

An Analysis of the Competitive Dynamics Behind the Disruptor's Dilemma

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This report is the result of my own work and includes nothing which is the outcome of work done in collaboration except where specifically indicated in the text.

Abstract

The introduction of a potentially disruptive technology into a mature multisided ecosystem often faces a seemingly dilemmatic challenge: persuading a critical mass of incumbents to support the technology that might eventually disrupt them. We analyse this apparently perplexing phenomenon under the lens of a global coordination game of incomplete public and private information; and more precisely an adaptation of a game of regime change. Incumbents can decide to support or not the potential disruptor, who becomes successful only if a sufficient mass of supporters is attained. The proposed model assumes a multi-round game where each round gives the opportunity for yet-not-supporting incumbents to irrevocably side with the potential disruptor. Only a two-round game is detailed, while elements for generalization to an arbitrary number of rounds are suggested. The first round constitutes a rather *typical*—i.e., extensively scrutinized in the literature—global game, for which it has already formally been established that a monotone equilibrium exists and is unique provided an adequate precision of the information structure. Subsequently, when making their decision during the second round, incumbents gain additional information derived from the first round. Although we do not formally prove the results, we conducted an extensive set of simulations revealing that the new information leads to either no equilibrium or a multiplicity of equilibria. Bearing in mind that our model is overly stylized, those observations suggest that the second round is prone to coordination failure; whereas the precision of information plays an essential role during the first round for incumbents to make an informed decision. It follows that a wise strategy consists for the potential disruptor in investing, at the very outset, in communicating precise information so as to ensure the existence of a unique equilibrium and, should the underlying fundamentals allow, succeed in the first round.

Keywords: disruptive innovation, multisided platforms, global games, coordination games, incomplete information, multiple equilibria.

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Attempting to enter a mature and multisided business ecosystem with a potentially disruptive technology may reveal a thorny path. Mature business ecosystems revolving around multi-sided platforms appear to possess solid means of preventing any new player posing threat to existing players from entering the sphere; so much that a potential disruptor's success vastly depends on the support of the to-be-disrupted incumbents, a conundrum recently referred to as the *disruptor's dilemma* (Ansari et al., 2016). Although it is not difficult to understand why the potential disruptor would want to seek support from incumbents, it is much less clear why incumbents would be willing to engage in any sort of collaboration. Such an observation suggests that disruption in such an ecosystem counts as a triumph. Yet, disruptions not only happen, but it is the fate of all businesses.

We present a game theoretic model of incomplete information towards analysing the dynamics of decision-making by incumbents based on their beliefs formed (at least partly) via information divulged, either privately or publicly, by the potential disruptor. More precisely, we use a global game model (Carlsson and van Damme, 1993; Morris and Shin, 2001; Frankel et al., 2003), and even more precisely a global game of regime change (Angeletos et al., 2007). Following a similar development as in the work of Angeletos et al. (2007), we start by a static game which differs from the one discussed by Angeletos et al. (2007) only in the payoff structure. We then examine a more realistic scenario in which incumbents can make their decision to support the potential disruptor in a second round, where further information is gained from observing the *noisy* outcome of the first one. We succinctly discuss the generalization to an arbitrary number of rounds.

In games of imperfect information (also known as Bayesian games), the assumed rationality implies that each incumbent acts in a way to maximize its payoff. Each incumbent's payoff depends on

its decision, on the decision of other incumbents in the ecosystem and on some unknown economic fundamentals (Morris and Shin, 2001); therefore, the incumbent's decision must repose on its beliefs regarding economic fundamentals, and on its appreciation of the other players' beliefs as well, which gives rise “to an infinite regress in reciprocal expectation on the part of the players” (Harsanyi, 1967, p. 5) due to endless higher order beliefs—although, in practice, there seem to be a limit (Strzalecki, 2014). Considering the entire set of higher order beliefs together with a high-dimensional representation of economic fundamentals may become rapidly overwhelming, to the point of not being practicable. Global games offer a simplified representation of such a situation where economic fundamentals are captured by a single parameter θ , and each player receives a different signal of θ —the difference is due to noise (Morris and Shin, 2001).

Although a global game model may lack sophistication, or may even appear overly stylized, to fully capture the intricate dynamics of the disruptor's dilemma, “[r]emember that all models are wrong; the practical question is how wrong do they have to be to not be useful” (Box and Draper, 1987, p. 74). The work introduced throughout this paper should be regarded as a preliminary step in constructing tools to help both the potential disruptor and the incumbents in making strategic decisions when confronting the dilemma. Those tools should belong to a broader portfolio of tools and other existing frameworks (as a complement), and are not intended to provide definite answers.

A brief look at the literature in global games reveals an obvious frequently recurring pattern consisting in, first, presenting a set of assumptions, on top of which a model is developed; then, subsequently, in giving formal proofs of the existence of equilibria and other properties together with conditions that guarantee a unique equilibrium (see, e.g., Carlsson and van Damme, 1993; Chamley, 1999; Angeletos et al., 2007; Frankel et al., 2003; Edmond, 2013). We do

not follow this pattern. Instead, we rely on extensive simulations to discover equilibria. One can argue that simulations' results should be loosely considered and are unsuitable for making conclusive claims about a larger context than the one in which simulations are conducted (i.e., generalizations are at best insubstantial). On the other hand, such results are meaningful for developing insights on the matter. Such an insight can be valuable in practice; besides, it can be a first exploratory step towards devising formal proofs of the suggested/observed results.

The rest of this paper is structured as follows: In Section 1 we extensively delve into the disruptor's dilemma. Our proposed model and conducted simulations are presented in Section 2. Finally, in Section 3, we discuss the limitations of our model and suggest some future directions of investigation.

1. The Disruptor's Dilemma

The simplest description of the dilemma can trivially be grasped by the observation that “[f]irms introducing disruptive innovations into multi-sided ecosystems confront the disruptor's dilemma: gaining the support of the very incumbents they disrupt” (Ansari et al., 2016, page 1). Central to this description of the dilemma are the terms *disruptive innovations* and *multisided ecosystems*, which calls for further elaboration.

1.1. Disruptive Innovations

Ansari et al. (2016, note 1) define disruptive innovations as:

[N]ew technologies, products or business models that are financially unattractive to incumbents They can be (1) “low-end” innovations that target customers “overserved” by the functionality of their current provider, such as discount department stores (e.g., Walmart), (2) “new-market” innovations that target “non-served” customers, i.e., those unable to access, use or even afford the product, such as online auctions (e.g., eBay), or (3) hybrids, that combine both overserved and non-consumers, such as low-cost airlines (e.g., Southwest Airlines).

Technology-wise, disruption is not necessarily achieved via *performance superiority*, as common sense may suggest—as well as suggested in some preliminary works (Utterback and Abernathy, 1975)—but through a complex evolutionary mechanism where the trajectory of offered performance grows much faster than the trajectory of needed performance. Consequently, the performance of the quasi-unnoticed and seemingly inferior technology eventually becomes what users need (Christensen, 1997). Based on Christensen (1997)'s work, Adner (2002, p. 2) contends that “[d]isruptive technologies are technologies that introduce a different performance package from mainstream technologies and are inferior to mainstream technologies along the dimensions of performance that are most important to mainstream customers.”

By contrast, Kavadias et al. (2016) argue that disruptions happen via a combination of both new technologies and new business models, for a new technology alone might not suffice. They identified six traits that seem to be recurrently recognized in a number of recent successful business models (and absent from the ones that proved unsuccessful). They also observe that the odds of success for a potential disruptor remain meager: “Most attempts to introduce a new model fail—but occasionally one succeeds in overturning the dominant model, usually by leveraging a new technology” (Kavadias et al., 2016, p. 3).

It is worth noting that, although disruptions appear to be exceedingly rare, this is, paradoxically, the fate of all successful business organizations (Christensen, 1997); we further elaborate on that point in the next section (Section 1.2).

In spite of having received much attention by academics and industrials, given the absence of precise consensus, remarking the fact that many works, such as the ones cited above, justify their claim by finding *a few* examples of situations that somehow corroborate the claim—a context obviously prone to the confirmation bias, for the cases that disconfirm the theory are conveniently ignored (Nickerson, 1998)—and noting the undeniable alarmingly high number of failed attempts (Marmer et al., 2011), the mechanism leading to successful innovations (and therefore disruptions) is still to be identified. Further, the possibility that such a mechanism does not exist cannot be ruled out, those radical changes might happen by sheer *luck* or serendipity—a phenomenon falling under

the umbrella of the so-called black swans (Taleb, 2008). Whether such a mechanism exists seems to be still an open question that some scholars have been attempting to elucidate; Christensen (1997), one of them, expresses strong presumptions in favour of its existence.

The disruptive consequences of some innovations are not always intentional. There are cases where both the instigator of a new technology and the incumbents had not foreseen the full disruptive power of the new technology. As a case in point, consider the introduction of the iPhone in 2007, “[Apple] aims to sell 10 million iPhones through the end of 2008, which would account for about 1% of the annual global handset market” (Yuan and Bryan-Low, 2007, para. 5); whereas some analysts from prominent financial institutions reported that 2 million units could be sold at best (Yuan and Bryan-Low, 2007). A modest ambition from Apple and an amusing prediction from analysts when we now know the actual figures: Apple exceeded its target for 2008 (Cheng, 2008), and went on to reach a staggering cumulative sales of 1 billion units during 2016 (Apple Inc., 2016), making this product “the most successful product of all time” (Reisinger, 2017, para. 3). Not only has the iPhone been generating tremendous wealth for the shareholders, but it has also disrupted the entire personal computer paradigm and industry. From targeting a niche market to the decade-longed so-called Post-PC era (Press, 1999; Weiser, 1991), the iPhone and its ecosystem offers the quintessence of an unexpected vastly disruptive and far-reaching innovation.

