

# The disclosure decision game: Subsidies and incentives for R&D activity<sup>☆</sup>

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## ABSTRACT

This article presents a three-stage non-cooperative disclosure decision game (DDG), in which R&D-investing firms choose whether to disclose R&D-related information to the rival in a Cournot-like environment. Though firms have no (private) incentive to disclose information unilaterally on their cost-reducing R&D activity to prevent a rival from engaging in free appropriation, this work reveals opportunity for the government to design an optimal policy aimed at incentivising R&D disclosure. Following this welfare-improving path, sharing R&D-related information becomes a Pareto-efficient Nash equilibrium strategy. These findings suggest that using public subsidies to R&D disclosure can lead to a win-win result, eliminating the unpleasant non-disclosing outcome from a societal perspective.

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## 1. Introduction

Through the Lisbon Strategy, which was launched in 2000, the European Council defined a crucial target for the EU “to become the most dynamic and competitive knowledge-based economy in the world by 2010 capable of sustainable economic growth with more and better jobs and greater social cohesion and respect for the environment” (European Commission, 2010, p. 2). Within this target, innovation (and thus R&D research) is the key element. However, this aim was disregarded considering the finding that “R&D spending in Europe is below 2%, compared to 2.6% in the US and 3.4% in Japan, mainly as a result of lower levels of private investment” (European Commission, 2020, p. 12). The current objective is “strengthening knowledge and innovation as drivers of our future growth. This requires improving the quality of education, strengthening our research performance, and promoting innovation and knowledge transfer throughout the Union, making full use of information and communication technologies and ensuring that innovative ideas can be turned into new products and services” (European Commission, 2020, pp. 11–12).

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Proponents of the initiative, referred to as the “Innovation Union”, aim “to re-focus R&D and innovation policy on the challenges facing our society” and claim that the objective “to prioritise knowledge expenditure, including by using tax incentives and other financial instruments to promote greater private R&D investments” (European Commission, 2020, pp. 12–13).

It seems crucial for Europe to promote private R&D activity and the corresponding knowledge spillovers through the spreading of R&D information by announcing the use of ad hoc publicly financed incentives. This is also because public firms invest more in R&D than private firms, as also recently shown by Feldman et al. (2021).<sup>1</sup>

This article represents a theoretical attempt to investigate the feasibility of a policy aimed at improving R&D knowledge disclosure by selfish, rational, non-cooperative, private firms belonging to strategic competitive markets (Cournot oligopoly). The work contributes to the literature developed by d’Aspremont and Jacquemin (1988, 1990; AJ henceforth), building on a model of cost-reducing R&D with (exogenous) spillovers. The study follows Hinloopen (1997, 2000) and Millioui (2009), and a recent contribution by Amir et al. (2019), aiming also to be part of the debate on public subsidies to innovation in the pharmaceutical industry and the development of vaccines against COVID-19 following the recent pandemic of the SARS-CoV-2 virus (see, e.g., Xue and

<sup>1</sup> See also Engel et al. (2016) for an empirical analysis of the effects of project R&D subsidies on the behaviour of firms in Germany and Buchmann and Kaiser (2019), who concentrate on the study of subsidies on the German biotech industry, showing that they can effectively increase patent output.

Ouellette (2020), European Commission (2021), Xie et al. (2021) and Gori et al. (2023)). Our analysis departs from Hinloopen (1997), who specifically considers the effects of R&D subsidies on cooperative and non-cooperative R&D in an AJ setting, and then aims to study the individual incentives of sharing the results of private R&D research in a non-cooperative game.

Inspired by AJ and Hinloopen (1997), this article adds a third (disclosure decision) stage to a standard two-stage Cournot game with homogeneous products, in which non-cooperative firms competitively choose both the amount of cost-reducing innovation and production. The work shows that the public provision of R&D subsidies can change the perspective of non-cooperative firms on the disclosure side, letting them be incentivised to spread R&D knowledge as a Pareto-efficient outcome of the game, thereby achieving both the maximisation of social welfare and the main Lisbon Strategy's goal. This contrasts the absence of public intervention, in which only the Pareto-inefficient Nash equilibrium of perfect patenting exists (no disclosure).

The literature follows the seminal AJ work and related extensions by Henriques (1990) and Suzumura (1992), which develop interesting trajectories closely related in spirit to our contribution. A first strand of the literature is represented by the works of Kamien et al. (1992), Ziss (1994), De Bondt (1996), Amir (2000), Amir et al. (2003), and Lambertini and Rossini (2009), which concentrate on cooperative R&D decisions amongst firms competing in the product market and indicate that this behaviour is socially beneficial. In this literature, spillovers are exogenous, i.e., each firm has no direct control over the extent of the disclosure.

A second strand of the literature assumes that firms endogenously control spillovers and investigates the owners' decisions about information sharing. These works can be divided into two groups. One group (Poyago-Theotoky, 1999; Atallah, 2004; Lambertini et al., 2004) examines the case in which firms decide on information sharing after they invested in R&D (i.e., spillovers do not affect the extent of R&D activity). The main result of this branch of literature is to have firms keeping their R&D knowledge secret, thereby implying no spillovers (non-disclosure). The second group (Gersbach and Schmutzler, 2003; Gil-Moltó et al., 2005; Piga and Poyago-Theotoky, 2005; Milliou, 2009) considers the possibility of firms choosing whether to share R&D outcomes before they invest in R&D (i.e., spillovers do affect the extent of R&D activity). Protecting or sharing knowledge depends on price or quantity competition (the first paper) on location (the second and third papers), and if the extent of R&D spillovers is not too strong, firms can let R&D knowledge flow to competitors (the last paper). The main result of this branch of literature is that firms choose to disclose R&D knowledge to their rivals.

Another important contribution close to our argument—though with a different modelling approach and perspectives—is Amir and Wooders (1999). Specifically, they consider a duopoly with asymmetric firms (an innovator and an imitator) that invest in R&D. The spillover rate follows a stochastic binomial process that has as realisations the extreme cases of perfect patenting (no disclosure) or full disclosure (no protection) in the model. This has consequences on the structure of the duopoly and the degree of cooperation between firms. Unlike them, in our model, the realisation of no disclosure (i.e., the choice of perfect patenting) and that of positive disclosure (i.e., the choice to spread R&D outcomes) are not random but are the result of a rational choice in a deterministic context according to a game-theoretic non-cooperative setting.

The present article belongs to the literature on exogenous spillovers, in which non-cooperative competitive firms must choose whether to disclose R&D outcomes before deciding on cost-reducing investments. The assumption of exogenous spillovers implies that the spillover rate is not chosen by firms as

a profit-maximising variable, i.e., its extent is determined by the state of the art of the existing technology. However, the spillover rate represents the choice variable of players in the first stage of the disclosure decision game (DDG), in which each firm must choose to keep secret the result of its R&D activity (no disclosure or perfect patenting) or to disclose at a rate determined by the existing technology.

The work explicitly considers the cases of exogenous and (second-best) optimal policies and offers policy implications that can be applied, amongst others, to the pharmaceutical industry for the development of vaccines against the COVID-19 outbreak.

The article now outlines the context of the DDG according to the following line of reasoning: (1) firms can fully protect their R&D-related information by choosing to unublish R&D research reports or engage in non-costly patenting (*no disclosure decision*); (2) firms can let the R&D-related information spread by publishing R&D research reports or choosing not to patent their R&D outcomes (*disclosure decision*) following the rules dictated by the existing technology, which are taken as given by the firms. The extent of R&D spillovers depends only on the (exogenous) degree of compatibility between the productive technologies of firms or on the ability of the rival to transform the external R&D information in an internal cost reduction. This implies that, if one firm chooses to disclose, then the rate at which the R&D outcomes flow to the competitor is exogenously determined by technological, entrepreneurial, and engineering factors (which are common knowledge).

In summary, the present article introduces a new non-cooperative game (DDG) in an AJ Cournot setting and considers the active role of the government that uses a specific fiscal tool to incentivise firms to disclose R&D outcomes. The major features and results of the article are as follows:

- The spillover rate is (1) *exogenous* on the firm side, as it is not chosen to maximise profits but is taken as given according to the state of the art of the existing technology, and (2) an *endogenous* variable of the game-theoretic setting, as firms choose whether to disclose R&D outcomes in the first stage of the non-cooperative DDG.
- Firms can choose to patent or spread knowledge to the rival according to their selfish interest in a strategic setting. In the former case, they simply keep secret the R&D outcomes (at no cost). In the latter case, they choose to disclose at the exogenous rate determined by elements outside their control.
- In the absence of R&D subsidies, firms choose not to disclose (ND) so that the Pareto-inefficient sub-game perfect Nash equilibrium (SPNE) is (ND,ND). The game is a prisoner's dilemma, and conflict arises between the self-interest and mutual benefit of R&D disclosure. Firms gain higher profits by jointly spreading knowledge, but this is at odds with their unilateral interest. This strategic outcome causes society to be worse off in equilibrium.
- The introduction of ad hoc R&D subsidies to disclosure can solve the dilemma. The SPNE becomes the Pareto efficient (D,D), and the DDG an anti-prisoner's dilemma (deadlock) in which self-interest and mutual benefit of R&D disclosure do not conflict. The best strategic outcome is not at odds with the firm's unilateral interest. This strategic outcome contributes to let society be better off in equilibrium (win-win result).

The remainder of the article is organised as follows. Section 2 outlines the model developed by AJ with and without disclosure. Section 3 studies the DDG and discusses the SPNE outcomes with and without public intervention. Section 4 concentrates on the optimal policy. Section 5 concludes the article. The Appendix provides the mathematical details of the model and the main results.

**Table 1**  
Equilibrium outcomes in the AJ model when both firms disclose ( $\beta_i = \beta_j = \beta > 0$ ).

$x^*(\beta)$	$\frac{2(1-w)(2-\beta)}{9g-2(1+\beta)(2-\beta)}$
$q^*(\beta)$	$\frac{3g(1-w)}{9g-2(1+\beta)(2-\beta)}$
$p^*(\beta)$	$\frac{3g(1+2w)-2(1+\beta)(2-\beta)}{9g-2(1+\beta)(2-\beta)}$
$\Pi^*(\beta)$	$\frac{g(1-w)^2[9g-2(2-\beta)^2]}{[9g-2(1+\beta)(2-\beta)]^2}$
$CS^*(\beta)$	$\frac{18g^2(1-w)^2}{[9g-2(1+\beta)(2-\beta)]^2}$
$W^*(\beta)$	$\frac{4g(1-w)^2[9g-(2-\beta)^2]}{[9g-2(1+\beta)(2-\beta)]^2}$

## 2. The model

The economy comprises three types of agents: firms, consumers, and the government. The production side consists of a competitive industry producing the numeraire good  $y$  and a duopolistic quantity-setting industry in which firm  $i$  and firm  $j$  ( $i = \{1, 2\}$ ,  $i \neq j$ ) produce homogeneous goods,  $q_i$  and  $q_j$ , respectively. Both firms non-cooperatively invest in cost-reducing innovation along the line of the model of AJ, augmented later by Bacchiega et al. (2010) and Buccella et al. (2023, 2022), who show that investing in R&D represents the unique SPNE of a non-cooperative investment decision game.

The present work adds another stage to AJ's two-stage game by reasonably considering that firms always undertake R&D investment. In the additional stage (the first one), each firm – before determining the extent of cost-reducing R&D activity – chooses (1) to disclose R&D-related information (the disclosure decision stage), thus allowing R&D dissemination at an *exogenous* level of spillovers dictated by the existing technology (i.e., each firm has no direct control over the extent of the disclosure for, e.g., technological reasons), or (2) keep R&D knowledge secret.

On the one hand, playing the non-cooperative DDG without a public intervention aimed at subsidising external R&D flow leads to a Pareto-inefficient SPNE in which self-interest and the mutual benefit of sharing knowledge conflict (see Section 3). This is because keeping secret R&D-related outcomes is in the unilateral interest (dominant strategy) of each non-cooperative firm in the AJ setting, which indicates a preference to free-ride on the R&D activity of the rival. On the other hand, spreading R&D-related information is one of the main aims of the EU's Lisbon Strategy 2020, leading to an increase in consumer surplus and social welfare, thus showing the importance of public intervention to increase social welfare.

We now briefly sketch a normalised version of the AJ Cournot duopoly (Buccella et al., 2023), in which both firms disclose, and we then summarise the main equilibrium outcomes in Table 1.

Both firm  $i$  and firm  $j$  non-cooperatively invest in process innovation and then non-cooperatively compete in the product market to produce homogeneous goods. The normalised linear (inverse) demand is:

$$p = 1 - Q, \quad (1)$$

where  $p$  denotes the market price and  $Q = q_i + q_j$ . The total cost of production and the R&D cost incurred by (representing the R&D investment of) firm  $i$  are respectively given by the functions  $C_i$  and  $X_i$ , where  $x_i$  and  $x_j$  represent the monetary equivalent of the

resulting R&D activity of firm  $i$  and firm  $j$ , respectively. Following AJ, these functions are as follows:

$$C_i = (w - x_i - \beta_j x_j) q_i, \quad (2)$$

and

$$X_i = \frac{g}{2} x_i^2, \quad (3)$$

where  $g > 0$  is a parameter measuring R&D efficiency. It scales up/down R&D investment total costs and represents an exogenous index of technological progress measuring, for example, the appearance of new, cost-effective technology. Technological advancements are given by a reduction in  $g$ . In addition,  $\beta_j \in [0, 1]$  captures the extent of the spillovers (externality) of the R&D activity of firm  $j$  exogenously flowing as a cost-reducing device towards firm  $i$ . We assume that both firms share this characteristic of the extent of technological spillovers: firm  $i$  discloses at the rate  $\beta_i$  towards firm  $j$ , and firm  $j$  discloses at the rate  $\beta_j$  towards firm  $i$ .

This scenario represents the standard case of exogenous spillovers for which a fixed fraction of a firm's R&D process innovation exogenously flows to competitors. Thus, each firm has no direct control over the extent of disclosure for, e.g., technological reasons, and directly follows AJ and the subsequent contributions by Henriques (1990), Suzumura (1992), Kamien et al. (1992), De Bondt (1996), Bacchiega et al. (2010), and Buccella et al. (2023, 2022). When  $\beta_j = 0$ , there are no R&D externalities from firm  $j$  to firm  $i$ . When  $\beta_j = 1$ , the R&D information produced by firm  $j$  is fully shared with firm  $i$ .

From (2) the inequality  $w - x_i - \beta_j x_j > 0$  must hold, where  $0 < w < 1$  measures the unitary technology of production cost regardless of R&D activity.

