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Contests as innovation policy instruments: lessons from the US federal agencies' experience

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Abstract

An increase of the innovation contests and their associated prizes have been observed since the 90s especially in the US through the sponsorship of the American Federal Agencies. The purpose of this article is to shed light on some of the direct and indirect effects of US federal agency contests not only on economic dynamics but also on social dynamics. Based on recent case studies, this paper describes the various positive impacts that federal agency contests may have: i) contests may display a strong incentive effect ex-ante and during the contest; ii) they may produce favorable spillovers after the contests, at innovation and economic levels in specified economic/industry sectors and iii) they may also play a beneficial social role, contributing to citizens' education and awareness. Nevertheless, as a contest remains a sophisticated device, public decision makers must comply with certain requirements if they wish to benefit from this particular policy tool in order to spur innovation.

Keywords

Contests, prizes, innovation, patents, public policy

1. Introduction

Prizes or contests are among the oldest incentive measures used to spur innovation (Scotchmer, 2006). Although their popularity decreased in the 18th century, renewed interest in them has been observed from the 1980s onwards in a movement largely initiated and carried out by the United States (see Crosland and Galvez, 1989; Hanson, 1998). Contests awarding incentives have returned to the spotlight along with the emergence of major projects, leading Adler (2011) to talk of the renaissance of contests and prize-awarding systems. Based on a study analysing around 200 international contests, a report by McKinsey (2009) pointed out that during the 2000s, there was a steep rise in ‘Grand Challenges’ with 60 new projects awarding around US\$250 million. This movement initially emerged on private platforms (Innocentive, NineSigma, etc.) and via philanthropic organisations, rapidly reaching the heights of US Federal Agencies at the beginning of the 2000s. By June 2017, more than 760 competitions had been launched by over 100 federal agencies and departments via a dedicated Internet platform, challenge.gov, created in 2010 (OST, 2016). Over the last two decades, the sharp rise in publicly-funded contests in the US (i.e. launched by federal agencies) has born witness to this growing enthusiasm (Deloitte, 2014).

Our article focuses on innovation contests or prizes. These tools consist of a private and/or public sponsor launching a challenge based on an idea, study or invention, and usually rewarding the winner(s) with a monetary prize (Scotchmer and Gallini, 2002; Bullinger and Mösllein, 2010). We consider innovation, following partly Equist and Zabala (2012) as new creations mainly carried out by companies: new products (goods or intangible services), new processes (technological or organizational). But, as regards contest, the scope of innovation is enlarged and includes innovations also carried out by citizens and individuals, and innovations as societal solutions contributing to change citizen behaviours. In this view, contests appear both the vector of new concrete products and the catalysts for future innovation. A distinction, now widely shared in studies, is made between “recognition prizes” and “inducement prizes” (Scotchmer, 2006; Morgan, 2008; Adler, 2011). The former offer ex post recognition to major research efforts over an extended period (e.g. the Nobel Prize). The latter generally initiate research or innovative processes related to a specific issue by stimulating potential candidates with a prize established by a sponsor ex ante (Gallini and Scotchmer, 2002).

Although a great number of studies has been published in both managerial and economic literature investigating innovation contests (for a recent review, see Adamczyk et al., 2012), the study of innovation contests as policy tools has recently emerged. Yet, contributions do not fully cover all the relevant issues. On the one hand recent studies have essentially focused on the effective /optimal contest design for public actors (Besharov and Williams, 2012; Kay, 2012; Berstein and Murray, 2015). On the other, policy discussions on innovation inducement prizes converge on boosting the development of a new technology, but do not take into account the ex post impact of such policy instruments (Besharov and Williams, 2012). As the number of contests funded by public actors such as US federal agencies continues to increase, there is an urgent need to begin assessing the impacts of such contests on economic dynamics,

following on from Schumpeter's contributions. Until now, little attention has been paid whether to assess the success or failure of innovation inducement prizes, therefore empirical evaluation appears as crucial.

The purpose of this article is to spell out some of the direct and indirect effects of US federal agency contests not only on economic dynamics but also on social dynamics, taking into account the fact that many contests launched by US federal agencies have societal goals (Desouza and Mergel, 2013). Despite the lack of a counterfactual conditional to compare worlds with and without contests, our aim is to examine the observed effects of several US federal agency contests using recent case studies analysed in depth by certain academics, as well as illustrations found in various academic and administrative reports. Our aim is not to propose an exhaustive assessment of the federal agencies' outcomes, but rather to explore the first feedbacks, which may be useful to public authorities wishing to use contests as policy instruments.

Based on recent case studies, academic literature's and history's contributions concerning innovation contests, this research describes the various positive impacts that federal agency contests may have: i) contests may display a strong incentive effect ex-ante and during the contest; ii) they may produce favourable spillovers after the contests, at innovation and economic levels in specified economic/industry sectors and iii) they may also play a beneficial social role, contributing to citizens' education and awareness.

Moreover, our point is that the potential positive effects of public federal contests are intrinsically linked to the particular contest design chosen and to its ability to change and adjust during the contest period if required. Under these conditions and for pre-defined goals, using innovation contests as political tools may prove to be effective and generate feedback. Our results contribute to extend the recent innovation policy's literature regarding the choice of effective policy instruments (Autio and al. 2014, Edlerg and Faderberg, 2017). More precisely this study contributes to enhance the strand of the literature dedicated to the demand side policy and mission-oriented innovation.

In the following section, we will examine the theoretical background associated with innovation contests, including the management and economic contributions as well as the policy innovation literature. The third section, after focusing on the flexibility of contests design, will review the historical and institutional context of the emergence of US federal agencies' innovation contests over recent decades. In the fourth section relying on empirical evidence, we will expound the various positive impacts that may be generated by innovation contests launched by federal agencies. The fifth section will focus on the article's contribution to the innovation's policy literature and propose new directions for public actions in the area of innovation's support. The last section will stand for the conclusion.

2. Theoretical background

As management studies are interested in the managerial dimension of the innovation process, one could think that economic studies are, *a priori*, more appropriate to study the real impact of innovation contests, through an innovation policy perspective. Nevertheless, the issue of contests/performances on innovation processes has often been addressed using theoretical models that are aimed to compare the contests' performances with other inducement innovation tools such as patents and grants. We will first underline the limits of these standard economic approaches and explain the lessons learned from the history. Second, the place of contests in the innovation policy literature will be evoked.

2.1 Contests: management, economy and findings

Management studies generally focus on the innovation contests' managerial aspects such as the participants' integration, the co-creation process, the users' motivations, the underlying platform design, etc. In addition, the "Internet-based" dimension of the contests is at the heart of the issues raised (Piller and Walcher, 2006 ; Ebner et al., 2009). In parallel, the economic perspective addresses theoretical models of innovation contests, which are often designed as competitive games (see Fullerton and McAfee, 1999). The issues examined include the duration, the number of solvers and the determination of the appropriate amount of the award (Adamczyk et al., 2012). Most of the time, the main objective of these models has been to compare the contests' performances with other inducement innovation tools such as patents and grants (Wright, 1983; De Laat, 1997 ; Gok, 2013 ; Shavell and Van Ypersele, 2001 ; Clancy and Moshini, 2013 ; Maurer and Scotchmer, 2004 ; Brennan et al. , 2012 ; Penin, 2005; Kremer, 1998). But, finally, none of these models reaches a definitive conclusion regarding the superior effectiveness of prize or patent. Furthermore, this literature presents some limitations.