1.2. Disruption: An Inevitable Destiny

It appears that being disrupted is inherent/intrinsic to any business endeavour, and thus unavoidable. That is to say, present successful disruptors will eventually and quasi-inexorably be, in turn, disrupted. The stratagem consists then in postponing the occurrence as much as value creation can be sustained; and, in due course, gracefully exiting (e.g., by being part of the superseding business).

High barriers to entry might delay the downfall, but not prevent it. Agarwal and Gort (1996) substantiate that, in spite of strong barriers to entry, increased innovation and increase in market entries are correlated.

In his book, Christensen (1997) provides numerous

examples of once renown firms praised and acclaimed for their seemingly flawless management and subsequent well-deserved success (e.g., Sear, IBM, DEC and Xerox to which we can add the like of Kodac, RIM, Nokia, Sun Microsystems); yet that have since then either vanished altogether or are now hostilely criticized for the disappointment they have been causing to the stockholders. In many of those examples, the recurrent pattern is that those firms, while enjoying and resting on their seemingly eternal laurels, failed to recognize the turning wind (or at least failed to act on it), and in retrospect, many of those firms appeared to have been adequately positioned to benefit from the new wind direction. Those observations should justify and fuel the fear of certain healthy companies of missing “the next big thing”—in the words of the late former Apple CEO Steve Jobs, who is often regarded as a visionary and a serial disruptor (Isaacson, 2011)—making them more inclined to *collaborate*¹ with potential disruptors; e.g., Google was acquiring over one company per week on average a few years ago (Rusli, 2011). Apple, Facebook, IBM or Microsoft, among other titans of the Internet—a sector driven by innovations and thus prone to disruption—are exhibiting a similar behaviour (Wikipedia, 2017a, 2016b, 2017b,c).

1.3. Multisided Ecosystems

Multisided ecosystems revolve around platforms that synergistically link the different sides together (Hagi, 2014). Throughout this paper, we use interchangeably the terms multisided ecosystems and multisided platforms (although this is a slight abuse of language, as the former concept is *larger* than the latter).

Multisided platforms (MSPs) systematically exhibit, or even are characterized by, a strong network effect—also referred to as network externalities in the literature (Rochet and Tirole, 2003). That is to say, for one side, the perceived value of the MSP increases with the sizes of the other sides. The terms *cross-side network effects* or *indirect network effects* are used to describe this setting—by contrast, *direct network effect* of goods refers to a situation where

¹The term *collaborate* might spur some controversies, for the term is arguably not adequate for, e.g., hostile takeovers or *acquisitions to kill*, a phenomenon often triggering heated polemics in the specialized press—e.g., Yahoo is notorious for this practice (Lapowsky, 2014).

the perceived value to a user increases with the total number of users (Hagiu, 2014).

Once well-established, an MSP enjoys a comfortable position and is likely to last—due to the stability offered by the network effect and switching costs mechanisms² (Farrell and Klemperer, 2006; Zhu and Mitzenmacher, 2008). “[S]uccessful MSPs occupy privileged and often hard-to-assail positions in their respective industries” (Hagiu, 2014, p. 3). However, establishing a successful MPS is not an easy task. Failure at building such a platform remains the norm (Hagiu, 2014). The so-called chicken-and-egg problem lies at the heart of the challenge. Hagiu (2014) identifies four critical decisions to be made: number of sides, platform design, pricing structure and governance rules. Rochet and Tirole (2003) thoroughly address the pricing structure decision in a two-sided market. It has been observed and theorized that, often, the MSP must subsidize at least one side (*loss leader*) to reach and sustain a critical mass of participants. Rochet and Tirole (2003) provide a number of such occurrences, including, e.g., platforms as diverse as video games, credit cards, operating systems, newspapers, TV networks and a lot more.

The concept of MSP is related to the notion of *complementor* coined by Brandenburger and Nalebuff (2011). “A complementor is the opposite of a competitor. It’s someone who makes your products and services more, rather than less, valuable” (Brandenburger and Nalebuff, 2011, Foreword). At least one side of the platform appears as a complementor to the MSP; besides, the sides of the platform other than the consumers are complementors to one another as well (Boudreau and Hagiu, 2008). For instance, a video game developer and a joystick manufacturer for a given video game console platform are complementors. Bear in mind, though, that complementors are not necessarily linked via a MSP (Gawer and Henderson, 2007).

1.4. Disruption in Multisided Ecosystems

Let’s examine why and how disruptions happen in multisided ecosystems. Attacking a new market is hard: “Newcomers to a business face many disad-

vantages. They lack proven products, brands, loyal customers, manufacturing experience, and relationships with suppliers. As a challenger, if you go head-to-head with an incumbent, you’re likely to lose”³ (Brandenburger and Nalebuff, 2011, p. 236). Yet, the difficulty is exacerbated many folds in a multisided environment, due to the network effects, possible switching costs and other barriers to entry, as discussed above.

The distinction between a new entrant as *yet-another-player* in the ecosystem and a new entrant as a potential disruptor is essential. MSPs surely benefit from the new comers docilely filling their role on one side of the platform, e.g., Markman and Waldron (2014, p. 6) note that “the legions of micro entrants, including startups, that collectively offer more than 700,000 iPhone and Android applications ... bolster Apple’s and Google’s positions in the smart phone ecosystem.” Encouraging a multitude of such new entrants can even constitute a divide-and-conquer strategy in order to keep the full control of the platform, as implemented by Nintendo, which limited the number of games a firm could develop per year or short-supplied retail chains (Brandenburger and Nalebuff, 2011). By sharp contrast, the emergence of an innovation with a potential for disruption is most assuredly not welcomed.

Considering the tremendous difficulties to develop a mature MSP (Hagiu, 2014), it is without surprise that ecosystem’s participants adopt an overly conservative stance when facing a potential disruptor. Even if the innovative technology appears appealing to the platform itself or to one side, the MSP may demonstrate a high level of scepticism and be extra-cautious, for it might have the potential to wipe out the benefit of the platform to at least one other critical side⁴, which would then jeopardize the critical balance/link between sides, to finally endanger the survival of the whole ecosystem. “[T]he need to please many different and heterogeneous

³McCann and Vroom (2010) shows that the impact of new entrants on incumbents are not always negative, and can even be positive. However, their argumentation, largely based on the *agglomeration effect* (Potter and Watts, 2010), may certainly not hold when the new entrant is perceived as a potential disruptor.

⁴For example, for an MSP consisting of “one side as a profit center and the other as a loss leader” (Rochet and Tirole, 2003, p. 2), if the technology appeals to the former, but repel the latter. The TiVo case offers a concrete example (Ansari et al., 2016); while TV viewers may appreciate the option to skip advertisings, advertising companies would desert TV network platforms, which would then, in all likelihood, collapse.

²Hagiu (2014) notes that the network effect alone does not necessarily constitute a strong barrier to entry, as illustrated by the Groupon example which saw its valuation plummet when investors realized the absence of switching costs.

platform constituents greatly constrains an MSP’s ability to innovate by introducing truly groundbreaking features” (Hagiu, 2014, p. 5).

In spite of that, disruptions in MSP ecosystems happen—coherently with our discussion in Section 1.2—as illustrated by the TiVo case (Ansari et al., 2016) or by the upheaval in the music industry caused by the advent of digitalization in the recent decades (Easley et al., 2003; Dolata, 2011; Moreau, 2013).

This massive, to the point of being seemingly insurmountable, hurdle for a potential disruptor to enter a multisided ecosystem leads to the disruptor’s dilemma (Ansari et al., 2016). The aspirant disruptor is doomed to failure unless it gains the support of the ecosystem’s incumbents.

From the incumbents’ perspective. Why *mighty* incumbents would deliberately collaborate with a *frail* threatening challenger in lieu of proactively crushing it straightaway? Although we do not pretend to fully elucidate this question, various elements of response can be advanced.

Drawing on the literature, Markman and Waldron (2014) studied the entrant-incumbent relations, and observed that although incumbents typically retaliate when a new player of comparable size attempt an entry, they might tolerate the entry of much smaller entrants. However, the argumentation is based on the assumption that the “micro entrant” has no disruptive capacity (i.e., poses no threat); an assumption that does not hold in our context.

Intuitively, several factors can be hypothesized. Healthy firms are constantly in the look up for growth opportunities (ailing firms might just be focusing on staying afloat—but reposing on similar tactics). For a MSP, one way consists in growing each side, while keeping an adequate balance, which is not trivial, Hagiu (2014, p. 6) indicates that:

The most difficult MSP design decisions are those that involve features putting the interests of different sides of the MSP at odds with each other or with those of the MSP. Such features create strategic trade-offs for the MSP because they generate positive value for some participant groups or for the MSP itself, but negative value for other participant groups.

The TiVo case provides us with a perfect illustra-

tion. TiVo generates positive value to TV viewers—advertising is quantified in terms of hindrance for the audience (Ambrus et al., 2016; Kind et al., 2007; Reisinger, 2012)—and negative value for advertisers. Another example is given by Hagiu (2014) with Microsoft and the *do-not-track* feature in Internet Explorer 9.