By using (1)–(3), profits of firm  $i$  can be written as follows:

$$\Pi_i = (1 - Q) q_i - (w - x_i - \beta_j x_j) q_i - \frac{g}{2} x_i^2. \quad (4)$$

Table 1 summarises the equilibrium outcomes of the AJ model when  $\beta_i = \beta_j = \beta > 0$  (disclosure). The case of no disclosure can easily be obtained by setting  $\beta = 0$ . The feasibility conditions that hold in the AJ model are as follows (see Buccella et al., 2023 for a thoughtful analysis on this issue)<sup>2</sup>:

$$g > \frac{2(1-\beta)(2-\beta)}{3} \text{ if } 0 < \beta < \frac{1}{2} \text{ (stability condition, SC, when } x_i \text{ and } x_j \text{ are strategic substitutes),} \quad (5)$$

$$g > \frac{2(1+\beta)(2-\beta)}{9} \text{ if } \frac{1}{2} < \beta \leq 1 \text{ (stability condition, SC, when } x_i \text{ and } x_j \text{ are strategic complements),} \quad (6)$$

$$g > \frac{2(2-\beta)^2}{9} \text{ (second-order condition, SOC),} \quad (7)$$

$$g > \frac{2(1+\beta)(2-\beta)}{9w} \text{ (R\&D cost condition, T).} \quad (8)$$

From Table 1,  $W^*(\beta) > W^*(0)$  holds, where  $W^* = CS^* + 2\Pi^*$  is the equilibrium social welfare computed as the sum of the consumer surplus ( $CS^*$ ) and producer surplus (profits).<sup>3</sup>

<sup>2</sup> The SOC is automatically fulfilled when the conditions emerging from the SC are satisfied. The R&D cost condition,  $T$  (meaning “threshold”), emerges from the inequality  $w - x_i - \beta_j x_j > 0$ . For an analysis of the stability conditions of the equilibrium, see Seade (1980), Bacchiega et al. (2010), and Buccella et al. (2023).

<sup>3</sup> A first step to show this result is given by  $\frac{\partial CS^*(\beta)}{\partial \beta} \Big|_{\beta=0} = \frac{72g(1-w)^2}{(9g-4)^3} > 0$ ,  $\frac{\partial \Pi^*(\beta)}{\partial \beta} \Big|_{\beta=0} = \frac{4g(1-w)^2(27g-16)}{(9g-4)^3} > 0$  for any  $g$  that satisfies the feasibility conditions of the model, and  $\frac{\partial W^*(\beta)}{\partial \beta} \Big|_{\beta=0} = \frac{32g(1-w)^2}{(9g-4)^2} > 0$ . A more articulated analysis showing that  $W^*(\beta) > W^*(0)$  is presented in the Appendix.

This reveals that sharing R&D outcomes is beneficial to society. However, adding the disclosure decision stage to AJ's two-stage game, in the absence of ad hoc subsidies, leads to a Pareto-inefficient SPNE of the DDG in which both firms are entrapped in a dilemma. This is because every firm unilaterally prefers to keep secret the results of the R&D activity to avoid favouring the rival by reducing its production costs (free appropriation). Though the circulation of knowledge is beneficial to society, it cannot be achieved through the non-cooperative choices of profit-maximising innovating firms in a strategic context.

To overcome this lacuna, we consider R&D subsidies following as established literature (Hinlopen, 1997, 2000; Milliou, 2009; Amir et al., 2019) and introduce a public tool to incentivise disclosure.

Subsidies to firm  $i$  ( $\Sigma_i > 0$ ) and firm  $j$  ( $\Sigma_j > 0$ ) are financed at a balanced budget with a uniform non-distorting lump-sum tax ( $T > 0$ ) on the side of consumers. The available post-tax exogenous nominal income of the representative consumer ( $M - T > 0$ ) is high enough to avoid corner solutions (see Amir et al., 2017). The gross nominal income of the consumer,  $M$ , is exogenous as it does not depend on labour supply decisions. Therefore, in what follows, we do not compute the share of tax in income and assume that the income is always high enough to guarantee the financing of the policy.

The government budget constraint is:

$$T = \Sigma_i + \Sigma_j, \quad (9)$$

where  $\Sigma_i = \sigma \beta_i \frac{g}{2} x_i^2$ ,  $\Sigma_j = \sigma \beta_j \frac{g}{2} x_j^2$  and  $\sigma \geq 0$  is the subsidy rate. Notice that  $\sigma = 0$  corresponds to the scenario with no government subsidy, which will be studied in-depth in the next section.

The timing of the events of the DDG is as follows. The government first announces the policy, which can be exogenous (Section 3) or endogenous (Section 4). Then, firms are engaged in a multi-stage non-cooperative DDG with complete information in which they choose whether to disclose R&D outcomes (at the exogenous rate  $\beta$ ) in the first *disclosure decision-making stage*. In the second *R&D stage*, firms compete on the extent of process R&D. In the third *market stage*, firms compete on quantities in the product market. This implies that firms decide on information sharing before they invest in R&D (e.g., Gersbach and Schmutzler (2003)). As usual, the game is solved by adopting the backward induction logic.

### 3. The disclosure decision game

This section develops the non-cooperative, Cournot-like DDG and studies the sub-games in which (1) both firms disclose, (2) no firms disclose, and (3) one firm discloses and the rival does not. Then, it characterises the SPNE of the game emerging in the first stage, by showing – amongst other things – that the SPNE in the absence of subsidies ( $\sigma = 0$ ) is the Pareto-inefficient non-disclosing outcome (prisoner's dilemma).

#### 3.1. The symmetric sub-game in which both firms disclose (D/D)

Let us assume that both firms disclose ( $\beta > 0$ ) and the government is financing subsidies to favour disclosure ( $\sigma > 0$ ). The profit function of firm  $i$  becomes:

$$\Pi_i^{D/D} = (1 - Q)q_i - (w - x_i - \beta_j x_j)q_i - \frac{g}{2} x_i^2 (1 - \beta_i \sigma), \quad (10)$$

where  $\sigma < \frac{1}{\beta_i}$  to preserve the incentive to invest in R&D unilaterally. As is clear from (10), sharing R&D outcomes under D/D generates benefits and costs to each firm: it reduces the need of R&D effort through the public subsidy and reduces the total cost

of production of the rival, thus increasing its incentive to free ride on existing knowledge avoidance.

The exogenous Nash equilibrium outcomes in the sub-game D/D are as follows<sup>4</sup>:

$$x_i^{*D/D} = \frac{2(1-w)(2-\beta)}{9g(1-\beta\sigma) - 2(1+\beta)(2-\beta)}, \quad (11)$$

$$q_i^{*D/D} = \frac{3g(1-w)(1-\beta\sigma)}{9g(1-\beta\sigma) - 2(1+\beta)(2-\beta)}, \quad (12)$$

$$p_i^{*D/D} = \frac{3g(1-\beta\sigma)(1+2w) - 2(1+\beta)(2-\beta)}{9g(1-\beta\sigma) - 2(1+\beta)(2-\beta)}, \quad (13)$$

$$\Pi_i^{*D/D} = \frac{g(1-w)^2(1-\beta\sigma)[9g(1-\beta\sigma) - 2(2-\beta)^2]}{[9g(1-\beta\sigma) - 2(1+\beta)(2-\beta)]^2}. \quad (14)$$

The feasibility conditions that guarantee meaningful equilibrium values in the sub-game D/D are as follows (see the Appendix for details):

$$g > \frac{2(1-\beta)(2-\beta)}{3(1-\beta\sigma)} := g_{SC}^{D/D, \beta_{low}}(\beta, \sigma) \text{ if } 0 < \beta < \frac{1}{2}, \quad (15)$$

$$g > \frac{2(1+\beta)(2-\beta)}{9(1-\beta\sigma)} := g_{SC}^{D/D, \beta_{high}}(\beta, \sigma) \text{ if } \frac{1}{2} < \beta \leq 1, \quad (16)$$

$$g > \frac{2(2-\beta)^2}{9(1-\beta\sigma)} := g_{SOC}^{D/D}(\beta, \sigma), \quad (17)$$

$$g > \frac{2(1+\beta)(2-\beta)}{9w(1-\beta\sigma)} := g_T^{D/D}(\beta, \sigma, w). \quad (18)$$

Lemma 1 clarifies which threshold amongst those reported in (15)–(18) is binding in the sub-game D/D.

**Lemma 1.** (1) If  $w < \frac{1}{3}$ , then for any  $0 < \beta \leq 1$  and  $\sigma < \frac{1}{\beta}$ ,  $g_T^{D/D}(\beta, \sigma, w)$  is binding in the  $(\beta, g)$  space.

(2) If  $w > \frac{1}{3}$ , then

(2.1) for any  $\beta < \beta_T^{D/D}$ ,  $g_{SC}^{D/D, \beta_{low}}(\beta, \sigma)$  is binding in the  $(\beta, g)$  space, and

(2.2) for any  $\beta > \beta_T^{D/D}$ ,  $g_T^{D/D}(\beta, \sigma, w)$  is binding in the  $(\beta, g)$  space.

(3) If  $w \rightarrow 1$ , then for any  $0 < \beta < \frac{1}{2}$  and  $\sigma < \frac{1}{\beta}$ ,  $g_{SC}^{D/D, \beta_{low}}(\beta, \sigma)$  is binding in the  $(\beta, g)$  space, and for any  $\frac{1}{2} < \beta \leq 1$  and  $\sigma < \frac{1}{\beta}$ ,  $g_{SC}^{D/D, \beta_{high}}(\beta, \sigma)$  is binding in the  $(\beta, g)$  space.

**Proof.** Appendix.

From (11)–(14), the equilibrium values of the gross consumers surplus ( $CS^{*D/D}$ ), the lump-sum tax used to finance the R&D subsidy at a balanced budget ( $T^{*D/D}$ ) and the producer surplus ( $PS^{*D/D}$ ) are as follows:

$$CS^{*D/D} = 2 \left( q_i^{*D/D} \right)^2 = \frac{18g^2(1-w)^2(1-\beta\sigma)^2}{[9g(1-\beta\sigma) - 2(1+\beta)(2-\beta)]^2}. \quad (19)$$

$$T^{*D/D} = \frac{4g\beta\sigma(1-w)^2(2-\beta)^2}{[9g(1-\beta\sigma) - 2(1+\beta)(2-\beta)]^2}. \quad (20)$$

and

$$PS^{*D/D} = 2\Pi_i^{*D/D} = \frac{2g(1-w)^2(1-\beta\sigma)[9g(1-\beta\sigma) - 2(2-\beta)^2]}{[9g(1-\beta\sigma) - 2(1+\beta)(2-\beta)]^2}. \quad (21)$$

<sup>4</sup> The analytical details and all mathematical steps to compute the equilibrium values of the main variables and the feasibility conditions in the sub-game D/D are reported in the Appendix.



Therefore, equilibrium social welfare is given by:

$$W^{*D/D} = CS^{*D/D} - T^{*D/D} + PS^{*D/D} \\ = \frac{4g(1-w)^2[9g(1-\beta\sigma)^2 - (2-\beta)^2]}{[9g(1-\beta\sigma) - 2(1+\beta)(2-\beta)]^2}. \quad (22)$$

where  $CS^{*net} := CS^{*D/D} - T^{*D/D}$  is the net consumer surplus.

Section 2 already showed that, when both firms disclose ( $\beta > 0$ ), social welfare is greater than the corresponding value when both firms do not disclose ( $\beta = 0$ ) in the absence of policy. Eq. (22) allows us to show the existence of a second-best optimal subsidy.

**Proposition 2.** *The introduction of R&D subsidies to incentivise R&D disclosure is welfare improving. The (second-best) optimal subsidy is:*

$$\sigma = \sigma^{OPT} := \frac{3}{2(1+\beta)}, \quad (23)$$

where  $\sigma^{OPT} < \frac{1}{\beta}$ ,  $\sigma^{OPT} \rightarrow \frac{3}{2}$  if  $\beta \rightarrow 0$  and  $\sigma^{OPT} = \frac{3}{4}$  if  $\beta = 1$ .

**Proof.** From (22) one gets:

$$\left. \frac{\partial W^{*D/D}}{\partial \sigma} \right|_{\sigma=0} = \frac{216g^2\beta^2(2-\beta)(1-w)^2}{[9g - 2(1+\beta)(2-\beta)]^3} > 0, \quad (24)$$

and

$$\frac{\partial W^{*D/D}}{\partial \sigma} = \frac{72g^2\beta^2(2-\beta)(1-w)^2[3 - 2(1+\beta)\sigma]}{[9g(1-\beta\sigma) - 2(1+\beta)(2-\beta)]^3} \\ = 0 \iff \sigma = \sigma^{OPT}. \quad (25)$$

Therefore,  $\frac{\partial W^{*D/D}}{\partial \sigma} > 0$  if  $\sigma < \sigma^{OPT}$  and  $\frac{\partial W^{*D/D}}{\partial \sigma} < 0$  if  $\sigma > \sigma^{OPT}$ .  $\square$

Proposition 2 resembles Amir et al. (2019, Proposition 7, p. 1214) about the existence of a social optimum via R&D subsidies and has a policy application. Public policies aiming at directly subsidising R&D spillovers generate a trade-off between (net) consumer surplus and profits. On the consumer side, the policy provides benefits by allowing an increase in production, which increases the net welfare of consumers in the market. This means that the benefits of financing this kind of subsidy – given the increased R&D effort they cause, which increases production – allows consumers to generally offset the cost of the lump-sum taxation, so that consumers are better off when  $\sigma > 0$  than when  $\sigma = 0$ .<sup>5</sup> On the producer side, the effect is a priori uncertain, as the subsidy can increase firms' profits until the percentage increase in production is larger than the subsequent percentage reduction in the market price that consumers are willing to pay (the market demand is downward sloping). However, profits might reduce if the percentage reduction in the market price is large enough to more than compensate for the positive effects on profits due to the increase in output production. If marginal benefits (as measured by the increase in both the net consumer surplus and profits followed by the augmented production) exceed marginal costs (as measured by the societal

cost to finance the policy, i.e., the reduction in available income of consumers and the reduction in the profits they cause), then it is convenient to increase the R&D subsidy to increase welfare. In contrast, when economic costs outweigh economic benefits, it is convenient to reduce the R&D subsidy to increase welfare. Social welfare is maximised only when marginal benefits equal the corresponding marginal costs. At the (second-best) social optimum, this policy eliminates the inefficiencies related to the imperfect appropriability of R&D innovation.

