Universitat Pompeu Fabra Barcelona
Department of Economics and Business

Economics Working Paper Series

Working Paper No. 1895

Supply chain disruption and precautionary industrial policy

Massimo Motta and Michele Polo

October 2024

Supply chain disruption and precautionary industrial policy*

Massimo Motta† Michele Polo‡

October 31, 2024

Abstract

The paper analyzes the design of industrial policies, in the form of subsidies to innovation activity or to local production, when domestic firms are inefficient and there is a risk of supply-chain disruption. We first establish a case for research subsidies, since private investment (to improve the inferior technology) is lower than the socially optimal one. We next show the equivalence with subsidies to (inefficient) local production in case of intertemporal economies of scale. Then, within a general framework, we analyze profit and welfare maximizing investments and optimal subsidies in case of segmented markets and an integrated market organized as a duopoly, a monopoly or a research joint-venture. We show that research joint ventures or a public research center socially outperform the other environments since they benefit from a larger integrated market and a wider circulation of the innovation while preserving a competitive market. Finally, in large markets with significant technology gaps, it may be convenient to concentrate all the research in a single lab while maintaining a competitive market.

Keywords: Resilience, industrial policy, **JEL Classification:** L40, L52, O31, O32

*Comments by Ignacio Balaguer, Patrick Rey, Roland Strausz and participants in the MaCCI Summer Institute (Mannheim, June 2024) are gratefully acknowledged. Massimo Motta acknowledges financial aid from the Spanish Agencia Estatal de Investigación (AEI) (project AEI-PID2019-109377GB-I00) and from the AEI through the Severo Ochoa Programme for Centres of Excellence in R&D (Barcelona School of Economics CEX2019-000915-S). Michele Polo acknowledges financial support from Baffi-Carefin Centre and IGIER (Università Bocconi). None of the authors has done consulting work on cases related to this topic.

†ICREA-Universitat Pompeu Fabra and Barcelona School of Economics, massimo.motta@upf.edu.

‡Università Bocconi (Department of Economics), michele.polo@unibocconi.it.

1 Introduction

A number of events in the past few years have led to consider the downsides of a fully globalised economy where part or whole of certain key products or services are sourced from abroad.[1] The Covid-19 pandemic has revealed that several countries were relying on China for the supply of key products, from facemasks to ventilators.[2] The restrictions associated with the pandemic also determined a slowdown in production and trade in many industries. A particularly significant case is the semiconductor industry, which has experienced a disruption leading to a shortage of chips and affecting several sectors, including carmaking, long after the Covid emergency was over. The 2021 Suez Canal obstruction disrupted global maritime transport and exposed the fragility of supply chains that, all over the world, are highly interconnected and depend on imports to a large extent. The Ukraine war, and the consequent reduction of gas imports from Russia, has led to an acute energy crisis in Europe, which has been looking for alternative sources of supply, both internally and from abroad. The war has also stressed the importance of more independence in military, defence, and strategic sectors.

All these geo-political shocks pointed out the weakness of European manufacturing, and its dependence on imports. In turn, this has called for active policies aimed at creating a more resilient industrial system.[3]

In parallel with such developments, several commentators, politicians, and policy-makers — in the US and in Europe — have been advocating for a more active industrial policy and for protectionist actions, with the declared objective of strengthening the domestic industries. In the US, the Inflation Reduction Act of 2022 is probably the most important legislative initiative in this respect. In the EU, both the Council and the European Commission have commissioned high-profile reports with the task of proposing plans and policies that are aimed at strengthening the European industrial system, improving its resilience, and contrasting its slow productivity growth.[4]

There are common recipes in such reports. In particular, they share the belief that the EU should go for deeper market integration between its Member States, rather than having highly fragmented national markets which might hinder the benefits from scale economies; however, they share some ambiguity towards the role of competition, mentioning the positive role of competition while stating the need for market consolidation (achieved through weaker enforcement of merger control) which would allegedly allow EU firms to achieve scale economies; and by advocating throughout for a bigger role for state intervention and more active industrial policies, in particular in certain sectors which are considered strategic

[1] See, e.g., Schwellnus et al. (2023).