One major limitation of those models is based on the hypothesis that the two systems (patents and contests) are opposed and cannot be complementary. As Adler suggests (2011), "*The two need not be mutually exclusive. On the contrary, prizes and patent protection can be complementary. While patent protection provides a background inducement for all commercially marketable innovations, prizes augment the reward for types of innovations that have been identified ex ante as having particular social value*" (p. 15). Moreover, contests are considered in a very simple way in the standard economic approach, unlike the complex institutional nature of the contest (Kremer and Williams 2009, Williams 2012)¹. These approaches do not allow a sufficient understanding of the logic behind public authorities' more recent use of contests, particularly because they consider patents and contests as formally equivalent (Brennan et al., 2012). In other words, the wide variety of contests that agencies propose cannot be understood using the classic framework of analysis (Liotard and Revest, 2016). As we will see later, some innovation contests are launched even when agencies have no information about the costs and value of the innovation. Others are characterized by their association with technological and societal objectives and, as a result,

¹ See, for instance, Gök (2013) "This theoretical discussion has generally been helpful in understanding the efficiency of prizes, although it relies on many assumptions and frames prizes in a very simplistic sense" (p. 8).

are extremely difficult to evaluate ex ante. One final contest category is characterised by an absence of monetary prizes, taking instead a societal approach.

Lastly, one might wonder whether the recent approach using field experiments will overcome the initial limitations -or some- aforementioned (Besharov and Williams, 2012). On the one hand, through construction, randomised field experiments can provide a reliable counterfactual analysis. On the other, some conclusions were drawn from case studies and revealed opposite viewpoints regarding the effect of contests on the process of innovation².

One can finally agree that economic models or experiments cannot replace historical approaches and/or case studies because these enable us to latch both on the complexity and the richness of innovation contests, and better understand their recent use by US federal agencies. Historical studies of large-scale programs (Brunt et al., 2012; Nicholas, 2013; Moser and Nicholas 2013; Moser 2013) have addressed the issue of the impact of real contests on the innovation process and economic dynamics. More precisely, such research has highlighted the consistent positive effects of contests. Brunt et al. (2012) conducted an analysis of English contests between 1839 and 1939 in the agricultural domain, based on both monetary and non-monetary ex post rewards. They demonstrated that the prize system had a positive effect on innovation and technological development, prompting not only the winners but also the “losing” innovators (those not chosen by the public sponsor) to apply for patents. They found that the large entry effects came from the non-pecuniary gold medal awards. In addition, the innovations derived from the contest appeared to be of high quality.

Historical studies also demonstrate that, in most cases, contests do not require intellectual property to be released into the public domain if it existed before the contest or arose during the contest. Historical cases of patents released into the public domain, such as the example of the Daguerre patent or the patent on Whitney’s cotton gin in the United-States, are rare (Kremer, 1998). On the contrary, Burton and Nicholas (2016) demonstrate that prizes and patents were used in a complementary manner for the Longitude Prize and maintain “*that the prize provided the catalyst for skilled inventors to direct their efforts towards solving the longitude problem because patent alone could not generate sufficient incentives for private investments. As the prize provided a boost to innovation, inventors used patents to secure private returns*” (p 7).

2.2 Innovation policy literature and contests

Innovation policy literature has generally paid no or little attention to contests as specific policy tools (Autio et al, 2014 ; Georgiou et al 2014 ; Edler et Yeow , 2016 ; De Vries et al, 2015 ; Borras et Edquist, 2013 ; Kochekova et al 2016). In a recent review, Edler and Faderbeg (2017) categorized innovation policy studies into three major groups: mission-

² In the field of experimental economy, based on case studies, some conclusions reveal opposite viewpoints regarding the effect of contests on the process of innovation. While Boudreau and al. (2011) underline the positive effects of the TopCoder experiment, other studies offer a more pessimistic view on the use of contests (Bruggermann and Meub, 2015).

oriented, invention-oriented or system-oriented. Mission-oriented policy tends to produce new practical solutions to specific public goals, while invention-oriented policy is aimed at supported innovation through the R&D/invention step. System-oriented policy focuses on the potential interactions between the different components of the system. In addition the policy literature discriminates instruments focusing on the supply or the demand for innovation. Recently, an increasing literature relating to a specific tool for demand side has emerged: Public Procurement for Innovation (PPI) (see Edquist and Zabala, 2012). PPI are defined as “the process by which public organizations place an order for the fulfillment of certain functions by a new product (good, service, system) that does not yet exist, and whose development and diffusion will influence the direction and rate of technological change and other innovation processes” (Edler and Yeow, 2016, p 1766). The interest in the use of procurement as a technology policy tool is not new, but the current popularity of PPI stems from several arguments supporting a demand side approach to stimulate innovation. Indeed, for a long time policy innovation assessment has relied on the assessment of supply innovation policy tools (Guerzoni and Raiteri, 2015). Yet, focusing only on a supply-oriented theory of innovation support tells us half of the story (Metcalfe and Ramlogan, 2008). Knowledge of market opportunity is critical for innovation, and innovative processes depend on the disposition of both producers and consumers to modify their behaviors and be oriented toward novelty. In addition, it is well known that in the past, governments played a crucial role in the spread of new technologies, being the early purchaser, especially in technological intensive industries (Slavtchev and Wiederhold, 2011; Block and Keller, 2011; Mazzucato, 2013). Regarding the USA, the aforesaid examples have since the 90's included the emergence of Iphone, microships, cellular communication and biotechnology (see Mazzucato, 2013). Consequently, focusing on demand side instruments may be viewed as a powerful driving force for the development and diffusion of innovations (Edquist and Zabala, 2012).

In this context, it appears crucial to consider the great variety of innovation policy instruments that exist on both sides of innovation. Edler and al (2016) propose a taxonomy of 15 innovation policy instruments using this classification (demand versus supply), attaching each tool to the goal(s) pursued; one can observe that less tools are focused on the demand side than on the supply side. If we do not take into account the categories situated on both sides³, as for the demand the following items can be found: private demand for innovation, public procurement (policies and pre-procurement) and inducement innovation prizes. This taxonomy tends to illustrate the similarity between inducement prizes and PPI.

At last, the US innovation policy's history has had two programs: DARPA and SBIR. Mission-oriented innovation policy was successful in the past encouraging high technology innovation in the US society (Block and Keller, 2011). DARPA -created in 1958- has allowed the USA to acquire technological high ground in different sectors that have influenced both defense and civil society. Not only does DARPA provide funds to academic research, but it supports defined targets, plays a broker role between public and private actors, stimulates private VC to sustain projects and facilitate commercialization (Block and Keller, 2011; Mazzucato, 2013). SBIR that emerged in the 80's, shares with DARPA, a proactive and

³ These categories are “standard, regulation, technology foresight” (Edler and al., 2016).

mission-oriented role in supporting innovative behaviours. SBIR which aim is to sustain small independent companies, has supported a great deal of highly innovative start-ups. One major feature of these two programs is that they do not function alone, their effectiveness rely on a network of institutions that notably ease the commercialization of new products/processes.

Innovation contests and innovation policy being characterized as mission-oriented and as a demand side innovation policy, one may tackle the differences between contests and PPI on the one hand, or programs such as DARPA on the other (see argument in section 6).

3. Emerging publicly-funded contests in the US in the 2000s: political context

The renewed interest in innovation contests can be found in two arguments. Firstly, in a context of tighter IP regulation and some recognised negative effects (Boldrin and Levine, 2013), economic and political actors have turned back to the energising effect contests have had on technological breakthroughs in the past (Brunt et al, 2012). Secondly, the emergence of Internet combined with the high flexibility of innovation contest design has also played a crucial role in the attractiveness of this ancient device (Master, 2008). These features appear to be fundamental in explaining the revival of interest in innovation contests, especially for political actors (Kremer and Williams 2009). In the late 1980s, the beneficial effects of contests throughout history led US philanthropic and State organisations to focus on innovation contests as a promising tool to encourage innovation. Contests were at the heart of an institutional movement that ended with the creation of a web platform dedicated to federal agencies: challenge.gov. Before addressing this issue, we need to turn our attention to the issue of the contest's design.