The optimal subsidy in (23) is decreasing in the extent of the R&D externality. As far as the degree of R&D disclosure increases, the lower the government's need to subsidise a dissemination activity on the producer side. When disclosure tends to its minimum intensity (i.e.,  $\beta \rightarrow 0$  so that knowledge tends to be a private good), the optimal subsidy is at its highest level. When disclosure reaches its maximum intensity (i.e.,  $\beta = 1$  so that knowledge is a pure public good), the optimal subsidy is at its smallest level.

### 3.2. The symmetric sub-game in which both firms do not disclose (ND/ND)

Let us assume now that both firms do not disclose ( $\beta = 0$ ). Profits of firm  $i$  under ND/ND are:

$$\Pi_i^{ND/ND} = (1-Q)q_i - (w - x_i)q_i - \frac{g}{2}x_i^2, \quad (26)$$

The exogenous Nash equilibrium values of the main variables can be obtained by setting  $\beta = 0$  in (11)–(14). They are given by:

$$x_i^{*ND/ND} = \frac{4(1-w)}{9g-4}, \quad (27)$$

$$q_i^{*ND/ND} = \frac{3g(1-w)}{9g-4}, \quad (28)$$

$$p_i^{*ND/ND} = \frac{3g(1+2w)-4}{9g-4}, \quad (29)$$

$$\Pi_i^{*ND/ND} = \frac{g(1-w)^2(9g-8)}{(9g-4)^2}. \quad (30)$$

The same holds about the feasibility conditions from (15), (17), and (18), which are now as follows:

$$g > \frac{4}{3} := g_{SC}^{ND/ND, \beta_{low}}, \quad (31)$$

$$g > \frac{8}{9} := g_{SOC}^{ND/ND}, \quad (32)$$

$$g > \frac{4}{9w} := g_T^{ND/ND}(w). \quad (33)$$

Lemma 3 complements Lemma 1 and clarifies which condition, amongst those reported in (31)–(33), is binding in the sub-game ND/ND.

**Lemma 3.** (1) If  $w < \frac{1}{3}$ , then  $g_T^{ND/ND}(w)$  is binding. (2) If  $w > \frac{1}{3}$ , then  $g_{SC}^{ND/ND, \beta_{low}}$  is binding.

**Proof.** (1) If  $w < \frac{1}{3}$ , then  $g_T^{ND/ND}(w) > g_{SC}^{ND/ND, \beta_{low}}$ . (2) If  $w > \frac{1}{3}$ , then  $g_T^{ND/ND}(w) < g_{SC}^{ND/ND, \beta_{low}}$ .  $\square$

### 3.3. The asymmetric sub-game in which only one firm discloses (D/ND)

This section considers the asymmetric sub-game in which firm  $i$  discloses ( $\beta_i = \beta > 0$ ) and the rival, firm  $j$ , does not ( $\beta_j = 0$ ). The profit functions of the disclosing firm  $i$  (reporting the role

<sup>5</sup> Introducing R&D disclosure subsidisation is always beneficial to consumers. This is because  $\left. \frac{\partial CS^{*net}}{\partial \sigma} \right|_{\sigma=0} = \frac{4g\beta(2-\beta)(1-w)^2(2\beta^3-6\beta^2+27\beta g+8)}{(9g-4+2\beta^2-2\beta)^3} > 0$  for any  $0 \leq$

$\beta \leq 1$  and  $g$  belonging to the feasible region. If  $\beta < \frac{9}{4}g + 2 - \frac{3}{4}\sqrt{9g^2 + 16g}$ , then  $CS^{*net}$  is monotonically increasing in  $\sigma$  for any  $0 < \sigma < 1$ . If  $\beta > \frac{9}{4}g + 2 - \frac{3}{4}\sqrt{9g^2 + 16g}$ , then  $CS^{*net}$  is an inverted U-shaped function of  $\sigma$  and there exists a subsidy rate, given by  $\sigma^{CS} := \frac{2(4-3\beta^2)+2\beta^3+27g\beta}{9g\beta(1+\beta)} < 1$ , that maximises  $CS^{*net}$  for any  $0 < \sigma < 1$ . However,  $\sigma$  can also be larger than one. A more thoughtful analysis of the behaviour of the net consumer surplus is presented in the Appendix.

of the subsidy) and the non-disclosing firm  $j$  read respectively as follows:

$$\Pi_i^{D/ND} = (1 - Q)q_i - (w - x_i)q_i - \frac{g}{2}x_i^2(1 - \beta\sigma), \quad (34)$$

and

$$\Pi_j^{D/ND} = (1 - Q)q_j - (w - x_j - \beta x_i)q_j - \frac{g}{2}x_j^2. \quad (35)$$

Eq. (34) shows that the disclosing firm  $i$  cannot benefit from any cost-reducing activity generated by the R&D effort of the rival but receives the R&D subsidy to promote disclosure. Eq. (35) shows that the non-disclosing firm  $j$  benefits from the (cost-reducing) externality generated by the stream of knowledge shared by the disclosing rival, but it does not receive subsidies.

The exogenous Nash equilibrium outcomes of the main variables in the sub-game D/ND are as follows<sup>6</sup>:

$$x_i^{*D/ND} = \frac{2(1 - w)(2 - \beta)(3g - 4)}{27g^2(1 - \beta\sigma) - 6g[4(1 - \beta\sigma) + 2(2 - \beta)^2] + 8(2 - \beta)}, \quad (36)$$

$$x_j^{*D/ND} = \frac{4(1 - w)(2 - \beta)[3g(1 - \beta\sigma) - 2(1 - \beta)(2 - \beta)]}{27g^2(1 - \beta\sigma) - 6g[4(1 - \beta\sigma) + 2(2 - \beta)^2] + 8(2 - \beta)}, \quad (37)$$

$$q_i^{*D/ND} = \frac{3g(1 - w)(1 - \beta\sigma)(3g - 4)}{27g^2(1 - \beta\sigma) - 6g[4(1 - \beta\sigma) + 2(2 - \beta)^2] + 8(2 - \beta)}, \quad (38)$$

$$q_j^{*D/ND} = \frac{3g(1 - w)[3g(1 - \beta\sigma) - 2(1 - \beta)(2 - \beta)]}{27g^2(1 - \beta\sigma) - 6g[4(1 - \beta\sigma) + 2(2 - \beta)^2] + 8(2 - \beta)}, \quad (39)$$

$$p^{*D/ND} = \frac{9g^2(1 - \beta\sigma)(1 + 2w) - 6g[2(1 + w)(2 - \beta\sigma) - \beta[1 + w(3 - \beta)]] + 8(2 - \beta)}{27g^2(1 - \beta\sigma) - 6g[4(1 - \beta\sigma) + 2(2 - \beta)^2] + 8(2 - \beta)}, \quad (40)$$

$$\Pi_i^{*D/ND} = \frac{g(1 - w)^2(1 - \beta\sigma)(3g - 4)^2[9g(1 - \beta\sigma) - 2(2 - \beta)^2]}{[27g^2(1 - \beta\sigma) - 6g[4(1 - \beta\sigma) + 2(2 - \beta)^2] + 8(2 - \beta)]^2}, \quad (41)$$

$$\Pi_j^{*D/ND} = \frac{g(1 - w)^2(9g - 8)[3g(1 - \beta\sigma) - 2(1 - \beta)(2 - \beta)]^2}{[27g^2(1 - \beta\sigma) - 6g[4(1 - \beta\sigma) + 2(2 - \beta)^2] + 8(2 - \beta)]^2}. \quad (42)$$

The equilibrium values reported in (36)–(42) are positive if the feasibility conditions discussed in the previous section are fulfilled. The only constraint that must be fulfilled in the sub-game D/ND, to guarantee that the equilibria are meaningful, comes from the inequality  $w - x_j - \beta x_i > 0$  of the disclosing firm  $i$  and implies that

$$g > g_T^{D/ND}(\beta, \sigma, w), \quad (43)$$

<sup>6</sup> The analytical details and all mathematical steps to compute the equilibrium values of the main variables and the feasibility conditions in the sub-game D/ND are reported in the [Appendix](#).

**Table 2**

The DDG (payoff matrix).

Firm 2 → Firm 1 ↓	D	ND
D	$\Pi_1^{*D/D}, \Pi_2^{*D/D}$	$\Pi_1^{*D/ND}, \Pi_2^{*D/ND}$
ND	$\Pi_1^{*ND/D}, \Pi_2^{*ND/D}$	$\Pi_1^{*ND/ND}, \Pi_2^{*ND/ND}$

representing its R&D cost condition, whose expression is reported in the [Appendix](#).

### 3.4. The disclosure decision stage: Nash equilibria and discussion

This section examines the first decision-making stage of the game, in which every firm (after observing the government's announcement about R&D disclosure subsidisation at the rate  $\sigma$ ) chooses whether to share its R&D outcomes to the rival in a non-cooperative quantity-setting environment à la AJ. Section 4 will consider the case of optimal subsidy ( $\sigma = \sigma^{OPT}$ ).

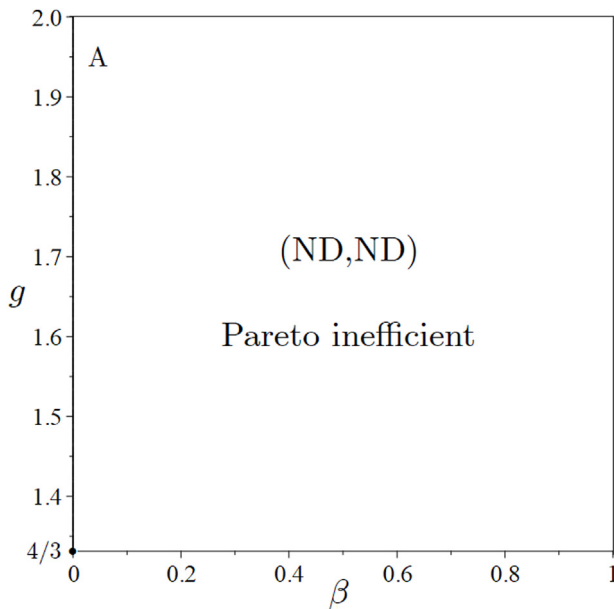
The equilibrium profits reported in Table 2 (payoff matrix) come from Eqs. (14), (30), (41) and (42). The feasible region of the DDG, which guarantees meaningful SPNE in the space  $(\beta, g)$ , is bounded by the constraints discussed in the previous section. The shape of these constraints generally depends on  $\beta, \sigma$ , and  $w$ . The analysis of the shape and position of the relevant constraints in the  $(\beta, g)$  space is a complex exercise. To avoid lengthening the exposition, we leave the complete analysis to a geometrical representation in this section (Figs. 1–4) and in Section 4 about the case of optimal subsidy (Fig. 5). Overall, when  $w < \frac{1}{3}$  (resp.  $w > \frac{1}{3}$ ), the DDG is generally bounded by the constraints reported in (31) and (43) (resp. (15), (18), (31), and (43)).

Let us now define the profit differentials  $\Delta\Pi_a := \Pi_i^{*D/ND} - \Pi_i^{*ND/ND}$ ,  $\Delta\Pi_b := \Pi_i^{*ND/D} - \Pi_i^{*D/D}$ ,  $\Delta\Pi_c := \Pi_i^{*ND/ND} - \Pi_i^{*D/D}$  ( $i = \{1, 2\}, i \neq j$ ).<sup>7</sup> The first threshold defines the incentive of firm  $i$  to deviate from D to ND when its sign is negative (and vice versa when its sign is positive) when the rival, firm  $j$ , is playing ND. The second threshold defines the incentive of firm  $i$  to deviate from ND to D when its sign is negative (and vice versa when its sign is positive) when the rival, firm  $j$ , is playing D. The third threshold determines the Pareto efficiency/inefficiency of a symmetric SPNE.

The solutions of  $\Delta\Pi_a = 0$ ,  $\Delta\Pi_b = 0$ , and  $\Delta\Pi_c = 0$  for  $\beta$  as a function of  $g$  and  $\sigma$  allow us to determine the loci of points that divide the plane  $(\beta, g)$  into areas in which the profit differentials are positive from those in which they are negative. These solutions are given by  $\Delta\Pi_a = 0 \Rightarrow \beta_a(g, \sigma)$ ,  $\Delta\Pi_b = 0 \Rightarrow \beta_b(g, \sigma)$ , and  $\Delta\Pi_c = 0 \Rightarrow \beta_c(g, \sigma)$ . Unfortunately, these expressions cannot be dealt with in a neat, analytical form. However, the sign of  $\Delta\Pi_a$  is negative (resp. positive) if  $\beta < \beta_a(g, \sigma)$  (resp.  $\beta > \beta_a(g, \sigma)$ ), the sign of  $\Delta\Pi_b$  is positive (resp. negative) if  $\beta < \beta_b(g, \sigma)$  (resp.  $\beta > \beta_b(g, \sigma)$ ), and the sign of  $\Delta\Pi_c$  is negative (resp. positive) if  $\beta < \beta_c(g, \sigma)$  (resp.  $\beta > \beta_c(g, \sigma)$ ).

To overcome this lacuna, Proposition 4 ( $\sigma = 0$ ) and Proposition 5 ( $0 < \sigma < \frac{1}{\beta}$ ) show the SPNE emerging in the DDG for any  $0 < w < 1$  and are accompanied by a geometrical analysis for  $w = 0.5$  (Figs. 1–4), which is nevertheless representative of the general qualitative outcomes of the game. The feasible (resp. unfeasible) region in the figures is reported in white (resp. is sand-coloured). The figures report the loci  $\beta_a(g, \sigma)$ ,  $\beta_b(g, \sigma)$  and  $\beta_c(g, \sigma)$  for increasing values of  $\sigma$  in the plane  $(\beta, g)$  and the relevant feasibility constraints.

<sup>7</sup> We do not explicitly report the expressions of these differentials, as they are cumbersome and not highly informative for our purposes.



**Fig. 1.** The DDG when  $w = 0.5$  and  $\sigma = 0$ : SPNE. The DDG is a prisoner's dilemma regardless of the parameter values.

First, Proposition 4 summarises the SPNE of the DDG in the absence of policy.

**Proposition 4.** If  $\sigma = 0$ , then (ND,ND) is the unique, Pareto-inefficient SPNE, and the DDG is a prisoner's dilemma in which self-interest and mutual benefit of R&D disclosure conflict.