[2] Similar concerns have been raised regarding the technological leadership of China and Europe dependence on Chinese export in several key sectors for the green transition, as solar panels or batteries.

[3] For a general equilibrium analysis of policies for resilience see Grossman et al. 2023. For a resilience policy in energy markets see Fabra et al. (2022).

[4] See the Reports prepared respectively for the European Council and for the European Commission: Letta (2024) and Draghi (2024).

and fundamental for the EU productivity.

Our paper is motivated by the abovementioned policy debates. In particular, we study a situation where possible geo-political shocks create risks of disruption in supply chains, and the possible benefits of industrial policies which aim to reduce those risks, thereby increasing the resilience of an industrial system.

In our model, there is a country or a set of countries (think of the European Union, for instance) whose industry is lagging behind in the production of a necessary input: the input can be imported from abroad at a lower price (also discounting for tariffs, transportation costs, etc) than if it were produced in the home country. Investment in R&D might with some probability achieve the same level of efficiency as foreign production, but could not become higher than it. In other words, at best the investment might allow to catch up, but not leapfrog the foreign technology.[5] We also assume that imports are sold at cost (think of a competitive fringe of input producers located abroad), so foreign market power is not an issue. In a static, stable environment with such characteristics, there would be no reason whatsoever to subsidise domestic investment. (The same would hold — i.e., there would be no scope for domestic subsidies — if we considered a model with learning-by-doing or inter-temporal scale economies where the cost of producing the input may decrease with greater local production.)

Consider now a situation where trade flows are currently seamless, but there is some probability that in the future an exogenous shock may completely disrupt trade. Within this environment, which mimics the abovementioned geo-political risks that could disrupt supply chains, we address the following questions, which evoke the points discussed above.

Does it make sense to subsidise R&D investments (or domestic production) in industries subject to geo-political risks but which suffer from an efficiency gap? If so, which policy instruments could be used and in what circumstances? Could the promotion of market integration help domestic technology (or competitiveness of local production) catch up? To what extent could weaker competition enforcement, particularly in the shape of weaker merger control, as some commentators nowadays advocate, help?

Outline of the paper and preview of the main results To address those questions, the paper is organised in the following way. In Section 2 we propose a simple three-stage game where a monopolist in the home country is exposed to the risk of supply disruption and can invest to develop an efficient local technology. In the first stage, the government chooses a R&D subsidy, then the firm decides R&D investments and finally, after knowing whether there is a supply-chain shock and once the research activity is realized, the monopolist serves the market with the most efficient technology available. We show that, even absent subsidies, the domestic monopolist will invest to reduce risk. However, private investment is insufficient from a social welfare perspective, as the monopolist

[5] This is a conservative assumption: we want to study the scope for subsidies even in a situation in which a country cannot overtake the current technological leaders.

does not internalize the negative effects of the shock on consumers, implying that there is room for public intervention in the form of a 'precautionary subsidy' to enhance the 'investment in resilience'.

In Section 3 we show that the same qualitative result arises in a two-period model where the local cost of producing the input may decrease over time thanks to some form of inter-temporal scale economies. Even in this case the monopolist would 'invest' to insure against the risk of disruption by sponsoring early inefficient local production, but at an insufficient rate, that justifies a subsidy to reduce the cost of local production. A similar outcome may be reached by imposing a minimum local content requirement, by shifting the burden of the investment on the firm, as long as it does not imply a negative profit. (In the remainder of the paper, we limit ourselves to the R&D investment version of the game.)

Section 4 analyses the argument for public intervention in an economy which faces possible supply chain disruptions within a more general framework. We analyze a market that can sustain two production and research units (rather than a monopoly like in the previous sections), considering three different market configurations: a duopoly, where each firm chooses independently on both product market and research decisions; a research joint-venture, where firms coordinate their R&D decisions but compete in the product market; and a (multi-unit) monopoly, where a merged entity runs both plants and research units. We also consider the existence of possible spillovers, both voluntary and involuntary, taking place between different units. Given the different incentives to share the innovation, we assume throughout the paper that when research is coordinated in the two labs, as in research joint-ventures and in the merged entity, its outcomes, if successful, are seamlessly transferred to both firms/plants. In case of a duopoly, instead, the degree of (involuntary) spillover can range from nil to complete, depending on the enforcement of property rights and other factors affecting the possibility of imitation.

