repeatedly in the same industry. Thus, logrolling multiple standards negotiations effectively form a repeated-game (relational) transfer. Finally, we have adopted a reduced-form approach toward many of the institutional details that address ex post opportunism. These include disclosure requirements for standard-essential patents[43] as well as the extent and nature of licensing commitments regarding the intellectual property incorporated in the standard.[44] In

[43] Ganglmair and Tarantino (2014) study the incentives to conceal a standard-essential patent from the SSO to subsequently hold up other members.

[44] Some consortia (e.g., W3C) require ex ante commitment to royalty-free licensing, as opposed to the more common and vague requirement of ex post "reasonable and non-discriminatory" licensing terms. See Lemley (2002) and Layne-Farrar and Padilla (2011) for details on intellectual property in SSOs.

addition, we do not compare the choice of technology in market-based vs. committee-based standardization, which is the focus of Farrell and Saloner (1988) and Llanes and Poblete (2015). We also abstract from competition among standards bodies and the related phenomenon of "forum shopping" described in Lerner and Tirole (2006).

8 Conclusions

We have analyzed a collective decision-making problem in which members of an organization develop projects and negotiate over adoption decisions. When the agents have conflicting preferences over the outcomes, a key trade-off emerges between the total value of the projects pursued by the agents and the incentives to exert effort toward their development. The agents' expectations over future negotiations influence the specific projects pursued. Lack of contractibility of effort levels and project characteristics make the socially efficient outcome unattainable in equilibrium. Agreeing to pursue the more socially efficient project induces insufficient compromise. The second-best combination of compromise and effort levels can be achieved in equilibrium, provided the selection criterion favors later projects.

At a broader level, our paper relates the organization of research and development efforts. An intuitive approach suggests letting "a thousand flowers bloom" prior to adopting a project. In contrast, we have shown that when project choice is endogenous, a dynamic model of decision making can yield an ex ante efficient outcome by utilizing the preemption motive, even in the absence of any costs of discerning among completed projects. However, our model is quite stylized. Introducing a stochastic element to project quality leads to sequential sampling, which makes adopting the first complete project unlikely to be optimal. Similarly, additional information is often learned during the development process, creating benefits to collecting multiple projects before making a final selection. The benefits of dynamic competition are likely to remain even in models with a richer structure. At the same time, the flexibility of our model can be leveraged in two promising directions, both of which suggest other reasons why collecting multiple proposals may be beneficial.

Endogenous Project Quality. In our model, the agents' payoffs from adopting any project x are deterministic. In many cases, the overall value of a developed project is not known ahead of time, and agents may be able to influence it. For example, agents may choose whether to pursue: low-risk, low-return methods that deliver a low-quality project with high probability; or more challenging, but more rewarding methods that deliver a high-quality project with a lower probability. Alternatively, the quality of any project could be randomly determined upon its completion. The development phase then becomes analogous to a sequential-sampling problem: each agent can generate multiple projects with similar characteristics and heterogeneous quality levels; he then submits all projects above a threshold quality level as a formal proposal.

Multi-step Projects and Learning. The completion of a project is rarely an all-or-nothing outcome. Instead, most projects progress in multiple steps. In such a setting, completion of an intermediate step by an agent may encourage or discourage the other agent's development efforts. In particular, if the degree of initial compromise is sufficiently high, the other agent may choose to abandon his own project, and join forces on the project closer to completion. Furthermore, the success of any particular project may be uncertain, with additional information learned during the development process or upon completion of an intermediate step. In such a setting, an important team-design variable is whether to publicly release information about the progress level of each project.

Appendix

Proof of Proposition 1. (1.) Fix a pair of projects (x_1, x_2) such that $x_1 > x_2$, and denote agent i's payoff from each project by $v_i \triangleq v_i(x_i)$ and $y_i \triangleq v_i(x_j) = \phi(v_j)$. Note that $x_1 > x_2$ implies $v_i > y_i$ for both agents. Because effort and delay are costly, but agents can guarantee themselves zero by not exerting effort, each agent's continuation payoff $V_{i,t}$ is bounded by

$$V_{i,t} \in [0, v_i) . \tag{15}$$

in any equilibrium. We now write each agent's problem recursively as follows:

$$rV_{i,t} = \max_{a_{i,t}} \left[a_{i,t}(v_i - V_{i,t}) + a_{j,t}(y_i - V_{i,t}) - ca_{i,t}^2/2 + \dot{V}_{i,t} \right] .$$

A necessary condition for optimal effort is given by

$$ca_{i,t}^* = \max \{ v_i(x_i) - V_{i,t}, 0 \} . \tag{16}$$

The bounds in (15) imply that in any equilibrium we must have $a_{i,t}^* > 0$ for both agents. Substituting $a_{i,t}^*$ into the HJB equation for each agent, we obtain a system of two differential equations for the continuation values $V_{i,t}$:

$$\dot{V}_{i,t} = rV_{i,t} - \frac{(v_i(x_i) - V_{i,t})^2}{2c} - \frac{v_j(x_j) - V_{j,t}}{c}(v_i(x_j) - V_{i,t}). \tag{17}$$

We first show that there exists a unique stationary equilibrium. Setting the right-hand side of equation (17) to zero, we obtain the two loci in (V_1, V_2) space where $\dot{V}_{i,t} = 0$. For each i, the locus $\dot{V}_{i,t} = 0$ is given by

$$V_{j,t} - v_j = \frac{(v_i - V_{i,t})^2 - rV_{i,t}}{y_i - V_{i,t}}. \tag{18}$$

The two functions $V_j^*(V_i)$ defined by (18) cross only once over the set $[0, v_1] \times [0, v_2]$. In order to show this, suppose first that

$$v_i + r - \sqrt{r^2 + 2rv_i} > y_i$$

for both players. Then the numerator in (18) is negative when $V_i = v_i$ and $V_j^* = v_j$ for some $V_i > y_i$. It then follows that $V_j^*(V_i)$ is increasing in V_i for $V_i < v_i$. Furthermore, the two loci in (V_1, V_2) space are increasing and concave as

$$\begin{aligned}\frac{\partial V_i^*}{\partial V_j} &= \frac{r+v_1+v_2-V_1-V_2}{V_j-y_j} > 0, \\ \frac{\partial^2 V_i^*}{(\partial V_j)^2} &= \frac{-(v_j-y_j)^2+2ry_j}{(V_j-y_j)^3} < 0.\end{aligned}$$

Therefore, the two loci cross once over the set $[y_1, v_1+r-\sqrt{r^2+2rv_1}]\times[y_2, v_2+r-\sqrt{r^2+2rv_2}]$. Furthermore, we have $V_j^*(V_i) \to -\infty$ as $V_i \to y_i^+$ and $V_j^*(V_i) > v_j$ for all $V_i < y_i$, hence they cross only once over the entire range $[0, v_1] \times [0, v_2]$. Next, suppose that

$$v_i + r - \sqrt{r^2 + 2rv_i} < y_i$$

for both players. Then $V_j^*(V_i) > v_j$ for all $V_i > y_i$ and $V_j^*(V_i)$ is decreasing in V_i over $[0, y_i)$. The two loci must cross at least once because $V_j^* : [0, y_1) \to (-\infty, v_j + v_i^2/y_i]$. Furthermore, they cross at most once because their slopes are ranked. Indeed, $y_i > V_i$ implies

$$\begin{aligned}\frac{\partial V_2^*}{\partial V_1} - \frac{\partial V_2}{\partial V_1^*} &= \frac{y_2-V_2}{r+v_1+v_2-V_1-V_2} - \frac{r+v_1+v_2-V_1-V_2}{y_1-V_1} \\ &< \frac{v_2-V_2}{r+v_1+v_2-V_1-V_2} - \frac{r+v_1+v_2-V_1-V_2}{v_1-V_1} < 0.\end{aligned}$$

Finally, the case where $v_i + r - \sqrt{r^2+2rv_i} < y_i$ but $v_j + r - \sqrt{r^2+2rv_j} > y_j$ follows easily from the previous steps. In particular, V_i^* is increasing and V_j^* is decreasing. Therefore, there exists a unique constant equilibrium path, in which $(V_{1,t}, V_{2,t}) = (V_1, V_2)$ is given by the unique intersection (V_1^*, V_2^*) of the two loci (18). The stationary equilibrium payoffs satisfy

$$V_i^* = \frac{a_i v_i + a_j y_i - c a_i^2}{r + a_i + a_j}. \tag{19}$$

We now rule out all paths $(V_{1,t}, V_{2,t})$ with initial condition $(V_{1,0}, V_{2,0}) \neq (V_1^*, V_2^*)$. Note that the dynamic system defined by the two ODEs (17) has a unique rest point which is unstable. In particular, differentiating the right-hand side of (17) with respect to $V_{i,t}$ we obtain

$$r + v_i(x_i) + v_j(x_j) - V_{i,t} - V_{j,t} > 0.$$

Thus $\partial \dot{V}_{i,t}/\partial V_{i,t} > 0$ and the locus for $\dot{V}_2 = 0$ crosses the locus for $\dot{V}_1 = 0$ from above (below) when the latter is increasing (decreasing). Thus, for any initial condition $(V_{1,0}, V_{2,0}) \neq (V_1^*, V_2^*)$, the corresponding path $(V_{1,t}, V_{2,t})$ explodes, violating the bounds in (15) and ruling out $(V_{1,t}, V_{2,t})$ as equilibrium payoffs.