When making those decisions, MSPs might underestimate the disruptive power of the new feature (let a seemingly harmful player in). A conjecture in line with the *principles of disruptive innovation* elaborated by Christensen (1997). Conversely, without underestimation, an MSP might be deliberately applying this principle⁵ (and not being a *victim* of it) and see an opportunity (especially in a context where there are competing platforms). In other words, MSPs might anticipate their disruption, and as a remedy, thrive to be part of the superseding platform. The discussion in Section 1.2 about the titans of the Internet acquiring startup companies on an industrial scale perfectly embodies this view. In that same vein, an ailing MSP—e.g., which might have been struggling to meet its objectives, unable to thwart a declining position, attempting in vain to fight emerging alternative platforms—might have become more keen on taking risks and thus on collaborating with its possible successor. The implantation of the iTunes platform in the music industry corroborates this hypothesis (Dolata, 2011).

Speculations from incumbents about the possible success of the innovative technology might engender keen interest in the technology. In particular, the fear of becoming obsolete in the ecosystem should other participants adopt the technology—a situation somewhat akin to a Keynesian beauty contest (Wikipedia, 2016a) and related to beliefs of higher order (Harsanyi, 1967, 1968a,b)—might lead to a self-fulfilling prophecy, where a number of incumbents start to cooperate, paving the way to success for the disruptor. For instance, in the TiVo case, a number of incumbents (including “AOL Time Warner, DirecTV, CBS, NBC, and Disney”) started to cooperate soon after its inception: “Some incum-

⁵It is quasi-undeniable that this work had an impact not only in academia—according to Google Scholar the book has been cited in a ridiculously large number of publications—but also in the industry as well, e.g., Isaacson (2011) reveals that Steve Jobs—who has taken over the helm of the soon-to-go-bankrupt Apple and made it the most valuable company in the world in terms of market cap—was influenced by it.

bents were prompted to engage due to a desire to “keep tabs” on TiVo’s new technology as well as the threat it posed to them” (Ansari et al., 2016, p. 10).

From the potential disruptor’s perspective. In the context of a multisided ecosystem consisting of various sides (themselves formed by a multiplicity of competitors), it appears that one strategy consists for the potential disruptor in gaining a critical mass of supporters as soon as possible; as quoted by Ansari et al. (2016, p. 11) in the TiVo case:

The long-term success of TiVo depends on its ability to quickly build a large subscriber base, integrate its functionality into a broad range of consumer electronics products, and develop new services and programming to enhance the TiVo service. In order to achieve these goals, the company has aggressively pursued strategic partnerships with cable and satellite network operators, television programmers, consumer electronics manufacturers, marketing support partners and suppliers of key components of the TiVo technology (Miller, 2000, p. 12).

The disruptor’s dilemma is, in essence, ingrained in the concept of coopetition (Brandenburger and Nalebuff, 2011). As maintained by Ansari et al. (2016), the potential disruptor must shrewdly promulgate information in order (i) to convince incumbents that they will find long-term benefits—“intertemporal coopetition”—(ii) to lessen the perceived threat—“dyadic coopetition”—and (iii) to smooth out friction between incumbents—“multilateral coopetition”—caused by one side’s favourable attitude towards the disruptor upsetting other sides (Hagiu, 2014).

2. A Global Game Model of the Disruptor’s Dilemma

Global games—a sphere of activity belonging to the realms of game theory and economics—are games of incomplete information first introduced by Carlsson and van Damme (1993)⁶, and subsequently furthered by Morris and Shin (2001); Frankel et al. (2003) and others (Angeletos and Pavan, 2013).

⁶Carlsson and van Damme (1993) coined the term *global games*.

Each player receives perturbed signals from which it⁷ derives an optimal action. As formulated by Morris and Shin (2001, p. 4), global games represent an environment where:

Uncertain economic fundamentals are summarized by a state θ and each player observes a different signal of the state with a small amount of noise. Assuming that the noise technology is common knowledge among players, each player’s signal generates beliefs about fundamentals, beliefs about other players’ beliefs about fundamental, and so on.

Global games of regime change—a sub-discipline of global games—are coordination games of incomplete information in which a status quo is abandoned in favour of its alternative when a sufficiently large mass/fraction of agents decides to support the alternative.

Such games appear particularly well suited for concocting a somewhat reasonable mathematical representation of the disruptor’s dilemma. As we elaborated earlier (see Section 1), the success of a disruptive innovation (i.e., the aspirant disruptor) depends on the number of incumbents that decide to support it. At the outset, the status quo is defined by the current technology on which the multisided ecosystem reposes. When face with an alternative—potentially disruptive—technology, each incumbent must decide whether to support it or to ignore it. If, eventually, the new technology is adopted and supersedes the status quo, the incumbents that contributed to its success receive a positive payoff; whereas the ones that ignored it (in practice, even fought it—see Section 3.2 for further discussion on that point) incur a cost (e.g., deterioration of their positions on the market, to the point of ultimately declaring bankruptcy). This cost embodies the disruptive power of the innovation. By contrast, should the new technology turn unsuccessful, the incumbents that supported it lose the amount they contributed, whereas the ones that ignored it remain unimpacted. To take action, each incumbent receives both public and private information entangled with noise. In practice, this information is disseminated by the potential disruptor—

⁷Throughout this paper the terms *agent*, *player* and *incumbent* are used interchangeably; besides, to solve any gender ambiguity that may surface, the neutral personal pronouns *it* is used in place of those terms when the grammatical structure allows.

e.g., in the TiVo case, “[they] hired an executive familiar with the media industry to reach out to ecosystem incumbents and emphasize the potential benefits of its DVR” (Ansari et al., 2016, p. 10) or “[they] launched an aggressive \$150 million marketing campaign” (Ansari et al., 2016, p. 11). One can remark that the former quote describes a private channel, while the latter describes a public channel.

2.1. Related Literature

Applications of global games abound in the literature, e.g., Morris and Shin (1998) and Hellwig et al. (2006) study currency attacks; Dasgupta (2007) presents project investment decisions; Chamley (1999) addresses the problem of economic regime switch; Argenziano (2005), Angeletos et al. (2007) and Edmond (2013) examine political regimes change; Angeletos et al. (2006) discuss financial crises; Dewan and Myatt (2007) concentrate on party leadership; Angeletos and Pavan (2004) deal with social welfare; Goldstein and Pauzner (2005), Rochet and Vives (2004) and Zwart (2007) tackle bank run phenomena and debt crises.

Typically, those works strive to determine conditions (e.g., on the information structure) that yield a unique equilibrium (Angeletos and Pavan, 2013), for a multiplicity of equilibria is often of little help in many situations due to the non-unicity of the plausible outcome (Morris and Shin, 1998; Hellwig, 2002). “[I]t is hard to base any policy recommendation on their model, since it systematically possesses multiple equilibria” (Rochet and Vives, 2004, p. 3). We do not follow this pattern; instead, we observe the influence of various parameters on the model behaviour via simulations. Indeed, a notable difference between our work and most of the contributions in this discipline arises from our simulation-based approach as opposed to formal mathematical proofs. Although we appreciate the benefits brought about by formal demonstrations—as observations from simulations do not provide tangible evidences of correctness, and thus cannot be generalized beyond the experimental context—we contend that extensive simulations provide a solid insight that can be of significance in a practical context.

The model discussed throughout this section is a rather typical global game model as described in the work of Carlsson and van Damme (1993); Chamley (1999); Angeletos et al. (2007); Morris and

Shin (1998); Edmond (2013); Argenziano (2005) and others. However, the nearest model to the one introduced below is the one presented by Angeletos et al. (2007). In particular, the same assumptions of normality for parameters are made (with the same motivations). For clarity—and ease to refer to their work for additional details and various proofs—we use (almost) the same notations. In our model, the payoff structure slightly differs, though, for we introduce a possible loss for incumbents that decide not to support the potential disruptor. Furthermore, in the dynamic version of the game, we use the previous number of supporters as a public and private information, and the number of supporters is cumulated over the periods (translating the fact that once an incumbent decides to support the potential disruptor, it cannot retract itself later on).

Our work also presents some similarities with the dynamics of project investment decisions studied by Dasgupta (2007); he discusses a two-period global game where agents can decide either to invest during the first period (with the prospect of a higher payoff) or to invest during the second one (with more accurate private information, but a lower payoff). His model assumes that, during the first period, each agent takes into account the possibility to invest during the second period in its decision-making process. By sharp contrast, in our model, the incumbents do not anticipate a possible next round of opportunity; besides, in our model, not only private, but also public signals from previous rounds are observed.

2.2. Modelling the Disruptor’s Dilemma

We consider a uniformly distributed continuum of incumbents $[0, 1]$. Incumbents make decision simultaneously and are risk-neutral. Each incumbent i must decide whether it supports or not the potential disruptor; the boolean variable $s_i \in \{0, 1\}$ represents that decision. Table 1 summarizes the payoff. If i decides to support the potential disruptor (i.e., $s_i = 1$) a cost $c \in [0, 1]$ is incurred. This investment is lost if the potential disruptor at last fails; if, however, it becomes eventually successful, i receives a payoff of $1 - c \geq 0$. Alternatively, if i decides not to support the potential disruptor, i.e., $s_i = 0$, it risks incurring a loss $b \in [0, 1]$, should the disruptor be eventually successful—and a payoff of zero, otherwise. Figure 1 depicts a decision tree of the game.