Within this framework, we solve a three-stage model where first government chooses a R&D subsidy, then firms decide R&D investments, and finally (once shocks and innovations are known) they take product market decisions. We then derive and characterise the profit-maximizing and welfare-maximizing equilibrium solutions for the different market configurations, by assuming reduced-form profits. In most of our analysis we assume a sufficiently steep increasing marginal cost of investment, to focus on symmetric interior solutions.

Intuitively, the equilibrium investments increase in the probability of disruption and shrinks with the decreasing returns to innovation. More interestingly, it is the variation, rather than the level, of payoffs (profits and welfare) due to innovation that affects the equilibrium investments. This variation, in turn, is affected by the degree of spillovers in the different cases. Comparing the private and social investments in each environment we derive the optimal subsidies that align the two.

Section 5 then turns to a comparison of the equilibrium outcomes in the different market environments, deriving the results in the general framework and showing two applications to Bertrand and Cournot competition with homogeneous products.

We first compare the profit-maximizing investment absent subsidies. First, we show that, for given market structure (monopoly), an integrated market leads to higher investment than two segmented ones. The driving force is the ability of a monopolist in the integrated market to transfer to all production units the innovation if any of the labs successfully develops the more efficient technology, fully exploiting the larger market served.

Focussing on the integrated market, a research joint-venture and a monopoly transfer similarly the results of R&D to all firms/plants, but the increase in profits is larger in a monopoly, since full imitation dilutes the profits of the duopolists participating in the joint-venture. In the comparison between duopoly and monopoly, the degree of spillover is different, being partial in the former and complete in the latter. When spillovers in duopoly are limited, the innovating duopolist has a larger increase in profits than the monopolist, recalling the Arrow replacement effect, and the duopoly dominates in terms of investment, the opposite occurring when imitation is significant.

To understand this result, consider that when spillovers are sufficiently high there is a positive investment externality occurring between the competing firms (the successful investment of a firm raises the profits of the rival): a merger or a research joint venture between them allows to internalise the externality and will result in higher investment. If instead spillovers are low, the externality is negative (investment by a firm harms the rival), so if the two firms merged or coordinated their investment decisions, they would reduce, rather than increase, their investment levels.

Further, we compare the different economic environments looking at the welfare-maximizing investments that the social planner is able to implement in each of them, and at the expected welfare that thereby is obtained. Even in a public policy perspective the integrated market performs better than segmented ones. Moreover, research joint-venture score at the top both in terms of investment and expected welfare, contrary to what happens with private investments. They dominate the monopoly outcome, since the increase in welfare when sharing the innovation is larger in a more competitive market. And they dominate the duopoly case since the research joint-venture allows to spread the innovation to both firms.

Finally, we show that the ranking of welfare-maximizing investments across environments coincides with that when comparing the expected welfare at the socially optimal investment. Even in this case, research joint ventures dominates the other environments, providing the highest expected welfare.

We conclude our analysis in Section 6, considering the case where the benefits of the innovation increase — for instance due to a larger market or to the catch-up of a larger technology gap — up to a point where the symmetric solutions do not exist and the welfare maximizing investment entails investing heavily in one lab. With a sufficiently large benefit, decreasing returns to R&D do not prevent from fully investing in research. Depending on the market environment, it may be socially optimal to maintain active (at a lower rate) a second lab, as when the market is a duopoly, to ensure that also the second firm innovates with positive probability, or to shut it down, when the innovation, obtained for sure in the larger lab, is transferred to all firms/plants. We show that research joint-ventures outperform the other cases even in large markets, requiring the concentration of all the research activity in a single lab while keeping the product markets competitive.

Overall, therefore, our results do not appear to provide much support to arguments calling for a relaxation of competition: at least in our framework, a merger (even under the favourable assumption that an innovation at one unit always fully benefits both affiliates) might under certain circumstances give rise to more investment, but from a welfare perspective both a duopoly and a joint venture seem preferable options. Moreover, when markets are large and the technology gap is significant, the policy prescription is to concentrate the research activity, even under public control, but preserve competitive product markets.

