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Research funding and price negotiation for new drugs*

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Abstract. This paper analyzes the negotiation process, which leads to basic research funding and price setting for new drugs in regulated health insurance markets. Its results bring answers to the following questions; should basic research be privately funded, publicly funded or produced by an independent lab? Under which conditions is public integration of basic research efficient? How do pharmaceutical prices respond to different organizations of basic research? We show that efficiency and prices are higher when basic research is integrated in the firm that commercializes the drug as compared to independent basic research. In both organizations, the higher the negotiation power of the research labs relative to the one of the public health authority is, the higher the prices and the efficiency are. We thereby confirm the traditional trade-off between price containment and dynamic efficiency. We identify one important exception to this trade-off. Indeed, public integration of basic research can result in lowest prices and highest efficiency, as compared to the other possible organizations, in particular when basic and applied research are highly complementary.

Keywords. Pharmaceutical innovation; drug prices; negotiation; basic research; applied research.

JEL codes. I1; L65; O3.

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1. Introduction

Pharmaceutical innovations result from the successful achievement of basic and applied research. Applied research labs generally make use of the fundamentals from basic research to develop tradable innovations.[1] Applied research mostly lies in the hands of private companies that commercialize innovations, while basic research is traditionally financed by the government and was mainly developed in the public sector. Cohen *et al.* (2002) document that public research importantly affects industrial R&D across much of the manufacturing sector and that university research largely generates new ideas for industrial R&D projects. The traditional case for government funding of basic research is based on knowledge spillovers and imperfect intellectual-property-rights protection: the economic value associated with some ideas cannot be fully appropriated by the developers of these ideas, leading to private-sector underinvestment in "basic" research. Aghion *et al.* (2008) provide a new powerful argument to justify public early-stage research and private applied research based on the trade-off between creative control versus focus. They show that, by serving as a pre-commitment mechanism that allows scientists to freely pursue their own interests, academia can be indispensable for early-stage research. At the same time, the private sector's ability to direct scientists towards higher-payoff activities makes it more attractive for later-stage research. The hierarchical link between basic and applied research, with the former preceding and providing the foundation to the latter also appears in De Fraja (2016). He studies how a government having a preference for applied research should distribute funds among research institutions that perform both basic and applied research.[2]

Nowadays, private forms of basic research are emerging so that basic research is not confined to public universities and institutes any more. In the United States, for example, where basic research was mainly funded by federal government and mainly performed within universities and research institutes, the government funding steadily diminished in the 2010s and private funding became increasingly important (see Broad, 2014). Independent spin-offs, start-ups, joint ventures appeared and independent basic research labs are now sometimes integrated in the research department of big private corporations (see Gonzalez *et al.,* 2016, and Billette de Villemeur and Versaevel, 2019, among others).

The changing organization of basic research is concomitant with the public debate about the fast rising prices of innovative drugs. On the one hand, the patent system provides innovators with a monopoly rent. On the other hand, the existence of either public or compulsory health insurance justifies the public concern for rising prices that generate an ever-higher burden on the public budget. Indeed, insurance subsidies decrease the price elasticity of the patients' demand. The monopoly producer anticipates this effect and, absent regulation and price negotiation, accordingly sets prices that are increasing in the generosity of insurance (Jelovac, 2015). Hence, insurance reimbursement of pharmaceuticals increases innovators' rents above the traditional monopoly rents associated

[1] The National Science Foundation defines "basic research [. . .] as systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind." Conversely, "applied research is defined as systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met" (NSB, 2008; see also De Fraja 2016).

[2] Institutions differ in reputation and efficiency and have an information advantage. He shows that the government awards funding for basic research in such a way that institutions with better reputation do more research than otherwise identical ones, and applied research is inefficiently concentrated in the most efficient high-reputation institutions.

with patents.

Drugs' excessive pricing has recently been recognized as a main issue in OECD countries and the document titled "Excessive Prices in Pharmaceutical Markets" has been delivered in 2018 (OECD 2018).[3] As it is increasingly acknowledged, effective drug price negotiation can curb such prices downwards. In the USA, an update of the Medicare Prescription Drug Price Negotiation Act has been proposed few years ago and is still under debate. This update requires the Centers for Medicare & Medicaid Services (CMS) to negotiate with pharmaceutical companies regarding prices for drugs covered under the Medicare prescription drug benefit. Current law prohibits the CMS from doing so. This is called the "non-interference clause." In contrast, other government programs, like Medicaid, are allowed to negotiate. As a result, Medicare Part D pays on average 73% more than Medicaid for brand name drugs. The federal government could save between $15.2 and $16 billion a year if Medicare Part D paid the same prices as Medicaid (National Academies of Sciences, 2017).

With this update, the Medicare Prescription Drug Price Negotiation Act would satisfy the recommendation by Tefferi *et al.* (2015), among others, to negotiate drug prices to curb the fast-increasing prices of innovative cancer drugs. However, negotiation seems a necessary but not sufficient condition to assure lower prices. Bargaining powers matter too. In France, drug prices are negotiated and patients are protected against catastrophic out-of-pocket expenses, nevertheless prices of all innovative drugs are high and increasing. As a consequence, the Cour des Comptes has recommended to provide the Comité Économique des Produits de Santé with increased financial and legal resources to raise its negotiation power (Cour des Comptes, 2017).[4] As we will make it clear later on, our results suggest that increasing the bargaining power of the Secretary of the Department of Health and Human Services in the US, and of the Comité Économique des Produits de Santé in France, reduces negotiated prices but has an ambiguous effect on efficiency.

Our contribution to this debate rests on a very simple model focusing on the negotiation process which leads to basic research funding and price setting for new drugs in regulated health insurance markets. We want to reply to the following questions; should basic research be privately funded, publicly funded or produced by an independent lab? Under which conditions is public integration of basic research efficient? How do pharmaceutical prices respond to different organizations of basic research?

Our analysis makes a bridge between different papers. Some authors analyzed the financing and organization of basic and/or applied research (see, for example, Aghion et al., 2008, Lacetera and Zirulia, 2012, De Fraja, 2016, and Billette de Villemeur and Versaevel, 2019). Some papers analyzed price negotiation in health care regulated markets: Siciliani and Stanciole (2013) model the bargaining process between the health authority and a hospital; Jelovac (2015) considers the bargaining process between the health

[3]Antitrust authorities discussed a large number of cases concerning the excessive pricing of pharmaceutical products starting from the 1970s. In Germany, the most representative case was the Valium case. In 2001 in UK, the Office of Fair Trade pursued a case relating to the excessive pricing of morphine products. A more recent case is the one of an anti-epileptic drug called Epatunin. In 2016 in the US, following the sudden price increase of EpiPens manufactured by Mylan, the Federal Trade Commission started an investigation for possible antitrust violations. In 2016 the Italian Competition Authority found that Aspen had charged an excessive price for a portfolio blood cancer drugs after their price was raised by 300%-1,500%.

[4]The Cour des Comptes is a French administrative court charged with conducting financial and legislative audits of most public institutions; the Comité Économique des Produits de Santé is the French public authority in charge of drug price negotiations.

authority and a monopolist producing a new drug (for an overview of earlier works on bargaining in health care markets see Barros and Martinez-Giralt, 2012). To a lesser extent, our paper is also related to those studies which analyze drug innovations (e.g. Bardey et al., 2010, and Dubois et al., 2015).

In our model, the health authority, the lab producing basic research and the lab producing applied research interact and agree on the investments in basic and applied research and on the final price of the drug. Our setting describes a stylized regulated market for a new drug: the health authority can actually influence the price of a new drug because it partially or totally pays this price to the pharmaceutical firm when providing public health insurance coverage to its citizens. In our interpretation, basic research represents an intermediate input necessary to finalize the new drug so that it is produced upstream. Applied research is instead produced downstream by the pharmaceutical firm that commercializes the innovation and negotiates with the health authority the price of the drug. The collectivity attaches some social value to the innovation that enters the payoff of the health authority.

We first analyze the funding of basic research when all three agents are independent. We then investigate in turn Private and Public Integration of basic research. The former implies a merger between the basic and the applied research labs. The latter illustrates instead the case of basic research within the public sector. In all the three organization's structures basic and applied research are underprovided. Interestingly we show that, under Public Integration, complementarity between basic and applied research improves efficiency, while it exacerbates distortions in the other settings.

Under No-integration, applied research is underprovided because, when anticipating the final negotiated price, the pharmaceutical firm expects to earn only a share of the total surplus. Similarly, basic research is underprovided because, when anticipating the negotiated private funding, the basic research lab expects to earn only a share of another share of the surplus, which is the one of the pharmaceutical firm. Distortions are lower when the negotiation power is high enough for the basic research lab and low enough for the health authority. Final prices are higher the lower the negotiation power of the health authority, implying that efficiency and high prices go hand in hand.