Let p denotes the probability of the potential

disruptor to succeed. The incumbent i would support the disruptor if and only if

$$(1) \quad (1 - c)p - c(1 - p) \geq -bp$$

$$\text{i.e., } p \geq \frac{c}{1 + b}.$$

The potential disruptor is successful if and only if the aggregate value of supporters

$$(2) \quad \mathcal{S} = \int_0^1 s_k dk$$

is greater than a threshold $\theta \in [0, 1]$. The parameter θ embodies the hurdle for the potential disruptor to succeed.

As mentioned earlier, b embodies the disruptive effect; θ , on the other hand, symbolizes the strength of the status quo, which is connected to the barriers to entry, in particular the network effect (Zhu and Mitzenmacher, 2008).

If it is publicly known that $\theta = 0$, the potential disruptor does not require any support to be successful⁸; and thus, all incumbents will support it, as otherwise they will become obsolete (a fact expressed by the negative payoff $-b$). At the other extreme, if $\theta = 1$, the potential disruptor will fail regardless of the support it may receive; hence no incumbent will support it (as otherwise the incumbent would lose the efforts invested in its support initiative, translated by the negative payoff $-c$).

Let $\mathbf{s} = (s_k)_{k \in [0,1]}$ denotes the decision profile over all incumbents. Incumbent i 's payoff is given by:

$$(3) \quad u_i(\mathbf{s}, \theta) = (\mathbf{1}_{\{\mathcal{S} \geq \theta\}} - c) s_i - (\mathbf{1}_{\{\mathcal{S} \geq \theta\}} - s_i) b$$

$$+ (\mathbf{1}_{\{\mathcal{S} \geq \theta\}} - 1) s_i b$$

$$= \mathbf{1}_{\{\mathcal{S} \geq \theta\}} (s_i(1 + b) - b) - cs_i,$$

where $\mathbf{1}_{\{\cdot\}}$ is the indicator function.

As noted by Angeletos et al. (2007), if θ is a public information precisely known by all incumbents, two pure-strategy equilibria exist: either all incumbents support the potential disruptor (i.e., $\mathcal{S} = 1$) or none of them does (i.e., $\mathcal{S} = 0$).

In practice, however, θ is not known, and each incumbent has a mixture of noisy public and private information to make its choice.

⁸Barring any idiosyncratic risks, which are not considered in the presented model.

Table 1: Payoff for incumbent i

	success ($\mathcal{S} \geq \theta$)	failure ($\mathcal{S} < \theta$)
support ($s_i = 1$)	$1 - c$	$-c$
not support ($s_i = 0$)	$-b$	0

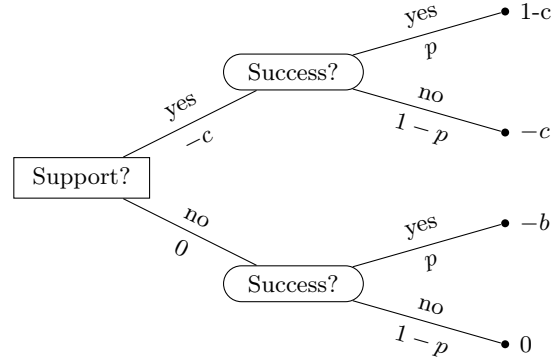


Figure 1: Decision tree for incumbent i

2.2.1. Static Game

At the outset, Nature randomly chooses θ from a common prior probability distribution

$$(4) \quad \mathcal{N}(z, 1/\alpha),$$

i.e., assumed to be commonly known by all incumbents.

Further to the shared prior, each incumbent i receives a private information

$$(5) \quad x_i = \theta + \varepsilon_i,$$

with the noise parameter

$$(6) \quad \varepsilon_i \sim \mathcal{N}\left(0, \frac{1}{\beta}\right)$$

independent and identically distributed across the population.

As described by Angeletos et al. (2007), “[t]he Normality assumptions allow us to parameterize the information structure parsimoniously with (β, α, z) , that is, the precision of private information, the precision of the common prior, and the mean of the common prior.”

Monotone equilibrium. A monotone strategy is a strategy for which there exists a threshold value below which the incumbent decides one action, and above which it decides the alternative action. More formally, an incumbent i follows a monotone strategy if it exists $x_i^* \in \mathbb{R}$ such that $s_i = 1$ if and

only if $x_i \leq x_i^*$. A symmetric Bayesian Nash equilibrium in monotone strategies (simply referred to as *monotone equilibrium* thereafter) has a threshold x^* that is common to all the incumbents (hence the term *symmetric*):

$$(7) \quad \exists x^* \in \mathbb{R} \mid \forall i \in [0, 1], s_i = \begin{cases} 1 & \text{iff } x_i \leq x^* \\ 0 & \text{otherwise.} \end{cases}$$

When an incumbent i (at equilibrium, i.e., $x_i = x^*$) decides to support the potential disruptor, it rightly believes that all the other incumbents j that have received a signal $x_j \leq x^*$ decide to support the potential disruptor as well (Dasgupta, 2007).

Assuming the existence of x^* , the measure of incumbents that decide to support the potential disruptor \mathcal{S} is a function of θ and is given by:

$$(8) \quad \mathcal{S}(\theta) = \Pr(x \leq x^* \mid \theta),$$

which, given our assumption (6), becomes

$$(9) \quad \mathcal{S}(\theta) = \Phi\left(\sqrt{\beta}(x^* - \theta)\right),$$

where $\Phi : \mathbb{R} \rightarrow [0, 1]$ denotes the cumulative distribution function for the normal distribution.

Recalling that the potential disruptor is successful if and only if $\mathcal{S}(\theta) \geq \theta$ and following the same development as the one presented by Angeletos et al. (2007), one can observe that $\mathcal{S} : \mathbb{R} \rightarrow [0, 1]$ is strictly decreasing in θ ; therefore, the potential disruptor becomes successful if and only if $\theta \leq \theta^*$, where $\theta^* \in \mathbb{R}$ solves for θ the equation $\theta = \mathcal{S}(\theta)$.

From assumptions (4) and (6), the posterior—or updated—distribution for θ given observation (5) is (by Bayesian normal updating):

$$(10) \quad \mathcal{N}\left(\frac{\beta x_i + \alpha z}{\beta + \alpha}, \frac{1}{\beta + \alpha}\right).$$

Incumbent i believes that the posterior probability of success for the potential disruptor is yielded by

$$(11) \quad \Pr(\theta \leq \theta^* \mid x_i) = \Phi\left(\sqrt{\beta + \alpha}\left(\theta^* - \frac{\beta x_i + \alpha z}{\beta + \alpha}\right)\right).$$

The function $p : x_i \mapsto \Pr(\theta \leq \theta^* \mid x_i)$ is decreasing, and from equation (1), one can derive that the incumbent i offers its support if and only if $p(x_i) \geq c/(1+b)$, i.e., if and only if $x_i \leq x^*$, where $x^* \in \mathbb{R}$ solves $p(x^*) = c/(1+b)$.

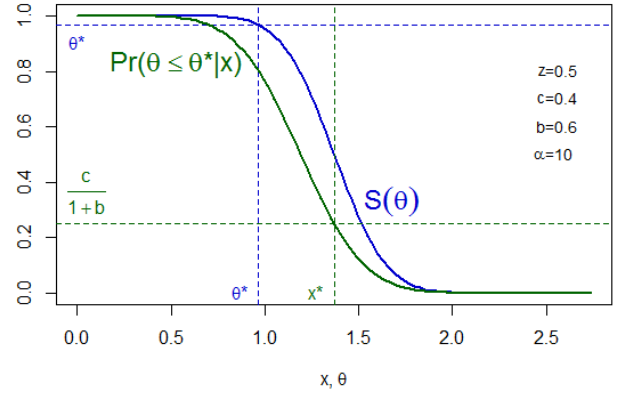


Figure 2: Monotone equilibrium (x^*, θ^*) given by the solution of the system of equations (12).

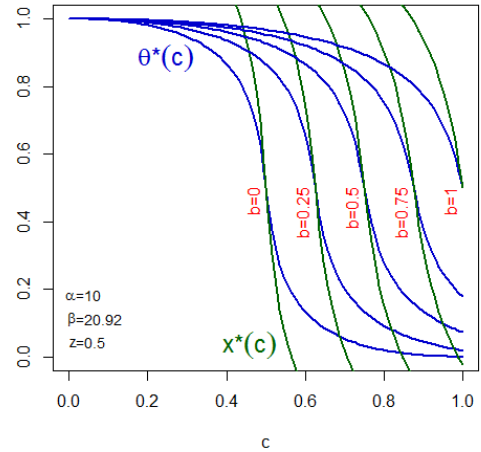


Figure 3: θ^* and x^* as a function of c for various values of b .

It follows that a monotone equilibrium is given by the solution (x^*, θ^*) of the following system of equations:

$$(12) \quad \begin{cases} \Phi\left(\sqrt{\beta}(x^* - \theta^*)\right) = \theta^* \\ \Phi\left(\sqrt{\beta + \alpha}\left(\theta^* - \frac{\beta x^* + \alpha z}{\beta + \alpha}\right)\right) = \frac{c}{1+b}. \end{cases}$$

An incumbent i supports the potential disruptor if and only if $x_i \leq x^*$; and the potential disruptor is successful if and only if $\theta \leq \theta^*$. Figure 2 shows the curves $p : x \mapsto \Pr(\theta \leq \theta^* \mid x)$ and $S : \theta \mapsto \Pr(x \leq x^* \mid \theta)$.