Relationship to the literature. Our paper contributes to the literature on industrial policy, which goes back a long way and touches upon several issues (from strategic trade policies and infant industry arguments to innovation policies) but has known a recent resurgence. For recent discussions, one may refer to Juhász et al. (2024) and (for a more EU-centric perspective) Piechucka et al. (2024) or Tagliapietra and Veugelers (2023). One important subset of this broader issue deals with how to make economies more resilient vis-à-vis the risk of supply-chain disruptions, which is precisely the main focus of our work. Most papers in this strand of literature do not rely on formal models.[6] From a more practical perspective, Arjona et al. (2023) develop a methodology aimed to identify industries subject to the risk of supply-chain disruption, which is the likely first step for a policy intervention.

Our analysis is also related to the recent literature on mergers and innovation. Motta and Tarantino (2021) study the effects of mergers on (deterministic) investments within a general model. Denicolò and Polo (2021) analyse a similar problem with different degrees of transfer of the innovation within the plants of the merged entity. Federico et al. (2018) highlight the negative effects of mergers on innovation considering a wide range of models of the demand side. Denicolò and Polo (2018) show that when the benefits from innovation are large compared with the degree of decreasing returns to R&D, concentrating all the research in one lab may be optimal. Finally, Bourreau et al. (2024) offer a comprehensive framework to analyze the different effects of mergers on innovation.

2 Benchmark: a case for precautionary subsidies

Let us start our analysis with the simplest possible case in which in a country there is only one firm running one lab. (This might be because market size is not

[6]For an exception, see Grossman et al. (2023).

sufficiently large, given fixed costs in production and research, to sustain more than one firm and one lab.) In what follows we use superscript S (segmented monopoly) to refer to this case.

The objective function of the firm is the profit Π and that of the social planner is total welfare $W = \Pi + CS$, where CS stands for consumer surplus.

There are two production technologies available to the firm: a foreign efficient (best practice) technology with constant marginal cost normalized to 0 and a (status quo) inefficient domestic technology with constant marginal cost $\bar{c} > 0$. Hence, $\bar{c}$ represents the technology gap with respect to the efficient technology. In what follows we refer to them as the 0 and $\bar{c}$ technologies.

The firm can invest $x \in [0, 1]$ by sinking a cost $C(x) = \frac{\beta}{2}x^2$ to develop with the corresponding probability x the efficient technology 0. Hence, by investing x the firm can catch-up but it cannot leapfrog the foreign technology.

The firm has free access to the foreign efficient technology 0 with probability $1-\mu$, whereas in case of disruption, that occurs with probability μ, the efficient technology is available only if it has been internally developed.

The social planner can affect the firm's decision on the research investment x through a transfer s that covers a corresponding proportion of the research costs. We assume that, instead, in a second best perspective, the social planner cannot affect the market strategy of the firm.

The timing is as follows:

- at stage 1 the social planner chooses a transfer[7] rate $s \in [-1, 1]$ to the firm applied to its research costs $C(x)$;
- at stage 2, having observed the transfer rate, the firm chooses the investment x bearing a cost $(1-s)\beta x^2/2$ and developing the efficient technology 0 with probability $x \leq 1$;
- at stage 3 nature determines whether disruption occurs or not; then, the firm adopts the most efficient technology available and sets the price.

The market outcome in stage 3 depends on the most efficient technology available to the firm, $c \in \{0, \bar{c}\}$. Let us denote as $\Pi^S(c)$ the maximum profit that the firm can obtain when adopting technology c. The expected profit of the firm at stage 2 when choosing the investment is

$$\Pi^S(x) = (1-\mu)\Pi^S(0) + \mu\left\{x\Pi^S(0) + (1-x)\Pi^S(\bar{c})\right\} - \frac{(1-s)\beta}{2}x^2.$$

Given the FOC [8]

$$\frac{d\Pi^S}{dx} = \mu(\Pi^S(0) - \Pi^S(\bar{c})) - (1-s)\beta x = 0,$$

[7] If $s < 0$, the subsidy is negative, i.e., R&D is taxed, rather than subsidised.