(2.) Consider stationary equilibria first. Since payoffs can be written as in (19), the symmetric equilibrium effort level for each player satisfies

$$a^* = \arg\max_a \left[\frac{av + a^*\phi(v) - ca^2/2}{r + a + a^*} \right].$$

Solving the first-order condition for a^* yields the expression in (4). Each agent's symmetric equilibrium payoff is then given by

$$V(v) = \frac{2v + \phi(v) + \rho - \sqrt{(v - \phi(v) - \rho)^2 + 6\rho v}}{3}. \tag{20}$$

Conversely, suppose there exists a non stationary equilibrium. The evolution of each player's payoff (17) can be written as

$$c\dot{V}_t = \rho V_t - \frac{(v - V_t)^2}{2} - (v - V_t)(\phi(v) - V_t). \tag{21}$$

However, because $\partial \dot{V}_t / \partial V_t > 0$, any path V_t with initial condition other than $V_0 = V^*$ must violate the bounds on symmetric equilibrium payoffs, i.e.,

$$V_t \in [0, (v + \phi(v))/2).$$

(3.) Differentiating the expression for $a_i^*(x_i)$ in (4) with respect to r, we obtain

$$\frac{\partial a_i^*}{\partial r} \propto \frac{3v_i(x_i) - \Delta(x_i) + cr}{\sqrt{c^2r^2 - 2cr\Delta(x_i) + 6v_i(x_i)cr + \Delta(x_i)^2}} - 1,$$

which has the same sign as

$$\begin{aligned} & (3v_i(x_i) - \Delta(x_i) + cr)^2 - \left(c^2r^2 - 2cr\Delta(x_i) + 6v_i(x_i)cr + \Delta(x_i)^2\right) \\ = \; & 3v_i(x_i)(v_i(x_i) + 2v_i(1 - x_i)) > 0. \end{aligned}$$

The remaining comparative statics also follow by differentiating $a_i^*(x_i)$ in (4). ■

Proof of Proposition 2. (1.) Because agents use stationary strategies, differentiate the expression for payoffs (19) to obtain agent i's best reply

$$a_i^*(a_j) = -r - a_j + \sqrt{(r + a_j)^2 + 2a_j(v_i(x_i) - v_i(x_j)) + 2rv_i(x_i)}. \tag{22}$$

Differentiating (22) with respect to a_j, we obtain

$$\frac{\partial a_i^*(a_j)}{\partial a_j} \geq 0 \iff v_i(x_i) - v_i(x_j) - \sqrt{2v_i(x_j)cr} \geq 0. \tag{23}$$

(2.) If the social planner maximizes the sum of the agents' payoffs (3), her objective function is given by

$$W(x_1, x_2) = \int_0^\infty e^{-\int_0^t (r+a_{1,s}+a_{2,s})\mathrm{d}s} \Sigma_{i=1}^2 \left[a_{i,t}\left(v_1(x_i) + v_2(x_i)\right) - ca_{i,t}^2/2\right] \mathrm{d}t.$$

The value function W_t can be written recursively as

$$rW_t = \max_{a_{i,t}} \left[\Sigma_{i=1}^2 \left(a_{i,t}\left(\left(v_1(x_i) + v_2(x_i)\right) - W_t\right) - ca_{i,t}^2/2\right) + \dot{W}_t\right].$$

Given a pair of symmetric projects, the planner's objective is maximized by the first-best effort levels

$$a_i^{FB}(x_i) \triangleq \frac{-cr + \sqrt{c^2r^2 + 4cr\left(v_i(x_i) + v_i(1-x_i)\right)}}{2c}. \tag{24}$$

Setting $a_{i,t}^*$ in (4) equal to $a_{i,t}^{FB}$ in (24) and solving for $v_i(1-x_i)$, we obtain the condition

$$v_i\left(1 - x_i^E\right) = \Delta\left(x_i^E\right)^2/2cr,$$

i.e. equation (10) in the text.

We then show the efficient-effort projects are symmetric. Recall these projects are characterized by $\partial a_i^*(x_1, x_2)/\partial a_j = 0$. Set the right-hand side of equation (23) to zero for each agent, and solve for ρ. Using the notation $v_i = v_i(x_i)$ and $\phi(v_i) = v_j(x_i)$, we obtain the condition

$$\frac{\phi(v_2)}{\left(v_1 - \phi(v_2)\right)^2} - \frac{\phi(v_1)}{\left(v_2 - \phi(v_1)\right)^2} = 0. \tag{25}$$

Differentiate the left-hand side of (25) with respect to v_1. We obtain

$$-\frac{2\phi(v_2)}{\left(v_1 - \phi(v_2)\right)^3} - \frac{\left(v_2 + \phi(v_1)\right)\phi'(v_1)}{\left(v_2 - \phi(v_1)\right)^3},$$

which is strictly positive for $v_1 = v_2$. Now suppose there exists a root of (25) with $v_1 > v_2$. Fix v_2 and consider the lowest v_1 for which the condition holds. Solve for $v_1 - \phi(v_2)$ and evaluate the derivative at the candidate root. Because $\phi(v)$ is decreasing and concave, we obtain

$$-2\phi(v_1)\sqrt{\frac{\phi(v_1)}{\phi(v_2)}}-(v_2+\phi(v_1))\phi'(v_1)>0.$$

This contradicts the assumption that v_1 is the smallest root. Therefore condition (25) is satisfied for $v_1=v_2$ only.

(3.) Let $i=1$, so that $v_i(x_i)$ is increasing in x_i. By the concavity of the frontier, $a_{i,t}^{FB}(x_i)$ in (24) is decreasing in x_i for all $\Delta(x_i)\geq 0$, while the equilibrium effort level $a_{i,t}^*$ in (4) is strictly increasing in $\Delta(x_i)$ and hence in x_i. Therefore, the expressions $a_{i,t}^*-a_{i,t}^{FB}$ and $\Delta(x_i)-\sqrt{2v_i(1-x_i)cr}$ have the same sign, and the latter is equal to zero only for the projects x_i^E defined in (10). ■

Proof of Proposition 3. (1.) When agents use stationary strategies, agent i's effort level can be written in terms of his equilibrium payoff as in (16). Normalizing $c=1$ (which is without loss for payoffs), the social planner's objective can be written as

$$V_1+V_2=v_1+v_2-a_1-a_2.$$

The planner's payoff is a continuous function of (v_1,v_2) defined over a compact set, hence it admits a maximum. Suppose towards a contradiction that the maximum is attained at the interior point (v_1,v_2) with $v_1>v_2$. It must then hold that

$$1-\frac{\partial a_1}{\partial v_1}-\frac{\partial a_2}{\partial v_1}=1-\frac{\partial a_2}{\partial v_2}-\frac{\partial a_2}{\partial v_2}=0.$$

Rewrite the best replies defined in (22) as

$$\begin{aligned}(r+a_1+a_2)^2 &= (r+a_2)^2+2a_2(v_1-\phi(v_2))+2rv_1, &(26)\\ (r+a_1+a_2)^2 &= (r+a_1)^2+2a_1(v_2-\phi(v_1))+2rv_2. &(27)\end{aligned}$$