3.1 The flexibility of contests' devices

As soon as contests are considered as institutional devices, their design becomes crucial. From a general perspective, our position is akin to the institutional approaches that view individuals as acting and deciding within a given institutional environment in which institutions are not limited to restraining the behaviour of individuals, but instead also contribute towards their development (see, for instance, Hodgson, 2007). Therefore, innovation contests as institutional tools can supply diverse organisational architectures or designs. While the patent system is comprised of fixed rules that are difficult to change for the large majority of innovations (patent registration and grant conditions, duration of protection, etc.), contests, in contrast, emerge as more flexible and adaptable mechanisms. They can have a wide variety of possible forms in order to take into account the specificity of the research question and increase the probability of success. The set of rules and institutional arrangements that make up the architecture of each contest varies greatly and is more or less tailored for the challenge proposed. This involves the rules governing access to the contest, the conditions of participation, the potential for coordination, the duration, the submission of solutions and so on. For example, the prize could be delivered ex post (Nobel Prize) or ex ante (inducement

prize); prize targets may be specific (targeted prizes) or general (blue-sky prize); some prizes have one winner, others have multiple winners (Master, 2008; Maurer and Scotchmer, 2004). The taxonomy of contests proposed by Master (2008) clearly illustrates the wide variety of possible combinations of different criteria: (i) the needs described in the challenge may be narrowly or broadly defined; (ii) funding may come from different sources: private, public or mixed; (iii) the prize may be monetary, non-monetary, fixed or proportional; (iv) the evaluation criteria may be discrete (success or failure) or more complex (combined with other qualitative or quantitative criteria). In this last case, if, for example, the contest's sponsor believes diffusion of the innovation to be essential, then the payment of the prize may be proportional to the number of units of the innovative product sold or distributed (instead of being fixed ex post). This last characteristic is especially present in the case of innovations in the medical field and those intended for developing countries (Kremer and Williams, 2009). To a large extent, the effectiveness of a contest depends on the quality of the match between the challenge and the organisational architecture of the contest (Adamczyk et al., 2012). Thus, this mechanism offers the sponsor the opportunity to benefit from a multitude of potential configurations, making it possible to find a balance between the specificity of the research question and the different intrinsic criteria of the contest. Lastly, the adaptability of these contests, now associated with the advantages provided by Web 2.0, allows both made-to-measure contests to be constructed and a worldwide public to be accessed (Bullinger and Moeslein, 2010).

3.2 The recent history viewpoint

Federal agencies' increasing interest in innovation contests can be seen on an American institutional level in the development of laws and reports, especially between 1999 and 2011, subsequently supplying this public measure with support for contests that encourage innovation. Specific attention began to be paid to this measure in 1999⁴, and from then on, an assortment of official documents gradually emerged to fuel the debate. Later, in 2005 and 2006, laws were passed to enable the NSF, NASA and the Energy Secretary to establish a suitable program⁵ (Kalil, 2006; Brennan et al., 2012; Adler 2011). These laws enable agencies to launch contests with significant prizes (up to US\$10 million for the Energy Act) in order to stimulate innovation for applied and fundamental research and to create prototypes. 2009 was a year of transition, with the publication of President Obama's report on the American strategy for innovation (A Strategy for American Innovation: driving towards sustainable growth and quality jobs) that proposed themes to promote and strengthen innovation. Among all the paths explored, the path of contests and prizes was clearly represented with the creation of "Grand Challenges". The momentum initiated by the 2009 report would lead to events accelerating in more recent years, creating measures that would increase US public authorities' use of contests, whether through the development of a dedicated Internet site or

⁴ In 1999, the National Academy of Engineering (NAE) report *Concerning federally sponsored inducement prizes in Engineering and Science*, represented a preliminary paper.

⁵ Energy Policy Act (2006), NASA Authorization Act (2005) Medical Innovation Fund Prize Act (2005)

the publication of recent laws⁶. As the report states, “*The Federal government should take advantage of the expertise and insight of people both inside and outside the Federal government, use high-risk, high-reward policy tools such as prizes and challenges to solve tough problems, support the broad adoption of community solutions that work, and form high-impact collaborations with researchers, the private sector, and civil society*”. The steady decrease in public R&D funding over an extended period⁷ consequently formed one of the major reasons behind the American administration’s preference for contests, being, as it was, a way of outsourcing costs and shouldering risk onto competing teams, as well as rewarding only the best solution or technology.

The Guidance Document on the use of challenges and prizes to promote open government (2010) offered a practical explanation of the steps to be taken while also providing a full series of recommendations for agencies about how to choose the most suitable type of contest, the form of prizes to grant, issues regarding intellectual property, etc. In September 2010, this collection of recommendations became concrete with the creation of the website challenge.gov, which enabled agencies to upload their contests online (see below).

3.3 Challenge.gov and the specificity of US Federal Agency contests

In the 2000s, many private Grand Challenges were indisputably the catalyst for the public challenges that have appeared since 2010 with challenge.gov. The website challenge.gov has become an essential tool for Federal Agencies (FA) wishing to launch contests. As of 2014, more than 300 contests were uploaded by 46 public and semi-public agencies. Among these, some were particularly active, proposing several dozen contests, for example NASA, the HHS (Health and Human Services), the DOD (Department of Defence) and the DOE (Department of Energy). Until recently, around US\$31 million was awarded in prizes and close to 42,000 participants responded (source: www.digitalgov.gov). Using data from the www.challenge.gov website, Desouza and Mergel (2013) propose an original analysis based on 179 challenges posted in 2011 by 46 public or parapublic agencies. The challenges are divided into major themes that, unsurprisingly, correspond to the main orientations of the Obama Innovation report: 40% in Science and Technology, 18% in Health, 12% in Energy and the Environment, 12% in Education, and 9% in Economics.

Generally speaking, the launch of a publicly-funded contest – and the construction of its organisational design – adheres to the following procedure: firstly, public agencies decide which opportunities can be transformed into challenges. Identifying these opportunities is achieved either through the agency’s internal process, or through external methods (inter-agency relations, the reading of publications, think tanks, etc.). A committee may be in charge of discovering new opportunities (by way of a vote). The design or structure of the public

⁶ America COMPETES Reauthorization Act de 2010; this measure strengthened the whole system of contests by giving more freedom to federal agencies (Bershney and Van Roekel, 2011). Section 24 (dedicated to contests) of the Stevenson-Wyder Technology Innovation Act also demonstrated the government’s desire to encourage the use of contests

⁷ See NSF, Science and Engineering Indicators, 2012

contest is then defined in relation to the nature of the needs (targeted or broad) and the nature of the aim (abstract, concrete, technological, social, mixed, etc.) Collaboration with private sponsors may equally influence the form of the contest's organisational structure. Finally, terminating conditions for licenses, if IP is involved, can be varied and are fixed *ex ante* in order to avoid any potential conflict. History has shown that contest structures can essentially be "custom built". Such structures present a large variety of possible combinations using different criteria (cf. Table 1 column 2 and 3). If, for example, the contest organiser judges the spread of innovation to be crucial, then the prize payment can be proportional to the number of innovative product units sold or distributed. In their definition of the advantages of prizes, Brennan et al (2012) underline this significant criterion and give the NetFlix contest as an example. This contest, offering a prize of US\$1 million, also issued annual intermediary prizes of around US\$50,000 until the final stage of the contest. The criteria employed in the evaluation of different publicly-funded contests illustrate the diversity of approaches and aims. Certain contests rely on purely technical reward criteria, while others are more complex, also combining the latter with financial criteria (e.g. cost constraints of carrying out the solution), or with organisational criteria (quality of teams, degree of collaboration between members, etc.). Rebuilt by Design, launched by the US Department of Housing and Urban Development clearly underlined that one of their evaluation criteria was related to the composition of the team, the quality of previous research and the ability to stimulate collaboration between teams (OST, 2014).