Angeletos et al. (2007) prove that the equilibrium exists and is unique for all $z \in \mathbb{R}$ if and only if $\beta \geq \alpha^2/(2\pi)$. Although our payoff structure differs from theirs, the proof remains valid and the conclusion unchanged.

A few observations. Figure 3 depicts the impact of the cost to support on the equilibrium; as dictated by intuition, the higher the cost, the less likely the potential disruptor gains supporters. This is

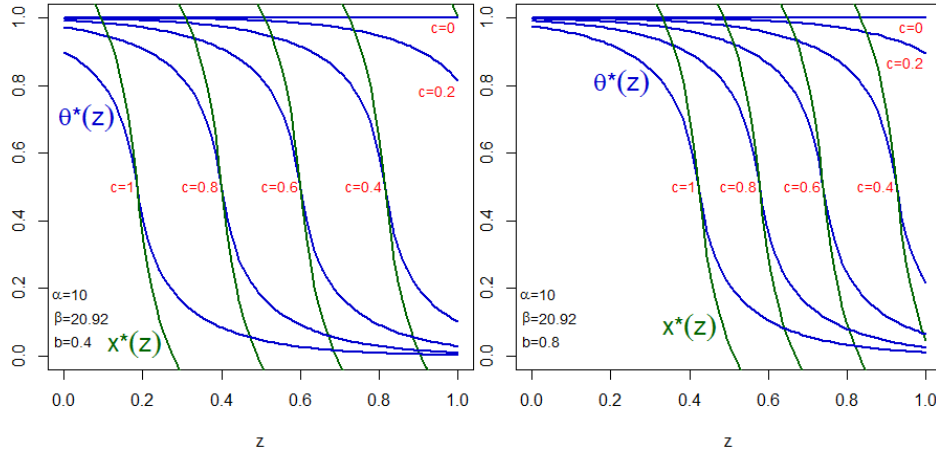


Figure 4: θ^* and x^* as a function of z for various values of c .

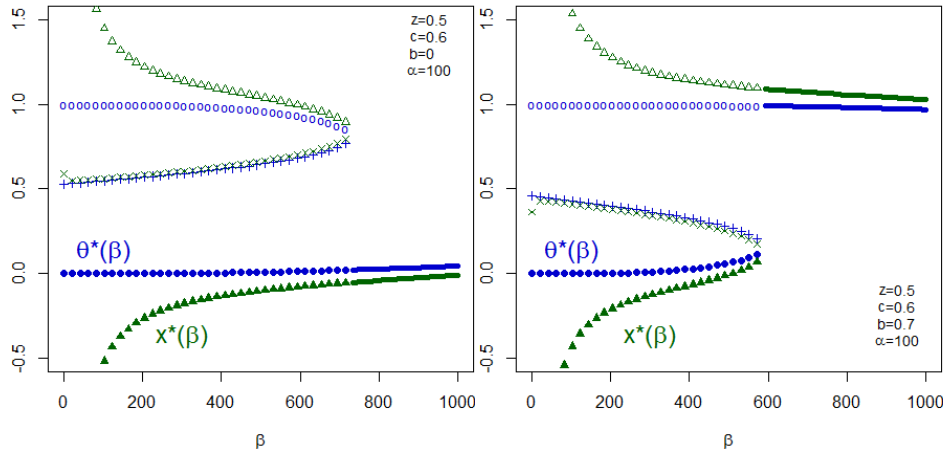


Figure 5: Monotone equilibria. The difference between the left graph and the right graph is the value of b (in the left graph, there is no downside not to support the potential disruptor). A continuous line connotes the fact that the equilibrium is unique, whereas the points—the triangles and ‘x’ for $x^*(\beta)$, and circles and ‘+’ for $\beta^*(\beta)$ —show equilibrium that are not unique.

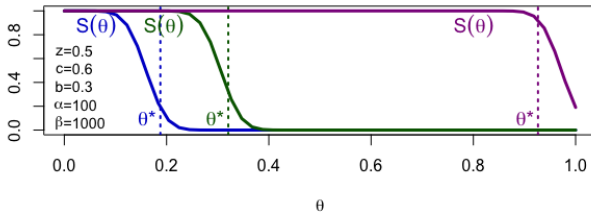


Figure 6: Number of supporters S as a function of θ in a scenario where there are three equilibria.

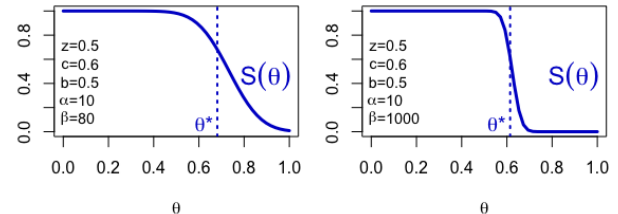


Figure 7: Number of supporters S as a function of θ , with a somewhat low precision (left) and a rather high precision (right) of the private signal.

balanced, though, with the loss incurred when not supporting a successful disruptor (i.e., b). For instance, assuming $z = 0.5$, if $c = b = 1$, then $(\beta^*, x^*) = (0.5, 0.5)$.

Figure 4 illustrates the effect of the strength of the status quo (i.e., the difficulty for the potential disruptor to succeed). It shows that when the payoff of supporting is null ($c = 1$), incumbents have still some incentive to support the potential disruptor in order to avoid the downside of not supporting while it eventually succeeds (i.e., a loss of b). Evidently,

at the other extreme, when there is no cost to support the potential disruptor ($c = 0$), all incumbents support it.

Figure 5 depicts the non-uniqueness of equilibria when the condition $\beta \geq \alpha^2/(2\pi)$ is not satisfied. Figure 6 gives the number of supporters in yet another example of such a situation.

Figure 7 shows that when the precision is high (little noise on the private signal—i.e., β is large), a small variation in θ can lead to a rapid and drastic reversal

of situations. This phenomenon is described in detail elsewhere (Angeletos and Werning, 2006).

2.2.2. Two-Round Game

We update the static game discussed in the previous section 2.2.1 so that when the potential disruptor does not receive a sufficient number of supporters during the first round, a second round is organized.

We consider, thus, two time periods t_1 and $t_2 > t_1$. The first round at t_1 is equivalent to the static game described above. Should the first round turn unsuccessful for the potential disruptor (i.e., $\mathcal{S}(\theta) < \theta^*$), a second round is considered. The incumbents that decided to support the potential disruptor during the first round are still supporting it during the second round (i.e., once an incumbent has decided to offer its support, it cannot reverse its decision—in yet other words, the decision to support is irrevocable). The existence of a possible second round is not anticipated by the incumbents at period t_1 . Note that this is in sharp contrast with the work of Dasgupta (2007), in which the agents can anticipate the possibility to play a second round from the outset. However, if a second round is indeed organized, the incumbents receive both public and private information from the outcome of the first round (namely the measure of incumbents that are supporting the potential disruptor).

Supporting the potential disruptor at t_2 entails a “penalty” of ω on the payoff should the disruptor eventually succeed; in that case, the payoff is $1 - \omega - c$, with $0 \leq \omega \leq 1 - c$.

Let $s_{i,t} \in \{0, 1\}$ denotes the decision of incumbent i at period t , and $\mathcal{S}_t \in [0, 1]$ the measure of incumbents that support the potential disruptor at period t . At period t , the potential disruptor becomes successful if and only if $\mathcal{S}_t \geq \theta$.

The accumulated information at period t_2 is two-fold: a private signal about θ and both a public and a private signals about the measure of supporters $\mathcal{S}_{t_1}(\theta)$ observed in the previous period.

At each period t , each incumbent i (that has yet to decide) receives a private signal

$$(13) \quad \tilde{x}_{i,t} = \theta + \varepsilon_{i,t},$$

where

$$(14) \quad \varepsilon_{i,t} \sim \mathcal{N}\left(0, \frac{1}{\eta_t}\right)$$

is independent and identically distributed across the entire population of incumbents.

At t_2 , we assume that each incumbent has collected information about the size of the supporters observed at t_1 . The same normality assumption as in the work of Dasgupta (2007) are made⁹. At period t_2 , a public signal

$$(15) \quad \psi_{t_2} = \Phi^{-1}(\mathcal{S}_{t_1}) + \xi_{t_2}$$

is received by all incumbents, where

$$(16) \quad \xi_{t_2} \sim \mathcal{N}\left(0, \frac{1}{\delta_{t_2}}\right).$$

Furthermore, a private signal

$$(17) \quad \varphi_{i,t_2} = \Phi^{-1}(\mathcal{S}_{t_1}) + v_{i,t_2}$$

is received by incumbent i , where

$$(18) \quad v_{i,t_2} \sim \mathcal{N}\left(0, \frac{1}{\gamma_{t_2}}\right)$$

is independent and identically distributed across the entire population of incumbents.

Monotone equilibrium. At period t_1 , incumbents decide to support the potential disruptor as in the static game discussed above, and the measure of supporters is yielded by

$$(19) \quad \mathcal{S}_{t_1}(\theta) = \Phi\left(\sqrt{\beta_{t_1}}(x_{t_1}^* - \theta)\right),$$

where $\beta_{t_1} = \eta_{t_1}$.