Totally differentiating the system of best replies, the planner's first-order conditions imply

$$\begin{aligned}&(a_1+r)(a_2+r+v_1-\phi(v_2))-a_2\phi'(v_2)(a_1+r+v_2-\phi(v_1)) &(28)\\ =\;&(r+a_1+a_2)^2-(a_2-v_2+\phi(v_1))(a_1-v_1+\phi(v_2)),\end{aligned}$$

and

$$\begin{aligned}&(a_2+r)(a_1+r+v_2-\phi(v_1))-a_1\phi'(v_1)(a_2+r+v_1-\phi(v_2)) &(29)\\ =\;&(r+a_1+a_2)^2-(a_2-v_2+\phi(v_1))(a_1-v_1+\phi(v_2)).\end{aligned}$$

Combining conditions (26)-(27) and (28)-(29), we obtain the following necessary conditions for an interior optimum:

$$\begin{aligned}
(r+a_2)^2 + 2a_2(v_1 - \phi(v_2)) + 2rv_1 &= (r+a_1)^2 + 2a_1(v_2 - \phi(v_1)) + 2rv_2 \\
(a_1(1+\phi'(v_1)) + r)(a_2 + r + v_1 - \phi(v_2)) &= (a_2(1+\phi'(v_2)) + r)(a_1 + r + v_2 - \phi(v_1)).
\end{aligned}$$

Given v_1 and v_2, these conditions identify two loci in (a_1, a_2) space. When $v_1 = v_2$, the two loci correspond to the 45-degree line. When $v_1 > v_2$, the two loci do not cross. To see this, solve each equation for a_2. We obtain the two functions

$$\begin{aligned}
a_2^I(a_1) &= \frac{-(1+\phi'(v_1))\,a_1(v_1 - \phi(v_2)) - ra_1\phi'(v_1) + r(v_2 + \phi(v_2) - v_1 - \phi(v_1))}{-(v_2 - \phi(v_1))(1+\phi'(v_2)) - r\phi'(v_2) + a_1(\phi'(v_1) - \phi'(v_2))}, \\
a_2^{II}(a_1) &= -r - v_1 + \phi(v_2) + \sqrt{v_1^2 + (a_1 + r)(a_1 + r + 2v_2) - 2a_1\phi(v_1) + \phi(v_2)(\phi(v_2) - 2(r + v_1))}.
\end{aligned}$$

Both functions are strictly increasing in a_1, with $a_2^I(0) > 0 > a_2^{II}(0)$. Furthermore, $a_2^I(a_1)$ is strictly convex while $a_2^{II}(a_1)$ is strictly concave. Finally, the distance between the two loci increases in a_1. Let $\hat{a}_1$ denote the unique solution to $a_2^{II}(\hat{a}_1) = 0$, and notice that

$$\frac{\partial a_2^I(a_1)}{\partial a_1} - \frac{\partial a_2^{II}(a_1)}{\partial a_1} > \frac{\partial a_2^I(0)}{\partial a_1} - \frac{\partial a_2^{II}(\hat{a}_1)}{\partial a_1} \quad \text{for all } a_1 \geq \hat{a}_1. \tag{30}$$

The right-hand side of (30) may be written as

$$\frac{((v_2 - \phi(v_1))(1+\phi'(v_1)) + r\phi'(v_1))((v_1 - \phi(v_2))(1+\phi'(v_2)) + r\phi'(v_2))}{((v_2 - \phi(v_1))(1+\phi'(v_2)) + r\phi'(v_2))^2} - \frac{r + v_2 - \phi(v_1)}{r + v_1 - \phi(v_2)}.$$

This difference is increasing in r. Therefore, let $r = 0$ and obtain

$$\frac{(v_1 - \phi(v_2))(1+\phi'(v_1))}{(v_2 - \phi(v_1))(1+\phi'(v_2))} - \frac{v_2 - \phi(v_1)}{v_1 - \phi(v_2)} > 0,$$

which rules out an interior maximum of the planner's objective. Finally, extreme points (i.e., $v_1 = 1$) can be ruled out by showing that the planner's objective is decreasing in v_1 if agent 2's best-reply is increasing in a_1. In other words, for sufficiently high v_1, condition (29) cannot be satisfied. In particular, this is always the case when $v_2(x_1) = \phi(v_1) = 0$.
(2.) Suppose the agents develop symmetric projects. Rewrite each agent's symmetric equilibrium payoff in terms of v as

$$V(v) = \frac{a(v)(v + \phi(v)) - ca(v)^2/2}{r + 2a(v)}. \tag{31}$$

The equilibrium effort level $a(v)$ can be written as

$$a(v) = \frac{v - \phi(v) - \rho + \sqrt{(v - \phi(v) - \rho)^2 + 6\rho v}}{3c}. \tag{32}$$

The total derivative of the agent's payoff is given by

$$V'(v) = \frac{\partial V}{\partial a} a'(v) + \frac{\partial V}{\partial v}.$$

Simplifying, we obtain

$$V'(v) \propto 2 + \phi'(v) - \frac{(v - \phi(v) - \rho)(1 - \phi'(v)) + 3\rho}{\sqrt{(v - \phi(v) - \rho)^2 + 6\rho v}}. \tag{33}$$

Because the payoff frontier is symmetric, the sum of the agents' payoffs $\Sigma_i v_i(x)$ attains a maximum at $x = 1/2$. Substituting $\phi(v) = v$ and $\phi'(v) = -1$ into (33), we obtain

$$1 - \frac{\rho}{\sqrt{\rho^2 + 6\rho v}} > 0.$$

As $x \to 1$, we obtain $v = 1$ and $\phi(v) = 0$. Furthermore, by the concavity of the payoff frontier, we have $\phi'(1) < -1$. Substituting into (33), we obtain

$$1 - \frac{2 + \rho}{\sqrt{(1 - \rho)^2 + 6\rho}} < 0,$$

which implies $V(v)$ attains its maximum at an interior v. Now suppose the maximizer $v^*(\rho)$ were such that $\partial V/\partial a \leq 0$, i.e. effort levels were above the first-best. Because $a'(v) > 0$ and $\partial V/\partial v \propto 1 + \phi'(v) < 0$, reducing v (i.e. induce more compromise) would increase the agents' payoffs. Hence, the optimal v^* must satisfy $\partial V/\partial a > 0$, and therefore $a(v^*(\rho)) < a\left(v^E(\rho)\right)$ for all $\rho > 0$.

(3.) Solving the first-order condition (33) for ρ, we obtain the inverse function $\rho^*(v)$ in closed form,

$$\rho^*(v) = -\frac{1 + 2\phi'(v)}{2(2 + \phi'(v))} \frac{(v - \phi(v))^2}{v + \phi(v) + v\phi'(v)}. \tag{34}$$

Notice that (34) implies $\rho^*(v) = 0$ when $\phi(v) = v$, which corresponds to project $x_i = 1/2$ for each i. It also implies $\phi'(v^*(\rho)) \to -1$ as $\rho \to 0$. Therefore, for ρ close to zero, we have $\phi'(v^*(\rho)) > -2$ and $v + \phi(v) + v\phi'(v) > 0$. Then as v increases, the first term (which is positive) increases. The numerator of second term increases, while the denominator decreases (since $\phi'(v) < -1$). As v increases, the term $v + \phi(v) + v\phi'(v)$ decreases, and $\phi'(v) > -2$ as long as $v + \phi(v) + v\phi'(v) \geq 0$. Therefore $\rho^*(v)$ is increasing in v, and grows without bound as v approaches the root of $v + \phi(v) + v\phi'(v)$, which is itself bounded away from 1. ■

Proof of Proposition 4. Suppose the first project x_1 has been developed, and consider the continuation value of agent 2. If he adopts x_1, he obtains $v_2(x_1)$, whereas if he vetoes it, he can achieve an expected payoff of $u(v_2(1 - x_1))$. He will therefore adopt all projects x_1 that yield a sufficiently high value $v_2(x_1)$. Proceeding backwards, agent 1's expected payoff is increasing in x_1 if agent 2 adopts the first project, and decreasing in x_1 (because $x_2 = 1 - x_1$ will ultimately be adopted) if agent 2 vetoes it. Therefore, agent 1 develops the project x_1 that makes agent 2 indifferent. Using the definition of $u(\cdot)$ in (12), this project satisfies

$$v_2(x_1) = v_2(1 - x_1) + \rho - \sqrt{\rho^2 + 2v_2(1 - x_1)\rho}.$$

Recalling the notation for symmetric projects $v_i(x_j) = \phi(v)$, and solving for ρ, we obtain

$$\rho = \frac{(v - \phi(v))^2}{2\phi(v)}, \tag{35}$$

which is the condition for the efficient-effort projects (10) given in the text. ■