4. Effects of contests: lessons from several cases studies

Political actors urgently need to learn more about how to use contests in an effective way and for which targets. Based on empirical literature addressing case studies in addition to fragmented empirical evidence from various materials (economic and political reports⁸, media articles, contests website⁹, government website¹⁰, etc.), we propose to undertake a "case study review" to shed light on the contests' potential positive outcomes on economic and social dynamics. The following contests have been scrutinized: the Ansari X Prize, the SunShot Prize, the Northrop Grumman Lunar Lander (NGLLC), the MIT Clean Energy Prize and the PIAXP challenge. The Ansari X prize is the only contest examined that has not been sponsored by a US federal agency, yet its success has played a catalytic role on the public incentive to spread contests and has paved the way for federal agencies' challenges. In other words, the Ansari X prize has been at the initiative of the wave of public contests in the 90's. All other contests have been selected for the following reasons: i) they were governed at least by one US federal agency; ii) they have been launched on the website challenge.gov; iii) they are all closed and there are ample materials and evidence in order to analyse them; iv) the challenges' topics matched totally with Obama's recommendations (energy, new vehicle, education) in the 2009 report.

⁸ Reports from the Office of Science and Technology ; Obama's report (2009) A Strategy for American Innovation: driving towards sustainable growth and quality jobs

⁹ www.xprize.com, www.energy.gov/eere/sunshot/, <http://cepgrandfinals.com/>

¹⁰ www.challenge.gov, www.digital.gov, www.whitehouse.gov, many sites of specific contests

Our methodology is as follows: firstly, we adopt a time approach that distinguishes the impact of the contest *ex ante* (before it starts), during the process, and *ex-post* (after the end). Secondly, we derive from the empirical materials three main potential positive effects of contests and link them to the time analysis: i) effective incentives (*before*), ii) stimulating the innovation process and interaction rules (*during*), and iii) desired economic and social spillovers (*after*). Besides federally-funded contests, we also examine the prizes launched by the X Prize Foundation. This foundation strongly influenced the revival of contests among US political actors, and is a recurrent partner of federal agencies for launching contests.

4.1 Before the contests: incentives and intrinsic motivations

Contests provide enterprises and individuals with effective incentives to engage in innovative activities (Kalil, 2006; Morgan, 2008; McKinsey, 2009). Firstly, teams engaged in a contest are able to accept a level of monetary reward they esteem satisfactory in relation to their initial motives. Secondly, the prize system encourages competition between teams (by inciting a race to the finish) and very often leads to the overall investment made by the various teams exceeding the value of the prize (Kalil, 2006; Morgan, 2008)¹¹. Thirdly, while the argument of incentivising innovation is largely used in theoretical economic literature, the focus usually remains on the award granted – however, empirical evidence tends to show that the incentive characteristic of contests exceeds the simple motivation of a monetary reward. In essence, participating in a contest may be a way of starting out as an innovator, attracting media coverage and, as such, indicating one's skills to others. The competitor's interest in participating is equally linked to publicity and the reputation gained if they win (Maurer and Scotchmer, 2004; Kalil, 2006). For example, the FTC Robocall Challenge offered a prize of US\$50,000 for the creation of a system that could block illegal telephone calls made by automatic machines; however it also underlined that "*the winner will also receive opportunities for promotion, exposure, and recognition by the FTC*" (OST, 2014). From this perspective, the prize involves a signaling impact and this could also be relevant to motivation. The cognitive evaluation theory is helpful for understanding motivations. The distinction between intrinsic and extrinsic motivation (Deci and Ryan, 2002) could be applied with contest experience. "*When participants are extrinsically motivated, they are not driven by the activity itself, but by the extrinsic consequences associated with performing the activity – cash payment. Alternatively, when participants are intrinsically motivated they choose to engage in a given activity because they perceive it to be interesting and are able to gain some level of simultaneous satisfaction from the activity itself – donation, psychological gains*" (Allison et al., 2014, p4). The success of English contests between 1839 and 1939 (Brunt et al., 2012) in agriculture, largely based on non-monetary *ex post* rewards (medals) testifies to the potential power of intrinsic motivations.

¹¹ By using the mechanism of contests, the weight of risk and uncertainty is shouldered by the external researcher (or research team) rather than the sponsor.

4.1.1 The X Prize Foundation and the Ansari X Prize: the turning point

The X Prize Foundation is a US-based philanthropic organisation established in 1996, which was created with the support of several large private companies such as Cisco, Google, Nokia, Qualcomm and the Steel Oil companies. The Foundation's main mission is to spur "*radical breakthrough for the benefit of humanity through incentivised competition*" (Hossain and Kauranen, 2014). According to this perspective, the Foundation organises contests in five broad categories: education, global development, energy and environment, life science and exploration. After the success of the Ansari X Prize (see below), the Foundation offered a string of prizes including the Archon X Prize for Genomics, the Google Lunar X Prize, the Progressive Insurance Automotive X Prize, etc. Some prizes are closed, but new contests have been initiated¹². The Foundation is now recognized as a harbinger in facilitating prize competitions and collaborates with several universities and US federal agencies (Hossain and Kauranen, 2014).

The Ansari X prize is a very famous contest that has been studied extensively (Kalil, 2006; Adler, 2011; Kay, 2011; Brennan et al., 2012; McKinsey, 2009; Hossain and Kauranen, 2014). It covered the period 1996-2005 and the aim of the contest was to reward a non-governmental organisation capable of building and launching the first reusable manned spacecraft into space twice in a two week period. The prize was the astronomical sum of US\$10 million. Collectively, the competing teams invested US\$100 million¹³. 26 private enterprises from different countries entered the competition, which was won in 2005 by an American enterprise, Scaled Composites, specialising in aircraft conception. This company made the greatest R&D effort, estimated at US\$30 million (Kay, 2011). The various teams' motivations were revealed as diverse. While the pursuit of the monetary reward was recognised as a unanimous objective, the majority of the teams questioned mentioned the existence of other motivations such as opportunities related to publicity and the achievement of personal and/or organisational objectives (Kay, 2011)¹⁴. "*For many participants, these softer motivations outweigh the financial incentives*" (p 5). Furthermore, 18 out of 26 candidates were non-conventional candidates, illustrating the positive externalities that may be created by these types of contests. Most of the teams were created the same year the contest was launched and would probably never have been formed in other circumstances; "*People that would never look at a government contract*" (Diamandis, 2004). While one third of the teams were start-ups, another third was already working in the spaceflight field and the final third was originally from different fields, and was interested in winning the prize (Hossain and Kauranen, 2014). The X Prize's success galvanised the US Government's

¹² See www.xprize.org

¹³ According to Schooner and Castellano (2015) "*one signature benefit that the prize offer derives from the non-monetary incentives is that it spurs individual participants to invest more in the competition than they would devote to traditional government contracts, because the theatre of the contest plays out in the public eye through the entire R&D process*" (page 400).

¹⁴ As Cormack et al (2013) suggest "a respected prize has a valuable credentialing effect, legitimizing an innovator's pursuit of a problem, and a well-designed completion can help entrants build skills and expertise through education and mentoring (p. 5).

interest in contests, consequently leading to their large-scale implementation by US Federal Agencies (Murray et al., 2012).