In the same vein as for the static game discussed above, the potential disruptor succeeds if and only if $\theta \leq \theta_{t_1}^*$, where $\theta_{t_1}^* \in \mathbb{R}$ solves $\theta_{t_1}^* = \mathcal{S}_{t_1}(\theta_{t_1}^*)$; and incumbent i supports the potential disruptor if and only if $\tilde{x}_{i,t_1} \leq x_{t_1}^*$, where $x_{t_1}^* \in \mathbb{R}$ solves $\Pr(\theta \leq \theta_{t_1}^* | x_{t_1}^*) = c/(1+b)$ —equation (11) gives a closed-form expression of the right-hand side of this equation.

If $\theta > \theta_{t_1}^*$, then a second round occurs at t_2 , during which incumbent i receives the three additional signals \tilde{x}_{i,t_2} , φ_{i,t_2} and ψ_{t_2} .

From equations (15) and (17), it follows that

$$(20) \quad \psi_{t_2} = \sqrt{\beta_{t_1}}(x_{t_1}^* - \theta) + \xi_{t_2}$$

$$(21) \quad \varphi_{i,t_2} = \sqrt{\beta_{t_1}}(x_{t_1}^* - \theta) + v_{i,t_2}$$

⁹Dasgupta (2007) assumes that the signal received by the agents at t_2 regarding the ratio of agents that did participate at t_1 is private. By contrast, we assume that the agents receive two signals, one private and one public.

We adapt the reasoning presented by Angeletos et al. (2007) in their online supplement; the posterior belief of incumbent i about $\theta \mid \tilde{x}_{i,t_1}, \tilde{x}_{i,t_2}, \varphi_{i,t_2}, \psi_{t_2}$ is (by Bayes's rule)

$$(22) \quad \mathcal{N} \left(\frac{\beta_{t_2} x_{i,t_2} + \alpha_{t_2} z_{t_2}}{\beta_{t_2} + \alpha_{t_2}}, \frac{1}{\beta_{t_2} + \alpha_{t_2}} \right),$$

with

$$(23) \quad \beta_{t_2} = \beta_{t_1} + \eta_{t_2} + \beta_{t_1} \gamma_{t_2}$$

$$(24) \quad \alpha_{t_2} = \alpha + \beta_{t_1} \delta_{t_2}$$

and

$$(25) \quad x_{i,t_2} = \frac{\beta_{t_1} \tilde{x}_{i,t_1} + \eta_{t_2} \tilde{x}_{i,t_2}}{\beta_{t_2}} + \frac{\beta_{t_1} \gamma_{t_2}}{\beta_{t_2}} \left(x_{t_1}^* - \frac{\varphi_{i,t_2}}{\sqrt{\beta_{t_1}}} \right)$$

$$(26) \quad z_{t_2} = \frac{\alpha_{t_1} z}{\alpha_{t_2}} + \frac{\beta_{t_1} \delta_{t_2}}{\alpha_{t_2}} \left(x_{t_1}^* - \frac{\psi_{t_2}}{\sqrt{\beta_{t_1}}} \right).$$

A monotone equilibrium is characterized by the existence of $x_{t_2}^* \in \mathbb{R}$ such that $s_{i,t_2} = 1$ if and only if $x_{i,t_2} \leq x_{t_2}^*$. Each incumbent i receives the new signals \tilde{x}_{i,t_2} , φ_{i,t_2} and ψ_{t_2} ; however $\mathcal{S}_{t_1}(\theta)$ of them already made the irrevocable decision to support the potential disruptor at period t_1 —hence only $1 - \mathcal{S}_{t_1}(\theta)$ of them have yet to decide. The measure of supporters at t_2 is then given by:

$$(27) \quad \mathcal{S}_{t_2}(\theta) = \mathcal{S}_{t_1}(\theta) + (1 - \mathcal{S}_{t_1}(\theta)) \Pr(x \leq x_{t_2}^* \mid \theta).$$

At period t_2 the precision of the private information increases due to the newly received signals (Angeletos et al., 2007)—see Equation (23)—and we have

$$(28) \quad \Pr(x \leq x_{t_2}^* \mid \theta) = \Phi \left(\sqrt{\beta_{t_2}} (x_{t_2}^* - \theta) \right).$$

Given that \mathcal{S}_{t_2} is decreasing in θ (see Appendix A), the potential disruptor becomes successful at t_2 if and only $\theta \leq \theta_{t_2}^*$, where $\theta_{t_2}^* \in \mathbb{R}$ solves for θ the equation

$$(29) \quad \theta = \mathcal{S}_{t_2}(\theta).$$

Let us consider the function $x_{i,t_2} : \tilde{x}_{i,t_2} \mapsto x_{i,t_2}(\tilde{x}_{i,t_2})$, which is unambiguously defined from (25), and the function $p : x \mapsto \Pr(\theta \leq \theta_{t_2}^* \mid x, \theta >$

$\theta_{t_1}^*)$. One can observe that the function $x \mapsto p \circ \tilde{x}_{i,t_2}(x)$ is strictly decreasing. It follows that incumbent i supports the potential disruptor at t_2 if and only if it exists $x_{t_2}^* \in \mathbb{R}$ such that $x_{i,t_2} \leq x_{t_2}^*$ and

$$(30) \quad \Pr(\theta \leq \theta_{t_2}^* \mid x_{t_2}^*, \theta > \theta_{t_1}^*) = \frac{c}{1 - \omega + b}.$$

Using the updated posterior belief about θ given by Equation (22),

$$\begin{aligned} & \Pr(\theta \leq \theta_{t_2}^* \mid x_{t_2}^*, \theta > \theta_{t_1}^*) \\ &= \frac{\Pr(\theta \leq \theta_{t_2}^*, \theta > \theta_{t_1}^* \mid x_{t_2}^*)}{\Pr(\theta > \theta_{t_1}^* \mid x_{t_2}^*)} \\ &= 1 - \frac{\Phi \left(\sqrt{\beta_{t_2} + \alpha_{t_2}} \left(\frac{\beta_{t_2} x_{t_2}^* + \alpha_{t_2} z_{t_2}}{\beta_{t_2} + \alpha_{t_2}} - \theta_{t_2}^* \right) \right)}{\Phi \left(\sqrt{\beta_{t_2} + \alpha_{t_2}} \left(\frac{\beta_{t_2} x_{t_2}^* + \alpha_{t_2} z_{t_2}}{\beta_{t_2} + \alpha_{t_2}} - \theta_{t_1}^* \right) \right)}. \end{aligned}$$

Substituting $x_{t_2}^*$ with x in this expression gives a closed-form expression of the function $f : x \mapsto p \circ \tilde{x}_{i,t_2}(x)$. As observed by Angeletos et al. (2007) in a comparable setting, the function f is continuous and strictly decreasing; furthermore, $\lim_{x \rightarrow -\infty} f(x) = 1$ and $\lim_{x \rightarrow +\infty} f(x) = 0$, therefore assuming that $c/(1 - \omega + b) \in]0, 1]$, a solution $x_{t_2}^*$ for Equation (30) exists.

As discussed by Angeletos et al. (2007) for *signals about past attacks*—see their online supplement as well—and observed from Equations (30) and (26), at period t_2 , the thresholds $(\theta_{t_2}^*, x_{t_2}^*)$ are functions of ψ_{t_2} ; a monotone equilibrium is therefore characterized by $(\theta_{t_1}^*, x_{t_1}^*) \in \mathbb{R}^2$ and $(\theta_{t_2}^*, x_{t_2}^*)$, where $\theta_{t_2}^* : \mathbb{R} \rightarrow [0, 1]$ and $x_{t_2}^* : \mathbb{R} \rightarrow \mathbb{R}$.

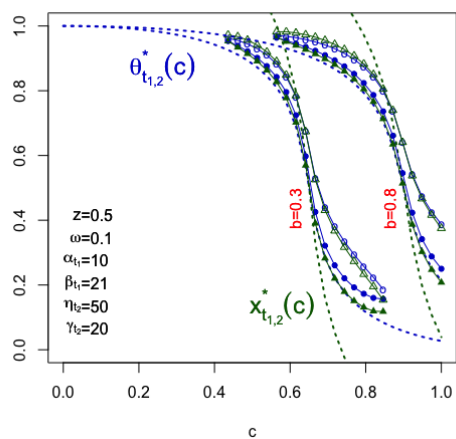
Assuming $\delta_{t_2} = 0$, i.e., assuming that the incumbents do not receive any further public information during the second round¹⁰, the monotone equilibria are of the form $\{(\theta_{t_1}^*, x_{t_1}^*), (\theta_{t_2}^*, x_{t_2}^*)\}$, where $(\theta_{t_1}^*, x_{t_1}^*)$ is a solution of the system (12) and $(\theta_{t_2}^*, x_{t_2}^*) \in \mathbb{R}^2$ is a solution of the system of equations

$$(31) \quad \begin{cases} \theta_{t_2}^* = \mathcal{S}_{t_2}(\theta_{t_2}^*) \\ \Pr(\theta \leq \theta_{t_2}^* \mid x_{t_2}^*, \theta > \theta_{t_1}^*) = \frac{c}{1 - \omega + b}, \end{cases}$$

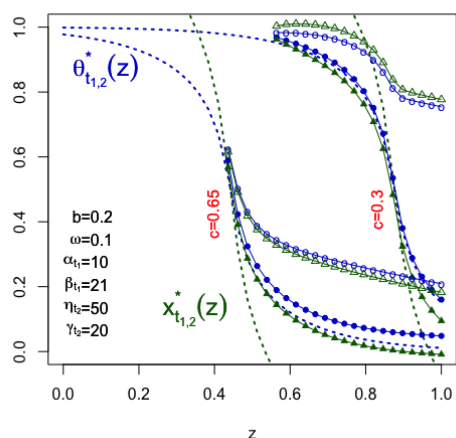
with the constraint that $\theta_{t_2}^* > \theta_{t_1}^*$, for we know that $\theta > \theta_{t_1}^*$, otherwise there would be no second round.