**Proof.** If  $\sigma = 0$ , then  $\Delta\pi_a < 0$ ,  $\Delta\pi_b > 0$ , and  $\Delta\pi_c < 0$  for any  $0 \leq \beta \leq 1$ , and  $g$  belonging to the feasible region.  $\square$

Second, Proposition 5 summarises the SPNE of the DDG for any  $0 < \sigma < \frac{1}{\beta}$ . When  $\sigma > 0$ , the feasible values of  $\beta$  are  $0 \leq \beta \leq 1$  if  $\sigma < 1$  and  $0 \leq \beta < \frac{1}{\sigma}$  if  $\sigma > 1$ .

**Proposition 5.** If  $\sigma > 0$ , then the SPNE of the DDG are as follows.

[1] If  $0 < \sigma \leq 1$ , then

(1.1) for any  $0 \leq \beta < \beta_b(g, \sigma)$  (ND,ND) is the unique Pareto-inefficient SPNE, and the DDG is a prisoner's dilemma in which self-interest and mutual benefit of R&D disclosure conflict;

(1.2) for any  $\beta_b(g, \sigma) < \beta < \beta_a(g, \sigma)$  (ND,ND) and (D,D) are two symmetric SPNE (D payoff dominates ND), and the DDG is a coordination game;

(1.3) for any  $\beta_a(g, \sigma) < \beta \leq 1$  (D,D) is the unique Pareto-efficient SPNE, and the DDG is an anti-prisoner's dilemma (deadlock) in which self-interest and mutual benefit of R&D disclosure do not conflict.

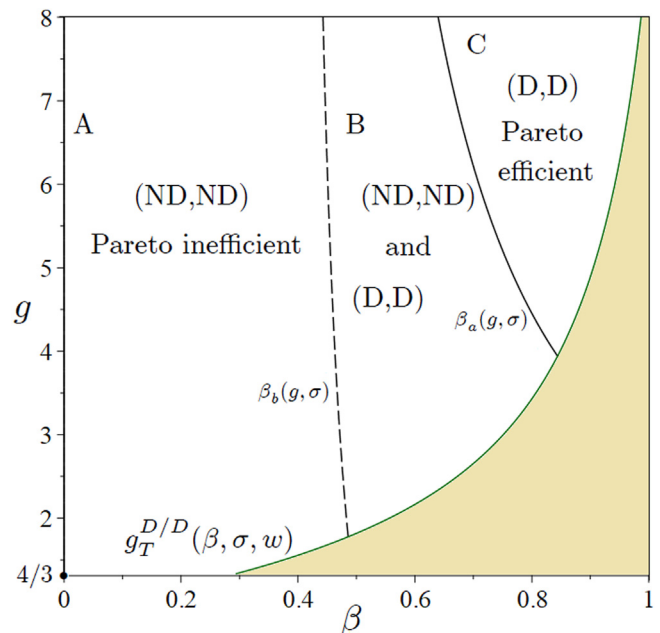
[2] If  $\sigma > 1$ , then

(2.1) for any  $0 \leq \beta < \beta_b(g, \sigma)$  (ND,ND) is the unique, Pareto-inefficient SPNE, and the DDG is a prisoner's dilemma in which self-interest and mutual benefit of R&D disclosure conflict;

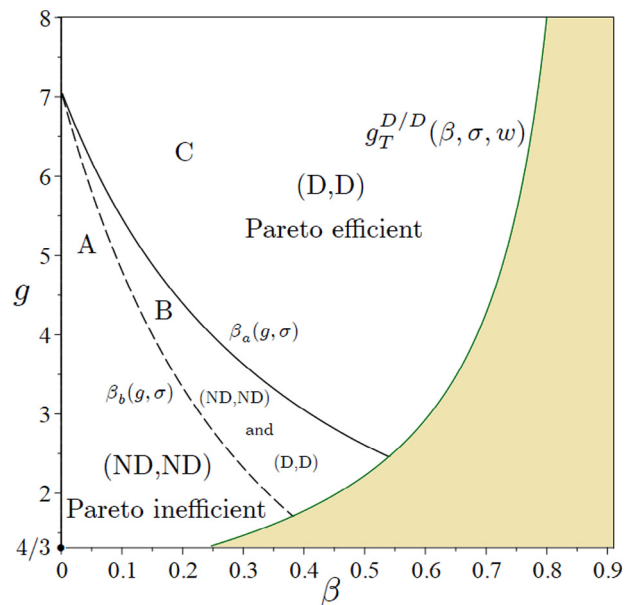
(2.2) for any  $\beta_b(g, \sigma) < \beta < \beta_a(g, \sigma)$  (ND,ND) and (D,D) are two symmetric SPNE (D payoff dominates ND), and the DDG is a coordination game;

(2.3) for any  $\beta_a(g, \sigma) < \beta < \beta_c(g, \sigma)$  (D,D) is the unique, Pareto-efficient SPNE, and the DDG is an anti-prisoner's dilemma (deadlock) in which self-interest and mutual benefit of R&D disclosure do not conflict;

(2.4) for any  $\beta_c(g, \sigma) < \beta < \frac{1}{\sigma}$  (D,D) is the unique, Pareto-inefficient SPNE, and the DDG is a prisoner's dilemma in which self-interest and mutual benefit of R&D non-disclosure conflict.

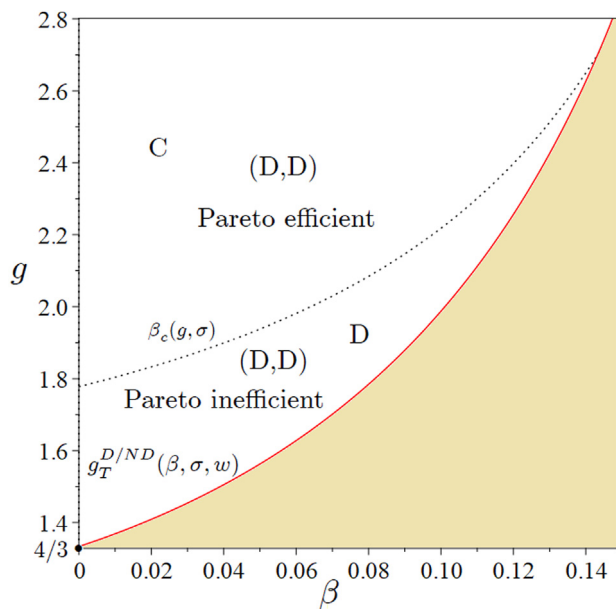


**Fig. 2.** The DDG when  $w = 0.5$  and  $\sigma = 0.9$ : SPNE. The DDG is (1) a prisoner's dilemma with non-disclosing firms (area A), (2) a coordination game (area B), and (3) a deadlock with disclosing firms (area C).



**Fig. 3.** The DDG when  $w = 0.5$  and  $\sigma = 1.1$ : SPNE. The DDG is (1) a prisoner's dilemma with non-disclosing firms (area A), (2) a coordination game (area B), and (3) a deadlock with disclosing firms (area C).

**Proof.** If  $0 < \sigma \leq 1$ , then (1.1)  $\Delta\pi_a < 0$ ,  $\Delta\pi_b > 0$ , and  $\Delta\pi_c < 0$  for any  $0 \leq \beta < \beta_b(g, \sigma)$  and  $g$  belonging to the feasible region; (1.2)  $\Delta\pi_a < 0$ ,  $\Delta\pi_b < 0$ , and  $\Delta\pi_c < 0$  for any  $\beta_b(g, \sigma) < \beta < \beta_a(g, \sigma)$  and  $g$  belonging to the feasible region; (1.3)  $\Delta\pi_a > 0$ ,  $\Delta\pi_b < 0$ , and  $\Delta\pi_c < 0$  for any  $\beta_a(g, \sigma) < \beta \leq 1$  and  $g$  belonging to the feasible region. If  $\sigma > 1$ , then (2.1)  $\Delta\pi_a < 0$ ,  $\Delta\pi_b > 0$ , and  $\Delta\pi_c < 0$  for any  $0 \leq \beta < \beta_b(g, \sigma)$  and  $g$  belonging to the feasible region; (2.2)  $\Delta\pi_a < 0$ ,  $\Delta\pi_b < 0$ , and  $\Delta\pi_c < 0$  for any  $\beta_b(g, \sigma) < \beta < \beta_a(g, \sigma)$  and  $g$  belonging to the feasible region; (2.3)  $\Delta\pi_a > 0$ ,  $\Delta\pi_b < 0$ , and  $\Delta\pi_c < 0$  for any  $\beta_a(g, \sigma) < \beta < \beta_c(g, \sigma)$  and  $g$  belonging to the feasible region.



**Fig. 4.** The DDG when  $w = 0.5$  and  $\sigma = 4$ : SPNE. The DDG is (1) a deadlock with disclosing firms (area C) or (2) a prisoner's dilemma with disclosing firms (area D).

region; (2.4)  $\Delta\pi_a > 0$ ,  $\Delta\pi_b < 0$ , and  $\Delta\pi_c > 0$  for any  $\beta_c(g, \sigma) < \beta < \frac{1}{\sigma}$  and  $g$  belonging to the feasible region.  $\square$

The economic intuition of the different scenarios follows the narrative of, and the cases detailed in, Proposition 5, considering first the benchmark case of no subsidies. Preliminarily, we note that the subsidy always increases profits directly, as it reduces the cost of R&D effort. However, it also has an indirect equilibrium feedback effect on R&D activity, production, and market price. It tends to increase the R&D effort by allowing for an increase in output (leading to an increase in profits) and a reduction in the market price (which instead leads to a reduction in profits). The outcome of the combination of the direct and indirect effects is a priori ambiguous when  $\sigma$  varies. (i) If  $\sigma$  is low, the percentage reduction in the market price is dominated by the percentage increase in output following the increase in R&D activity. Then, the equilibrium feedback effect goes in the same direction as the direct effect, and profits increase. (ii) If  $\sigma$  becomes larger, the percentage reduction in the market price dominates the percentage increase in output following the increase in R&D activity. Then, the equilibrium feedback effect goes in the opposite direction as the direct effect, and profits reduce if the latter is larger than the former.

**Case 1** (Fig. 1). With no public subsidies ( $\sigma = 0$ ), the comparison between profits of the two firms supports the action ND, and the signs of the three profit differentials are  $\Delta\pi_a < 0$ ,  $\Delta\pi_b > 0$ , and  $\Delta\pi_c < 0$ . The payoff matrix (that can be generated for any pair  $(\beta, g)$  satisfying the relevant constraints of the model) shows that each player would be fully satisfied if he were the only one that is not sharing R&D information, thereby free riding on the R&D activity generated by the rival. This allows the former to increase output at the rival's expense by increasing its profits. However, everyone would prefer to collaborate by jointly sharing R&D outcomes than giving up information dissemination entirely. This allows each firm to benefit from the increased output following the mutual cost-reducing innovation activity.

Nonetheless, everyone would prefer not to disclose than be the only one suffering from the rival's free riding. This situation represents a standard prisoner's dilemma, with a conflict

between self-interest and mutual benefit to disclose R&D outcomes. Therefore, in the absence of subsidies, the maximisation of the individual aim contrasts the wishes of Lisbon's Strategy, leading to an undesirable outcome (collective failure). Society is also worse off, as producers and consumers would be better off under disclosure. Though the two players are aware that they can achieve this disappointing outcome, they cannot achieve an agreement allowing disclosure (this is clear from Eq. (4) by setting  $\sigma = 0$ , also noting that, in this case, the cons against disclosure are augmented by the indirect feedback effect that increases rivals' production and profits through free riding). On the one hand, choices are consistent with one another only when players choose not to disclose. Thereafter, no one will regret it because, if all of them had unilaterally decided to disclose, they would have favoured the rival at their expense (allowing them to free ride by increasing both the market size and profits), being therefore worse off. On the other hand, choices are not consistent with one another if players had jointly chosen to deviate towards D. Indeed, each player will regret it, because if all of them had played ND, they would have increased their profits, being thus better off. Therefore, players will be able to avoid disclosure, as everyone is aware that no one is interested in deviating upon playing D if the rival will comply with it. Players, however, will not be able to disclose (non-consistent choices), as everyone knows that no one will be interested in complying with such an agreement if the rival complies with it.

**Case 2** (Fig. 2). Introducing public subsidies greatly can greatly change the individual incentives opening the possibility of a coordination game or a deadlock with disclosing firms. When the R&D activity is efficient (lower values of  $g$ ), spillovers are less important, so spreading R&D knowledge does not give rise to a change in the individual incentives to modify players' actions unilaterally (the game is still a prisoner's dilemma), though intense spillover effects are not viable. This is because combining an intense disclosure with an efficient R&D activity leads to excessive R&D activity in this strategic setting (see Bacchiaga et al., 2010), which then contributes to reducing excessively the total cost of production of each firm under D/D. This would increase output and reduce the market price by over-increasing the degree of competition. In contrast, for larger values of  $g$ , there is room for  $\beta$  to change the individual incentives within the feasible region. When the extent of spillovers is relatively low, the subsidy is not effective, and we then observe the same prisoner's dilemma, so that the signs of the three profit differentials are still  $\Delta\pi_a < 0$ ,  $\Delta\pi_b > 0$ , and  $\Delta\pi_c < 0$ . When the spillover of the R&D activity increases,  $\Delta\pi_b < 0$ , so that firm  $i$  has an incentive to play D (instead of ND) when the rival is playing D. This changes the nature of the game from a prisoner's dilemma to a coordination game with no dominated strategies, in which every player has the incentive to play the same strategy as the rival, and two pure-strategy Nash equilibria arise (D,D) and (ND,ND). However, D payoff dominates ND. The spreading of knowledge increases R&D activity, output, and profits when both firms are disclosing. It also reduces (resp. increases) R&D activity, output, and profits of the disclosing (resp. non-disclosing) firm in the asymmetric sub-games. However, both firms jointly benefit from disclosure, as the observed percentage increase in profits under D/D is larger than the percentage increase in profits of the non-disclosing free-riding firm in the asymmetric sub-games. This is the reason  $\Delta\pi_b$  becomes negative. Therefore, subsidising R&D to favour disclosure can prevent the pursuit of individual success from causing collective failure by letting coordination emerge.

The payoff matrix in this case reveals that players get the best possible outcome if each of them discloses. Moreover, both would prefer not to disclose by free riding on the R&D outcome of the rival's investment activity rather than considering the R&D



activity as a pure private good. However, each of them would prefer to abstain from disclosing rather than obtaining the worst possible outcome by being the only one to disclose. In these circumstances, each player is interested in getting the benefits of disclosure through a sharp increase in R&D activity and output if the rival is disclosing to get the best possible outcome. However, no one is willing to disclose if the rival is not disclosing, as no one wants to get the worst possible outcome of suffering from the rival's free-riding and the reduction in R&D activity, output, and profits. Consequently, there are two Nash equilibria: players will not regret if they both disclose (achieving a Pareto-efficient outcome) or not disclose (achieving a sub-optimal outcome).