The Google Lunar X Prize provides another illustration, implemented by the X Prize Foundation from 2007 to 2015, with 35 teams from 17 countries. The US\$30 million contest challenged teams to land a rover on the surface of the moon and broadcast high-definition video back to Earth. (Hossain et Kauranen, 2014; McCormack et al., 2013). Once again, the competition led to the creation of new structures. Dozens of teams represented a wide spectrum of constants such as big structures, collaborative and international consortiums. 7 of the 17 teams studies by Kay (2011) were created exclusively to enter this competition. The challenge motivation was not only linked to monetary goals – among the other goals quoted were: demonstration of leadership technology, inspiration, hands-on experience or pursuing sustainable commercial opportunities. Accordingly, the Google Lunar X Prize has opened up opportunities not only to pursue challenging technical and commercial goals but also to gain reputation or visibility, and to develop relations and collaboration (Kay, 2011).

4.1.2 Incentives and federal agency contests: a recent review

Building on the success of the Ansari X Prize and in order to boost incentives, federal agencies have greatly increased the number of challenges launched, and, consequently, the prize amounts, as the following graph suggests (see Figure 1). A 2014 Deloitte report found that between 2010 and 2014 (based on 319 challenges) “*incentive prizes have transformed from an exotic open innovation tool to a proven innovation strategy*” with US\$64 million in total prize money being offered through challenge.gov.

Insert figure 1

As the Federal Prize Report (2015) indicates, 83% of challenges (116 challenges in 2015) were designed to achieve multiple goals: the most common goals are to “solve a specific problem” (50%); “develop technology” (50%); “engage new people and communities” (47%); “highlight ideas” (42%); “inform and educate the public” (33%) and “stimulate the market” (10%)¹⁵. Other data also suggest that agencies use a large fraction of prize competitions for hardware and scientific solutions as well as to seek a “business plan”. The latter goal seems to highlight the objective of start-up creation. As Kalil (2012) claims, “*Grand Challenges are compelling and intrinsically motivating. They should capture the public's imagination...*” This “guiding research objective” is clear in Obama’s 2009 report. In the majority of cases, the clear aim is to launch a competition based on new themes that lead to the discovery of original approaches that emerge from new talents in diverse disciplines. This feature can be seen in the MIT Clean Energy Prize, largely designed for MIT students and launched in 2008. In this case, the intrinsic motivations (students’ passion for the topic) were revealed to be as

¹⁵ See Figure 3 in Implementation of Federal Prize Authority: fiscal Year 2015 progress report, p. 26.

effective as extrinsic rewards (Lakhani and Tong, 2012). The PIAXP challenge is another example that demonstrates the wide variety of motivations that drive candidates to apply and participate (see the detailed example in section 5.3)¹⁶. As Murray et al. (2012) mention for the PIAXP challenge, the survey of participants' motivations shows "winning the prize" as the 5th highest-ranked response: more important was the "desire to gain publicity", "enhance reputation" and "address environmental concerns".

4.2 During the competition period: innovation process and interaction rules

Contests stimulate the innovation process, not only *ex ante* by means of appropriate incentives, but also during the competition. Using a relevant design, they can provide favourable conditions to support innovative activities at various stages (R&D, marketing, manufacturing, etc.). In addition, non-expected interactions and synergies among various players may emerge during the process itself.

4.2.1 Interdisciplinarity and collaboration between experts

Via a contest, the sponsor can expect feedback with regard to complex problems that can only be solved through interdisciplinarity and collaboration between experts in different fields. Historically, the prize mechanism has encouraged teams and individual innovators to overcome existing constraints and propose new solutions appropriate for new challenges (see the British Longitude Prize; Davis and Davis, 2004¹⁷). Solutions to technical problems are often found by people in seemingly unrelated fields. One illustration is provided by a NASA challenge, launched via the Innocentive platform, aimed at finding a predictive algorithm to better protect American astronauts from radiation exposure in space. 500 solvers from 53 countries answered NASA's call (Lakhani and Tong, 2012). NASA received a solution from a retired radio-frequency engineer who had never worked with the government, and his solution surpassed the NASA requirements. The prize system may favour the diffusion of knowledge and enhance partnership to the same degree as the patent system, though it does so via an alternative path. Firstly, contests may prompt a group of university researchers, or other players with a shared interest, to come together for the purpose of competing. Information exchanges and coordination may be incited at the behest of the sponsor, who may desire that the (mixed) teams join and interact together. In this context, collaboration would be included in the contest design. Consequently, the contest can act as a structural element in collective innovation¹⁸.

Several examples of federal agency contests illustrate the way in which sponsors encourage cooperation between different players. The DOE SunShot Prize justified using the prize rather than an alternative form (e.g. grants) by highlighting the diversity of competitors

¹⁶ The PIAXP was created by the X Prize Foundation.

¹⁷ The British Longitude Prize is a renowned example; John Harrison, the winner, was an amateur clockmaker (Davis and Davis, 2004).

¹⁸ According to the same perspective, patents are also considered a sign of skill, and therefore allow for collaboration between actors (Penin, 2005; Cohendet et al., 2006).

and notably the involvement of teamwork; “*The SunShot Prize not only rewards result in a cost effective way, it increases the number and the diversity of individuals, organisations, and teams that are addressing the problem*” (OST, 2014)¹⁹. Another example is the Centennial Challenge Program initiated by NASA. This program involved heterogeneous teams made up of researchers, students and individual inventors working on research program in the aerospace industry field on a diverse range of subjects (creating new gloves for astronauts, reducing noise, improving the energetic efficiency of aeroplanes, etc.)²⁰ (Knight et al., 2010).

4.2.2 The emergence of non-conventional teams and sponsor rules

The Northrop Grumman Lunar Lander is emblematic with regard to the configuration of non-conventional teams. Between 2006 and 2009, the Northrop Grumman Lunar Lander (NGLLC) took shape as an annual contest, sponsored by both NASA and the Northrop Grumman enterprise with a total prize reaching US\$2 million (Kay, 2011). The challenge consisted in constructing rocket-propelled space vehicles that respected certain conditions related to efficiency. Twelve American corporations were implemented, with the end-prize being attributed in 2009 and shared between two start-ups: Masten Space System and Armadillo Aerospace. Cooperation between different teams and also between teams and the public represented an early positive externality generated by this contest (Pomerantz, 2010). The organizers had encouraged the participation of the Armadillo Aerospace enterprise, anticipating that it might generate a certain appeal to the program development field dedicated to space projects thanks to its dynamic nature and skills. The majority of interested enterprises were non-conventional candidates, i.e. independent R&D groups, each composed of a small number of people. The exchanges between non-conventional teams were fruitful, illustrating a Schumpeterian-type process – with the entry of new contestants rousing already-established enterprises with propositions of new technologies responding to untapped niches. Many teams were driven by the goal of the challenge as well as the opportunity to accomplish a personal goal (Kay 2011). And, as in the case of the Ansari X Prize, US\$20 million was spent on R&D within 4 years by all the teams.

Federal agencies may also play a coordinating role to increase interactions, especially with the private sector (Lakhani and Tong, 2012). In a certain number of cases, the agency provides the prize, while their private partner’s role is associated with support, administration and granting certain funds. For example, the 2011 contest organised by NASA NTL (Harvard-NASA Tournament Lab) enabled them to gain two well-known partners (Harvard University and the TopCoder platform) with the necessary skills to succeed in contests. The first partner brought expertise and experience in the rigorous empirical evaluation of prizes, while the second was an innovation platform for software and algorithms. NASA played the role of coordinator and NASA managers worked closely with the NTL team to devise prizes. In turn, NTL teams coordinated with various NSA operational facilities to “facilitate challenge

¹⁹ Initiated by the DOE in 2012, the aim of the SunShot Prize was to render solar energy competitive in relation to fossil fuel energies (by proposing solutions such as solar panels that can be installed on roofs quickly, easily and at a lower cost).