When we move to integration (or equivalently, to merger), we consider the realistic situation in which the bargaining power of an integrated entity is weakly higher than the bargaining powers of each of its constituting parties. We show that Private Integration of basic research increases both efficiency and the negotiated price relative to No-integration. Distortions are lower and prices are higher the higher the negotiation power of the integrated lab relative to the health authority. Hence, here again efficiency and high prices go hand in hand. Complementarity increases distortions because of a feedback effect which makes underprovision of the two investments in research worse off.

In the case of Public Integration of basic research, the higher the complementarity is, the lower the downward distortion of basic research is. In addition, via complementarity, the lower distortion of basic research mitigates the underprovision of applied research. Public Integration can therefore result in a higher overall efficiency compared to the case of No-integration and of Private Integration, and the more so if complementarity is high. Provided that the efficiency gain from Public Integration is not too high, the negotiated price is lower under Public Integration than in the other settings because of the stronger negotiation power for the integrated body.

All together, our results show that Public Integration can combine the highest efficiency with the lowest negotiated price if complementarity between basic and applied research and the bargaining power of the (integrated) health authority are sufficiently high. This indicates that, via complementarity, Public Integration mitigates the trade off between prices and (dynamic) efficiency. Instead, if complementarity is low, efficiency tends to be higher under Private Integration; but it will be associated with a high negotiated price.

In the light of our results, the decreasing role of Public Integration and the low bargaining power of health authorities may help to explain the dramatic increase of pharmaceutical prices in the past decades. The Medicare Prescription Drug Price Negotiation Act is a reform in the right direction because it gives relatively more negotiation power to the US regulator and helps curbing pharmaceutical prices. However, in light of our results, its impact on the efficiency of R&D activities is ambiguous in the case of Public Integration and negative in the case of no-integration and Private Integration.

The remaining of the paper is organized as follows. Section 2 describes our theoretical setting and characterizes the efficient amounts of basic and applied research. Section 3 solves the model in case of an independent lab producing basic research. Section 4 illustrates Private and Public Integration. Section 5 provides a welfare comparison of the three possible regimes. Section 6 shows that our results are robust to alternative modeling strategies and it explains why, under No-integration and under Private Integration, the health authority does not contribute to basic research. Section 7 concludes. Proofs of the Lemmas and the Propositions are relegated to the appendix together with an example using an explicit function for the social benefit of the innovation.

2. Model setup

Consider three agents: a health authority, H; a laboratory B producing basic research b; and a lab A producing applied research a. In our interpretation, basic research b represents an intermediate input necessary to finalize a new drug (see also Aghion *et al.* 2008). Thus, lab B produces upstream whereas lab A produces downstream.[5] The monopoly power of firm A is justified by some guaranteed protection (patent) of the innovation. The monopoly power of lab B is justified by the fact that B is the unique lab able to provide basic knowledge complementary to a in the production function $V(a,b)$.

We assume that the decision about the amount b invested in basic research is always made before the decision about the amount a invested in applied research. In addition, lab A commercializes the new drug. Hence, it negotiates with the health authority H the final price of the drug P, which the health authority pays to the lab. The basic research lab B negotiates some compensation X_A from firm A, which is equivalent to outsourcing of basic research.

The value of innovation to the health authority positively depends on the investments in the two research activities and we denote it $V(a,b)$. Hence, $V_a(a,b), V_b(a,b) \geq 0$, where V_a and V_b are the first derivatives of $V(a,b)$. Both inputs are necessary to produce the new drug: $V(a,0) = V(0,b) = 0$. The variable cost of producing the pharmaceutical innovation is null. Complementarity between basic and applied research requires that $V_{ab}(a,b) \geq 0$, where V_{ab} is the cross derivative of $V(a,b)$. In addition, we assume that $V(a,b)$ is concave:[6] $V_{aa}(a,b) \leq 0$, $V_{bb}(a,b) \leq 0$ and $V_{aa}(a,b)V_{bb}(a,b) \geq V_{ab}^2(a,b)$, where V_{aa}

[5] Research activity is a black box in our simple model whose focus is on the relationship between research funding and drug prices. We thus depart from the papers modeling incentives for scientists performing research (see Lacetera and Zirulia, 2012, and Martinez and Parlane, 2018, among others).

[6] The function $V(a,b)$ is concave if and only if its Hessian matrix is negative semidefinite for all (a,b).

and V_{bb} are the second derivatives of $V(a,b)$ with respect to the two arguments. Hence, the condition $0 \leq V_{ab}(a,b) \leq \sqrt{V_{aa}(a,b)V_{bb}(a,b)}$ must hold, meaning that the degree of complementarity compatible with concavity is bounded upward.

The value of innovation that we model in function $V(a,b)$ incorporates the benefits deriving from the use of a new drug, such as its efficacy, or the positive effects of the drug net of its side effects for a single patient, the benefits in terms of public health (severity of the treated illness, prevalence, medical need, impact on the quality of life, impact on morbidity and mortality, impact on the delivery of health care), either its preventive or its curative properties, etc.[7]

Definition 1. *The surplus is defined as the value of the innovation net of the investments in basic and applied research:*

$$v\,(a,b) = V(a,b) - a - b.$$

The efficient investment in basic and applied research, respectively b^{FB} and a^{FB}, maximizes the surplus by equating marginal cost and marginal benefit:

$$V_a(a^{FB}, b^{FB}) = 1; \tag{2.1}$$

$$V_b(a^{FB}, b^{FB}) = 1. \tag{2.2}$$

To assure that the first-best investments in basic and applied research and the resulting first-best surplus are strictly positive, we assume that $V_a(0,b) > 1$ and $V_b(a,0) > 1$. In other words, we assume that research is relevant or that investments in basic and applied research are worth their associated expenses. We sum up our assumptions below:

Assumption 1. *The function $V(\cdot)$ is such that $V_a(a,b) \geq 0$, $V_b(a,b) \geq 0$, $V_a(0,b) > 1$, $V_b(a,0) > 1$, $V_{aa}(a,b) \leq 0$, $V_{bb}(a,b) \leq 0$, $V_{ab}(a,b) \geq 0$ and $V_{aa}(a,b)V_{bb}(a,b) \geq V_{ab}^2(a,b)$.*

All else equal, the higher the complementarity is, the higher the surplus $v\,(a,b)$ is. We will show however that, in a second-best world, complementarity affects distortions of applied and basic research in different ways in the different settings.

3. No-integration

In case of successful negotiations entailing $a, b > 0$, the objective functions of the health authority, labs A and B are as follows:

$$W^S = V(a,b) - P; \tag{3.1}$$

$$\Pi_B^S = X_A - b; \tag{3.2}$$

$$\Pi_A^S = P - X_A - a. \tag{3.3}$$

The health authority maximizes the value of the innovation net of the price for the new drug paid to firm A and $X_A > 0$ is a transfer from lab A to lab B aimed at financing

[7] Even though new knowledge from research has an undeniable intrinsic benefit to the lab producing it, the function $V(a,b)$ in our model does not reflect such component of the value since we focus on the part that is priced in the end. Instead, the preference of scientists for independent research is crucial in Aghion, Dewatripont and Stein (2008). Martinez and Parlane (2018) also model intrinsic preference for basic research to provide a theoretical rationale for private investment in basic research.

basic research.[8]

The superscript S in (3.1)-(3.3) stands for successful negotiation. The specific disagreement payoffs of any two bargaining agents in the different stages of the game will be defined below. We assume that, if no agreement is reached in the last stage, the drug is not reimbursed by the health authority and the social benefit $V(a,b)$ is lost.[9]

The timing of the game is as follows.

1. Lab B chooses its investment in basic research b.
2. Lab B negotiates transfer X_A with the downstream lab A.
3. The downstream lab A decides the amount a to invest in applied research.
4. The health authority H and lab A negotiate the price of the drug P.

Note that the choice of b precedes the choice of a. In addition, investment b is decided anticipating the negotiation of payment X_A occurring in the subsequent period. Similarly, investment a is decided anticipating the negotiation of payment P carried out in the subsequent period.[10]

We define β_H, β_B and β_A the negotiation power of the three agents. We do not impose any constraint on the three parameters except that, in any bargaining stage, the *relative* negotiation powers of any two bargaining agents must sum to one.