[8] The SOC is $\frac{d^2\Pi^S}{dx^2} = -(1-s)\beta < 0$.

the profit-maximizing investment is therefore

$$\hat{x}^S(s) = \min\left\{\frac{\mu\Delta\Pi^S}{(1-s)\beta}, 1\right\}, \tag{1}$$

where

$$\Delta\Pi^S \equiv \Pi^S(0) - \Pi^S(\overline{c}) > 0 \tag{2}$$

is the increase in profits allowed by the innovation. From (1) we observe that, when the solution is interior, there is a one-to-one mapping between the subsidy s and the investment $\hat{x}(s)$ that the firm chooses. Hence, to derive the optimal policy, we can find the welfare-maximizing investment and then obtain the subsidy that implements it as the optimal choice of the firm. Letting $W^S(c)$ denote total welfare at the profit maximizing market strategy of the firm when the technology adopted is $c \in \{0, \overline{c}\}$, the expected welfare given the investment x is:

$$W^S(x) = (1-\mu)W^S(0) + \mu\left\{xW^S(0) + (1-x)W^S(\overline{c})\right\} - \frac{\beta}{2}x^2. \tag{3}$$

The welfare-maximizing investment is therefore:

$$\tilde{x}^S = \min\left\{\frac{\mu\Delta W^S}{\beta}, 1\right\}, \tag{4}$$

where

$$\Delta W^S \equiv W^S(0) - W^S(\overline{c}) > 0 \tag{5}$$

measures the increase in welfare when adopting the innovative technology 0. The socially optimal level of investment is decreasing in β, the marginal cost of R&D, whereas it rises with the probability of disruption μ and the welfare gain from innovation ΔW^S.

Comparing the welfare-maximizing investment $\tilde{x}^S$ with the level of investment chosen by the firm absent subsidies, $\hat{x}^S(0)$, we see that the firm under-invests, since it calibrates the investment only to its private profit:

$$\tilde{x}^S - \hat{x}^S(0) = \frac{\mu\Delta CS^S}{\beta} > 0,$$

where $\Delta CS^S \equiv CS^S(0) - CS^S(\overline{c})$ is the increase in consumer surplus CS when the efficient technology is adopted. Hence, at stage 1 the social planner sets:

$$\tilde{s}^S = 1 - \frac{\Delta\Pi^S}{\Delta W^S} > 0, \tag{6}$$

implementing the welfare-maximizing level of investment.

We summarize the discussion in the following:

Lemma 1 (Segmented monopoly) *When there is a single firm running one lab, there is under-investment in case of a positive probability of disruption. In this case the social planner is willing to subsidize the firm setting (6) to implement the socially optimal investment (4).*

Example 1: Segmented monopoly

Let us assume the demand function $Q = \bar{n}(1-p)$, where $\bar{n}$ is the size of the market. We also assume non-drastic innovation, i.e. $\bar{c} < 1/2$. In this case, if $\beta > 3\mu\bar{n}(2-\bar{c})\bar{c}/8$ we have an interior solution.

- $\Delta\Pi^S = \bar{n}(2-\bar{c})\bar{c}/4 > 0$, and hence the optimal investment under monopoly will be:
$$\hat{x}^S(s) = \frac{\mu\bar{n}(2-\bar{c})\bar{c}}{4(1-s)\beta}.$$
- $\Delta W^S = 3\bar{n}(2-\bar{c})\bar{c}/8 > 0$, and hence the optimal investment for the social planner, conditional on having a monopolist in the industry, will be:
$$\tilde{x}^S = \frac{3\mu\bar{n}(2-\bar{c})\bar{c}}{8\beta}.$$
- The optimal subsidy in case of monopoly will therefore be:
$$s^S = \frac{1}{3}.$$

In this simplified case we observe that some level of investment is desirable to insure against the risk of disruption that, absent investment, would force the firm to use the inefficient technology $\bar{c}$. The need of a subsidy is due to the firm under-investing, since it considers private profits rather than total welfare. Hence, some room for precautionary industrial policy might emerge in case of a possible supply chain disruption.

3 Learning effects and local content requirements

We consider now a two-period setting in which the improvement in the production technologies derives from learning by doing.[9] In this case, the firm can either run production in a plant that adopts the efficient foreign technology (e.g. it acquires the efficient input from the foreign firm), with constant marginal cost normalized to 0, or produce (part of its output) x in an inefficient plant. In this latter case in the second period the production unit will enhance its productivity to the efficient technology 0 with a probability that depends on the first period production x.