²⁰ https://www.nasa.gov/directorates/spacetech/centennial_challenges/index.html

identification and problem formulation". Prizes were posted on the TopCoder website that gave access to a large community of developers.

4.3 The economic and social consequences of innovation contests

The history of innovation contests is closely associated with the history of science and technology, and some studies have pointed out the beneficial repercussions of contests on the patentability dynamic (Morgan, 2008, Saar, 2006, Nicholas 2013, Brennan et al, 2012 among others). However, recent US federal contests do not enable an objective and exhaustive analysis of their performances to be conducted. We propose to draw attention to some economic (the creation of new companies, new jobs; money raised) and social benefits that US federal agency contests have produced.

4.3.1 The economic impact: initial assessments

Fairly limited evidence is available regarding the real economic impact of US challenges. However, some relevant elements can be gleaned regarding raising finance, creating new companies and generating new jobs. Since 2010, as the White House pointed out, more than 80 federal agencies have engaged 250,000 Americans to address tough problems via over 700 challenges on challenge.gov²¹. These competitions have made more than US\$220 million available to entrepreneurs and innovators and have led to the formation of over 275 start-up companies with more than US\$70 million in follow-on funding, creating over 1,000 new jobs. See, for instance, the experience of the DEBUT challenge (Design by Biomedical Undergraduate Teams). Launched in 2012 by the NSH (National Institute of Health), the competition challenged student teams. One of them won the US\$ 10,000 prize, which helped it to create its own start-up (Sparo Labs)²². More generally, many challenges aim directly to create new businesses: "*Create new businesses to commercialize promising energy technologies developed at US schools and national laboratories*" (see challenge launched by DOE National Clean Energy Business Plan) or "*inspire teams of entrepreneurs to create business plans and start new companies to commercialize technologies that can advance breast cancer research*" (challenge launched by NIH, NCI and Avon Foundation, Breast Cancer Start Up). This point is emphasised by the public authorities²³.

Moreover, the impact of public contests stimulating private investment seems significant. The MIT Clean Energy Prize initiated by DOE distributed around US\$ 2.6 million to winning teams from 2008 to the present. These teams, according to Lakhani and Tong (2012) and the MIT CEP website,²⁴ have gone on to raise over US\$430 million in investment capital and research grants. The challenge eventually led to the creation of more than 725 jobs. These figures demonstrate how government-funded prizes can be catalysts

²¹ <https://www.whitehouse.gov/the-press-office/2016/06/21/impact-report-100-examples-president-obamas-leadership-science>

²² <https://www.challenge.gov/files/2015/09/FINAL-DEBUT-09302015.pdf>

²³ See Implementation of Federal Prize Authority: Fiscal Year 2015 Progress Report, August 2016

²⁴ <http://www.cepggrandfinals.com/impact/>

for private sector investment. The same positive impact has been observed for the SunShot Prize backed by the DOE²⁵. Launched in 2011, the challenge aims to develop solar energy to become cost-competitive with traditional forms of electricity by 2020 without subsidies. The catalyzing role of this program is underlined in the SunShot Initiative fact Sheet²⁶, particularly through SunShot's incubator program. US\$138 million in awarded government funding has leveraged the investment of more than US\$3 billion in follow-on private funding in incubator companies.

Lastly, we should also mention the contests that apparently failed but nevertheless gave rise to some progress or positive externalities. This was the case for the Archon Genomics X prize that was cancelled in the middle of the competition process²⁷. The prize, created in 2006, offered US\$10 million to the first team that could sequence 100 human genomes in 30 days (Hossain and Kauranen, 2014). The aim was to prompt breakthrough innovations and technologies in genome sequencing that could lead to improvements in various medical diagnoses and treatments. However, the competition did not incentivise technological changes because many companies were already able to sequence genomes at low cost and in a few days. As a result, the competition was cancelled. Despite of the failure of the project, the competition produced some valuable outcomes such as a unique collection of blood samples and the creation of a Validation Protocol to assess the overall quality of entire genome sequences. Ultimately, the contest did benefit the global genomics community. The Super Efficient Refrigerator (SERP) is another example of an apparent failure that nevertheless had positive technological spillovers. The SERP contest was sponsored by the US Environmental Protection Agency in partnership with non-profit companies, utilities and environmental groups (Davis and Davis, 2004)²⁸. The objective was to stimulate manufacturers to develop and market a competitively-priced CFC refrigerator that used at least 25% less energy than existing regulations prescribed. The contest was launched in 1991 with a US\$30 million award. Particular attention was paid to cost: the “new” refrigerators should be sold at a price comparable to existing units with the same characteristics. Furthermore, each applicant should manufacture at least 1,000,000 refrigerators over the first 4 years of the contest. In 1995, Whirlpool was designated the winner of the contest. However, Whirlpool did not manage to sell 250,000 units before July of the same year, and did not receive the award. As a result, the company decided to withdraw from the project. Nonetheless, the *positive* result in this case regards the technology objective: Whirlpool successfully completed the technological requirements: to generate and manufacture a refrigerator that used less energy. The SERP contest therefore generated a positive spillover in more desirable technologies, even if the aim was not fully achieved. Ultimately, these two examples underline the importance of both contest design and dynamics properties it should have (being able to adjust when faced with external constraints). We will return to this issue in the next section on policy implications.

²⁵ <http://energy.gov/eere/sunshot/>

²⁶ <http://energy.gov/sites/prod/files/2016/02/f29/T2M%20Fact%20Sheet-508.pdf>

²⁷ Launched by the X Prize Foundation

²⁸ Included in the Golden Carrot Program (see Davis and Davis, 2004).

4.3.2 The social impact

The large majority of contests posted online on challenge.gov do not offer monetary prizes (Mergel and al., 2014). Studying 200 contests posted in 2012, the authors show that, in addition to the solving of complex challenges in the defence, science and technology sectors, three other objectives are often declared: raising awareness, service and knowledge. Most of the time, these objectives are associated with non-monetary prizes. A study conducted by Desouza (2012) on US public contests on challenge.gov's platform underlines that 60% of the contests are associated with monetary prizes, while the rest of them offer non-monetary awards (distinctions, medals, gifts, ceremonies, visibility, publicity, etc.). Crowdsourcing is then used as a means to disseminate information to the public, raise awareness about particular subjects, influence aspects of people's behaviour or educate them. In the study by Mergel and al. (2014), raising public awareness appears to be a major element in most contests, posted massively by the HHS, at the intersection of concerns in health, science and education. These "*awareness challenges*" may have an action on a precise subject (such as the environment challenge launched by the EPA). They may call for the evaluation of a public service. Lastly, they may be intended to modify people's behaviour. For example, the HHS "stop bullying video challenge" asked students to submit videos that "*send a positive message to youth about the importance of being 'more than a bystander' to bullying in their schools and communities*".

The Climate Change in Focus contest, launched by the EPA (US Environmental Protection Agency), whose aim was to produce a video that raised awareness about the effects of climate change and targeted students, rewarded the winners of the contest (who were teenagers) with subscriptions to reviews and collections and also published the best video on their agency website.