Solving the game backwards, we start by deriving the final negotiated price, which is the solution to the following Nash Bargaining Program between the health authority and the downstream lab:

$$\max_P \frac{\beta_H}{\beta_H+\beta_A} ln\left(W^S - W^F\right) + \frac{\beta_A}{\beta_H+\beta_A} ln\left(\Pi_A^S - \Pi_A^F\right).$$

Let us consider disagreement payoffs W^F and Π_A^F, where the superscript F stands for failed negotiation. The health authority's payoff when the negotiation fails is $W^F = 0$. Given that, in the last stage of the game, the transfer X_A and the investment a are already sunk for lab A, its disagreement payoff amounts to $\Pi_A^F = -X_A - a$.

Substituting successful and disagreement payoffs, the previous program can be rewritten as:

$$\max_P \frac{\beta_H}{\beta_H+\beta_A} ln(V(a,b) - P) + \frac{\beta_A}{\beta_H+\beta_A} ln(P).$$

The Nash Bargaining solution provides the following negotiated final price:

$$P^* = \frac{\beta_A}{\beta_H+\beta_A} V(a,b). \tag{3.4}$$

[8]As an example of X_A, think about a pharmaceutical firm signing a contract with a research team belonging to a private University or financing a chair in it.

In principle, we could also have a transfer X_H from the health authority to the lab producing basic research but we proved that such transfer is always zero. As an intuition, consider that the health authority already contributes to basic research via the price P, transfer X_H turns out to be redundant. We discuss this point in more detail in Section 6.

[9]This is just a normalization. In case of disagreement, consumers have to pay the monopoly price for the drug. This generates a negative shift of demand, a lower purchased quantity and both a lower consumers' surplus and a lower profit for lab A (see Jelovac, 2015). Without this normalization results would be qualitatively equivalent but expressions would be less transparent.

[10]Reverting the order of the choice of a and b and of the payments X_A and P would result in no investment in basic and applied research.

Intuitively, the negotiated price (3.4) lies at a level that depends on the negotiation power of the downstream lab relative to the one of the health authority.

Substituting P^* in Π_A^S we can now move to the third stage of the game where the downstream lab chooses applied research a solving:

$$\max_a \quad \Pi_A^S = \tfrac{\beta_A}{\beta_H+\beta_A} V(a,b) - X_A - a.$$

The investment in applied research is implicitly given by:

$$a^*(b) : \frac{\beta_A}{\beta_H+\beta_A} V_a(a^*(b), b) = 1. \tag{3.5}$$

Moving to the second stage of the game, we now consider the negotiation between the two labs for the transfer X_A. The two labs solve:

$$\max_{X_A} \frac{\beta_B}{\beta_A+\beta_B} ln(\Pi_B^S - \Pi_B^F) + \frac{\beta_A}{\beta_A+\beta_B} ln(\Pi_A^S - \Pi_A^F).$$

Given that, in the second stage of the game, the investment b is already sunk, the disagreement payoff of lab B amounts to $\Pi_B^F = -b$. As for the downstream lab, the disagreement payoff amounts to $\Pi_A^F = 0$.

The previous program can be rewritten as:

$$\max_{X_A} \frac{\beta_B}{\beta_A+\beta_B} ln(X_A) + \frac{\beta_A}{\beta_A+\beta_B} ln\left(\frac{\beta_A}{\beta_H+\beta_A} V(a^*(b), b) - X_A - a^*(b)\right).$$

Solving for X_A:

$$X_A^* = \frac{\beta_B}{\beta_A+\beta_B}\left(\frac{\beta_A}{\beta_H+\beta_A} V(a^*(b), b) - a^*(b)\right)$$

that we substitute in Π_B.

Finally, in the first stage, the upstream lab chooses b solving:

$$\max_b \quad \Pi_B^S = \tfrac{\beta_B}{\beta_A+\beta_B}\left(\tfrac{\beta_A}{\beta_H+\beta_A} V(a^*(b), b) - a^*(b)\right) - b.$$

Applying the Envelope Theorem, the optimal investment in basic research can be written as:

$$b^* : \frac{\beta_B}{\beta_A+\beta_B}\frac{\beta_A}{\beta_H+\beta_A} V_b(a^*, b^*) = 1 \tag{3.6}$$

Finally, substituting P^* in (3.1)-(3.3) we obtain the agents' final payoffs in this no-integration scenario :

$$W^* = \frac{\beta_H}{\beta_H+\beta_A} V(a^*, b^*); \tag{3.7}$$

$$\Pi_A^* = \frac{\beta_A}{\beta_A+\beta_B}\left(\frac{\beta_A}{\beta_H+\beta_A} V(a^*, b^*) - a^*\right); \tag{3.8}$$

$$\Pi_B^* = \frac{\beta_B}{\beta_A+\beta_B}\left(\frac{\beta_A}{\beta_H+\beta_A} V(a^*, b^*) - a^*\right) - b^*. \tag{3.9}$$

The following Lemma summarizes results without integration of basic research:

LEMMA 1 (No-integration). *Investments a^* and b^* are implicitly given by the two equations:*

$$V_a(a^*, b^*) = 1 + \frac{\beta_H}{\beta_A}, \tag{3.10}$$

$$V_b(a^*, b^*) = \left(1 + \frac{\beta_H}{\beta_A}\right)\left(1 + \frac{\beta_A}{\beta_B}\right). \tag{3.11}$$

(i) *Basic and applied research are both underprovided; distortions increase with β_H and with complementarity but decrease with β_B.*

(ii) *The payoffs of the three agents are given by (3.7)-(3.9) and are non-negative.*

(iii) *The price follows (3.4) and it is decreasing in β_H and increasing in β_A.*

Equations (3.10) and (3.11) are obtained rearranging (3.5) and (3.6). In Appendix A.1 we show that (3.10) and (3.11) imply underprovision of the two types of research. Intuitively, this is a consequence of the vertical structure of negotiations. When anticipating the final negotiated price, the two labs expect to earn only a share of the total surplus. This decreases labs' incentives in investing in research. Also note that downward distortions of applied and basic research are increasing in the r.h.s. of (3.10) and (3.11). Hence, efficiency increases when β_H is low and β_B is high. In Appendix A.1 we also show that complementarity exacerbates downward distortions. Intuitively, via complementarity, an inefficient investment in basic research makes the investment in applied research more inefficient and, similarly, an inefficient investment in applied research makes the investment in basic research more inefficient.

Point (ii) of the Lemma is derived in Appendix A.2. To grasp the intuition recall that both basic and applied research are necessary to produce the innovation. Profits (3.8)-(3.9) are non negative because, when choosing its investment in research, each lab has always zero investment and zero profit as an alternative option.

Summing up the three payoffs one obtains surplus $v(a^*, b^*) = V(a^*, b^*) - a^* - b^* < v(a^{FB}, b^{FB})$. Surplus $v(a^*, b^*)$ is high when distortions of basic and applied research are low or when β_H is low whereas β_B is high. Thus, the best performance of the No-integration organization structure realizes when the lab producing basic research is a strong negotiator while the health authority is relatively weaker. By comparing the payoffs of the two labs we also observe that low distortions are likely to be associated with $\Pi_A^* < \Pi_B^*$. However, from part (iii) of the lemma, we conclude that when the health authority is a weak negotiator, the counterpart to relatively high efficiency is a high final price.

4. INTEGRATION OF BASIC RESEARCH

In this section, we ask the following question. Does integration with the basic research lab increase efficiency? This is interesting because basic research has been traditionally carried out in public institutions but private forms of basic research are currently emerging.

We consider two types of integration. Private integration realizes when the applied research lab and the basic research lab merge. Public integration occurs instead when the health authority and the upstream lab merge.

4.1. Private integration of basic research

Suppose that the upstream and downstream labs are integrated. In case of successful negotiations, the objective functions of the health authority and of the integrated lab are as follows:

$$W^S = V(a,b) - P;$$
$$\Pi^S_{AB} = P - a - b.$$

The timing is now:

1. The integrated lab AB chooses investment in basic and applied research a and b.
2. The health authority H and the integrated lab AB negotiate the price of the drug P.

We assume that $\beta_{AB} \geq \max\{\beta_A, \beta_B\}$, or that the bargaining power of the integrated lab AB is at least as high as the one of each of the two merging labs.

We relegate the analysis of the game to Appendix A.3 because the procedure follows steps that are similar to the ones of No-integration.