From the lemma 2 of Angeletos et al. (2007) we can infer that a solution to (31) does not always exist (depending on the value of $\theta_{t_1}^*$ and β_{t_2}). Besides, when a solution exists, it may not be unique.

¹⁰If $\delta_{t_2} = 0$, then, from Equation (26), $z_{t_2} = z$, i.e., z_{t_2} no longer depends on ψ_{t_2} .



(a) θ^* and x^* as a function of c for different values of b .



(b) θ^* and x^* as a function of z for different values of c .

Figure 8: The dashed blue line represents $\theta_{t_1}^*$, the dashed green line represents $x_{t_1}^*$, the blue circles represent $\theta_{t_2}^*$ and the green triangles represent $\theta_{t_2}^*$.

A few observations. We conducted some simulations during which we assume $\delta_{t_2} = 0$, i.e., we assumed that, at t_2 , the incumbents only receive private information about the mass of incumbents that decided to support the potential disruptor during the first round.

Figure 8 depicts the presence of multiple equilibria. Although we have not investigated the conditions under which an equilibrium exists, and when it exists the conditions that guarantee its unicity, our rather extensive set of simulations revealed that system (31) has either no solution¹¹ or exactly two

¹¹We have relied on *nleqslv*’s package (<https://goo.gl/9eoEO0>) to implement a numerical method to solve (31)—and draw the various graphs presented throughout this paper. It is essential to bear in mind that *no solution* found does not necessarily means that the system has no solution; it might be simply due to some anomalies caused by numerical limitations. Likewise, found solutions might not exist in theory, but given a tolerable error those solutions are acceptable in practice; having said that, we

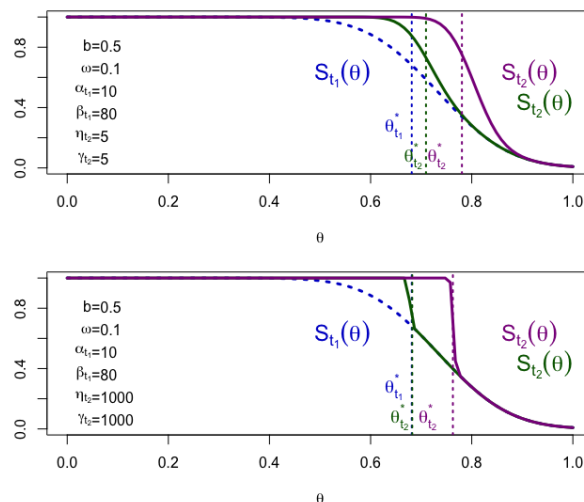


Figure 9: Number of supporters S_{t_1} and S_{t_2} as a function of θ , with a somewhat low precision (top— $\eta_{t_2} = \gamma_{t_2} = 5$) and a rather high precision (bottom— $\eta_{t_2} = \gamma_{t_2} = 1000$) of the private signal in the second round.

solutions. Angeletos et al. (2007) study in depth multiplicity of equilibria—see, e.g., Theorems 1 & 2—however, their model differs from ours to the point that there is no obvious adaptation.

Figure 9 illustrates again that when the precision is high in the second round (i.e., η_{t_2} and γ_{t_2} are large), a slight variation in θ leads to radically different outcomes. A “crisis” situation often observed in global-game applications (Angeletos and Werning, 2006; Angeletos et al., 2007).

Multiplicity of equilibria. Multiple equilibria in global games, and more broadly in games with imperfect information, has already received much attention among scholars (Angeletos and Pavan, 2013; Carlsson and Van Damme, 1989; Carlsson and van Damme, 1993; Angeletos et al., 2006; Morris and Shin, 2000; Myatt and Wallace, 2002; Morris and Shin, 2001; Morris et al., 2016; Cho and Kreps, 1987; Morris and Shin, 1998; Kohlberg et al., 1986; Chas-sang, 2010; Zwart, 2007; Hellwig, 2002; Harsanyi, 1995; Cabrales et al., 2007; Diamond and Dybvig, 1983; Obstfeld, 1986), and is regarded as an undesirable setting, for it is propitious for coordination failures. Hellwig (2002, p. 2) asserts that:

Equilibrium multiplicity makes it impossible to draw determinate economic predictions or policy implications from dynamic

obtain a minimum number of solutions, for other solutions might exist, but not found by the algorithm—this scenario remains rather unlikely, though.

analysis or comparative statics, and qualitative conclusions are often restricted to informal predictions as to how policies may alter expectations or act as a coordination device towards one equilibrium.

Tamer (2003, p. 2) observes that “[t]o avoid multiplicity, economists studying these models [with a multiplicity of equilibria] have simplifying assumptions which either change the outcome space or impose ad hoc selection mechanisms in regions of multiplicity.”

The two observed equilibria in Figure 8 suggest the possibility of conflicting scenario. A situation in which the potential disruptor fails (i.e., a coordination failure), even though the underlying fundamentals were favourable for its success, becomes conceivable.

2.2.3. Multi-Round Game (Dynamic Game)

The two-round game detailed above can be generalized to n -round game, with $n \in \mathbb{N}_{>2}$. One can observe that the cumulative measure of the incumbents supporting the potential disruptor over time is recursively given by

$$(32) \quad \mathcal{S}_{t_n}(\theta) = \mathcal{S}_{t_{n-1}}(\theta) + (1 - \mathcal{S}_{t_{n-1}}(\theta)) \times \Pr(x \leq x_{t_n}^* \mid \theta),$$

with

$$(33) \quad \Pr(x \leq x_{t_n}^* \mid \theta) = \Phi\left(\sqrt{\beta_{t_n}}(x_{t_n}^* - \theta)\right),$$

with $\forall k \in \llbracket 1 \dots n \rrbracket$, $\beta_{t_k} = \beta_{t_{k-1}} + \eta_{t_k} + \beta_{t_{k-1}}\gamma_{t_k}$ and $\beta_{t_1} = \eta_{t_1}$ (Angeletos et al., 2007).

However, it appears that devising a closed-form expression of both ψ_{t_n} and φ_{i,t_n} at period t_n with $n > 2$ is not trivial—due to the non-linearity of Φ in equations (15) and (17). We do not detail any further the n -round game in the scope of this paper.

3. Discussions

3.1. Interpretation of the Findings

Our model suggests that (i) the existence of a unique equilibrium can be guaranteed during the first round on the condition that a sufficiently precise private information relative to the precision of the initial common prior is received by the incumbents (i.e.,

$\beta \geq \alpha^2/(2\pi)$, see Section 2.2.1); and (ii) during the second round, the new information derived from the outcome of the first round leads to multiple equilibria (or possibly no equilibrium).

One can note that, depending on the economic fundamentals, a unique equilibrium is not synonymous with success; but simply indicates that the assumed rational incumbents are expected to coordinate their action choices—hence a predictable behaviour. Likewise, a multiplicity of equilibria does not necessarily imply that the potential disruptor is doomed; it may, however, face major setbacks due to plausible coordination failures even when the fundamentals are favourable for its success.

Those observations point to one credible strategy that consists for the potential disruptor in astutely orchestrating information dissemination, at the very outset, so as to ensure the existence of a unique equilibrium—and thus to aid the incumbents to successfully coordinate their actions. If the underlying economic fundamentals permit (i.e., θ is not too high), the potential disruptor may then increase its chance of success during the first round.

3.2. Limitations

As already mentioned earlier, the presented model may be somewhat deficient in substantive elaboration; it is, however, well aligned with the noted Box’s aphorism about models’ inherent wrongness: “Since all models are wrong the scientist cannot obtain a “correct” one by excessive elaboration. On the contrary ... he should seek an economical description of natural phenomena” (Box, 1976, p. 792).

Global games constitute a reasonable means of obtaining this *economical description* of a considerably complex phenomenon; as puts by Morris and Shin (2001, p. 4): “[O]ptimal strategic behavior should be analyzed in the space of all possible infinite hierarchies of beliefs; however, such analysis is highly complex for players and analysts alike and is likely to prove intractable in general.” The trade-off between tractability and complexity seems appropriate judging from the plethora of global game applications reported in the literature (see, e.g., Morris and Shin, 1998; Chamley, 1999; Hellwig et al., 2006; Angeletos et al., 2006; Zwart, 2007; Angeletos et al., 2007; Angeletos and Pavan, 2013, and others).

Nevertheless, focusing specifically on the disruptor’s

dilemma, some assumptions might render the model overly stylized. Especially considering that our model appears to never yield a unique equilibrium during the second round¹². Tamer (2003, p. 5) qualifies such models with non-unique equilibrium as *incomplete econometric* models and notes that the “incompleteness is often the result of the unwillingness to impose strong (and sometimes untestable) assumptions.”