Proof of Proposition 5. (1.) Fix a pair of "target" projects $(\hat{x}_1, \hat{x}_2)$, and consider the following selection function that implements them:

$$\xi(\underline{x}, \underline{\tau}) = \begin{cases} x_1 & \text{if} \quad \tau_1 < \tau_2 \quad \text{and} \quad x_1 = \hat{x}_1, \\ x_1 & \text{if} \quad \tau_1 > \tau_2 \quad \text{and} \quad x_2 \neq \hat{x}_2, \\ x_2 & \text{otherwise.} \end{cases} \tag{36}$$

Under selection function (36), each agent must develop a project that is adopted. Suppose the first project developed is given by $x_1 \neq \hat{x}_1$. Agent 2 can adopt x_1 or pursue his favorite project, i.e. $x_2 = 0$, and adopt it immediately, leaving agent 1 with a payoff of zero. Similarly, agent 2 will adopt project $x_1 = \hat{x}_1$ immediately, because he cannot replace it with any other project at a later date. It remains to be verified whether agent 1 can develop any project $x_1 > \hat{x}_1$ and induce agent 2 to adopt it nonetheless. Because agent 2 could develop a project worth 1 to him, he adopts any project $x_1 \neq \hat{x}_1$ such that

$$v_2(x_1) \geq u(1),$$

i.e. any project $x_1 \leq \bar{x}_1(\rho)$. Therefore, if the $\hat{x}_1 < \bar{x}_1$, i.e. if the desired degree of compromise exceeds the maximum degree of compromise, then we have $v_2(\hat{x}_1) > u(1)$. It then follows that there exists by continuity another project $x_1 > \hat{x}_1$ that is adopted by agent 2 and constitutes a profitable deviation for agent 1. Thus, given the discount rate ρ the set of equilibrium projects contains all pairs $(x_1, x_2) \in [\bar{x}_1(\rho), 1] \times [0, \bar{x}_2(\rho)]$. Finally, the selection function described in (36) maximizes the option value of the agent who does not develop the first project, in the event that the first project deviates from the candidate equilibrium. Therefore, if there exists a profitable deviation $x_1 \neq \hat{x}_1$ under this selection rule, this deviation is also profitable under any other selection function. Hence no pair $(x_1, x_2) \notin [\bar{x}_1(\rho), 1] \times [0, \bar{x}_2(\rho)]$ can be developed in equilibrium.

(2.) We compare the maximum-compromise project values $\bar{v}(\rho)$ and the second-best project values $v^*(\rho)$. Writing the function $u(1,\rho)$ more explicitly, the maximum-compromise projects satisfy

$$\phi(v) = 1 + \rho - \sqrt{\rho(2+\rho)}.$$

Solving for ρ we obtain the inverse function

$$\bar{\rho}(v) = \frac{(1-\phi(v))^2}{2\phi(v)}. \tag{37}$$

We now compare this expression with the inverse function $\rho^*(v)$ in (34). Both functions are strictly increasing in v. Denote the value of project $x = 1/2$ as $v_0 = \phi(v_0)$. We then know $\rho^*(v_0) = 0$ while $\bar{\rho}(v_0) > 0$. We want to show that function $\bar{\rho}$ crosses ρ^* only once, and from above. Consider the following ratio:

$$P(v) \triangleq \frac{\rho^*(v)}{\bar{\rho}(v)} = -\frac{1+2\phi'(v)}{2+\phi'(v)} \frac{(v-\phi(v))^2}{v+\phi(v)+v\phi'(v)} \frac{\phi(v)}{(1-\phi(v))^2}.$$

Differentiate $P(v)$ and consider the coefficient on $\phi''(v)$ in the resulting expression. This is given by

$$\frac{1}{1+2\phi'(v)} - \frac{1}{2+\phi'(v)} - \frac{v}{v+\phi(v)+v\phi'(v)},$$

which is negative because the definition of $\rho^*(v)$ in (34) implies that

$$\phi'(v^*(\rho)) \in \left(-1 - \frac{\phi(v^*(\rho))}{v^*(\rho)}, -1\right), \text{ for all } \rho \geq 0.$$

Therefore, we can bound the derivative $P'(v)$ as follows:

$$P'(v) > \frac{2\phi(v)}{v(v-\phi(v))} + \frac{(v+\phi(v)(v+\phi(v)-3))\phi'(v)}{(v-\phi(v))(1-\phi(v))\phi(v)} + \frac{v+2\phi(v)}{v(v+\phi(v)+v\phi'(v))}. \tag{38}$$

The expression in (38) is convex in $y'(v)$, and grows without bound both as either $v \to v_0$ and $v \to 1$. We now use $\phi'(v) < -1$ and $\phi'(v) > -1 - \phi(v)/v$ to bound the last two terms of (38). We obtain

$$P'(v) > \frac{(v + \phi(v))(3 - v - \phi(v))}{(v - \phi(v))(1 - \phi(v))\phi(v)} > 0.$$

This implies the ratio $\rho^*(v)/\bar{\rho}(v)$ is strictly increasing in v. Therefore, the two functions can cross only once. The critical v for which $\rho^*(v) = \bar{\rho}(v)$ identifies the upper bound $\bar{\rho}$ above which the maximal degree of compromise is lower than the second-best degree of compromise.

(3.) For $\rho > \bar{\rho}$, the second-best projects are not developed in equilibrium. Because the agents' symmetric equilibrium payoffs (20) are concave in v, the highest equilibrium payoff (when $v^*(\rho)$ is not attainable) is obtained by minimizing $v(\rho)$, and hence selecting the maximum-compromise projects, which yield $\bar{v}(\rho)$. ■

Proof of Proposition 6. We first establish that agent-1 authority yields a higher total equilibrium payoff than the minimum-compromise projects (which are developed in equilibrium under unanimity). In the minimum-compromise equilibrium, payoffs are given by $V(1)$, as defined in (20) and exert effort levels $a(1)$ defined in (4). Now suppose agent $i = 1$ is assigned authority. Then agents develop projects $x_1 = 1$ and $x_2 = \bar{x}_2$. Let a_1 and a_2 denote the equilibrium effort levels. Now notice that

$$2V(1) < \frac{a(1) + a(1)(\bar{v} + \phi(\bar{v})) - 2c(a(1))}{r + 2a(1)} < \frac{a_1 + a_2(\bar{v} + \phi(\bar{v})) - c(a_1) - c(a_2)}{r + a_1 + a(1)},$$

where the first inequality follows from the concavity of the frontier,. The second inequality follows from the comparative statics of equilibrium effort, which imply $a_1 < a(1)$ and $a_1 > a_1^{FB}$. Finally, notice that $\phi(\bar{v}) = u(1)$ by construction. Hence, agent 2's effort imposes no externalities on agent 1, i.e. $a_2 = a_2^{FB}$. Therefore, the total value under unilateral authority satisfies

$$V_1^A + V_2^A = \frac{a_1 + a_2(\bar{v} + \phi(\bar{v})) - c(a_1) - c(a_2)}{r + a_1 + a_2} > 2V(1).$$

We now show that the agents' best equilibrium payoff under unanimity exceeds the payoff under unilateral authority. It suffices to show the result for the maximum-compromise projects, that is,

$$2V(\bar{v}) \geq V_1^A + V_2^A.$$

To do so, consider the agents' incentives to exert effort under agent-1 authority. The first-order conditions for effort imply

$$\begin{aligned} c'(a_1) &= 1 - V_1^A \\ c'(a_2) &= \bar{v} - V_2^A. \end{aligned}$$