The negotiated price writes:

$$P^{*AB} = \frac{\beta_{AB}}{\beta_H + \beta_{AB}} V(a,b); \tag{4.1}$$

while the two agents' payoffs are:

$$W^{*AB} = \frac{\beta_H}{\beta_H + \beta_{AB}} V(a^{*AB}, b^{*AB}), \tag{4.2}$$
$$\Pi^{*AB}_{AB} = \frac{\beta_{AB}}{\beta_H + \beta_{AB}} V(a^{*AB}, b^{*AB}) - a^{*AB} - b^{*AB}. \tag{4.3}$$

The following Lemma summarizes results with private integration of basic research :

Lemma 2 (Private integration). *Investments a^{*AB} and b^{*AB} are implicitly given by the two equations:*

$$V_a(a^{*AB}, b^{*AB}) = 1 + \frac{\beta_H}{\beta_{AB}}, \tag{4.4}$$
$$V_b(a^{*AB}, b^{*AB}) = 1 + \frac{\beta_H}{\beta_{AB}}. \tag{4.5}$$

(i) Basic and applied research are both underprovided and distortions increase with $\frac{\beta_H}{\beta_{AB}}$ and with complementarity.

(ii) The payoffs of the two agents are given by (4.2) and (4.3) and are non negative.

(iii) The price follows (4.1) and it is decreasing in $\frac{\beta_H}{\beta_{AB}}$.

Again, basic and applied research are both underprovided. And, as in the case of No-integration, complementarity exacerbates downward distortions (see Appendix A.1). The same intuition as before applies.

The proof of point (ii) follows the same line as the proof of the corresponding point of Lemma 1 and is thus omitted. Intuitively, the payoff of the integrated lab (4.3) is non negative because, when choosing investments in basic and applied research, lab AB has always zero investments and zero profit as an alternative option.

Finally, the sum of the two payoffs amounts to $v(a^{*AB}, b^{*AB}) = V(a^{*AB}, b^{*AB}) - a^{*AB} - b^{*AB}$. Given that distortions are increasing in the r.h.s of (4.4) and (4.5) (see Appendix A.1), the best performance of Private Integration realizes when $\frac{\beta_H}{\beta_{AB}}$ is low. Thus, private integration works well when the integrated lab is a strong negotiator while the health authority is relatively weak: $\beta_{AB} > \beta_H$. Again, we have a tension between efficiency and the negotiated price as part (iii) of Lemma 2 reports a price that is decreasing in $\frac{\beta_H}{\beta_{AB}}$.

The tension between price and efficiency can be interpreted in terms of the well known trade off between dynamic efficiency and static efficiency (see, among others, Jena and Philipson, 2008): the final price represents the return to the innovation for the integrated lab and the higher the price the higher the incentive to innovate. By studying the price negotiation between the innovator and the health authority the model emphasizes the role of the bargaining powers in this trade off: a high β_{AB} entails a high surplus generated by the innovation (corresponding to a high dynamic efficiency) but also a high share of the surplus appropriated by the integrated lab (corresponding to low consumers' surplus and high prices).[11]

4.2. Public integration of basic research

Suppose now that the public health authority and the basic research lab are integrated; they jointly decide on the investment in basic research b. They also negotiate the final price P with the pharmaceutical lab. Therefore, in case of successful negotiations, the payoff of the integrated public body and of the downstream lab are, respectively:

$$W^S_{HB} = V(a, b) - P - b;$$

$$\Pi^S_A = P - a.$$

Here the negotiated price can be interpreted as a price net of lab A's possible contribution to public basic research.[12] As before, we assume that $\beta_{HB} \geq \max\{\beta_H, \beta_B\}$, or that the negotiation power of the integrated public body is at least as high as the one of each merging agent.

The timing changes as follows.

1. The integrated public body HB chooses investment in basic research b.
2. The downstream lab A decides the amount a to invest in applied research.
3. The integrated public body HB and lab A negotiate the price of the drug P.

The analysis of the game is relegated to Appendix A.4.

[11] The tradeoff is more articulated under No-integration because, in that case, applied and basic research are produced by two different labs. Interestingly, while β_A and β_B have both the expected positive effect on the share of the surplus appropriated by the two labs, only β_B also has a clearcut beneficial effect on the surplus itself; see Lemma 1, point (i).

[12] Think about pharmaceutical firms signing research contracts with research teams or professors in public labs and public Universities or financing specific chairs and positions in public Universities. In this case, $W^S_{HB} = V(a, b) - P' + X_A - b$ and $\Pi^S_A = P' - X_A - a$; where $X_A \geq 0$ and $P' - X_A = P$.

The negotiated price writes:

$$P^{*HB} = \frac{\beta_A}{\beta_{HB} + \beta_A} V(a, b); \tag{4.6}$$

and the two agents' payoffs are:

$$W_{HB}^{*HB} = \frac{\beta_{HB}}{\beta_{HB} + \beta_A} V(a^{*HB}, b^{*HB}) - b^{*HB}, \tag{4.7}$$

$$\Pi_A^{*HB} = \frac{\beta_A}{\beta_{HB} + \beta_A} V(a^{*HB}, b^{*HB}) - a^{*HB}. \tag{4.8}$$

The following Lemma summarizes results with public integration of basic research :

Lemma 3 (Public integration). *Investments a^{*HB} and b^{*HB} are implicitly given by the two equations:*

$$V_a(a^{*HB}, b^{*HB}) = 1 + \frac{\beta_{HB}}{\beta_A}, \tag{4.9}$$

$$V_b(a^{*HB}, b^{*HB}) = \left(1 + \frac{\beta_A}{\beta_{HB}}\right) - \left(1 + \frac{\beta_{HB}}{\beta_A}\right) \frac{V_{ab}(\cdot)}{-V_{aa}(\cdot)}. \tag{4.10}$$

(i) *Basic and applied research are both underprovided and efficiency increases with complementarity.*

(ii) *The payoffs of the two agents are given by (4.7) and (4.8) and are non negative.*

(iii) *The final price follows (4.6) and it is decreasing in $\frac{\beta_{HB}}{\beta_A}$.*

Interestingly, in the case of Public Integration complementarity plays a completely different role. From (4.10) we observe that the downward distortion of basic research decreases with complementarity.[13] Instead, when the two inputs are independent ($V_{ab}(\cdot) = 0$), then (4.10) becomes $V_b(\cdot) = 1 + \frac{\beta_A}{\beta_{HB}}$ and b's distortion reaches its maximum. Note that in principle, for $V_{ab}(\cdot)$ sufficiently high, the r.h.s of (4.10) could be lower than 1. However, we show in Appendix A.5 that basic research is never overprovided.

Also note that the distortion of b decreases if $V_{aa}(\cdot)$ is close to zero, implying that $\frac{V_{ab}(\cdot)}{-V_{aa}(\cdot)}$ in (4.10) is large.

The distortion of applied research is instead similar to the one before because the r.h.s. of (4.9) is exogenous and larger than 1. From (4.9), the distortion in applied research is reduced if $\frac{\beta_{HB}}{\beta_A}$ is low, or if the public body is weak. From (4.10), the distortion in basic research is reduced if $\frac{\beta_{HB}}{\beta_A}$ is high, V_{aa} is small (less negative) and complementarity is high. The effect of $\frac{\beta_{HB}}{\beta_A}$ on efficiency is thus ambiguous.

Again, the proof of point (ii) follows the same line as the proof of the corresponding point of Lemma 1 and is thus omitted. The same intuition as before holds.

Total surplus amounts to $v(a^{*HB}, b^{*HB}) = V(a^{*HB}, b^{*HB}) - a^{*HB} - b^{*HB}$. Overall, distortions are low when the integrated public body is a relatively weak negotiator (so that a^{*HB} is not too distorted) provided that complementarity between basic and applied research is sufficiently high (so that b^{*HB} is closer to the efficient amount). The surplus is increasing in complementarity and it thus reaches its lowest level when complementarity

[13] The proof developed in Appendix A.1 cannot be generally applied to the case of Public Integration because the r.h.s. of (4.10) depends on $\frac{V_{ab}}{-V_{aa}}$ and is thus endogenous.

is absent. In the case of positive but low complementarity, low distortions are still possible if $-V_{aa}(\cdot)$ is close to zero, or if the concavity of $V(\cdot)$ with respect to a is low .

About point (iii), according to intuition the final negotiated price is low when the public integrated entity is a strong enough negotiator.

5. COMPARING THE DIFFERENT SETTINGS

The following propositions compare efficiency in the three scenarios (see Appendix A.6 and A.8 for formal proofs).

PROPOSITION 1 (Comparison between No-integration and Private Integration). (i) *From an efficiency perspective, Private Integration of basic research always dominates No-integration.* (ii) *The negotiated price is higher under Private Integration than under No-integration.*

Both basic and applied research are less distorted under Private Integration than with No-integration. Surplus is thus higher under Private Integration than under No-integration. The final price is always higher under Private Integration as compared to No-integration because the integrated labs enjoy a higher share of a larger surplus.