The following paragraphs discuss some assumptions that, we believe, could be refined.

Incumbents’ resistance. The assumption that incumbents can either support the potential disruptor or just ignore it is far-fetched. In practice, they might immediately retaliate via, e.g., smear campaigns and other demeaning manoeuvres. The Ansari et al. (2016, p. 9)’s quote illustrates this attitude:

And, when they [ecosystem incumbents] saw this thing [TiVo’s DVR], they’d just go completely nuts ... (and show) every emotion [such as] ... anger, hate ... And not only did they have a negative reaction and throw us out of their office ... but they talked to the press ... and would tell them that we were evil and that, if this took off, it was going to have a massive negative impact on the US economy, and all sorts of doomsday kind of statements (iinnovate.blogspot.com, 2016).

Such denigratory initiatives could be regarded as a mixture of public news (Angeletos et al., 2007) and information manipulation (Edmond, 2013). In effect, this amounts to different channels divulging somewhat diverging or even conflicting information about the fundamentals. Such information channels should not be ignored, for they may have the potential to achieve remarkable turnarounds. For example, in a context fairly comparable to a regime change situation, the very recent US presidential election was the arena of numerous controversies

¹²A *loose* conclusion inferred from simulations in which only additional private signal is considered (e.g., $\delta_{t_2} = 0$). However, Angeletos et al. (2007) already formally demonstrated that in a dynamic setting with public signals (e.g., public news), “there always exist multiple equilibria” (Angeletos et al., 2007, p. 23, theorem 2), a result that we would then observe when $\delta_{t_2} > 0$ —“[t]he multiplicity result of Theorem 2 thus extends directly” (Angeletos et al., 2007, online supplement, p. 2) to games with signals about the size of *past attacks*.

with regards to *fake news* that supposedly influenced the outcome; Allcott and Gentzkow (2017) examine this case and support the allegations: “We confirm that fake news was both widely shared and tilted in favor of Donald Trump” (Allcott and Gentzkow, 2017, p. 3).

Payoff structure. The payoff structure (see Table 1) assumes that if an incumbent i supports the disruptor, which eventually succeeds, then i is rewarded. This assumption is crucial in the incumbents’ decision. However, the reality may not reflect this assumption. The main issue lies in the fact that it is not easy to know the distribution of benefits after the occurrence of a disruption; that is to say that even though an incumbent does offer its support, it might find itself in trouble if the technology eventually becomes successful. A credible scenario which might repel potential supporters as expressed by Ansari et al. (2016, p. 10): “Particularly threatening to incumbents is the uncertainty over how the disruptor’s innovation will redistribute revenues and profits among ecosystem members. Consequently, it is likely that the newcomer will not gain support for its innovation.”

3.3. Future Works

Although the points raised in Section 3.2 should be addressed in the future, in this subsection we focus on the immediate next steps we see would be of great significance to complement the work that has been presented throughout this paper.

Signalling. As discussed in Section 2, the information received by incumbents is (partly) communicated by the potential disruptor. It is the case that this has a cost for the potential disruptor—which has limited resources. For example, TiVo committed a weighty amount of resources to reach incumbents, via, e.g., TV commercials (public signal): “TiVo launched an aggressive \$150 million marketing campaign” (Ansari et al., 2016, p. 11); or the hire of executives (private signal): “TiVo hired an executive familiar with the media industry to reach out to ecosystem incumbents” (Ansari et al., 2016, p. 10). This cost incurred by the potential disruptor, motivated by its expected subsequent payoff, should be captured by the model; which would then include two payoff structures, the one for incumbents—already in our current model, see Table 1—and the

one for the potential disruptor. Such considerations have already been studied, e.g., see the work of Angeletos and Pavan (2013), Angeletos et al. (2006) and Edmond (2013). Those previous works could serve as a starting point to enhance our model.

Anticipation of subsequent rounds. Our model substantially reposes on the assumption that incumbents do not anticipate a new opportunity for deciding whether or not to support the potential disruptor. Their decision is taken from observing past outcomes only. This assumption might appear overly restrictive, for it is easy to conceive that, during their first encounter with the new technology, incumbents expect/anticipate ulterior possibilities to be involved.

A conception corroborated by the TiVo case: “[T]he persistence required [by the potential disruptor] to forge such relational ties [with incumbents] despite being rebuffed repeatedly” (Ansari et al., 2016) strongly suggests an acknowledged (by both parties) multi-round process from the outset. It is worth bearing in mind, though, that in our model, the concept of rounds/periods (like t_1 and t_2) differs from a temporal snapshot—i.e., a single point on a linear representation of time, as often in physical sciences—but is rather subjectively defined by a set of somewhat related (in some sense) events taking place in a *rather narrowly* bounded period of time. Consequently, one could argue that those “repeated” attempts at convincing incumbents in the TiVo case belong to the same round (i.e., each attempt does not constitute a single round). Nevertheless, even with this loose view of a round (which may only weaken the TiVo illustration set forth above), the question of anticipating the next rounds when making a decision in the current one remains fully valid.

Dasgupta (2007) presents a global game in which participants have the option to delay their decision (which incurs a cost). “Agents will thus rationally trade off the possible excess gains to choosing early against the option value of waiting and choosing with more information at t_2 ” (Dasgupta, 2007, p. 7). His model assumes only a private signal during the first period, and a second private signal (a noisy information conveying the size of agents that have already decided to invest) during the second one. Besides, his presented development heavily reposes on the fact that there are exactly two periods (an assumption that greatly simplifies the matter).

Enriching the model by adding public information and an unknown number of future rounds appears not trivial (to say it euphemistically).

To maintain the parsimony of our model, it may be judicious to limit the number of rounds to a fixed value (e.g., two or three) assumed to be known by all incumbents. Doing so would allow us to adapt a similar approach as the one of Dasgupta (2007).

Formal proofs. To follow the pattern observed in the global game literature, we need to devise formal proofs of the results suggested by our simulations, and formally determine both the precise number of equilibria and the exact conditions that lead to those equilibria.

4. Concluding Remarks

In the course of this paper, we have extensively discussed the dilemma a potential disruptor faces when attempting to introduce its innovation in a mature multisided ecosystem which revolved around an MSP. We have observed that, in spite of occupying a seemingly unassailable position, MSP are eventually inexorably disrupted. We have then presented a global coordination game of incomplete information (more specifically, a global game of regime change) in an attempt to model the complex dynamics behind the disruptor’s dilemma.

Our model assumes a multi-round game where incumbents can decide, during each round, to irrevocably support the potential disruptor; which succeeds if and only if a critical mass of supporters is reached. Incumbents make their decision based on their belief formed from both public and private information communicated (in whole or in part) by the potential disruptor. A two-round game has been presented in detail, whereas only key aspects of the general case have been suggested. While the first round exhibits a unique monotone equilibrium provided a sufficiently precise information structure, the second round seem to systematically have multiple equilibria (or possibly no equilibrium). In such a setting, incumbents may fail to coordinate on the same strategy. Consequently, even when the Nature-dictated state of the world is favourable for the aspirant disruptor to flourish, failure to realize its potential due to ill coordination lurks all around. Factoring the limitations and (rather drastic) simplifications of our model in, it emerges from this obser-

vation that a possible strategy for the potential disruptor is to shrewdly manoeuvre to ensure the existence of a unique equilibrium in the first round—by investing, at the very beginning, in communicating precise information—so that if the underlying economic fundamentals are propitious, success is achieved in the first round. ■

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A. \mathcal{S}_{t_2} is (strictly) decreasing in θ

Proof. We have, $\forall \theta \in \mathbb{R}$,

$$\begin{aligned} \mathcal{S}_{t_2}(\theta) &= \mathcal{S}_{t_1}(\theta) \\ &\quad + (1 - \mathcal{S}_{t_1}(\theta)) \Pr(x \leq x_{t_2}^* \mid \theta), \end{aligned}$$

with

$$\begin{aligned} \Pr(x \leq x_{t_2}^* \mid \theta) &= \Phi\left(\sqrt{\beta_{t_2}}(x_{t_2}^* - \theta)\right) \\ \mathcal{S}_{t_1}(\theta) &= \Phi\left(\sqrt{\beta_{t_1}}(x_{t_1}^* - \theta)\right). \end{aligned}$$

One can easily verify that

$$\begin{aligned} \frac{d\mathcal{S}_{t_2}(\theta)}{d\theta} &= \sqrt{\frac{\beta_{t_1}}{2\pi}} \exp\left(-\frac{\beta_{t_1}(x_{t_1}^* - \theta)^2}{2}\right) \\ &\quad \times \left(\Phi\left(\sqrt{\beta_{t_2}}(x_{t_2}^* - \theta)\right) - 1\right) \\ &\quad - \sqrt{\frac{\beta_{t_2}}{2\pi}} \left(1 - \Phi\left(\sqrt{\beta_{t_1}}(x_{t_1}^* - \theta)\right)\right) \\ &\quad \times \exp\left(-\frac{\beta_{t_2}(x_{t_2}^* - \theta)^2}{2}\right). \end{aligned}$$

Given that $\Phi : \mathbb{R} \rightarrow]0, 1[$, and $\exp : \mathbb{R} \rightarrow \mathbb{R}_+^*$, we have

$$\frac{d\mathcal{S}_{t_2}(\theta)}{d\theta} < 0.$$

□