If one of the two players is a risk-taker choosing to disclose to avoid losing the opportunity to increase profits and the other one is risk-averse choosing to keep his technology secret to avoid facing the rival's free-riding activity, both regret their actions, as each of them can be better off choosing differently. Therefore, players' decisions are consistent or non-consistent, depending on their relative degree of risk aversion. If both players are risk takers and each of them is willing to be the only one to disclose, the Nash equilibrium is (D,D), and profits are the highest. If both players are risk averse and each of them is unwilling to be the only one to disclose, the sub-optimal Nash equilibrium is (ND,ND). If one of the two players is risk averse and the rival risk taker, decisions will be inconsistent. In the prisoner's dilemma, however, players now are interested in agreeing to disclose. Moreover, if they agree to collaborate, each of them is interested in complying with the agreement (even in the absence of binding contracts), as it is not possible to be better off choosing not to disclose. Definitively, the existence of a public subsidy to disclosure generates an incentive for collaboration. Increasing the size of the subsidy allows for a more articulated scenario, also giving a role to the R&D cost condition  $g > g_r^{D/ND}(\beta, \sigma, w)$ .

The shape and position of the loci  $g_a(\beta, \sigma)$ ,  $g_b(\beta, \sigma)$ , and  $g_c(\beta, \sigma)$  together with the feasibility constraints change when  $\sigma$  increases. The larger  $\sigma$ , the larger the region in which the SPNE is Pareto efficient (the game is a deadlock with no conflict between self-interest and mutual benefit to disclose R&D outcomes). This is clear by looking at Fig. 2 by letting  $\beta$  increase for a given value of  $g$ . For small values of  $\beta$ , there is a prisoner's dilemma ( $\Delta\pi_a < 0$ ,  $\Delta\pi_b > 0$ , and  $\Delta\pi_c < 0$ ). This implies that the intensity of the externality is too low to allow each firm to benefit from knowledge spillovers. For intermediate values of  $\beta$ , there is a coordination game ( $\Delta\pi_a < 0$ ,  $\Delta\pi_b < 0$ , and  $\Delta\pi_c < 0$ ) with multiple pure-strategy Nash equilibria, as firm  $i$  has an incentive to play D (instead of ND) when the rival is playing D. Finally, when knowledge tends to become a pure public good,  $\Delta\pi_a > 0$ , so that firm  $i$  has an incentive to play D (instead of ND) when the rival is playing ND. This still changes the nature of the game from a coordination game with no dominated strategies to a deadlock with a dominant strategy (D) and a Pareto-efficient SPNE, (D,D). From a strategic point of view, a deadlock is less interesting than a prisoner's dilemma. However, this outcome has a relevant policy perspective, going along the same trajectory as the Lisbon's Strategy.

The continued spread of knowledge increases R&D activity, output, and profits when both firms are disclosing (as expected). However, it eventually increases R&D activity, output, and profits of the disclosing firm in the asymmetric sub-games. This is the reason the sign of  $\Delta\pi_a$  becomes positive. Therefore, subsidising R&D at a higher rate can reconcile self-interest and mutual benefit, and the larger the  $\sigma$ , the larger the area of Pareto efficiency. In this sense, further increases in the public subsidy make the extent of the externality of R&D activity less important in determining the outcome of the game.

**Table 3**The DDG when  $\sigma = \sigma^{OPT}$  (payoff matrix).

Firm 2 → Firm 1 ↓	D	ND
D	$\pi_1^{*\sigma^{OPT} D/D}, \pi_2^{*\sigma^{OPT} D/D}$	$\pi_1^{*\sigma^{OPT} D/ND}, \pi_2^{*\sigma^{OPT} D/ND}$
ND	$\pi_1^{*\sigma^{OPT} ND/D}, \pi_2^{*\sigma^{OPT} ND/D}$	$\pi_1^{*ND/ND}, \pi_2^{*ND/ND}$

**Case 3** ( $\sigma = 1.1$  and  $\sigma = 4$ , Figs. 3 and 4, respectively). Finally, high values of  $\sigma$  contribute to a substantial increase in the output and a corresponding reduction in the market price to the extent that the percentage reduction in the latter more than compensates for the percentage increase in the former so that profits under D fall short of those under ND. For a given  $g$ , this happens when the externality of the R&D activity increases. Therefore, a subsidy that is too high becomes inefficient, and the game falls back into the prisoner's dilemma with D (rather than ND) as the dominant strategy.

#### 4. The disclosure decision game and the optimal subsidy

This section considers a government that first implements the second-best optimal policy, thereby letting firms play the DDG in the first stage. Substituting  $\sigma = \sigma^{OPT}$  in the profit equations in the various sub-games allows us to state the payoff matrix summarised in Table 3.

The analysis in the  $(\beta, g)$  space is restricted to the feasibility constraints discussed in the previous section but evaluated now at  $\sigma = \sigma^{OPT}$ .<sup>8</sup> The SPNE of the DDG under optimal policy can be studied considering the sign of  $\Delta\pi_a^{\sigma^{OPT}}$ :  $= \pi_i^{*\sigma^{OPT} D/ND} - \pi_i^{*ND/ND}$ ,  $\Delta\pi_b^{\sigma^{OPT}}$ :  $= \pi_i^{*\sigma^{OPT} D/ND} - \pi_i^{*ND/ND}$ , and  $\Delta\pi_c^{\sigma^{OPT}}$ :  $= \pi_i^{*ND/ND} - \pi_i^{*\sigma^{OPT} D/D}$  ( $i = \{1, 2\}$ ,  $i \neq j$ ). The first threshold defines the incentive of firm  $i$  to deviate from D to ND, at the second-best social optimum, when its sign is negative (and vice versa when its sign is positive) when the rival, firm  $j$ , is playing ND. The second threshold defines the incentive of firm  $i$  to deviate from ND to D, at the second-best social optimum, when its sign is negative (and vice versa when its sign is positive) when the rival, firm  $j$ , is playing D. The third threshold determines the Pareto efficiency/inefficiency of a symmetric SPNE considering the second-best social optimum.

If  $\sigma = \sigma^{OPT}$ , then  $\Delta\pi_c^{\sigma^{OPT}} < 0$ , regardless of the parameter values. Therefore,  $\pi_i^{*\sigma^{OPT} D/D} > \pi_i^{*ND/ND}$  always holds, whereas the sign of  $\Delta\pi_a^{\sigma^{OPT}}$  and  $\Delta\pi_b^{\sigma^{OPT}}$  change depending on the relative values of  $\beta$  and  $g$ .

The solutions of  $\Delta\pi_a^{\sigma^{OPT}} = 0$ ,  $\Delta\pi_b^{\sigma^{OPT}} = 0$  for  $g$  as a function of  $\beta$  allow us to determine the loci of points that divide the plane  $(\beta, g)$  into areas in which these profit differentials are positive from those in which they are negative. These solutions are given by  $\Delta\pi_a^{\sigma^{OPT}} = 0 \Rightarrow g_a^{\sigma^{OPT}}(\beta)$  and  $\Delta\pi_b^{\sigma^{OPT}} = 0 \Rightarrow g_b^{\sigma^{OPT}}(\beta)$ . The sign of  $\Delta\pi_a^{\sigma^{OPT}}$  is negative (resp. positive) if  $g < g_a^{\sigma^{OPT}}(\beta)$  (resp.  $g > g_a^{\sigma^{OPT}}(\beta)$ ), and the sign of  $\Delta\pi_b^{\sigma^{OPT}}$  is positive (resp. negative) if  $g < g_b^{\sigma^{OPT}}(\beta)$  (resp.  $g > g_b^{\sigma^{OPT}}(\beta)$ ).

**Proposition 6** summarises the SPNE for any  $0 < w < 1$  (see Fig. 5 for a geometrical representation of the results drawn for  $w = 0.5$ ),  $0 \leq \beta \leq 1$ , and  $g$  belonging to the feasible region.

**Proposition 6.** If  $\sigma = \sigma^{OPT}$ , then the SPNE of the DDG are as follows.

(1.1) For any if  $g < g_b^{\sigma^{OPT}}(\beta)$ , (ND,ND) is the unique Pareto-inefficient SPNE, and the DDG under optimal policy is a prisoner's

<sup>8</sup> We note that, when  $\sigma = \sigma^{OPT}$ , the constraint  $\beta < 1/\sigma$  is always fulfilled.

dilemma in which self-interest and mutual benefit of R&D disclosure conflict.

(1.2) For any if  $g_b^{\sigma^{OPT}}(\beta) < g < g_a^{\sigma^{OPT}}(\beta)$ , (ND,ND) and (D,D) are two symmetric SPNE (D payoff dominates ND), and the DDG is a coordination game.

(1.3) For any  $g > g_a^{\sigma^{OPT}}(\beta)$ , (D,D) is the unique Pareto-efficient SPNE, and the DDG is an anti-prisoner's dilemma (deadlock) in which self-interest and mutual benefit of R&D disclosure do not conflict.

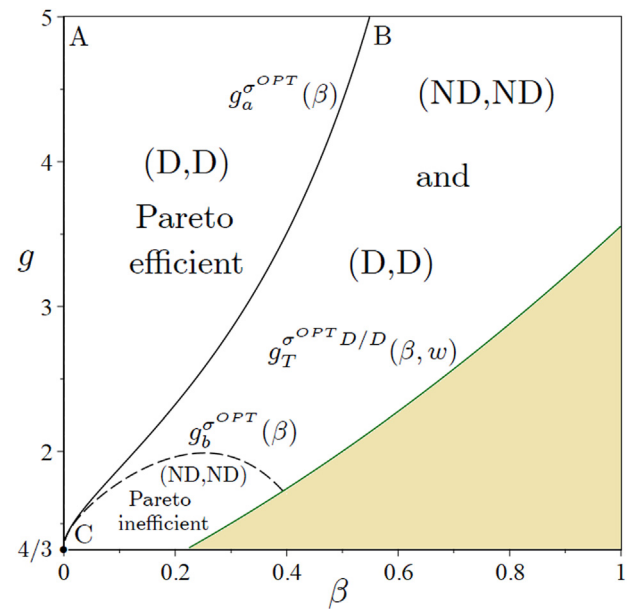
**Proof.** If  $\sigma = \sigma^{OPT}$ , then (1.1)  $\Delta\pi_a^{\sigma^{OPT}} < 0$ ,  $\Delta\pi_b^{\sigma^{OPT}} > 0$  and  $\Delta\pi_c^{\sigma^{OPT}} < 0$  for any  $g < g_b^{\sigma^{OPT}}(\beta)$  and  $0 \leq \beta \leq 1$ ; (1.2)  $\Delta\pi_a^{\sigma^{OPT}} < 0$ ,  $\Delta\pi_b^{\sigma^{OPT}} < 0$ , and  $\Delta\pi_c^{\sigma^{OPT}} < 0$  for any  $g_b^{\sigma^{OPT}}(\beta) < g < g_a^{\sigma^{OPT}}(\beta)$  and  $0 \leq \beta \leq 1$ ; (1.3)  $\Delta\pi_a^{\sigma^{OPT}} > 0$ ,  $\Delta\pi_b^{\sigma^{OPT}} < 0$  and  $\Delta\pi_c^{\sigma^{OPT}} < 0$  for any  $g > g_a^{\sigma^{OPT}}(\beta)$  and  $0 \leq \beta \leq 1$ .  $\square$

**Proposition 6** has a relevant implication showing that, at the optimum, a public subsidy can modify the unilateral incentive of every firm by sharply changing the scenario prevailing in the market. Although when  $\sigma = 0$ , the unique Pareto-inefficient SPNE is (ND,ND), the optimal policy can lead to the Pareto-efficient outcome (D,D) within the feasible region. This eventually replicates the case of know-how as a pure public good ( $\beta = 1$ ) if  $g$  is relatively high; i.e., obtaining a cooperative-like behaviour with respect to the R&D innovation in a non-cooperative game pairwise maximising social welfare at second best.

We now briefly comment on the emerging SPNE under optimal policy. The higher the efficiency of R&D activity (lower values of  $g$ ), the lower the need for technological spillovers. Indeed, firms already incur low production costs, so disclosure could be detrimental. In this sense, when  $g$  is low, the SPNE is given by the Pareto-efficient outcome (D,D) only when  $\beta$  is small enough; otherwise, the game becomes a prisoner's dilemma in which self-interest and mutual benefit of R&D disclosure conflict with each other. This is because of the sharp increase in profits that each firm can get if it is the only one that does not disclose by free riding on the R&D activity of the rival. If the efficiency of the R&D technology is lower (larger values of  $g$ ), knowledge spillovers are convenient. Therefore, increasing  $\beta$  by reducing the size of the optimal subsidy (because of the already high degree of disclosure) and necessitating fewer resources to finance it increases R&D, output, and profits if both firms are disclosing. However, a substantial increase in  $\beta$  reduces profits of the disclosing firm below the level it could earn by playing ND when the rival is not disclosing. This happens because of the emerging free-riding activity by the non-disclosing firm. Consequently, for high values of  $\beta$ , the game shows no longer a dominant strategy with a Pareto-efficient outcome, turning in a coordination game with two pure-strategy Nash equilibria. The lower the efficiency of R&D activity, the higher the unilateral interest of each firm to spill-over its R&D by preserving the Pareto-efficient outcome (D,D).