More precisely, by producing an amount x_1 in the first period in the inefficient plant at total cost $C(x_1) = \beta x_1^2/2$, with probability x_1 the firm will be able to produce with the efficient technology 0 in the second period in case of disruption (which occurs with probability μ). The fraction s of costs arising

[9]We model learning by doing in a way that facilitates the comparison with the case where improvements in technology result from successful R&D.

from production x_1 in the inefficient local plant is covered through a public subsidy to local production.

The timing of the game is as follows:

- period 0: the social planner chooses a rate $s \in [-1, 1]$ to be applied to the production costs in the inefficient local unit;
- period 1: having observed s, the firm chooses the total output q_1 and the fraction of it realized in the inefficient production unit, x_1, bearing a net cost $(1-s)\beta x_1^2/2$ on this part of the production;
- period 2: the firm is able to produce locally with the efficient technology 0 with probability x_1; then, nature determines whether disruption occurs (with probability μ); in all cases, the firm chooses the more efficient technology available and sets the price.

The current profits in period 1 can therefore be written as

$$\Pi_1^S(q_1, x_1; s) = R(q_1) - (1-s)\beta x_1^2/2,$$

where $R(.)$ are the revenues when the firm sells q_1. Total output q_1 is obtained in part (x_1) producing internally with costs $C(x_1)$ and for the residual $(q_1 - x_1)$ using the foreign technology at zero costs.

The possible states of the market in period 2 and the associated equilibrium profits are indexed by the technology $c \in \{0, \bar{c}\}$ available. The expected profits for the firm (assuming a discount factor equal to 1) can therefore be written as

$$\Pi^S = \Pi_1^S(q_1, x_1; s) + (1-\mu)\Pi_2^S(0) + \mu\left[x_1\Pi_2^S(0) + (1-x_1)\Pi_2^S(\bar{c})\right] \quad (7)$$

Since total production q_1 in the first period affects only Π_1^S as long as the equilibrium output $\hat{q}_1$ exceeds the equilibrium level of local production $\hat{x}_1$, the two decisions are independent, the first being based only on the first period profits and the second taking into account the first period costs and the intertemporal effects on the second period expected profits.[10]

The FOC in the choice of the local production x_1 is:

$$\frac{\partial \Pi^S}{\partial x_1} = \mu\Delta\Pi_2^S - (1-s)\beta x_1 = 0,$$

where $\Delta\Pi_2^S \equiv \Pi_2^S(0) - \Pi_2^S(\bar{c})$. We can observe that the FOC is equivalent to that in the R&D case, implying that the investment $\hat{x_1}^S(s)$ of the firm in case of learning by doing is the same as in the R&D case.

[10]In order to streamline the analysis, we normalize the market size so that the equilibrium output $\hat{q}_1$ does not exceed 1. We further assume that a firm cannot buy, or produce in the first period at marginal cost 0 more than it can currently sell. This might be due to high enough storage costs, for instance. Another possible explanation is that in a less streamlined model, foreign supply would not be infinitely elastic, and an increase in demand would lead to a steep price increase.

The expected welfare can be written (factoring out the cost of the local plant in period 1) as

$$W^S = W_1^S(q_1) - \beta x_1^2/2 + (1-\mu)W_2^S(0) + \mu\left[x_1 W_2^S(0) + (1-x_1)W_2^S(\bar{c})\right], \quad (8)$$

which is separable in q_1 and $x_{1,}$ implying the same solution as in the FOC of (3). We can therefore state the following:

Lemma 2 (Subsidy to local production) *The results of the R&D model extend to the case of learning by doing. In particular, a subsidy to domestic production equal to (6) would achieve the optimal level of domestic production in the first period. Equivalently, the imposition of a local content production equal to (4) in the first period to have access to public subsidies would achieve the same welfare-maximizing outcome.*

To sum up, if producing in an inefficient local plant enhances its efficiency — for instance through learning by doing — the firm itself will find it convenient to use its local inefficient production unit to a certain extent to insure against future disruption. As in the case of R&D however, local production is inefficiently low from a welfare perspective. The use of subsidies, then, pushes up local production. Equivalently, a public policy imposing a local minimum content production as a condition to benefit of subsidies will achieve the same effect.