Conversely, when both agents develop their *maximum-compromise* projects, their symmetric equilibrium effort levels are given by

$$c'(\bar{v}) = \bar{v} - V(\bar{v}).$$

Finally, the first-best effort under unanimity is characterized by

$$c'(a^{FB}(\bar{v})) = \bar{v} + \phi(\bar{v}) - V(\bar{v}).$$

Therefore, using the fact that $V_1^A = \phi(\bar{v})$, we obtain

$$c'(a^{FB}(\bar{v})) - c'(a_2) = V_1^A + V_2^A - 2V(\bar{v}).$$

In other words, mutual development of the maximum-compromise projects achieves a higher payoff than unilateral authority if and only if the effort level of the agent without authority exceeds the first-best effort level $a^{FB}(\bar{v})$ under mutual choice of of the maximum-compromise projects. Rewriting the two effort levels, we obtain

$$\begin{aligned} ca^{FB}(\bar{v}) &= \frac{-\rho + \sqrt{\rho\left(4 + 5\rho - 4\sqrt{\rho(2+\rho)} + 4\bar{v}\right)}}{2}, \\ ca_2 &= -\sqrt{\rho(2+\rho)} + \sqrt{\rho(2+\rho) + 2\sqrt{\rho(2+\rho)}\bar{v}}. \end{aligned}$$

Setting the two levels equal to each other, solving for $\bar{v}$, and replacing ρ with the threshold function $\bar{\rho}(\cdot)$ defined in (37), we obtain the following condition:

$$a_2 > a^{FB}(\bar{v}) \iff \bar{v} > (1 - \phi(\bar{v}))\left(\frac{\phi(\bar{v})}{1 + 3\phi(\bar{v})} + \sqrt{\frac{1 + \phi(\bar{v})}{1 + 3\phi(\bar{v})}}\right). \tag{39}$$

Because the term in the last parentheses is always smaller than one, the concavity of the payoff frontier ensures $\bar{v} + \phi(\bar{v}) \geq 1$ and thus that (39) is satisfied. ■

Proof of Proposition 7. (1.) Suppose agents develop the second-best projects (x_1^*, x_2^*). We construct a deadline for counteroffers $T(\rho)$ that makes the agent without the first project indifferent between adopting it and pursuing his favorite project under the deadline. Because the first agent who develops a project must induce adoption by the other agent (or else receive a payoff of zero), this condition is sufficient to induce the second-best projects. The second agent's continuation value $V(t,T)$ solves the following problem

$$\begin{aligned} rV(t,T) &= \max_a \left[a(1-V(t,T)) - ca^2/2 + V_t(t,T)\right], \\ \text{s.t. } V(T,T) &= 0. \end{aligned}$$

The solution to this problem is given by

$$V(t,T) = 1+\rho+\sqrt{\rho(2+\rho)}\frac{1+ke^{-r(t-T)\sqrt{1+2/\rho}}}{1-ke^{-r(t-T)\sqrt{1+2/\rho}}},$$

with constant of integration

$$k = \frac{1+\rho+\sqrt{\rho(2+\rho)}}{1+\rho-\sqrt{\rho(2+\rho)}}.$$

The critical deadline $T(\rho)$ solves the equation

$$V(0,T) = \phi(v^*(\rho)),$$

whose solution is given by

$$r\hat{T}(\rho) = \sqrt{\frac{\rho}{2+\rho}}\ln\left(\frac{1-\phi(v^*(\rho))\left(1+\rho-\sqrt{\rho(2+\rho)}\right)}{1-\phi(v^*(\rho))\left(1+\rho+\sqrt{\rho(2+\rho)}\right)}\right). \tag{40}$$

(2.) The right-hand side of (40) vanishes as $\rho \to 0$ (which implies $v^* \to \phi(v^*)$), and grows without bound as $\rho \to (1-\phi(v^*(\rho)))^2/2\phi(v^*(\rho))$, which is the bound defined in (37). Therefore, for $\rho > \bar{\rho}$, the optimal deadline in (40) (which is infinite) induces development of the maximum-compromise projects $(\bar{x}_1(\rho), \bar{x}_2(\rho))$.

(3.) From the proof of Proposition 5, we know $\phi'(v^*(\rho))$ can be bounded as follows:

$$\phi'(v^*(\rho)) \in \left[-\frac{(1-\phi(v^*(\rho)))\,\phi(v^*(\rho))}{(1+\phi(v^*(\rho)))\,\rho}, -1\right]. \tag{41}$$

Now differentiate totally expression (40), and use the bound in (41). We obtain

$$(2+\rho)\frac{d(rT)}{d\rho} > \frac{-2\phi(v^*(\rho))}{1+\phi(v^*(\rho))} + \frac{1}{\sqrt{\rho(2+\rho)}}\ln\frac{1-\phi(v^*(\rho))\left(1+\rho-\sqrt{\rho(2+\rho)}\right)}{1-\phi(v^*(\rho))\left(1+\rho+\sqrt{\rho(2+\rho)}\right)}. \tag{42}$$

We then note that the right-hand side of (42) is increasing in $\phi(v^*(\rho))$, and nil for $\phi(v^*(\rho)) = 0$. Therefore, the optimal deadline normalized by the discount rate $\rho\hat{T}(\rho)$ is increasing in ρ.

Finally, the optimal deadline $T(\bar{v})$ satisfies the following condition

$$\phi(v^*) = u(\phi(\bar{v}), T).$$

As $\bar{v}$ increases, the second-best projects remain constant, but the right-hand side decreases. The deadline T must consequently increase to preserve the equality. In particular, $T \to \infty$ as $u(\phi(\bar{v})) \to \phi(v^*)$. ■

Proof of Proposition 8. (1.) We show that under any optimal mechanism agents pursue the constrained-efficient projects

$$x_i(\rho) = \begin{cases} x_i^*(\rho) & \text{if} \quad \rho \leq \bar{\rho}, \\ \bar{x}(\rho) & \text{if} \quad \rho > \bar{\rho}, \end{cases}$$

and adopt the first project developed without delay. We establish this result in the following steps.

We first consider a relaxed problem in which we optimize directly over the two agents' expected payoffs at the time the first project is developed. As we focus on symmetric mechanisms, let v_t denote agent i's expected payoff from developing the first project at time t. Similarly, y_t denotes agent i's expected payoff if agent j develops the first project at time t. An optimal mechanism maximizes each agent's expected payoff over all feasible paths of v_t and y_t. Each agent's expected payoff is given by

$$V_0 = \int_0^\infty e^{-\int_0^t (r+2a_s^*)\mathrm{d}s} \left(a_t^*(v_t + y_t) - c(a_t^*)\right) \mathrm{d}t, \tag{43}$$

where a_t^* is the equilibrium effort path, given payoffs v_t and y_t. We first establish a bound on the equilibrium payoffs v_t and y_t.

Claim 1 *Under any mechanism, the receiver of the first proposal obtains an expected payoff*

$$y_t \leq \min\{W^*, \phi(v_t)\}, \tag{44}$$

where $W^* = u(1)$ is defined in (12).

Proof. Suppose agent j receives a proposal x_i at time τ_i. His continuation payoff at any future date $t \geq \tau_i$ is maximized by assigning him authority over all projects at all times. To see this, compare the outcome under authority with any equilibrium outcome under a different mechanism. When assigned authority, agent j can develop the same set of projects as under any mechanism, but can adopt (weakly) more projects than in the alternative mechanism. Therefore, the expected payoff level W^* provides a tight upper bound on his continuation payoff if the first project is never adopted. Finally, suppose agent j's expected payoff upon development of agent i's project x_i exceeds W^*. Then agent i can improve his own payoff by pursuing a more preferred project x_i' because the subsequent assignment of authority does not depend on project characteristics, and agent j adopts any proposal worth at least W^* as soon as he is granted the authority to do so. ■

Thus, an optimal mechanism maximizes (43) with respect to the paths v_t and y_t, subject to (44) and to the following equilibrium restriction on the function a_t^*,

$$a_t^* = \arg\max_{\{a_t\}} \int_0^\infty e^{-\int_0^t (r+a_s+a_s^*)\mathrm{d}s} \left(a_t v_t + a_t^* y_t - c\left(a_t\right)\right) \mathrm{d}t.$$