Given the results emerging in the analysis of the SPNE of the DDG under optimal policy, it would be of importance to pinpoint the social welfare outcomes corresponding to the Nash equilibria to identify possible areas leading to a win-win result. For doing this, we first define the consumer surplus differential, and the social welfare differential as follows:  $\Delta CS := CS^{*net} - CS^{*ND/ND}$ , where we recall that  $CS^{*net} = CS^{*D/D} - T^{*D/D}$ , and  $\Delta W := W^{*D/D} - W^{*ND/ND}$  both evaluated at  $\sigma = \sigma^{OPT}$ . These expressions are respectively given by:

$$\Delta CS = \frac{-24g\beta(1-w)^2(12g\beta^3 + 48g\beta^2 + 27g^2\beta - 27g^2 + 16\beta - 24g + 16)}{(9g - 4 - 4\beta^2 - 8\beta)^2(9g - 4)^2}, \quad (44)$$



**Fig. 5.** The DDG when  $w = 0.5$  and  $\sigma = \sigma^{OPT}$ : SPNE. The DDG is (1) a deadlock with disclosing firms (area A), (2) a coordination game (area B), and (3) a prisoner's dilemma with non-disclosing firms (area C).

which can be positive or negative for values of  $\beta$  and  $g$  belonging to the feasible region, and

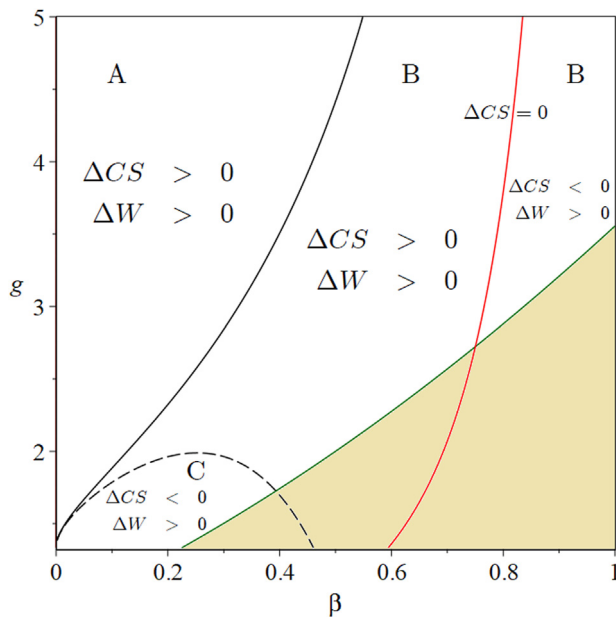
$$\Delta W = \frac{16g\beta(2+\beta)(1-w)^2}{(9g-4-4\beta^2-8\beta)(9g-4)} > 0, \quad (45)$$

for any  $0 \leq \beta \leq 1$  and  $g$  belonging to the feasible region.

**Fig. 6** overlaps the SPNE and the loci of points such that  $\Delta CS = 0$  (red line in the figure) and  $\Delta W = 0$ . Within the feasible region,  $\Delta W > 0$  always holds whereas  $\Delta CS$  can change sign. Specifically,  $\Delta CS > 0$  (resp.  $\Delta CS < 0$ ) to the left (resp. right) of the red line. This means that under optimal policy consumers are better off with R&D disclosure subsidisation (implying an increase in output) if the extent of the R&D externality ( $\beta$ ) is not too high; otherwise, the total burden of the lump-sum tax to finance the subsidy becomes too large so that the net consumer surplus under D/D falls below the corresponding value under ND/ND. **Fig. 6** clearly shows that within the region in (D,D) is a Pareto efficient SPNE consumers and firms are better off under (optimal) R&D disclosure subsidisation than under no disclosure leasing a Pareto superior (win-win) result for society (the SPNE emerging in area A overlaps with  $\Delta CS > 0$  and  $\Delta W > 0$  in **Fig. 6**). The goals of the anti-trust authority (which takes account of consumer interests) and the government (which takes account of society interests) may therefore converge. Clearly, in the absence of interventions, the outcome for society is Pareto inefficient, whereas under optimal policy it strictly depends on the SPNE emerging endogenously in the market, which, in turn, depends on the relative size of  $\beta$ , in which firms can have an interest to efficiently disclose or to inefficiently non-disclose R&D outcomes.

## 5. Conclusions

The present work is motivated by the importance of spreading R&D knowledge from a societal perspective, which is remarkable on the EU's political agenda. The analyses in based on the theoretical literature on cost-reducing (process) innovation pioneered by AJ in a Cournot duopoly and follows the public incentives (subsidies) studied by [Hinloopen \(1997\)](#) and [Amir et al. \(2019\)](#).



**Fig. 6.** The DDG when  $w = 0.5$  and  $\sigma = \sigma^{OPT}$ : SPNE, consumer surplus and social welfare. The DDG is (1) a deadlock with disclosing firms (area A), (2) a coordination game (area B), and (3) a prisoner's dilemma with non-disclosing firms (area C). Area A: win-win result. The red line is the loci of points in the space  $(\beta, g)$  such that  $\Delta CS = 0$ . (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The main aim is to develop a new, non-cooperative disclosure decision game (DDG) with complete information played by investing firms that choose to disclose (D) or not disclose (ND) in the first decision stage.

The article first shows that, in the absence of subsidies, the SPNE is Pareto inefficient (ND,ND), as the unilateral incentive of every firm is to foreclose R&D disclosure to prevent the rival from the free appropriation so that the DDG is a prisoner's dilemma. Unlike the received literature on knowledge spillovers, the results indicate that the government can design a second-best optimal policy and change the unilateral incentive to the firm's R&D disclosure: the SPNE is Pareto efficient (D,D), and the DDG becomes an anti-prisoner's dilemma. This outcome represents a win-win result from a societal perspective, as consumers and firms can be better off under disclosure than under non-disclosure. This is because, in equilibrium, profits and consumer surplus net of taxation can be larger than in the absence of the policy.

More in general, there exist four paradigms: (1) a prisoner's dilemma with a conflict between self-interest and mutual benefit of R&D disclosure, i.e., the mutually most beneficial action D is dominated by ND; (2) a coordination game with multiple pure-strategy SPNE such that it is mutually beneficial for each firm to play the same strategy as the rival does; (3) an anti-prisoner's dilemma (deadlock) with no conflict between self-interest and mutual benefit of R&D disclosure, i.e., the mutually most beneficial action D is dominant; and (4) a prisoner's dilemma with a conflict between self-interest and mutual benefit to not disclose R&D outcomes, i.e., the mutually most beneficial action ND is dominated by D.

The article aims to stimulate the debate on the strategic use of R&D subsidies in competitive markets.

## Data availability

No data was used for the research described in the article.

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## Appendix

### The disclosure decision game: the symmetric sub-game in which both firms disclose (D/D)

This section considers the symmetric sub-game in which the government subsidises R&D disclosure at the rate  $\sigma > 0$  – along the line of the policy discussed in Section 2 of the main text – and both firms disclose at the exogenous rate  $\beta > 0$  (Section 3.1 of the main text).

At the market stage of the game, each firm chooses output to maximise profits. Maximisation of Eq. (10) in the main text with respect to  $q_i$  leads to the following downward-sloping reaction function of firm  $i$  in the space  $(q_i, q_j)$  as a function of R&D efforts  $x_i$  and  $x_j$ , that is:

$$\frac{\partial \Pi_i^{D/D}}{\partial q_i} = 0 \Leftrightarrow \bar{q}_i^{D/D}(q_j, x_i, x_j) = \frac{1 - w - q_j + x_i + \beta x_j}{2}. \quad (\text{A.1})$$

Using Eq. (A.1) together with the symmetric counterpart for firm  $j$  allows us to obtain the system of output reaction functions that depend on the R&D effort. The solution of the system of output reaction functions  $\bar{q}_i^{D/D}(q_j, x_i, x_j)$  ( $i = \{1, 2\}, i \neq j$ ) allows us to get the following equilibrium output obtained at the third stage of the symmetric sub-game D/D:

$$\bar{q}_i^{D/D}(x_i, x_j) = \frac{1 - w + (2 - \beta)x_i + (2\beta - 1)x_j}{3}. \quad (\text{A.2})$$

Eq. (A.2) shows that the output of firm  $i$  depends on its R&D activity (due to a twofold reason) as well as on the R&D activity by rival (firm  $j$ ) through the R&D externality. On one hand, the R&D activity of firm  $i$  allows for a direct increase in the amount of its output (whose intensity is weighted by the coefficient 2) due to the strategic interaction with the rival. Therefore, firm  $i$  increases production through this channel. On the other hand,  $x_i$  has a mitigating effect on  $q_i$  because of the R&D activity flowing from firm  $i$  to firm  $j$  (whose intensity is weighted by the coefficient  $\beta$ ). Therefore, firm  $i$  reduces production through this channel. However, the strength of the latter effect can never counterbalance the strength of the former, including under the most extreme conditions, i.e., when disclosure is at its maximum intensity ( $\beta = 1$ ). Definitively, an increase in  $x_i$  monotonically increases  $q_i$ . Additionally, the R&D disclosure of both firms allows for a further increase in the output of firm  $i$  through the R&D activity of firm  $j$  if and only if the extent of technological spillovers is sufficiently large ( $\beta > \frac{1}{2}$ , i.e.,  $x_i$  and  $x_j$  are strategic complements), turning otherwise to a smaller extent if the technological spillovers are sufficiently small ( $\beta < \frac{1}{2}$ , i.e.,  $x_i$  and  $x_j$  are strategic substitutes).



Therefore, increasing market share in the product market needs a high rate of disclosure. Substituting Eq. (A.2) together with its counterpart for firm  $j$  in the profit Eq. (10) in the main text allows us to obtain  $\Pi_i^{D/D}(x_i, x_j)$ . Therefore, the maximisation of firm  $i$ 's profits with respect to  $x_i$  yields:

$$\frac{\partial \Pi_i^{D/D}(x_i, x_j)}{\partial x_i} = 0 \Leftrightarrow \bar{x}_i^{D/D} = \frac{2(2-\beta)[1-w+(2\beta-1)x_j]}{9g(1-\beta\sigma)+2\beta(4-\beta)-8}. \quad (\text{A.3})$$

Using Eq. (A.3) together with the corresponding counterpart for firm  $j$  provides the system of R&D reaction functions in the space  $(x_i, x_j)$ . Solving this system allows us to obtain the amount of equilibrium investment (denoted as usual with an asterisk) following the process innovation effort of firm  $i$  at the second stage of the game under D/D (and consequently the symmetrical firm  $j$ 's response), that is:

$$x_i^{*D/D} = \frac{2(1-w)(2-\beta)}{9g(1-\beta\sigma)-2(1+\beta)(2-\beta)}. \quad (\text{A.4})$$

From Eq. (A.4), which is reported as Eq. (11) in the main text of the article,  $x_i^{*D/D} > 0$  if and only if the denominator is positive, that is  $g > \frac{2(1+\beta)(2-\beta)}{9(1-\beta\sigma)} := g_{SC}^{\beta high}(\beta, \sigma)$ , as will be clear from Eq. (A.8), where the subscript SC denotes ‘‘Stability Condition’’.

The second-order condition for a maximum (concavity) requires that  $\frac{\partial^2 \Pi_i^{D/D}(x_i, x_j)}{\partial x_i^2} \Big|_{x_i=x_i^{*D/D}} < 0$ . This implies that the inequality

$$g > \frac{2(2-\beta)^2}{9(1-\beta\sigma)} := g_{SOC}^{D/D}(\beta, \sigma) \text{ (second-order condition)}, \quad (\text{A.5})$$

must hold to guarantee that the solution to the profit maximisation problem is meaningful, where the subscript SOC denotes ‘‘Second Order Condition’’. The R&D equilibrium characterised by the expression in (A.4) is stable (see Seade, 1980) if and only if the reaction functions defined in the R&D space cross adequately (Henriques, 1990). If the reaction functions are downward-sloping (resp. upward-sloping),  $x_i$  and  $x_j$  are strategic substitutes (resp. complements). This holds when  $\beta$  is small (resp. large). The stability conditions require that  $\left| \frac{dx_i}{dx_j} \right| < 1$ . Then, by computing:

$$\frac{dx_i}{dx_j} = \frac{2(2\beta-1)(2-\beta)}{9g(1-\beta\sigma)-2(2-\beta)^2}, \quad (\text{A.6})$$

one can see that the denominator is positive for any  $g > g_{SOC}(\beta, \sigma)$ . Then, if

$$g > \frac{2(1-\beta)(2-\beta)}{3(1-\beta\sigma)} := g_{SC}^{D/D, \beta low}(\beta, \sigma) \text{ if } 0 < \beta < \frac{1}{2}, \quad (\text{A.7})$$

$x_i$  and  $x_j$  are strategic substitutes, and

$$g > \frac{2(1+\beta)(2-\beta)}{9(1-\beta\sigma)} := g_{SC}^{D/D, \beta high}(\beta, \sigma) \text{ if } \frac{1}{2} < \beta \leq 1, \quad (\text{A.8})$$

$x_i$  and  $x_j$  are strategic complements, where  $g_{SC}^{D/D, \beta low}(\beta, \sigma) \geq g_{SC}^{D/D, \beta high}(\beta, \sigma)$  for any  $0 < \beta \leq \frac{1}{2}$  and  $\sigma < \frac{1}{\beta}$ , and  $g_{SC}^{D/D, \beta low}(\beta, \sigma) < g_{SC}^{D/D, \beta high}(\beta, \sigma)$  for any  $\frac{1}{2} < \beta \leq 1$  and  $\sigma < \frac{1}{\beta}$ . Therefore, the

second-order condition always holds if the stability conditions are satisfied. It is also important to pinpoint that an increase

in  $\sigma$  increases the incentive to invest in R&D, that is  $\frac{\partial x_i^{*D/D}}{\partial \sigma} = \frac{18g\beta(1-w)(2-\beta)}{[9g(1-\beta\sigma)-2(1+\beta)(2-\beta)]^2} > 0$ , whereas a change in  $\beta$  implies that

$$\frac{\partial x_i^{*D/D}}{\partial \beta} = \frac{-2(1-w)[9g(1-2\sigma)-2(2-\beta)^2]}{[9g(1-\beta\sigma)-2(1+\beta)(2-\beta)]^2}. \quad (\text{A.9})$$

As the denominator of (A.9) is always positive, then  $\frac{\partial x_i^{*D/D}}{\partial \beta} > 0$  for any  $\beta$  and  $g$  if  $\sigma \geq \frac{1}{2}$ . When the subsidy rate is sufficiently large, each firm has an incentive to increase the amount of cost-reducing R&D activity regardless of the relative size of the externality. When the subsidy rate is sufficiently low ( $\sigma < \frac{1}{2}$ ), the effect on  $x_i^{*D/D}$  of a change in  $\beta$  is always negative. In fact, if  $g > g_{SOC}^{D/D}(\beta, \sigma) > g_{SOC}^{D/D}(\beta, \sigma) \frac{1-\beta\sigma}{1-2\sigma}$ , then the term in brackets is positive and thus  $\frac{\partial x_i^{*D/D}}{\partial \beta} < 0$ , and the case  $g < g_{SOC}^{D/D}(\beta, \sigma) \frac{1-\beta\sigma}{1-2\sigma}$  cannot hold, as  $g > g_{SOC}^{D/D}(\beta, \sigma)$  must be fulfilled for concavity. This implies that providing public subsidies at a low rate is not sufficient to avoid the free riding of each firm on the rival's R&D activity, so that a firm has an incentive to reduce its R&D effort to avoid free appropriation by the rival.