The social dimension is also illustrated by the PIAXP challenge²⁹. Launched in 2006 by the X Prize Foundation, the PIAXP also relied upon the US Department of Energy. It offered a reward of US\$10 million for the construction of fuel-efficient vehicles. Murray et al. (2012) meticulously analysed the characteristics and operating conditions of this contest, drawing attention to the complexity of achieving such a program. This contest was one of the major innovation contests (Grand Challenges) supported by US federal agencies. Immediately after its launch, the X Prize Foundation clearly expressed its intention to "revolutionise the automobile industry" (according to a PIAXP organiser quoted by Murray et al. 2012). For the promoters, the technological breakthrough, measured in terms of fuel consumption efficiency, represented nothing more than one criterion among many. A willingness to exceed simple technological innovation and direct both manufacturers and users towards a new model of automobile was also one of the contest's overall aims, which included "To be beneficial to the world", "To offer manufacturers and users a playground", "To educate the public", and "To have a reasonable production price". Here, the contest was used as a tool to stimulate education and public participation, as well as to attract manufacturers both through reputation and image. "*GIPs cannot be viewed as a simple incentive mechanism through which*

²⁹ Progressive Insurance Automotive X prize.

government and others stimulate innovation where markets have failed. Rather they are viewed as a novel type of organization, where a complex array of incentives are considered and managed in order to assure successful innovation occurs” (Murray et al., 2012, p.1791). The designed vehicle could not merely be an abstract concept either; instead it had to have real utility for users.

More broadly, an important tendency of the recent contests sponsored either by the X Prize Foundation or US federal agencies is both to give more weight to social aims and increasingly to combine technological and social objectives. This feature constitutes a significant difference from the “old contests” of the 18th and 19th centuries, for example, which focused almost exclusively on technological issues. In addition, contests’ potential social dimension also represents a major difference between contests and patents, the latter being, by nature, dedicated to technological progress.

5 Contribution to the innovation policy’s literature and implications

In this section we will firstly propose to situate innovation contests in the general recent literature relating to public innovation policies (5.1). We will enlighten the main differences and common features between contests and PPI on the one hand and contests and two mission-oriented programs (DARPA and SBIR) on the other. Innovation contests do not appear to be substitute but complementary to existing US innovation policy tools. Secondly, relying on the case studies findings, we will draw from policy recommendations that they illustrate several goals -economic and or social - which may be favored by policy makers thereby contests seem relevant (5.2).

5.1 Contribution to the Innovation Policy’s literature

If contests as well as PPI are focused on the demand side of the innovation policy instruments, they show some specificities. Firstly, PPI are highly oriented toward commercialisation, allowing either to draw attention to emerging markets or to spur the expansion of existing markets (Aschhoff and Sofka, 2009). Furthermore, “PPI often involves a public agency/actor purchase or place an order for a product, service, good or system that does not exist, but which could probably be developed within a reasonable period of time” (Uyarra and Flanagan, 2010, p. 127). In this perspective, Pre-Commercial Procurement (PCP) corresponds to a major asset of PPI as policy tools to support market access (Georghiou and al., 2014). Innovation contests may be oriented toward commercialisation, as in the SERP experience mentioned before, but it is not always the case. Often contests are designed only to stimulate new ideas, new visions, without focusing on the commercialization step.

Secondly, thanks to the web 2.0, innovation contests appeal to the crowd and foster the emergence of new actors, new fields of research, and a cross-curricular approach. The contest mechanism includes, at least partially, an open innovation framework, capturing external

knowledge to meet the federal agency's challenges. Indeed, through contests the creative and imaginative dimensions of innovations are particularly targeted. In addition, contest allows to integrate multiple stakeholders (private/public) at different steps of the innovation process (contest design, implementing and assessing) (Desouza and Mergel, 2014; Kay, 2011). In other words, contests offer many possibilities, such as setting the goal only, or else they may be more binding to the processing. In contrast, through PPI, the government defines the functional characteristics of the desired products but not the design and realization.

Thirdly, contests mechanisms reward the result, and not the research conducted before obtaining it. Federal agencies will only remunerate the solutions that fit them. In comparison to PPI, the risk is transferred from the public agent to the private applicants. Consequently, as demands on the federal budget are highly concentrated, rewarding solely the solutions provides more legitimacy to the public funding and avoids public resources to be diverted from their initial objectives, as it was the case with the Partnership for a New Generation of Vehicles launched by the Clinton Administration³⁰.

Lastly, contests appear as protean instruments that allow targeting various specific defined needs, different publics (individuals - students, entrepreneurs, citizens-, organizations) and through several leverage effects. In addition, contests more easily allow to meet contemporaneous challenges that increasingly combine socio/economic/technological dimensions, meeting the requirements of Borras and Edquist (2013), that "socio-political objective must be translated onto concrete problems related to innovation intensities".

Besides, innovations contests appear as complementary tools to demand side programs such as DARPA or SBIR. They are more focused on the generation of new ideas, new representations, new practices than on the commercialization of new products. The combination of social and technological objectives demonstrates undoubtedly a high specificity of this mechanism. Nevertheless, contests share common features with these ancient programs. They are all mission-oriented programs and contribute both to innovation and entrepreneurship (SBIR); often policy instruments are solely aimed at one of these objectives (Autio et al, 2014, Westhead and Wright, 2013). All that strengthens the interactions between the demand and the supply as well as between all the different players involved, including the links between entrepreneurship and public partners such as universities (Grimaldi et al, 2011). Accordingly, these mechanisms meet at least partially, the need for linkage in innovation systems underlined by Edler and Yeow (2016) and the desire of having an interactive view on innovation's processes (Georghiou and ali, 2014). Finally, public contests and federal agencies' procurements, contribute to creating internal federal agencies repertoires of knowledge relating to specific challenges (see for the contests, Desouza and Mergel, 2013). As far as it goes, not only do public agencies play a role of intermediary, but they store new knowledge, new know-how, that may prove to be very useful in the future.

³⁰ The Major automakers involved took the money but did not intensify their effort toward the development of hybrid and electric vehicles (Bloch and Keller, 2011).

5.2 Policy Implications

The review of empirical evidence from case studies tends to show that innovation contests as a policy instrument may have several positive outcomes at different levels - innovation, economic and social. If the results will have to be supplemented by the examination of current federal challenges, they can contribute to public actors' reflections on the utility of contests. We will emphasise on the following potential beneficial effects: i) contests represent a motivating force to engage in innovative activities, even with non-monetary rewards; ii) contests may lead to non-conventional and interdisciplinary research teams that otherwise would never have emerged; iii) contests may stimulate interactions and synergies among participants during the innovation process itself, enhancing the collective dimension of the innovation process; iv) contests are proving stimulating for firms' entry, raising money from the private sector, and in some cases, for job creation; v) contests undoubtedly contribute to spreading social improvements, notably through awareness and education and vi) contests are well designed to support both technological and social advances/breakthroughs .

Among the remaining major issues are the conditions under which innovation contests may be effective tools for public actors. Certain conditions appear essential in order to be able to benefit from the effects described above.

Firstly, the relevant design of the contest is the primary key condition for increasing the probability of the contest's success. On the one hand, contests are characterized by their flexibility, and on the other, implementing a challenge requires accurately and appropriately defining all the rules mentioned above (table 1 column 2 and 3). A contest must cover all the sponsors' aims. The process of creating and developing appropriate rules is time consuming for the sponsor, but it is inescapable. As Kay (2011) lists, the required design features for innovation performance are (i) defining an exciting prize challenge; (ii) setting a prize reward with commercial opportunity and non-monetary benefits; (iii) simple and transparent prize rules and (iv) defining a scheme to finance the program (see table 1 column 4). Secondly, another crucial issue is the dynamic view of the contest. In other words, the contest should be able to change and adapt its own rules to new factors involving technology advancements and other environmental factors such as new regulations/policies or social actions (as lobbying behaviours during the contest). Based on a multi-stage competition, the rules during the PIAXP were changed very frequently, and this flexibility contributed to maintaining many teams in the competition (Murray and al., 2012; Murray and Berstein, 2015). However, although the rules have to be flexible, at the same time they must not produce an impression of subjectivity among participants. One consequence of this second requirement (the dynamic dimension) is that the sponsors need to designate experts who closely monitor the contest's progress at each step. In order to be effective, a contest does not operate on its own, but requires continual human supervision and intervention. IP rules also play a major role in contest design and the transparency of the process. According to several studies (Brennan et al., 2012; Kay, 2011; Kalil, 2006), in the majority of the contests analysed, the sponsor did not ask for a transferral of the IP and many rules are based on non-exclusive licenses (Google Lunar X Prize, or challenges launched by DARPA or NASA).