The integrated lab's payoff under Private Integration is larger than the sum of the two separated labs' payoffs under No-integration : $\Pi_{AB}^{*AB} > \Pi_A^* + \Pi_B^*$ (see Appendix A.7). This is because, under Private Integration, the integrated lab obtains a larger share of a larger surplus. Indeed, the Integrated Private body is now more powerful than a single pharmaceutical firm when negotiating the final price and distortions of basic and applied research are lower. As a consequence, the two labs are better off merging rather than not.[14]

PROPOSITION 2 (Comparison between Public and Private Integration). (i) *Absent complementarity, Private Integration is more efficient than Public Integration if the applied lab A (integrated or not) is a strong negotiator ($\beta_A\beta_{AB} \geq \beta_H\beta_{HB}$), otherwise the comparison is ambiguous.* (ii) *If complementarity is positive and high enough, then Public Integration may dominate Private Integration.* (iii) *The negotiated price is lower under Public Integration as long as $V(a^{*HB}, b^{*HB}) - V(a^{*AB}, b^{*AB})$ is small (or negative) and/or β_{HB} is high enough.*

Note that, when Public Integration dominates Private Integration, by transitivity it also dominates No-integration (see Proposition 1). Thus, in the above proposition we focus on the comparison between Public and Private Integration. In addition, given that complementarity increases distortions in Private Integration (and No-integration) but improves Public Integration (see Lemma 1, Lemma 2 and Lemma 3), we start our comparison from the case in which $V_{ab} = 0$.

[14]We can extend this argument to the outsourcing of clinical trials, which can be delegated to independent labs. Outsourcing clinical trials decreases the relative negotiation power of the downstream lab, which ultimately results in a lower price. Anticipating a lower final price, the pharmaceutical firm and the lab in charge of clinical trials negotiate a lower transfer. The independent lab therefore invests a lower amount in clinical trials, which are therefore more distorted. All together (higher distortions in research investments and lower final price) result in lower total benefits for both the downstream firm and the lab producing trials, as compared to in-house clinical trials. We therefore expect no gains from clinical trials outsourcing in our model.

Point (i) of Proposition 2 shows that, absent complementarity, the comparison between Public and Private Integration is in general ambiguous. Distortions in applied research are higher under Public Integration, but relative distortions in basic research depend on bargaining powers. In Appendix A.8 we show that $\beta_A\beta_{AB} \geq \beta_H\beta_{HB}$ is a sufficient condition to have Private Integration dominating Public Integration when $V_{ab} = 0$. The opposite inequality is a necessary but not sufficient condition to have Public Integration dominating Private Integration when $V_{ab} = 0$.

Point (ii) of Proposition 2 moves from no complementarity to positive complementarity. As mentioned before, distortions decrease under Public Integration and increase under Private Integration. Complementarity has an indirect effect on the two research investments and exacerbates their underprovision under Private Integration (see (A.3) and (A.4) in Appendix A.1). Complementarity has instead a direct positive effect on basic research under Public Integration and decreases distortions there (see (4.10)). Hence, if the complementarity between the two types of research is high enough, the investment in basic research is higher under Public than under Private Integration. As an intuition, when the public integrated body decides upon its investment in basic research, it internalizes the complementarity between basic and applied research. Therefore, when complementarity is high enough, it tends to invest more in basic research to mitigate the distortion due to the underprovision of applied research by the pharmaceutical firm.[15]

Finally, Point (iii) of the proposition refers to the comparison of negotiated prices. In both Private and Public Integration, prices are proportional to the private lab's relative negotiation power and to the total value of innovation. The different negotiation powers between the two integrative scenarios are one of the main drivers of the price comparison. First of all note that, in all settings, the higher the negotiation power of the health authority, the lower the negotiated price. In addition, the public negotiator is relatively more powerful under Public than under Private Integration. Therefore, if the value of innovation were constant across both types of integration, then the price would be unambiguously lower under Public Integration than under Private Integration. However, when efficiency gains from Public Integration are sufficiently high ($V(a^{*HB}, b^{*HB}) - V(a^{*AB}, b^{*AB}) \gg 0$), then the price under Public Integration may be higher or lower than the price under Private Integration. The price under Public Integration would correspond in this case to a relatively low share of a sufficiently large surplus and the price comparison becomes ambiguous. We can conclude that the negotiated price is lower under Public Integration as compared to Private Integration if the integrated public body is a sufficiently strong negotiator and if efficiency gains are not too high under Public Integration ($V(a^{*HB}, b^{*HB}) - V(a^{*AB}, b^{*AB})$ small or negative).

Considering Points (ii) and (iii) together, Public Integration of basic research can combine the highest efficiency with the lowest negotiated price if complementarity between basic and applied research and β_{HB} are sufficiently high. Hence, via complementarity, Public Integration mitigates the tradeoff between price and dynamic efficiency discussed at the end of Section 4.1. Instead, if the public negotiator is not powerful enough and complementarity is low, we can have situations in which both efficiency and the negotiated price are higher under Private Integration.

[15] In the same way as the comparison between Public and Private Integration, the comparison between Public Integration and No-integration is ambiguous (see Appendix A.8, point (ii)). Hence the comparison between the payoff of the integrated public body under Public Integration and the sum of the payoffs of the two merging agents under No-integration $\left(W_{HB}^{*HB} \lesseqgtr W^* + \Pi_B^*\right)$ is ambiguous as well. However, if complementarity is sufficiently high we expect $W_{HB}^{*HB} > W^* + \Pi_B^*$.

The following example illustrates Proposition 2 (see Appendix A.9 for a complete analysis). By using a quadratic function we can provide some comparative statics with respect to complementarity.[16,17]

Take the function $V(a,b) = 2a - \frac{1}{2}\lambda a^2 + 2b - \frac{1}{2}b^2 + \gamma ab$. Assumption 1 requires the following conditions. Marginal returns to basic and applied research are non negative if $V_a = 2 - \lambda a + \gamma b \geq 0$ and $V_b = 2 - b + \gamma a \geq 0$. Conditions $V_a(0,b) > 1$ and $V_a(0,b) > 1$ are always satisfied for positive values of a and b. Diminishing marginal returns to basic research ($V_{bb} \leq 0$) is always satisfied, diminishing marginal returns to applied research ($V_{aa} \leq 0$) requires $\lambda \geq 0$. Complementarity exists for $\gamma > 0$. Concavity is satisfied for $\lambda \geq \gamma^2$. In addition assume that $\beta_A = \beta_B = \beta_H = \frac{1}{3}$ and $\beta_{AB} = \beta_{HB} = \frac{2}{3}$. Under this parameters' configuration, no restrictions are necessary for the solution under Private Integration. Instead, conditions are necessary to have a well behaved solution under Public Integration. Specifically, Public Integration is possible in the following range of parameters: (a) $\frac{1}{2} < \gamma$ and $\frac{1}{12}\left(-\lambda + \sqrt{\lambda^2 + 48\lambda}\right) < \gamma < \frac{1}{2}\lambda$ or (b) $2 \leq \gamma < \sqrt{\lambda}$. The previous inequalities assure that a^{*HB}, b^{*HB}, $V_a(a^{*HB}, b^{*HB})$, $V_b(a^{*HB}, b^{*HB})$ and $v\left(a^{*HB}, b^{*HB}\right)$ are all strictly positive.

In this example, the negotiated price is always lower under Public Integration than under Private Integration. Furthermore, Public Integration is more efficient than Private Integration in the three following regions: (1) $\frac{5}{4} < \gamma \leq 2$ and $\frac{1}{4}\left(-\lambda + \sqrt{\lambda^2 + 20\lambda}\right) < \gamma < \frac{1}{2}\lambda$; (2) $\gamma > 2$ and $\frac{1}{4}\left(-\lambda + \sqrt{\lambda^2 + 20\lambda}\right) < \gamma < \sqrt{\lambda}$; (3) $\frac{5}{2} \leq \gamma < \sqrt{\lambda}$; where (1) and (2) are two sub-regions of (a) while (3) is a sub-region of (b). In addition, in line with Proposition 2, Public Integration dominates Private Integration when γ is sufficiently high (but Public Integration also dominates Private Integration for intermediate values of γ).

6. Discussion on alternative modelling strategies

To check the robustness of our results, we discuss here three variations on our model.[18] They show that our simple setting provides indeed quite general results.