Following the approach of Mason and Välimäki (2015), we write our maximization problem recursively, letting V_t denote each agent's continuation payoff. Furthermore, we normalize the cost parameter c to 1, and let $r = \rho$. We then obtain the following optimal-control formulation of our original problem:

$$\begin{aligned} & \max_{\{v_t, y_t\}} V_0 \\ \text{s.t.} \quad & \dot{V}_t = \rho V_t + \left(a_t^*\right)^2/2 - a_t^*\left(v_t + y_t - 2V_t\right), && (45) \\ & a_t^* = v_t - V_t, && (46) \\ & y_t \leq \min\left\{W^*, \phi\left(v_t\right)\right\}, \end{aligned}$$

where (45) is the law of motion of V_t and (46) is the recursive formulation of the agents' best-reply in terms of effort. We can then write the Hamiltonian as

$$H_t = \lambda_t\left(\rho V_t - \left(v_t - V_t\right)\left(\left(v_t - V_t\right)/2 + y_t - V_t\right)\right) + \mu_t\left(W^* - y_t\right) + \gamma_t\left(\phi\left(v_t\right) - y_t\right). \quad (47)$$

The necessary conditions for the Maximum Principle are the following:

$$\begin{aligned} \frac{\partial H_t}{\partial v_t} &= \frac{\partial H_t}{\partial y_t} = 0 \\ \dot{\lambda}_t &= -\frac{\partial H_t}{\partial V_t}. \end{aligned}$$

In addition, we impose the complementary slackness (49) and to transversality condition

(48) established by Michel (1982) for infinite-horizon problems:

$$\begin{aligned}\lim_{t\to\infty} H_t &= 0 &(48)\\ \mu_t\left(W^* - y_t\right) &= \gamma_t\left(\phi\left(v_t\right) - y_t\right) = 0. &(49)\end{aligned}$$

Seierstad and Sydsaeter (1987) establish that the Hamiltonian for this problem is identically zero along the optimal path. Finally, using the complementary slackness conditions (49), we conclude that $\dot{V}_t \equiv 0$. Because the optimal path V_t^* is constant, the optimal controls v_t^* and y_t^* are stationary. Using the fact that (45) is identically zero, the equilibrium value V^* as a function of the controls v and y is given by

$$V^*\left(v, y\right) = \frac{1}{3}\left(2v + y + \rho - \sqrt{\left(v - y - \rho\right)^2 + 6\rho v}\right). \tag{50}$$

Our original problem then reduces to maximizing (50) subject to (44). It is easy to verify that $V^*\left(v, y\right)$ is increasing in both of its arguments. Because $\phi\left(v\right)$ is strictly decreasing in v, we know the constraint $y^* \leq \phi\left(v^*\right)$ binds. This establishes that the optimal mechanism involves no dissipation on the equilibrium path. Finally, following the steps in the proof of Proposition 5, we can establish that the constraint $y^* \leq W^*$ binds depending on the value of ρ. In particular, we have the following characterization of the optimal policy v^*:

$$v^* = \begin{cases} v\left(x^*\left(\rho\right)\right) & \text{if} \quad \rho \leq \bar{\rho}, \\ \phi^{-1}\left(W^*\left(\rho\right)\right) & \text{if} \quad \rho > \bar{\rho}. \end{cases}$$

(2.) As $\rho \to 0$, the constrained-efficient projects coincide with the second-best projects $x_i^*\left(\rho\right)$ (see Proposition 5). A necessary condition for these projects to be adopted without delay is that each agent i wishes to develop $x_i^*\left(\rho\right)$ and that each agent j adopts the first project developed. In particular, we need

$$v_j\left(x_i^*\left(\rho\right)\right) \geq W_j\left(x_i^*, \rho\right),$$

where W_j denotes the continuation payoff of agent j upon receiving the first proposal. Now suppose the mechanism introduces no dissipation, and let $\rho \to 0$. The continuation payoff $W_j\left(x_i^*, \rho\right)$ converges to a weighted average of the payoffs from adopting the two projects x_i^* and x_j. Because the allocation of authority does not condition on project characteristics, and agent j can develop her favorite project second, it must be that

$$v_j\left(x_i^*\left(\rho\right)\right) \geq p_i v_j\left(x_i^*\left(\rho\right)\right) + \left(1 - p_i\right) \cdot 1, \tag{51}$$

where p_i is the probability of adopting the first project. Satisfying (51) requires $p_i \to 1$. Now consider the first agent's incentives to develop project $x_i^*(\rho)$. It must be that, for each agent i,

$$v_i\left(x_i^*(\rho)\right) \geq p_i, \tag{52}$$

because agent j would develop her favorite project second (which is worth zero to agent i). However, as $\rho \to 0$ and $p_i \to 1$, condition (52) cannot hold for $v_i\left(x_i^*(\rho)\right) < 1$, which is in fact the case for all values of ρ. ■

Claim 2 *In the game with a deadline T, efficient ex-post selection and unobservable project developments, there exists no pure-strategy equilibrium.*

Proof. Suppose players pursue projects (x_1, x_2). If both projects are equally valuable, each agent has an incentive to either (a) undercut the other one by choosing a socially more valuable project that is adopted with probability one, or (b) to deviate to his favorite project. The latter deviation is profitable if e.g. $x_1 = x_2 = 1/2$. If one project is socially preferable, the agent not developing it can profitably deviate to his favorite project. ■

Proof of Proposition 9. (1.) We look for a mixed-strategy equilibrium where players randomize over the projects they pursue. A similar logic to the previous claim suggests that each player's distribution over projects x cannot have atoms, and that its support must include each agent's most preferred project. Thus, we characterize a mixed-strategy equilibrium where players randomize over projects with values $[v_L, 1]$ according to an absolutely continuous $F(v)$. Let the expected payoff $\beta(v)$ associated with developing each project v in the support of $F(\cdot)$ be given by

$$\beta(v) = v - \int_{\beta}^{v} p(x)\left(v - \phi(x)\right) f(x)\,\mathrm{d}x, \tag{53}$$

where $p(v)$ denotes the probability of each agent succeeding in the development phase conditional on having chosen project v. Because each agent is randomizing, he must be indifferent among all projects in the support. Hence the constant (undiscounted) prize β must be equal to the lowest value in the support, i.e. v_L, because the highest-compromise project is adopted with probability one. Each agent's HJB is given by

$$rV_t = \max_a \left[a\left(e^{-r(T-t)}\beta - V_t\right) - c(a) + \dot{V}_t\right].$$

The first-order condition for effort at time t is given by

$$ca_t = e^{-r(T-t)}\beta - V_t.$$

Because expected payoffs β are constant in v, the optimal effort levels at each time t do not depend on the project chosen. Therefore, let p denote the probability of developing any project by the deadline,

$$p := 1 - e^{-\int_0^T a_t \mathrm{d}t}.$$

Each agent's value V_t then satisfies the following ODE and boundary condition:

$$\begin{aligned} rV_t &= \frac{\left(e^{-r(T-t)}\beta - V_t\right)^2}{2c} + \dot{V}_t, \\ V_T &= p \int_\beta^1 \phi(x) f(x) \mathrm{d}x =: w. \end{aligned}$$

We can then solve for V_t in closed form, and obtain

$$V_t(w, \beta) = e^{-r(T-t)} \left(\beta - \frac{2\rho(\beta - w)}{\left(1 - e^{-r(T-t)}\right)(\beta - w) + 2\rho} \right).$$

This implies effort levels are given by

$$a_t = \frac{2r(\beta - w)}{e^{r(T-t)}(\beta - w + 2\rho) - (\beta - w)}, \tag{54}$$

and integrating over time, we have

$$p = 1 - \left(\frac{2e^{rT}\rho}{(e^{rT} - 1)(\beta - w) + 2\rho e^{rT}} \right)^2.$$

Now rewrite the prize β as follows:

$$\beta = 1 - p + p \int_\beta^1 \phi(x) f(x) \mathrm{d}x = 1 - p + w.$$

This means

$$\beta - w = \left(\frac{2e^{rT}\rho}{(e^{rT} - 1)(\beta - w) + 2\rho e^{rT}} \right)^2,$$

which can be written in terms of $\beta - w$ as the following equation:

$$\sqrt{\beta - w}\,(\beta - w) = \left(1 - \sqrt{\beta - w}\right) \frac{2e^{rT}\rho}{e^{rT} - 1}. \tag{55}$$

Let the solution to (55) be given by

$$\beta - w = B\left(\frac{2e^{rT}\rho}{e^{rT} - 1} \right), \tag{56}$$

and notice that the function $B(\cdot)$ is strictly increasing. Finally, in order to derive the equilibrium distribution $F(v)$, we differentiate $\beta(v)$ and set equal to zero. We therefore solve the following initial-value problem:

$$\begin{aligned} 1 - pF(v) - pf(v)(v - \phi(v)) &= 0, \\ F(\beta) &= 0. \end{aligned}$$