Insert Table 1

A further consideration is linked to the type of innovation better supported by the contests' mechanisms. The contests posted on the challenge.gov platform tend to show that if contests are well designed, they can spur both incremental and radical innovation. However, it seems that contests are better able to support technology/science advancement than commercial progress. On the one hand, by nature, innovation contests offer an amazing potential for creativity, a brainstorming device that can boost technological, scientific and social advances. On the other, contest mechanisms appear less appropriate to support the transfer of these advances to the market. Probably, complementary mechanisms related to other existing policy innovation instruments should be mobilised to diffuse more broadly the innovations generated by contests.

Connected to the issue of the innovation type, a challenging topic remains the issue of cumulative innovation. The architecture of contests can be designed to spur cumulative innovation, and at the same time to avoid the penalising effect of patents in some circumstances (Besharov and Williams, 2012). In addition, contests may allow intermediate disclosure information producing better coordination and promoting convergent and overlapping experimentation that may be effective in situations where interactions are needed (Boudreau and Lakhani, 2015). Yet, following on Nelson's work (1961), viewing that innovation is a complex search process, innovation inducement prizes seem not to be appropriate for long term fundamental research (Kalil, 2006). Grants/ procurements seem better suited to fundamental research and breakthroughs, and contests appear better adapted to target challenges.

Based on the previous findings, we have gathered five situations defined by the ultimate economic and/or social goal for which the use of innovation contests by public deciders will be appropriate, under the conditions mentioned regarding the requirements for the contest design. In each case, we will underline that *a priori* - in the time scale - the impact on the innovation's process will be the highest.

i) A public sponsor who wishes to spur collaborations between various innovative players and to create industrial/research partnerships may rely on innovation contests. For instance a public agency, such as the US environment agency that desires to foster the adoption of green technologies may choose to stimulate collaborations between industrial/scientific partners characterized by complementary resources, in order to increase the probability of the emergence of new product/services including this "green" dimension. Thanks to contests and according to the public agencies' will, collaborations may emerge from various stakeholders: public, private, organizational, individuals (such as students), domestic, international.... Undeniably, contests on line offer a powerful means to stimulate unprecedented collaborations, able to gather complementary and multi-disciplinary knowledge. The contest's design should include competition's internal rules that take into account the result of "creating collaborations/partnership", and eventually that rewards this criterion. The effects on the innovation process may be observed during the competition and/or ex post.

ii) Innovation contests may also be considered as a stimulus for new companies and job creation. In the past federal contests have already resulted in the emergence of non-conventional teams, led to the formation of start-ups and new jobs³¹. Some agencies have also encouraged start-up creation for specific citizens. For example, the SBA (Small and Business Administration) challenge, with Innovate HER and the Growth Accelerator Fund Competition (launched on challenge.gov), provides an illustration of stimulating women to create their own companies. Whatever the objectives, the contest design may integrate for instance favorable fiscal arrangements in the case of starts-up and jobs creation. The results will probably be higher ex post, but it might be supposed that job creation process emerges during the competition.

iii) Contests may be mobilized in order to spur the demand and orient consumers toward defined markets. Several criteria may be combined to meet this goal. For instance, the future product/service price will not be higher than the product price including the existing technology and the amount of the reward will be subject to communication and marketization measures and product diffusion. In these circumstances, the emphasis will be put on the ex post level of the innovation process.

iv) Contests may be involved in educating citizens toward new behaviours, practices, conceptions (for instance in order to better protect the environment, to fight against inequalities, discrimination etc). With a view to influencing future citizens and behaviors, contests may preferably target high school and college students. The real effects will be detected especially at the ex post level.

v) Public sponsors may play a certification role toward industrial or investors and generate a leverage. Being awarded by a public agency contest will advertize the quality of the project/team and may increase future partnerships. In order to meet this goal, at the different stages of the competition, sponsors should include experts coming from various research fields, finance, industry etc. The pundits, participating in the process from designing the challenges through the competition governance to selecting the winners, may either be interested in carrying on the project involved or may get the winner (s) to benefit from their own networks. This will generate mostly ex post effects.

6. Conclusion

Since the 1990s, American public authorities have started to exploit the numerous advantages offered by contests with respect to their flexibility, variety and appeal. They therefore try to stimulate research in sectors deemed to be fundamental for the future (environment, energy, health, transport, etc.). Contests have emerged as a means to “guide” research toward fields that are currently considered essential for the future of the US for competitive reasons, social progress and more broadly for strengthening societal cohesion. Indeed, for the American

³¹ <https://www.whitehouse.gov/the-press-office/2016/06/21/impact-report-100-examples-president-obamas-leadership-science>

authorities, contests offer certain advantages over public grants or contracts. As a matter of fact, this is due to contests spreading risk over the competing team through the innovations ex post financing and because they are specifically adapted for hybrid innovation that combines technology with societal effects.

If the recent literature on public innovation contests has focused on the optimal conditions for a federal agency to launch a contest, no further developments have been done until now regarding when (in which circumstances) public decision makers should rely on contest (see Besharov and Williams, 2012; Kay, 2011). Based on several case studies findings, we gathered five proposals oriented toward public actors, that underline for which specific objectives (economic/social), contests may be conceived as effective policy tools. These recommendations should be further developed in the light of other experiences. Yet public decision makers should not turn a blind eye to the difficulties to launch and govern an innovation contest. Uncertainty is still prevailing, and a contest maybe a relevant choice only under restrictive terms (appropriate design, dynamic governance, specific targets).

Innovation contests do not replace existing tools as SBIR or DARPA programs, but are instead combined with them (see, for instance, the NASA Centennial Challenge). They emerge as an addition to the public arsenal in support of innovation. As NRC (2007) points out, “The Steering Committee views inducement prizes as a potential complement to, and not a substitute for, the primary instruments of direct federal support of research and innovation....” (pp 2-3). Accordingly, the increasing use of prizes by US federal agencies is related to other research concerning the pro-active role of the US Government in technological innovation processes that have been developing for several decades in the United States, yet it could fit, at least partially, into undergoing shifts of US policy innovation, turned toward “a policy of orchestration and combination of instruments” (Mazzucato and Robinson 2016, p. 3, quoting NASA’s example). Political players should use all these instruments depending on their innovation goals, and should use them in a coordinated way and as complementary tools.

In Europe³², an emerging challenge-oriented policy can be observed, essentially fed by the Horizon 2020 programs³³. A first series of four contests (Breaking the optical transmission barriers; Collaborative spectrum sharing ; Food scanner ; Better use of antibiotics) was awarded in 2016 (from €00 000 up to €1 million). If these contests are aimed at critical future issues, as in the USA, a special feature is that they rely on international cooperation between EU members (companies or universities). One may wonder about the share interest to extend in the future such as further cross-borders challenges besides national public challenges. In addition, international cooperation based on contests could provide, at least partially, answers to issues faced by developing countries which cannot afford to solve by themselves. Whatever their location in the world is, innovation contests seem to witness transformations not only in the way research and innovation are conducted, but also in policymaking itself.

³² See also NESTA program in the UK which has launched many challenge prizes (www.nesta.org.uk)

³³ See <http://ec.europa.eu/research/horizonprize/index.cfm>

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