Partial public contribution to basic research. In the first variation, we add the possibility for the health authority to directly finance basic research whenever the latter is not under its responsibility, that is, under No-integration and Private Integration. We remain flexible both about how such public funding is decided and about its timing. Specifically, the health authority and the lab in charge of basic research (either lab B or integrated lab AB) can negotiate the amount of public funds for basic research just before or just after the basic research investment stage. Alternatively, the health authority can unilaterally decide upon its amount one step before the investment decision for basic research.

In all cases, the result is the same: the amount of direct public funds for basic

[16] Even if, with the quadratic function, one input is sufficient to have an innovation (so that $V(0,b), V(a,0) \neq 0$), in practice both investments are necessary to have interior solutions and positive payoffs for the agents (see Appendix A.9 for more details).

[17] In an appendix available upon request to the authors we show the case of a Cobb-Douglas function: $V(a,b) = a^\alpha b^\delta$. Again we obtain both situations in which Public Integration dominates Private Integration and situations in which the opposite holds. Prices instead are always lower under Public Integration. However, we cannot discuss the effect of complementarity with such a function.

[18] The formal analysis of these variations is available from the authors upon request.

research is null. To understand why, it is important to realize that the health authority values the investments in basic and applied research as well as the resulting innovation the same, no matter whether it directly contributes to the funding of basic research or not, provided it anticipates a successful negotiation for the final price. Furthermore, the investment in basic research is independent on such a direct funding if the latter is decided beforehand and granted unconditionally. Lastly, the payoffs of the private lab(s) are non-negative, even in the absence of direct funds for basic research.[19] We conclude that in our setting, direct funding of basic research does not improve efficiency and the health authority is thus better off not spending such funds. Therefore, adding the possibility of direct public funds for basic research does not alter our results.

The health authority maximizes $\mathbf{V}(\mathbf{a}, \mathbf{b})$. In the second variation of the model, we assume an alternative objective function for the health authority. Rather than maximizing the value of the innovation net of public expenses, we consider here that the health authority aims at maximizing the value of the innovation under the constraint that public expenses cannot exceed such value: $\max V(a,b)\ s.t.\ W_i \geq 0$, where $i = \{\emptyset, AB, HB\}$. With such an assumption we confirm our main results, even if in a more clearcut form. First, we observe higher investments in research, compared to the settings of this paper. Second, Public Integration leads to the highest efficiency while No-integration to the lowest, no matter the degree of complementarity. Finally, Private Integration entails the highest negotiated price.

Uncertainty. In the third variation of our simple model, we acknowledge that uncertainty is a crucial aspect in all R&D activities. We thus analyze a version of the model incorporating uncertainty by defining the value of innovation as $q(a)r(b)V(a,b)$, where $r(b)$ is the probability that basic research is successful and $q(a)$ is the probability that applied research is successful conditionally on b being successful. We also assume that both probabilities of success positively depend on the investments in basic and applied research. We can show that all our results continue to hold with this specification of the model.

7. Conclusion

We propose a simple and parsimonious model of negotiation between a health authority and two labs producing basic and applied research, respectively. We provide a welfare comparison of three different organization structures for basic research: No-integration, Private and Public Integration. Because of the vertical relationships between the health authority and the two labs, basic and applied research are always underprovided, but to different extents according to the organization structure. Complementarity between basic and applied research exacerbates distortions under No-integration and Private Integration while it increases efficiency in research investments in the case of Public Integration.

Private Integration of basic research decreases distortions compared to the setting with No-integration. This implies relatively higher prices and a higher total surplus under Private Integration than under No-integration. When complementarity is high

[19] This holds true as long as we assume constant marginal costs. However, partial public funding of basic research may be justified to cover fixed costs for operating basic research.

enough, Public Integration tends to result in a higher overall efficiency compared to No-integration and also compared to Private Integration. Provided the efficiency gain due to Public Integration is not too high, the latter also entails the lowest price, and the more so the higher the negotiation power of the integrated public body.

As we discuss in Section 6, under No-integration and under Private Integration, the health authority would never provide a direct contribution to basic research because this would not be efficient. In different words, the health authority, being this option available, would optimally choose not to (partially) finance basic research. This is why in our simple model there is no role for a *partial* contribution to basic research by the health authority. Specifically, we analyzed only two extreme options: either the health authority is fully responsible for the financing of basic research (in the case of Public Integration) or it just pays the price of the final drug and no intermediate transfer exists (in the cases of No-integration and in the one of Private Integration). Advocating for more efficient negotiations in order to contain the price of cancer drugs, Maraninci and Vernant (2016) recommend to the heath authority to take into account not only *private* R&D expenses but also the costs of those *public* R&D expenditures that contributed to the production of the new drug. In this respect our model indicates that, when a unique agent is fully responsible of the financing of basic research, not only the accountability of the cost of basic research improves, but also overall efficiency increases.

The model predicts that negotiated prices are increasing in the bargaining power of the lab commercializing the innovation and decreasing in the one of the health authority. In the real world, labs commercializing new drugs are multinational big pharma companies that are characterized by high market shares and, thus, are likely to be strong negotiators. In light of our results, the widespread cases of excessive pricing reported in Footnote 2 and the hot debate on drugs' raising prices in OECD countries are not surprising. The Medicare Prescription Drug Price Negotiation Act actually goes in the right direction by increasing the bargaining power of the US regulator and should be effective in curbing pharmaceutical prices for Medicare part D patients.

The currently observed trend towards the development of spin-offs, start-ups and joint ventures producing basic research points to the rising of No-integration settings. Our model suggests that this is not a desirable change: efficiency is higher under integration and, in order to contain prices, Public Integration is the best option.

A limitation of our analysis relates to competition, which is often important even in a situation with patent protection. First, alternative therapeutic strategies may already exist and the value of pharmaceutical innovations must be appreciated with regards to existing therapies. This aspect of competition is compatible with our model if we define $V(a, b)$ as the added value of innovation as compared to existing therapies. However, there are other aspects of competition that are important and that we ignore. For instance, the analysis of competition between downstream labs both on the final market and for acquiring the necessary fundamental knowledge from basic research labs. In that respect, Billette de Villemeur and Versaevel (2019) construct a model where two firms can choose to outsource R&D to an independent lab, and/or engage in integrated R&D, before competing in a final market. One of their conclusion is that, the decision by competing firms to outsource early-stage research activities to the same independent basic research lab leads most expected value to be appropriated by these competing firms.

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. APPENDIX

A.1. Proof of point (i) in Lemma 1 and Lemma 2

We can write FOCs (2.1), (3.10) and (4.4) as follows:

$$V_a(a^i, b^i) = m^i,$$

where $i = FB, ^*, ^*AB$, and m^i refer to the following function of exogenous parameters:

$$\{m^{FB}, m^*, m^{*AB}\} = \left\{1, 1 + \frac{\beta_H}{\beta_A}, 1 + \frac{\beta_H}{\beta_{AB}}\right\}.$$

Similarly, we can write Equations (2.2), (3.11) and (4.5) as follows:

$$V_b(a^i, b^i) = n^i,$$

where n^i refer to the following function of exogenous parameters:

$$\{n^{FB}, n^*, n^{*AB}\} = \left\{1, \left(1 + \frac{\beta_H}{\beta_A}\right)\left(1 + \frac{\beta_A}{\beta_B}\right), 1 + \frac{\beta_H}{\beta_{AB}}\right\}.$$

Totally differentiating the equations $V_a(a^i, b^i) = m^i$ and $V_b(a^i, b^i) = n^i$ leads to the following *direct* relationships between the equilibrium investments in basic and applied research and the functions of the parameters m^i and n^i:

$$\frac{da^i}{dm^i} = \frac{V_{bb}}{V_{aa}V_{bb} - (V_{ab})^2} < 0, \tag{A.1}$$

and

$$\frac{db^i}{dn^i} = \frac{V_{aa}}{V_{aa}V_{bb} - (V_{ab})^2} < 0; \tag{A.2}$$

where the denominator is positive because of concavity. These *direct effects* indicate that, all else equal, the higher m^i the lower the investment in applied research; the higher n^i the lower the investment in basic research. Hence (A.1) and (A.2) show underinvestment of basic and applied research whenever m^i and n^i are above $m^{FB} = 1$ and $n^{FB} = 1$, respectively, which is the case for $i =^*,^* AB$.

We also find the following *indirect* relationships between the equilibrium investments in research and the exogenous variables:

$$\frac{da^i}{dn^i} = -\frac{V_{ab}}{V_{aa}V_{bb} - (V_{ab})^2} \leq 0, \tag{A.3}$$

and

$$\frac{db^i}{dm^i} = -\frac{V_{ab}}{V_{aa}V_{bb} - (V_{ab})^2} \leq 0. \tag{A.4}$$

These *indirect effects* indicate that, all else equal, the higher n^i the lower the investment in applied research; the higher m^i the lower the investment in basic research. As (A.3) and (A.4) show, both indirect effects depend on complementarity which, thus, exacerbates distortions. If $V_{ab} = 0$ then the *indirect effects* disappear.