The analysis made so far is augmented with the constraints on the side of the costs of production. As known from Eq. (2) in the main text, the unitary production cost  $w - x_i - \beta x_j$  must be positive. Therefore, by using Eq. (A.4) the inequality  $w - x_i - \beta x_j > 0$  is fulfilled if and only if:

$$g > \frac{2(1+\beta)(2-\beta)}{9w(1-\beta\sigma)} := g_T^{D/D}(\beta, \sigma, w), \text{ (R\&D cost condition)}, \quad (\text{A.10})$$

where the subscript  $T$  stands for ‘‘Threshold’’. The inequality in (A.10) must hold as an additional threshold in determining meaningful sub-game perfect Nash equilibrium outcomes of the game (see Section 3.4 in the main text). The shape of the threshold  $g_T^{D/D}(\beta, \sigma, w)$  also depends on  $w$ . Therefore, it is important to study the conditions under which the threshold  $g_T^{D/D}(\beta, \sigma, w)$  is binding compared to the stability conditions for the sub-game D/D.

The equilibrium values in (11) and (12) in the main text reveal that  $g > g_{SC}^{D/D, \beta high}(\beta, \sigma)$  is sufficient to guarantee positive values of R&D effort and output for both firms, where  $g_{SC}^{D/D, \beta high}(\beta, \sigma)$  is the stability condition that must be satisfied when  $x_i$  and  $x_j$  are strategic complements. The expressions reported in (13) and (14)

in the main text reveal that  $p_i^{*D/D} > 0$  if  $g > \frac{2(1+\beta)(2-\beta)}{3g(1-\beta\sigma)(1+2w)} :=$

$g_p^{D/D}(\beta, \sigma, w)$  and  $\Pi_i^{*D/D} > 0$  if  $g > g_{SOC}^{D/D}(\beta, \sigma)$ , where  $g_{SOC}^{D/D}(\beta, \sigma)$  is the second-order condition that must hold to guarantee that the solution to the profit maximisation problem is meaningful in this sub-game. We note that  $g_p^{D/D}(\beta, \sigma, w) < g_{SC}^{D/D, \beta high}(\beta, \sigma)$  for any  $0 < w < 1$  and  $g_p^{D/D}(\beta, \sigma, 1) \rightarrow g_{SC}^{D/D, \beta high}(\beta, \sigma)$  if  $w \rightarrow 1$ . Therefore, both thresholds are satisfied if either  $g > g_T^{D/D}(\beta, \sigma, w)$  or  $g > g_{SC}^{D/D, \beta low}(\beta, \sigma)$  holds, where  $g_T^{D/D}(\beta, \sigma, w)$  is R&D cost condition that must hold to guarantee that  $w - x_i - \beta x_j > 0$  is fulfilled and  $g_{SC}^{D/D, \beta low}(\beta, \sigma)$  is the stability condition that must be satisfied when  $x_i$  and  $x_j$  are strategic substitutes.

Comparison of (A.8) and (A.10) reveals that  $g_T^{D/D}(\beta, \sigma, w) > g_{SC}^{D/D, \beta high}(\beta, \sigma)$  for any  $w < 1$  and  $g_T^{D/D}(\beta, \sigma, 1) \rightarrow g_{SC}^{D/D, \beta high}(\beta, \sigma)$  from above for  $w \rightarrow 1$ . Differently, comparison of (A.7) and (A.10) reveals that  $g_T^{D/D}(\beta, \sigma, w)$  can be higher or lower than  $g_{SC}^{D/D, \beta low}(\beta, \sigma)$  depending on the relative size of  $\beta$ ,  $\sigma$ , and  $w$ . Lemma 1 in the main text (the proof is reported below) deepens this result by showing that  $g_T^{D/D}(\beta, \sigma, w)$  is binding in the  $(\beta, g)$  space depending on conditions on the main parameters of the problem. Let us first define  $\beta_T^{D/D} := \frac{3w-1}{1+3w}$  as a threshold value of the intensity of the R&D externality such that  $g_T^{D/D}(\beta, \sigma, w) = g_{SC}^{D/D, \beta low}(\beta, \sigma)$  in the  $(\beta, g)$  space. Then,  $\beta_T^{D/D} \rightarrow \frac{1}{2}$  if  $w \rightarrow 1$  and  $\beta_T^{D/D} < \frac{1}{2}$  for any  $w < 1$ . In addition,  $\beta_T^{D/D} < 0$  if  $w < \frac{1}{3}$  and  $\beta_T^{D/D} > 0$  if  $w > \frac{1}{3}$ .



**Proof of Lemma 1.** (1) If  $w < \frac{1}{3}$ , then  $\beta_T^{D/D} < 0$  and  $g_T^{D/D}(\beta, \sigma, w) > g_{SC}^{D/D, \beta_{low}}(\beta, \sigma)$  for any  $0 < \beta \leq 1$  and  $\sigma < \frac{1}{\beta}$ . (2) If  $w > \frac{1}{3}$  then  $\beta_T^{D/D} > 0$  and (2.1)  $g_T^{D/D}(\beta, \sigma, w) \leq g_{SC}^{D/D, \beta_{low}}(\beta, \sigma)$  for any  $0 < \beta \leq \beta_T^{D/D}$  and  $\sigma < \frac{1}{\beta}$ , and (2.2)  $g_T^{D/D}(\beta, \sigma, w) > g_{SC}^{D/D, \beta_{low}}(\beta, \sigma)$  for any  $\beta_T^{D/D} < \beta \leq 1$  and  $\sigma < \frac{1}{\beta}$ . (3) If  $w \rightarrow 1$  then  $\beta_T^{D/D} \rightarrow \frac{1}{2}$  and  $g_T^{D/D}(\beta, \sigma, 1) \rightarrow g_{SC}^{D/D, \beta_{high}}(\beta, \sigma)$  from above for any  $0 < \beta \leq 1$  and  $\sigma < \frac{1}{\beta}$ . Therefore,  $g_{SC}^{D/D, \beta_{low}}(\beta, \sigma) \geq g_{SC}^{D/D, \beta_{high}}(\beta, \sigma)$  for any  $0 < \beta \leq \frac{1}{2}$  and  $\sigma < \frac{1}{\beta}$ , and  $g_{SC}^{D/D, \beta_{low}}(\beta, \sigma) < g_{SC}^{D/D, \beta_{high}}(\beta, \sigma)$  for any  $\frac{1}{2} < \beta \leq 1$  and  $\sigma < \frac{1}{\beta}$ .  $\square$

### The disclosure decision game: The asymmetric sub-game in which only one firm discloses (D/ND)

This section considers the asymmetric sub-game in which the government subsidises R&D disclosure at the rate  $\sigma > 0$  only to the disclosing firm  $i$  (Section 3.3 of the main text).

At the market stage, the maximisation of the profit Eqs. (34) and (35) in the main text with respect to  $q_i$  and  $q_j$ , respectively, leads to the following downward-sloping output reaction functions:

$$\frac{\partial \Pi_i^{D/ND}}{\partial q_i} = 0 \Leftrightarrow \bar{q}_i^{D/ND}(q_j, x_i) = \frac{1 - w - q_j + x_i}{2}, \quad (\text{A.11})$$

and

$$\frac{\partial \Pi_j^{D/ND}}{\partial q_j} = 0 \Leftrightarrow \bar{q}_j^{D/ND}(q_i, x_i, x_j) = \frac{1 - w - q_i + x_j + \beta x_i}{2}. \quad (\text{A.12})$$

Eqs. (A.11) and (A.12) reveal that the output reaction functions of firm  $i$  and firm  $j$  are similar, but differ in one crucial respect: the non-disclosing firm  $j$  can produce more than the disclosing firm  $i$ , as it free rides on the R&D activity from the rival, so that an increase in the R&D externality shift outwards the reaction function of firm  $j$ , thereby contributing to increasing its production. The solution of the system of output reaction functions  $\bar{q}_i^{D/ND}(q_j, x_i)$  and  $\bar{q}_j^{D/ND}(q_i, x_i, x_j)$  ( $i = \{1, 2\}$ ,  $i \neq j$ ) allows us to get the following equilibrium output:

$$\bar{q}_i^{D/ND}(x_i, x_j) = \frac{1 - w + (2 - \beta)x_i - x_j}{3}, \quad (\text{A.13})$$

and

$$\bar{q}_j^{D/ND}(x_i, x_j) = \frac{1 - w + 2x_j + (2\beta - 1)x_i}{3}. \quad (\text{A.14})$$

A direct comparison of Eqs. (A.13) and (A.14) reveals that the R&D effort of the non-disclosing firm  $j$  monotonically reduces production of the disclosing firm  $i$ , whereas the R&D effort of the disclosing firm  $i$  increases production of the non-disclosing firm  $j$  if and only if the R&D externality is high enough ( $\beta > \frac{1}{2}$ ). Substituting out Eqs. (A.13) and (A.14) in the profit equations (34) and (35) in the main text allows us to obtain the profits of the investing and non-investing firms as a function of the R&D efforts  $x_i$  and  $x_j$ , i.e.,  $\Pi_i^{D/ND}(x_i, x_j)$  and  $\Pi_j^{D/ND}(x_i, x_j)$  whose maximisation at the second (R&D) stage of the game with respect to  $x_i$  and  $x_j$  yields a system of R&D reaction functions that can be solved to get the equilibrium R&D activity of firm  $i$  and firm  $j$  in the asymmetric sub-game D/ND, that is<sup>9</sup>:

<sup>9</sup> The second-order conditions are the same as those obtained in the symmetric sub-game D/D. We do not report the stability conditions for the asymmetric sub-games as they are never binding to defining the feasibility region of the DDG in the parametric space  $(\beta, g)$ .

$$x_i^{*D/ND} = \frac{2(1 - w)(2 - \beta)(3g - 4)}{27g^2(1 - \beta\sigma) - 6g[4(1 - \beta\sigma) + 2(2 - \beta)^2] + 8(2 - \beta)}, \quad (\text{A.15})$$

and

$$x_j^{*D/ND} = \frac{4(1 - w)(2 - \beta)[3g(1 - \beta\sigma) - 2(1 - \beta)(2 - \beta)]}{27g^2(1 - \beta\sigma) - 6g[4(1 - \beta\sigma) + 2(2 - \beta)^2] + 8(2 - \beta)}. \quad (\text{A.16})$$

Eqs. (A.15) (resp. Eq. (A.16)) shows that the numerator is positive for any  $g > \frac{4}{3}$  (resp.  $g > g_{SC}^{D/D, \beta_{low}}(\beta, \sigma)$ ). Note also that the denominator of both equations is always positive for all the values of  $g$  such that the relevant constraints of the disclosure decision game are binding (see Section 3.4 in the main text).

Like the other sub-games, we should augment the analysis by considering the additional constraints on the side of the costs of production of both the disclosing firm  $i$  and non-disclosing firm  $j$  by explicitly accounting for their R&D cost conditions resulting from the inequalities  $w - x_i > 0$  for the disclosing firm  $i$  and  $w - x_j - \beta x_i > 0$  for the non-disclosing firm  $j$ . This can be specialised by substituting out  $x_i^{*D/ND}$  and  $x_j^{*D/ND}$  from (A.15) and (A.16) into the last inequalities, showing that the only relevant constraint comes from the inequality of the disclosing firm  $i$ , i.e.:

$$g > g_T^{D/ND}(\beta, \sigma, w) = \frac{9w(1 - \beta\sigma)}{\times \{6w + 2 - \beta + \beta^2w - 4\beta w\sigma - 3\beta w} \\ \times \sqrt{\beta^4w^2 - 8\beta^3\sigma w + 16\beta^2\sigma^2w^2 - 6\beta^3w^2 + 24\beta^4\sigma w^2} \\ + 2\beta^3w - 16\beta^2\sigma w + 21\beta^2w^2} \\ + \sqrt{-48\beta\sigma w^2 + 10\beta^2w + 32\beta\sigma w - 36\beta w^2 + \beta^2} \\ + 36w^2 - 4\beta - 24w + 4\}. \quad (\text{A.17})$$

The inequality in (A.17) represents the R&D cost condition prevailing in the asymmetric sub-game D/ND. Overall, the expressions that determine the feasible region for the emergence of meaningful Nash equilibrium outcomes of the disclosure decision game (studied in Section 3.4 in the main text) in the  $(\beta, g)$  space are  $g > \frac{4}{3}$ ,  $g > g_T^{D/D}(\beta, \sigma, w)$ , and  $g > g_T^{D/ND}(\beta, \sigma, w)$ . When these constraints are binding, the other inequalities (e.g., the second-order conditions and the stability conditions) are satisfied accordingly. The shape of the R&D cost conditions depends, amongst other things, on the subsidy rate  $\sigma$ . The analysis of how the shape and position of these constraints change in the  $(\beta, g)$  space is a complex exercise. To avoid lengthening the exposition, we leave the complete geometrical analysis to Section 3.4 in the main text. Now, substituting out the expressions in (A.15) and (A.16) into (A.13) and (A.14) allows us to get the equilibrium expressions of  $q_i$  and  $q_j$ , that is:

$$q_i^{*D/ND} = \frac{3g(1 - w)(1 - \beta\sigma)(3g - 4)}{27g^2(1 - \beta\sigma) - 6g[4(1 - \beta\sigma) + 2(2 - \beta)^2] + 8(2 - \beta)}, \quad (\text{A.18})$$

and

$$q_j^{*D/ND} = \frac{3g(1 - w)[3g(1 - \beta\sigma) - 2(1 - \beta)(2 - \beta)]}{27g^2(1 - \beta\sigma) - 6g[4(1 - \beta\sigma) + 2(2 - \beta)^2] + 8(2 - \beta)}. \quad (\text{A.19})$$

which are positive for any  $g > \frac{4}{3}$  and  $g > g_{SC}^{D/D, \beta_{low}}(\beta, \sigma)$ , respectively.