The solution is given by

$$F(v) = \frac{1 - e^{-\int_\beta^v \frac{1}{x-\phi(x)}\mathrm{d}x}}{p},$$

where $p = 1 - (\beta - w)$ from above and $\beta - w$ is solved as a function of parameters only in (56). An equation for β is then given by

$$\beta - w = \beta - p\int_\beta^1 \phi(x) f(x)\,\mathrm{d}x = \beta + p\int_\beta^1 \phi'(x) F(x)\,\mathrm{d}x.$$

Using (56), the equilibrium β is therefore implicitly defined by the following equation:

$$B\left(\frac{2e^{rT}\rho}{e^{rT}-1}\right) = \beta - \phi(\beta) - \int_\beta^1 \phi'(v)\, e^{-\int_\beta^v \frac{1}{x-\phi(x)}\mathrm{d}x}\mathrm{d}v. \tag{57}$$

(2.) Differentiating the right-hand side of (57) with respect to β, we obtain

$$1 - \int_\beta^1 \frac{\phi'(v)}{\beta - \phi(\beta)} e^{-\int_\beta^v \frac{1}{x-\phi(x)}\mathrm{d}x}\mathrm{d}v > 0.$$

Because left-hand side is strictly increasing in its argument, the equilibrium β is strictly increasing in ρ and strictly decreasing in T.
(3.) This follows immediately from the first-order condition (54). ■

Equilibrium Payoffs and Optimal Deadline. As a preliminary step towards characterizing payoffs, define the equilibrium difference $\beta - w$ as following function:

$$z(\beta) := \beta - \phi(\beta) - \int_\beta^1 \phi'(v)\, e^{-\int_\beta^v \frac{1}{x-\phi(x)}\mathrm{d}x}\mathrm{d}v,$$

which is the right-hand side of (57). Differentiating, notice that $z(\beta)$ satisfies the following initial-value problem:

$$
\begin{aligned}
z'(\beta) &= \frac{z(\beta)}{\beta - \phi(\beta)}, \\
z(1) &= 1.
\end{aligned}
$$

Solving this problem, we obtain

$$z(\beta) = e^{-\int_\beta^1 \frac{1}{x=\phi(x)} \mathrm{d}x}.$$

Finally, we know the equilibrium β for a given T satisfies (56), i.e. $z(\beta) = B\left(2e^{rT}\rho / \left(e^{rT} - 1\right)\right)$.

Now consider the expression for the equilibrium payoff $V_t(\beta, w)$. Evaluating payoffs at $t = 0$, and substituting $z(\beta)$, we obtain

$$V_0(\beta) = e^{-rT}\left(\beta - \frac{2\rho z(\beta)}{(1 - e^{-rT})\, z(\beta) + 2\rho}\right).$$

Next, solving for e^{rT} from (55), we obtain

$$e^{-rT} = 1 - \frac{2\rho}{\sqrt{z(\beta)}}\left(1 - \frac{1}{z(\beta)}\right). \tag{58}$$

We can then simplify the payoff expression to

$$V_0(\beta) = \frac{\left(\beta - z(\beta)^{3/2}\right)\left(2\rho\left(z(\beta)^{1/2} - 1\right) + z(\beta)^{3/2}\right)}{z(\beta)^{3/2}}.$$

Differentiating with respect to β, setting equal to zero, and solving for ρ yields

$$\rho^*(\beta) = \frac{-z(\beta)^{3/2}\left(2\beta - 3z(\beta)^{3/2} - 2\phi(\beta)\right)}{2\left(\beta - z(\beta)^2 - 2\phi(\beta)\left(2\sqrt{z(\beta)} - 1\right)\right)}.$$

Using (58), we obtain an expression for the optimal deadline

$$e^{-rT^*} = \frac{\beta - z(\beta)^2 - 2\phi(\beta)\left(2\sqrt{z(\beta)} - 1\right)}{\left(2\sqrt{z(\beta)} - 3\right)\left(z(\beta)^{3/2} - \beta\right)},$$

and for the highest equilibrium payoff

$$V_0^*(\beta) = \frac{\left(\beta - z(\beta)^{3/2}\right)^2 \left(3 - 2\sqrt{z(\beta)}\right)}{\beta - z(\beta)^2 - 2\phi(\beta)\left(2\sqrt{z(\beta)} - 1\right)}.$$

Figure 6 plots the discount rate $\rho^*(\beta)$ and the values β and $V_0^*(\beta)$ parametrically.

Proof of Proposition 10. Let x denote the first project (developed by agent 1), and let the bargaining power of agent 2 be given by α. The equilibrium transfer from agent 1 to agent 2 is then given by

$$T(x) = \max\{(1-\alpha)(V_2(x) - v_2(x)) + \alpha(v_1(x) - V_1(x)), 0\}.$$

and so we can write agent 1's net benefit $b_1(x)$ from developing project x as

$$b_1(x) \triangleq v_1(x) - T(x) = \min\{v_1(x), (1-\alpha)(v_1(x) + v_2(x)) + \alpha V_1(x) - (1-\alpha)V_2(x)\}.$$

Agent 1 now chooses project x_1 to maximize $b_1(x)$, because for any x, agent 1 can compensate agent 2 through the appropriate transfer. Denote the solution to this problem by x_1^*. If $b_1(x_1^*) = v_1(x_1^*)$, agent 1 induces acceptance solely by providing a policy compromise, whereas if $T(x_1^*) > 0$ a positive transfer is made in equilibrium. Substituting $\alpha = 0$ and $V_i(x) \equiv V_i$, the result follows. ■

Proof of Proposition 11. (1.) Suppose the game reaches the stage with developed projects (x_1, x_2). The more valuable project is adopted, yielding each agent half the total surplus. In particular the outside options will never be binding in the second stage. As a result, if any agent develops a competing project second, he will pursue the social value-maximizing project $x = 1/2$ that yields $v(1/2)$ to each agent. Proceeding backwards, suppose that player 1 succeeds in developing project x_1 first. Player 2's option value of developing a competing project is then given by $W_2 := u(v(1/2))$. If project x_1 is not adopted, agent 1's continuation value is $W_1 \in (W_2, v(1/2))$ because delay is costly to both parties, but agent 2 has to suffer the cost of development. If project x_1 is adopted, agent 1 earns a payoff of

$$\max\left\{W_1, \frac{v_1(x_1) + v_2(x_1)}{2}\right\},$$

which is clearly maximized at $x_1 = 1/2$. Thus, pursuing the highest-value project is a dominant strategy in the first stage.

(2.) Let $v_i = v_i(x_i)$ for each agent $i = 1, 2$ and start again with the second period. First, suppose that the second agent decides to develop a project that is less attractive than the first one ($v_2 > v_1$). Since agent 1's project is adopted at this stage the payoff to agent 2 is given by

$$\frac{1}{2}\left(v_1 + \phi\left(v_1\right) - \phi\left(v_1\right) - \phi\left(v_2\right)\right) + \phi\left(v_1\right) = \frac{1}{2}\left(v_1 - \phi\left(v_2\right)\right) + \phi\left(v_1\right),$$

which is increasing in v_2. In short, if the agent develops a project that will not be adopted, its only is to influence the outside option of the first agent, and any compromise improves that outside option. Thus, the second agent chooses a fully selfish project. Now suppose $v_2 \leq v_1$, so that the second agent develops a project that is actually adopted. Then, his payoff is given by

$$\frac{1}{2}\left(\phi\left(v_2\right) + v_2 - \phi\left(v_1\right) - \phi\left(v_2\right)\right) + \phi\left(v_1\right) = \frac{1}{2}\left(v_2 - \phi\left(v_1\right)\right) + \phi\left(v_1\right),$$

which is again increasing in v_2. In other words, if an agent develops a competing project that is adopted, he will develop a project that only matches the social value of the first project.[45] Taken together, these two observations then imply that the value of any competing project x_2 is given by $v_2 = 1$. Because the first project will be adopted even if a second project is developed, the first project is adopted immediately on the equilibrium path. Let $V_1\left(v_1, v_2\right)$ and $V_2\left(v_1, v_2\right)$ denote the continuation payoffs if the game moves on to the second stage. Then agent 1's payoff in the first stage is given by

$$\begin{aligned} & \frac{1}{2}\left(v_1 + \phi\left(v_1\right) - \max\left\{\phi\left(v_1\right), V_2\left(v_1, v_2\right)\right\} - V_1\left(v_1, v_2\right)\right) + V_1\left(v_1, v_2\right) \\ = \; & \frac{1}{2}\left(v_1 + \phi\left(v_1\right) - \max\left\{\phi\left(v_1\right), V_2\left(v_1, v_2\right)\right\} + V_1\left(v_1, v_2\right)\right). \end{aligned}$$