A.2. Proof of point (ii) of Lemma 1

Investments a^* and b^* are the $\max\left\{0, \arg\max_a \Pi_A(a,b)\right\}$ and $\max\left\{0, \arg\max_b \Pi_B(a,b)\right\}$, respectively. Given that $V(0,b) = V(a,0) = 0$, if $A(B)$ does not invest in applied (basic) research, it obtains zero profits. In addition, each lab always earns negative profits when choosing a positive investment when the other lab chooses not to invest: $\Pi_A|_{a>0}(a,0) < 0$ and $\Pi_B|_{b>0}(0,b) < 0$. Hence, no matter the stage of the game, the investment in research will be strictly positive only when this assures a strictly positive payoff to the lab. If it does not, then the lab will prefer zero investment and zero profits. This implies that positive investments are always associated with positive payoffs for the two labs. We conclude that (3.9) and (3.8) are non negative.

A.3. Solving for Private Integration

Solving the Private Integration game backwards, we start deriving the final negotiated price, which is the solution to the following Nash Bargaining Program:

$$\max_P \frac{\beta_H}{\beta_H + \beta_{AB}} ln(W^S - W^F) + \frac{\beta_{AB}}{\beta_H + \beta_{AB}} ln(\Pi^S_{AB} - \Pi^F_{AB}).$$

Here $W^F = 0$ is the health authority's payoff when the negotiation fails. Investments a and b are already sunk for lab A; hence its disagreement payoff amounts to $\Pi^F_{AB} = -a-b$. The program can thus be rewritten as:

$$\max_P \frac{\beta_H}{\beta_H + \beta_{AB}} ln(V(a,b) - P) + \frac{\beta_{AB}}{\beta_H + \beta_{AB}} ln(P).$$

Hence, we derive the negotiated price (4.1) in the main text that we substitute in Π^S_{AB} and W^S.

In the first stage the integrated lab solves:

$$\max_{a,b} \quad \Pi^S_{AB} = \tfrac{\beta_{AB}}{\beta_H+\beta_{AB}} V(a,b) - a - b,$$

and optimal investments $(a^{*AB}, b^{*AB})$are:

$$\frac{\beta_{AB}}{\beta_H + \beta_{AB}} V_a(a, b^{*AB}) = 1; \tag{A.5}$$

$$\frac{\beta_{AB}}{\beta_H + \beta_{AB}} V_b(a^{*AB}, b) = 1. \tag{A.6}$$

Equations (4.4) and (4.5) in the main text directly follow from (A.5) and (A.6), respectively.

A.4. Solving for Public Integration

Solving the Public Integration game backwards, we start deriving the final negotiated price, which is the solution to the following Nash Bargaining Program:

$$\max_P \frac{\beta_{HB}}{\beta_{HB} + \beta_A} ln(W^S_{HB} - W^F_{HB}) + \frac{\beta_A}{\beta_{HB} + \beta_A} ln(\Pi^S_A - \Pi^F_A).$$

Here, $W^F_{HB} = -b$ is the integrated public body's payoff when the negotiation fails because the investment in basic research b is already sunk at this stage. In the same way, the investment a is already sunk for lab A; hence the latter's disagreement payoff amounts to $\Pi^F_A = -a$. The program can thus be rewritten as:

$$\max_P \frac{\beta_{HB}}{\beta_{HB} + \beta_A} ln(V(a,b) - P) + \frac{\beta_A}{\beta_{HB} + \beta_A} ln(P).$$

Hence, we obtain the negotiated price (4.6) in the main text.

In the previous stage, the downstream lab chooses investment in applied research solving:

$$\max_a \quad \Pi^S_A = \tfrac{\beta_A}{\beta_{HB}+\beta_A} V(a,b) - a.$$

Applied research is then defined by the following implicit function:

$$a^{*HB}(b) : \frac{\beta_A}{\beta_{HB} + \beta_A} V_a(a^{*HB}(b), b) = 1. \tag{A.7}$$

In the first stage, the integrated public body chooses its investment in basic research. Substituting P^{*HB}in W_{HB} and anticipating the optimal investment in applied research

$a^{*HB}(b)$, the public body solves:

$$\max_b \quad W^S_{HB} = \tfrac{\beta_{HB}}{\beta_{HB}+\beta_A} V\left(a^{*HB}(b), b\right) - b.$$

The optimal amount of basic research is:

$$b^{*HB} : \frac{\beta_{HB}}{\beta_{HB}+\beta_A}\left(V_a(\cdot)\frac{da^{*HB}(b)}{db} + V_b(\cdot)\right) = 1. \tag{A.8}$$

Fully differentiating (A.7) we obtain $\frac{da^{*HB}(b)}{db} = -\frac{V_{ab}(\cdot)}{V_{aa}(\cdot)} > 0$. Substituting it in (A.8):

$$b^{*HB} : \frac{\beta_{HB}}{\beta_{HB}+\beta_A}\left(V_b(\cdot) - V_a(\cdot)\frac{V_{ab}(\cdot)}{V_{aa}(\cdot)}\right) = 1. \tag{A.9}$$

From (A.7), $V_a(\cdot) = \frac{\beta_{HB}+\beta_A}{\beta_A}$ that corresponds to (4.9) in the main text, and can be substituted in (A.9). Hence, (A.9) can be rewritten as (4.10) in the main text.

A.5. Public Integration: overprovision of basic research is never optimal

Following the same argument as in Appendix A.2, $a^{*HB}(b)$ is part of the solution only if $\Pi_A(a^{*HB}(b), b) = \frac{\beta_A}{\beta_{HB}+\beta_A}V(a^{*HB}(b), b) - a^{*HB}(b) \geq 0, \forall b$. Otherwise, lab A would choose not to invest in applied research.

$\Pi_A(a^{*HB}(b), b) \geq 0, \forall b$, directly implies the following inequality:

$$W_{HB}(a^{*HB}(b), b) = v(a^{*HB}(b), b) - \Pi_A(a^{*HB}(b), b) \leq v(a^{*HB}(b), b), \forall b.$$

Therefore,

$$W_{HB}(a^{*HB}(b), b) = \frac{\beta_{HB}}{\beta_{HB}+\beta_A}V(a^{*HB}(b), b) - b \leq V(a^{*HB}(b), b) - a^{*HB}(b) - b, \forall b. \tag{A.10}$$

Let us now define: $a^{FB}(b) = \arg\max_a (V(a, b) - a - b), \forall b$, and note that $a^{FB}(b) \equiv a^{FB}$ when $a^{FB}(b) = \arg\max_a (V(a, b^{FB}) - a - b^{FB})$. Recall that instead $a^{*HB}(b) = \arg\max_a (\frac{\beta_A}{\beta_{HB}+\beta_A}V(a(b), b) - a(b))$. Therefore,

$$V(a^{*HB}(b), b) - a^{*HB}(b) - b \leq V(a^{FB}(b), b) - a^{FB}(b) - b, \forall b. \tag{A.11}$$

From (A.10) and (A.11), we have

$$\frac{\beta_{HB}}{\beta_{HB}+\beta_A}V(a^{*HB}(b), b) - b \leq V(a^{FB}(b), b) - a^{FB}(b) - b, \forall b.$$

Now, for $b = 0$, the functions in the two sides of the previous inequality are both zero, moreover they are increasing in zero and concave. Thus, we can conclude that

$$b^{*HB} = \arg\max_b \left(\frac{\beta_{HB}}{\beta_{HB}+\beta_A}V(a^{*HB}(b), b) - b\right) \leq b^{FB} = \arg\max_b (V(a^{FB}(b), b) - a^{FB}(b) - b).$$

A.6. *Proof of Proposition 1*

(i) Let us go back to the proof in Appendix A.1 and consider the values of m^i and n^i in first-best, No-integration and Private Integration, respectively. Recalling that $\beta_{AB} \geq \max\{\beta_A, \beta_B\}$, m^i and n^i rank as follow:

$$m^{FB} = 1 < m^{*AB} \leq m^*,$$

and

$$n^{FB} = 1 < n^{*AB} < n^*.$$

This proves that distortions are systematically lower under Private Integration than under No-integration. (ii) As for negotiated prices, comparing (3.4) and (4.1), we observe that the final price is always higher under Private Integration as compared to No-integration because the integrated labs enjoy a higher share of a larger surplus.