We can now determine the equilibrium value of the market price and the values of the profits of the disclosing firm  $i$  and non-disclosing firm  $j$  for the asymmetric sub-game D/ND, i.e.:

$$p^{D/ND} = \frac{9g^2(1-\beta\sigma)(1+2w) - 6g[2(1+w)(2-\beta\sigma) - \beta[1+w(3-\beta)]] + 8(2-\beta)}{27g^2(1-\beta\sigma) - 6g[4(1-\beta\sigma) + 2(2-\beta)^2] + 8(2-\beta)}, \quad (A.20)$$

$$\Pi_i^{D/ND} = \frac{g(1-w)^2(1-\beta\sigma)(3g-4)^2[9g(1-\beta\sigma) - 2(2-\beta)^2]}{[27g^2(1-\beta\sigma) - 6g[4(1-\beta\sigma) + 2(2-\beta)^2] + 8(2-\beta)]^2}, \quad (A.21)$$

and

$$\Pi_j^{D/ND} = \frac{g(1-w)^2(9g-8)[3g(1-\beta\sigma) - 2(1-\beta)(2-\beta)^2]}{[27g^2(1-\beta\sigma) - 6g[4(1-\beta\sigma) + 2(2-\beta)^2] + 8(2-\beta)]^2}. \quad (A.22)$$

The market price in (A.20) is positive when the relevant constraints of the model, as discussed so far, are fulfilled, whereas profits in (A.21) are positive if and only if  $g > g_{SOC}^{D/D}(\beta, \sigma)$  and profits in (A.22) are positive if and only if  $g > g_{SOC}^{ND/ND}$ . It is important to pinpoint that (1) the public subsidy towards the disclosing firm  $i$  monotonically incentivises its R&D effort, production, and profits, and (2) if the externality of R&D outcomes of the disclosing firm  $i$  towards the non-disclosing firm  $j$  is sufficiently small (resp. large), i.e.,  $\beta < \frac{1}{2}$  (resp.  $\beta > \frac{1}{2}$ ), then the equilibrium values of R&D effort, production, and profits of the non-disclosing firm  $j$  negatively (resp. positively) depend in a monotonic way on the subsidy rate  $\sigma$ . This means that, if the externality of R&D sharing generated by the disclosing firm  $i$  is small, the public provision of R&D subsidies towards disclosure favours the disclosing firm; however, this is detrimental to the non-disclosing rival, as the latter cannot benefit from the free-riding activity. Differently, if the externality of R&D sharing generated by the disclosing firm  $i$  is large the public provision of R&D subsidies towards disclosure favours both firms, as the non-disclosing rival can benefit from the free-riding activity.

### Social welfare analysis

This section of the Appendix shows that  $W^*(\beta) > W^*(0)$  holds for any  $g$  belonging to the feasible region. From Table 1 in the main text, we have that

$$W^*(\beta) = \frac{4g(1-w)^2[9g - (2-\beta)^2]}{[9g - 2(1+\beta)(2-\beta)]^2}. \quad (A.23)$$

Then, by evaluating Eq. (A.23) at  $\beta = 0$  and  $\beta = 1$  one gets:

$$W^*(0) = \frac{4g(1-w)^2}{9g-4}. \quad (A.24)$$

and

$$W^*(1) = \frac{4g(1-w)^2(9g-1)}{(9g-4)^2}. \quad (A.25)$$

First, we note that  $W^*(1) - W^*(0) = \frac{12g(1-w)^2}{(9g-4)^2} > 0$ . In addition,

$$\begin{aligned} \frac{\partial W^*(\beta)}{\partial \beta} \Big|_{\beta=0} &= \frac{32g(1-w)^2}{(9g-4)^2} > 0 \text{ and} \\ \frac{\partial W^*}{\partial \beta} &= \frac{8g(1-w)^2[2\beta^3 - 12\beta^2 - 3\beta(15g-8) + 4(9g-4)]}{[9g - 2(1+\beta)(2-\beta)]^3} \\ &\geq 0 \iff \beta \leq \beta^W(g), \end{aligned} \quad (A.26)$$

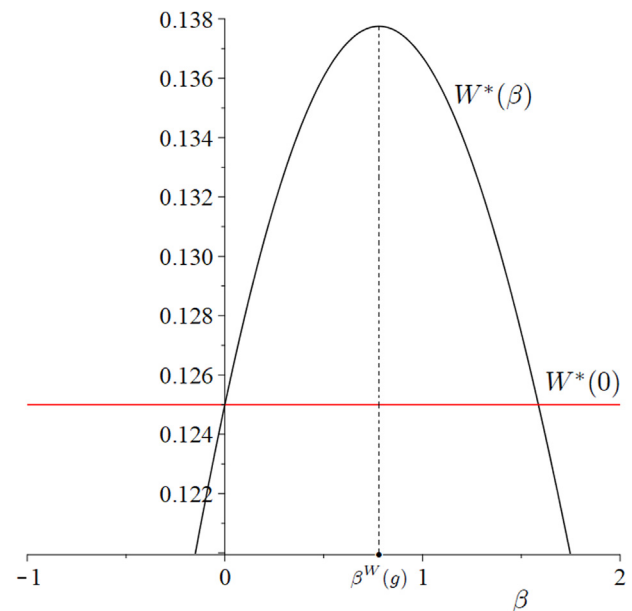


Fig. A.1. Social welfare as a function of  $\beta$  in an AJ duopoly à la De Bondt et al. (1992). The value of  $\beta$  that maximises  $W^*(\beta)$  is  $\beta^W(g) = 0.7798$  ( $g = 4$ ).

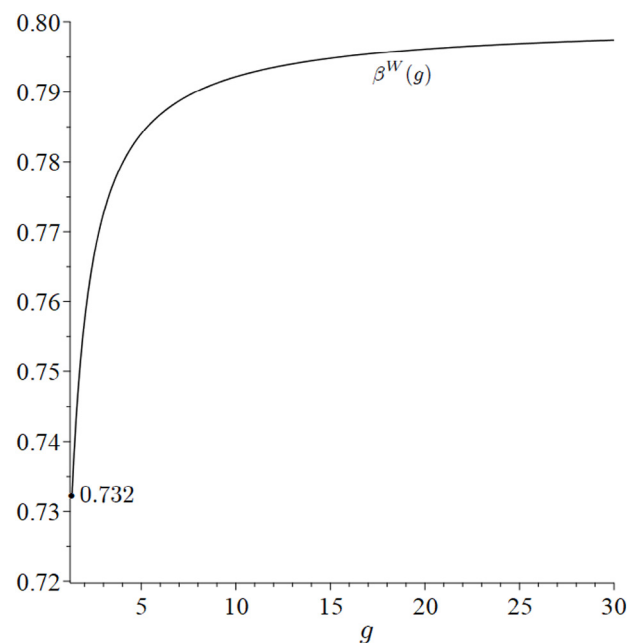


Fig. A.2. Shape of  $\beta^W(g)$  when  $g$  varies in an AJ duopoly à la De Bondt et al. (1992).

where the analytical solution of  $\beta^W(g)$ , which depends only on  $g$ , is complex and cannot be presented in a neat analytical form (see De Bondt et al., 1992). However, it is possible to resort to a geometrical projection depicting (1) the shape of  $W^*(\beta)$  when  $\beta$  varies for a given value of  $g$  ( $g = 4$ ), clearly showing the existence of a maximum of  $W^*$  corresponding to  $\beta^W(g)$  (Fig. A.1), and (2) the shape of  $\beta^W(g)$  revealing that  $\beta^W(g) \in (0.732, 0.8)$  as  $g$  increases (Fig. A.2) starting from the lowest possible value that this parameter can take, that is  $g = 4/3$ , emerging when the stability condition prevailing when  $x_i$  and  $x_j$  are strategic substitutes, that is  $g > \frac{2(1-\beta)(2-\beta)}{3}$ , is binding for  $\beta = 0$ . Therefore,  $W^*(\beta) > W^*(0)$  for any  $0 < \beta \leq 1$ .

### Consumer surplus and net consumer surplus

This section of the Appendix first considers the consumer surplus ( $CS^{*D/D}$ ) and the net consumer surplus ( $CS^{*net} := CS^{*D/D} - T^{*D/D}$ ) that can be observed in the sub-game  $D/D$  (i.e., when  $\beta > 0$ , positive disclosure) and then compares them with the consumer surplus that can be observed in the sub-game  $ND/ND$  (i.e., when  $\beta = 0$ , no disclosure).

From the main text, one can easily the following expressions:

$$CS^{*D/D}(\beta, \sigma) = \frac{18g^2(1-w)^2(1-\beta\sigma)^2}{[9g(1-\beta\sigma) - 2(1+\beta)(2-\beta)]^2}. \quad (A.27)$$

$$T^{*D/D}(\beta, \sigma) = \frac{4g\beta\sigma(1-w)^2(2-\beta)^2}{[9g(1-\beta\sigma) - 2(1+\beta)(2-\beta)]^2}. \quad (A.28)$$

$$CS^{*net}(\beta, \sigma) = \frac{2g(1-w)^2(9g + 9g\beta^2\sigma^2 - 18g\beta\sigma - 2\beta^3\sigma + 8\beta^2\sigma - 8\beta\sigma)}{[9g(1-\beta\sigma) - 2(1+\beta)(2-\beta)]^2}. \quad (A.29)$$

and

$$CS^{*ND/ND}(0, 0) = \frac{18g^2(1-w)^2}{(9g-4)^2}. \quad (A.30)$$

Eq. (A.27) represents the equilibrium gross consumer surplus under R&D disclosure subsidisation. Eq. (A.28) is the equilibrium lump-sum tax on the side of consumers levied by the government to finance (at a balanced budget) the R&D policy. Eq. (A.29) is the corresponding net consumer surplus and Eq. (A.30) is the equilibrium consumer surplus under no disclosure. By setting  $\sigma = 0$  from (A.27) or (A.29) one can get the equilibrium consumer surplus under positive disclosure and no subsidisation, which is given by the following expression:

$$CS^{*D/D}(\beta, 0) = \frac{18g^2(1-w)^2}{[9g - 2(1+\beta)(2-\beta)]^2}, \quad (A.31)$$

where  $CS^{*D/D}(\beta, 0) > CS^{*ND/ND}(0, 0)$  for any  $0 < \beta \leq 1$  and  $g$  belonging to the feasible region.

From (A.29)

$$\left. \frac{\partial CS^{*net}}{\partial \sigma} \right|_{\sigma=0} = \frac{4g\beta(2-\beta)(1-w)^2(2\beta^3 - 6\beta^2 + 27\beta g + 8)}{(9g - 4 + 2\beta^2 - 2\beta)^3} > 0, \quad (A.32)$$

for any  $0 \leq \beta \leq 1$  and  $g$  belonging to the feasible region, and

$$\text{sgn}\left\{\frac{\partial CS^{*net}}{\partial \sigma}\right\} = \text{sgn}\{-9g\beta^2\sigma + 2\beta^3 - 36g\beta\sigma - 6\beta^2 + 27g\beta + 8\}. \quad (A.33)$$

From (A.33),  $\frac{\partial CS^{*net}}{\partial \sigma} \geq 0$  if and only if  $\sigma \leq \sigma^{CS}$ , where

$$\sigma^{CS} := \frac{2(4 - 3\beta^2) + 2\beta^3 + 27g\beta}{9g\beta(1+\beta)} < 1 \quad (A.34)$$

If  $\beta < \frac{9}{4}g + 2 - \frac{3}{4}\sqrt{9g^2 + 16g}$ , then  $CS^{*net}$  is monotonically increasing in  $\sigma$  for any  $0 < \sigma < 1$ . If  $\beta > \frac{9}{4}g + 2 - \frac{3}{4}\sqrt{9g^2 + 16g}$ , then  $CS^{*net}$  is an inverted U-shaped function of  $\sigma$  and there exists a subsidy rate, given by  $\sigma^{CS} := \frac{2(4 - 3\beta^2) + 2\beta^3 + 27g\beta}{9g\beta(1+\beta)} < 1$ , that maximises  $CS^{*net}$  for any  $0 < \sigma < 1$ . However,  $\sigma$  can also be larger than one.

To show that the introduction of R&D disclosure subsidisation is beneficial to consumers we consider the optimal policy  $\sigma = \sigma^{OPT} := \frac{3}{2(1+\beta)}$  to simplify the analysis. Therefore, Eq. (A.29)

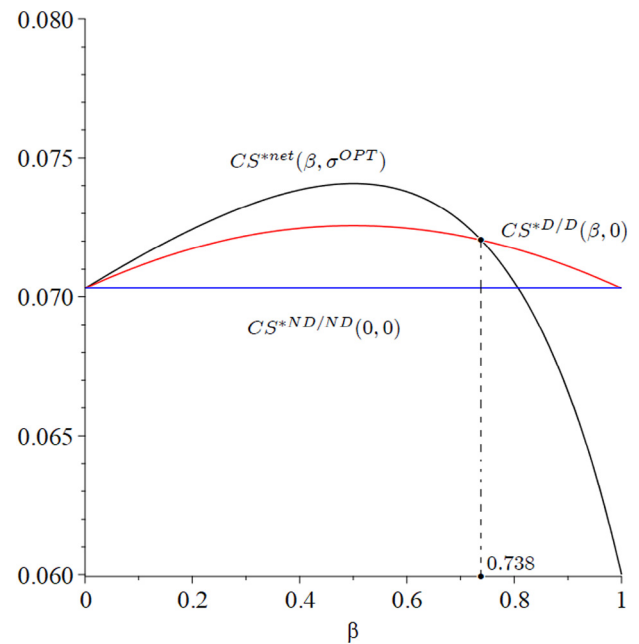


Fig. A.3. Consumer surplus and net consumer surplus. The threshold value of  $\beta$  such that  $CS^{*net}(\beta, \sigma^{OPT}) = CS^{*D/D}(\beta, 0)$  is  $\beta^{CS,TH}(g) = 0.738$  ( $g = 4$ ).

modifies to become:

$$CS^{*net}(\beta, \sigma^{OPT}) = \frac{6g(1-w)^2(3g - 4\beta - 4\beta^2)}{(9g - 4 - 8\beta - 4\beta^2)^2}. \quad (A.35)$$

Fig. A.3 shows that (1) the (second-best) optimal R&D subsidisation policy does not modify the value of  $\beta$  that maximises the consumer surplus (confirming the results of De Bondt et al., 1992), which is equal to  $\frac{1}{2}$ , (2) the consumer surplus under  $D/D$  is larger than the consumer surplus under  $ND/ND$ , confirming that disclosure is beneficial to consumers, and (3) the net consumer surplus is larger than the gross consumer surplus for a large range of  $\beta^{CS,TH}(g) \in (0.589, 0.8)$  as  $g$  increases starting from the lowest possible value that this parameter can take, that is  $g = 4/3$ . The figure is plotted for  $g = 4$  so that  $\beta^{CS,TH}(g) = 0.738$ . Within this range of values of  $\beta$  consumers are better off under R&D subsidisation net to the financing of the policy.

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