Suppose first that $\phi\left(v_1\right) > V_2\left(v_1, v_2\right)$. Then, the expression simplifies to

$$\frac{1}{2}\left(v_1 + V_1\left(v_1, v_2\right)\right),$$

which is unambiguously increasing in v_1. Alternatively, suppose that the binding outside option is for the second agent to develop a competing project in order to improve his bargaining position. Then, up to the factor 1/2, the payoff simplifies to

$$v_1 + \phi\left(v_1\right) - V_2\left(v_1, v_2\right) + V_1\left(v_1, v_2\right) = v_1 + \phi\left(v_1\right) + \frac{\left(\phi\left(v_2\right) - \phi\left(v_1\right)\right) a^* + ca^*/2}{r + a^*},$$

where a^* is the second agent's optimal effort level. Differentiating with respect to v_1, we

[45] We are again using the tie-breaking rule that selects the second project developed.

obtain

$$1+\phi'\left(v_1\right)\sqrt{\frac{\rho}{\rho+v_1+2\phi\left(v_1\right)}}. \tag{59}$$

Thus, $\phi'(1)$ is small enough in absolute value, the agents will not compromise at all. If compromise is sufficiently valuable, then (59) holds with equality and some compromise arises in equilibrium. This is the case, for instance, if the frontier satisfies an Inada condition. ■

Proof of Proposition 12. (1.) The proof is analogous to part (1.) of Proposition 4.
(2.) Suppose firm 1 develops the first project and let the pivotal voter be $\widehat{\theta} < 1/2$. For $(x_1, x_2) \neq (1,0)$, if the game continues, firm 2 will pursue its favorite project (if x_1 is eliminated) or a project that leaves voter 1/2 just indifferent between the two alternatives (if a runoff is held). For γ sufficiently close to 1/2, the pivotal voter $\hat{\theta}$ is close to $\theta = 1/2$, which implies that the voter has a strict preference for immediately accepting the first developed project. Firm 1 takes advantage of this and choose a more selfish project. A positive degree of compromise arises when the pivotal voter's preference in favor of firm 2 is sufficiently strong that she prefers to wait for firm 2 to develop its fully selfish project as a competing project, rather than accepting immediately firm 1's selfish project. This type is defined by

$$w(\Delta(\theta^*,1)) = \chi\left(\rho\right)w(\Delta(\theta^*,0)),$$

where

$$\chi\left(\rho\right) = 1-\frac{1}{\sqrt{1+\frac{2}{\rho}}} \tag{60}$$

is the expected delay until firm 2 completes its preferred project $x_2 = 0$ that is worth 1 to firm 2 and thus $v\left(\Delta\left(\theta^*,0\right)\right)$ to user θ^*. The minimum supermajority requirement is then given by $\underline{\gamma}(\rho) = 1 - F\left(\theta^*\left(\rho\right)\right)$. From equation (60) it is then immediate that since $\chi\left(\rho\right)$ is strictly decreasing, $\theta^*\left(\rho\right)$ is strictly decreasing too, with $\chi\left(0\right) = 1$ and $\theta^*\left(0\right) = 1/2$. Conversely, as ρ grows without bound, we have $\chi \to 0$ and $\theta^* \to 0$ which implies $\underline{\gamma} \to 1$. Symmetric calculations apply to the case where firm 2 develops the first project.
(3.) The elimination of the first project following a negative vote allows the second firm to pursue a fully selfish project. The equilibrium level of compromise is given by

$$w(\Delta(\hat{\theta},x_1)) = \chi\left(\rho\right)w(\Delta(\hat{\theta},0)).$$

Using the implicit-function theorem, it is immediate that $dx_1/d\hat{\theta} > 0$, so that the level of compromise is increasing in the supermajority requirement and decreasing in ρ.

If the first project is set aside until the runoff, the second firm can no longer pursue its preferred project, but must persuade the median voter. Thus, the level of compromise is now given by

$$w(\Delta(\hat{\theta}, x_1)) = \chi(\rho)\, w(\Delta(\hat{\theta}, 1 - x_1)).$$

Again, the degree of compromise is decreasing in ρ. As we shift the supermajority requirement (captured by $\hat{\theta}$), we need to be a little more careful since now the second firm's effort depends on the level of compromise and affects the discount factor χ. Totally differentiating the expression for the delay, we obtain

$$\begin{aligned} & \frac{dw(\Delta(\hat{\theta}, x_1))}{dx_1} - \chi \frac{dw(\Delta(\hat{\theta}, 1 - x_1))}{dx_1} - \frac{d\chi}{da_0}\frac{da_0}{dx_1} w(\Delta(\hat{\theta}, 1 - x_1)) \\ = & -\left[\frac{dw(\Delta(\hat{\theta}, x_1))}{d\hat{\theta}} - \chi \frac{dw(\Delta(\hat{\theta}, 1 - x_1))}{d\hat{\theta}}\right] \frac{d\hat{\theta}}{dx_1}. \end{aligned}$$

Because the payoffs depend only on the distance to the ideal point, we know that

$$\frac{dw(\Delta(\hat{\theta}, x_1))}{d\hat{\theta}} = -\frac{dw(\Delta(\hat{\theta}, x_1))}{dx_1}.$$

Because of the concavity of the payoff function, we know

$$\frac{dw(\Delta(\hat{\theta}, x_1))}{dx_1} > \frac{dw(\Delta(\hat{\theta}, 1 - x_1))}{dx_1}.$$

Finally, since $\chi \leq 1$, we obtain

$$1 - \underbrace{\frac{d\chi}{da_0}}_{>0} \underbrace{\frac{da_0}{dx_1}}_{<0} \underbrace{\frac{w(\Delta(\hat{\theta}, 1 - x_1))}{\frac{dw(\Delta(\hat{\theta}, x_1))}{dx_1} - \chi \frac{dw(\Delta(\hat{\theta}, 1 - x_1))}{dx_1}}}_{>0} = \frac{d\hat{\theta}}{dx_1} > 0.$$

Therefore, the degree of compromise is increasing in γ.

(4.) We establish an upper bound on the degree of equilibrium compromise. This arises when the second firm prefers to stop its development efforts. Then, even if there exist more extreme voters who would prefer the second firm, the endorsement by the second firm effectively ends the game. Firm 2 will continue as long as

$$u(1) \geq w(\Delta(0, x_1)),$$

which together with (12) defines the maximum compromise project $\bar{x}_1$. Thus, the condition

$$w(\Delta(\underline{\theta}(\rho), \bar{x}_1)) = \chi(\rho)\, w(\Delta(\underline{\theta}(\rho), 0))$$

defines the pivotal type $\underline{\theta}(\rho)$ and the bound on binding supermajority as $\overline{\gamma}(\rho) = F(1 - \underline{\theta}(\rho)) = 1 - F(\underline{\theta}(\rho)) < 1$. Because we know that equilibrium compromise is increasing in γ and that $x_1^* > \bar{x}_1$, there exists a unique $\gamma^*(\rho)$ that induces the second-best projects.

(5.) The upper bound on compromise is again given by the point at which firm 2 prefers to quit its development efforts, now simply under the requirement that the competing project it may pursue is $x_2 = 1 - x_1$ instead of $x_2 = 0$. This threshold is given by

$$u(w(\Delta(0, 1 - x_1))) = w(\Delta(0, x_1)),$$

which together with (12) defines x_1^E. We then define $\tilde{\theta}(\rho)$ as the user that is indifferent between the two alternatives. The resulting supermajority requirement $\tilde{\gamma}(\rho) = F(1 - \tilde{\theta}(\rho)) = 1 - F(\tilde{\theta}(\rho)) < 1$ bounds the equilibrium degree of compromise. ■

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