A.7. *Proof of* $\Pi_A^* + \Pi_B^* < \Pi_{AB}^{*AB}$

Consider that $\Pi_A^* + \Pi_B^* = \frac{\beta_A}{\beta_H+\beta_A} V(a^*, b^*) - a^* - b^*$, where

$$\begin{aligned} a^* &= \arg\max_a \Pi_A = \frac{\beta_A}{\beta_H + \beta_A} V(a,b) - a \text{ and} \\ b^* &= \arg\max_b \Pi_B = \frac{\beta_B}{\beta_A + \beta_B} \left(\frac{\beta_A}{\beta_H + \beta_A} V(a^*(b), b) - a^*(b) \right) - b. \end{aligned}$$

Whereas, in $\Pi_{AB}^{*AB} = \frac{\beta_{AB}}{\beta_H+\beta_{AB}} V(a^{*AB}, b^{*AB}) - a^{*AB} - b^{*AB}$,

$$a^{*AB}, b^{*AB} \in \arg\max_{a,b} \Pi_{AB} = \frac{\beta_{AB}}{\beta_H + \beta_{AB}} V(a,b) - a - b$$

and $\frac{\beta_{AB}}{\beta_H+\beta_{AB}} > \frac{\beta_A}{\beta_H+\beta_A}$.

A.8. *Proof of Proposition 2*

(i) Without complementarity, FOC (4.10) simplifies to $V_b(a^{*HB}, b^{*HB}) = \left(1 + \frac{\beta_A}{\beta_{HB}}\right) = n_0^{*HB}$, where n_0^{*HB} indicates the (now exogenous) r.h.s. of (4.10) when $V_{ab} = 0$. Recalling that $\beta_{HB} \geq \max\{\beta_H, \beta_B\}$, m^i and n^i rank as follow:

$$m^{FB} = 1 < m^{*AB} \leq m^* \leq m^{*HB},$$

and

$$\begin{aligned} n^{FB} &= 1 < n^{*AB} < n^* \text{ and} \\ n^{FB} &= 1 < n_0^{*HB} < n^*. \end{aligned}$$

Hence, distortions in applied research are the lowest under Private Integration and the largest under Public Integration. As for basic research, Public Integration entails lower distortions than No-integration, while the comparison with Private integration is ambiguous because $n_0^{*HB} \lesseqgtr n^{*AB}$. Specifically if $\beta_A\beta_{AB} \geq \beta_H\beta_{HB}$, then $n_0^{*HB} \geq n^{*AB}$

and Private Integration entails lower distortions in basic research than Public Integration. Hence, conditions $V_{ab} = 0$ and $\beta_A \beta_{AB} \geq \beta_H \beta_{HB}$ are jointly sufficient for Private Integration to dominate Public Integration. While $V_{ab} = 0$ and $\beta_A \beta_{AB} < \beta_H \beta_{HB}$ are necessary (but not sufficient) conditions to have Public Integration dominating Private Integration.

(ii) Suppose now that we increase complementarity starting from zero until we reach its maximum level compatible with concavity: $V_{ab} = \sqrt{V_{aa} V_{bb}}$. As we have shown in Lemma 1 and Lemma 2, under No-integration and under Private Integration complementarity increases distortions; while, from Lemma 3, under Public Integration, complementarity decreases distortions. Hence, when complementarity is sufficiently high we expect Public Integration to dominate Private Integration (and thus No-integration as well). Our examples with a quadratic function show that Public Integration outperforms Private Integration for V_{ab} sufficiently high.[20]

(iii) As for the negotiated prices, even when efficiency is higher under Public Integration than under No-integration and Private Integration, the price comparison is ambiguous (see (3.4), (4.1) and (4.6)). To see why consider that the following chain of inequalities holds: $\frac{\beta_{AB}}{\beta_H + \beta_{AB}} \geq \frac{\beta_A}{\beta_H + \beta_A} \geq \frac{\beta_A}{\beta_{HB} + \beta_A}$. Hence, when $V(a^{*HB}, b^{*HB}) > V(a^{*AB}, b^{*AB}) > V(a^*, b^*)$, P^{*HB} corresponds to a lower share of a larger surplus.

A.9. Example with a quadratic function $V(\cdot)$

Let us consider the following quadratic function (see also Footnote 16):

$$V(a, b; \lambda, \gamma) = 2a - \frac{1}{2}\lambda a^2 + 2b - \frac{1}{2}b^2 + \gamma ab.$$

Assumption 1 requires the following conditions. Marginal returns to basic and applied research are non negative if $V_a = 2 - \lambda a + \gamma b \geq 0$ and $V_b = 2 - b + \gamma a \geq 0$. Conditions $V_a(0, b) > 1$ and $V_a(0, b) > 1$ are always satisfied for positive values of a and b. Diminishing marginal returns to basic research ($V_{bb} \leq 0$) is always satisfied, diminishing marginal returns to applied research ($V_{aa} \leq 0$) requires $\lambda \geq 0$. Complementarity exists for $\gamma > 0$. Concavity is satisfied for $\lambda \geq \gamma^2$.

First-best investments and surplus are:

$$a^{FB} = \tfrac{1+\gamma}{\lambda - \gamma^2}, \quad b^{FB} = \tfrac{\lambda + \gamma}{\lambda - \gamma^2}, \quad v(a^{FB}, b^{FB}) = \tfrac{(\lambda+\gamma)(1+\gamma)}{(\lambda-\gamma^2)^2}$$

and are increasing in complementarity γ.

No-integration. With complementarity ($\gamma > 0$), $\beta_A > \beta_H$ assures that investments in basic and applied research and the surplus, $v(a, b)$, are all positive. Absent complementarity ($\gamma = 0$), the condition on bargaining powers becomes stricter: investments in basic and applied research and the surplus are all positive only if $\beta_B > \beta_A > \beta_H$.

Private integration. Independently of complementarity, $\beta_{AB} > \beta_H$ assures that investments in basic and applied research and the surplus, $v(a, b)$, are all positive. In addition, if $\mu \lesseqgtr 1$ then $b^{*AB} \lesseqgtr a^{*AB}$.

[20] Even if complementarity is not explicitly measurable with a Cobb-Douglas function, we find cases in which Public Integration outperforms Private Integration with such a function as well.

Public integration. Complementarity ($\gamma > 0$) is required to have positive investment in *both* applied and basic research. $b^{*HB} > 0$ if $\beta_{HB} > \frac{\lambda}{2\gamma+\lambda}\beta_A$ and $V_b > 0$ if $\beta_{HB} < \frac{\lambda}{\gamma}\beta_A$ so that it must be $\frac{\lambda}{2\gamma+\lambda}\beta_A < \beta_{HB} < \frac{\lambda}{\gamma}\beta_A$, which is compatible with $\beta_{HB} \lesseqgtr \beta_A$. The conditions for $a^{*HB} > 0$ are less transparent but they are still compatible with $\beta_{HB} \lesseqgtr \beta_A$. $V_a > 0$ always holds. The conditions for a positive surplus combine all the previous conditions and are still compatible with $\beta_{HB} \lesseqgtr \beta_A$.

Comparison between public and private integration. Let us assume that, without integration, bargaining powers are such that $\beta_A = \beta_H = \beta_B = \frac{1}{3}$ and that integration implies $\beta_{AB} = \beta_{HB} = \frac{2}{3}$. Given that $\beta_{AB} > \beta_H$, no restrictions are necessary for the solution under Private Integration. Instead, conditions are necessary to have a well behaved solution under Public Integration. Combining all conditions we obtain that Public Integration is possible in the following range of parameters: (a) $\frac{1}{2} < \gamma$ and $\frac{1}{12}\left(-\lambda + \sqrt{\lambda^2 + 48\lambda}\right) < \gamma < \frac{1}{2}\lambda$ or (b) $2 \leq \gamma < \sqrt{\lambda}$. The negotiated price is always lower under Public Integration. Public Integration is more efficient than Private Integration under the three following regions: (1) $\frac{5}{4} < \gamma \leq 2$ and $\frac{1}{4}\left(-\lambda + \sqrt{\lambda^2 + 20\lambda}\right) < \gamma < \frac{1}{2}\lambda$; (2) $\gamma > 2$ and $\frac{1}{4}\left(-\lambda + \sqrt{\lambda^2 + 20\lambda}\right) < \gamma < \sqrt{\lambda}$; (3) $\frac{5}{2} \leq \gamma < \sqrt{\lambda}$; where (1) and (2) are two sub-regions of (a) while (3) is a sub-region of (b).