Local content requirement without subsidies

Rather than subsidizing the inefficient local production, the government might be able to force, rather than incentivise, the firm to produce the optimal level of local production. This may be particularly relevant in cases where there is a cost of public funding, that we assume away in this paper for simplicity. Note also that whereas it would be difficult to observe and implement a certain level of R&D, it may be easier to observe and enforce an obligation to source locally a certain proportion of a firm's production.

In this case the profits of the firm correspond to (7) when $s = 0$ and welfare to (8), and the profit-maximizing and the welfare-maximizing investments are given by (1) absent subsidies and (4): the outcomes remain as with subsidized LCR, with the burden of investment shifting from the government to the firm. Moreover, $\hat{x}_1^S(s=0) < \tilde{x}_1^S$, implying that the imposition of a LCR bites and reduces the monopolist profits. However, as long as $\Pi^S(\tilde{x}_1^S) \geq 0$, the government will be able to attain the desired level of local production without having to fund its domestic firm. If instead $\Pi^S(\tilde{x}_1^S) < 0$, the government will have to either subsidise the firm, or to content itself to reduce the minimum local requirement to the level $\bar{x}_1^S < \tilde{x}_1^S$ such that $\Pi^S(\bar{x}_1^S) = 0$.

In the rest of the paper, we shall focus on R&D activity and subsidies to it.

4 A general framework

Having established an argument in favor of public subsidies in case the economy faces the risk of supply chain disruptions, we consider in this section a more general framework that allows us to analyze different economic environments.

Market environments. The market can sustain two production and research units, covering their fixed production or research cost. We consider three different cases depending on how the labs and the production units are run, indexing them by k. In a duopoly ($k = D$) each firm manages independently one plant and one lab and competes non-cooperatively in the product market. The mode of competition may range from Bertrand to full collusion. In a research joint-venture ($k = J$) the firms manage cooperatively the research labs, sharing the results achieved, but compete in the product market as duopolists.[11] Finally, in a merger to monopoly ($k = M$), the merged entity runs two plants and two labs,[12] implementing the monopoly solution. The plants $i = 1, 2$ are symmetric in terms of output (i.e. they supply a homogeneous product or symmetric varieties), while they may differ in the technology they adopt, that we denote by the marginal cost c_i.

Costs, innovation and spillovers. As in the previous section, each plant i may adopt a foreign efficient technology with constant marginal cost $c_i = 0$ or a local inefficient technology with marginal cost $c_i = \bar{c} > 0$. Moreover, each lab can run a research process and develop locally the efficient technology $c_i = 0$ with probability $x_i \in [0, 1]$ at cost $C(x_i) = \frac{\beta}{2} x_i^2$.

We assume there exists no correlation in the outcomes of the research processes. However, if the innovation $c_i = 0$ is developed in lab i and adopted in plant i, it might be at least partially adopted also by plant j.[13] The degree of imitation may differ across market environments, since in a duopoly the firms are independent and spillovers are involuntary, while a merged entity and a research joint-venture may purposely pursue a transfer of technology across plants/firms. More precisely, we assume that, if firm/lab i successfully develops the technology $c_i = 0$, the non-innovating firm/lab j in market $k = \{D, M, J\}$ has access to a technology $c_j^k = \lambda^k \bar{c}$, where $\lambda^k \in [0, 1]$. The technology transfer in market k may range from complete ($\lambda^k = 0$) to nil ($\lambda^k = 1$). Consequently, in our setting firm i in market environment k may have one of three technologies available – $c_i^k \in \{0, \lambda^k \bar{c}, \bar{c}\}$ – and three states of the technology are admitted in case of

[11] On cooperative R&D agreements and research joint ventures, see the pathbreaking contribution of D'Aspremont and Jacquemin (1988).

[12] Running two parallel labs is optimal when R&D is subject to relevant decreasing return, the case on which we focus for most of the analysis. Our framework, however, encompasses also the case in which it is optimal to run the two labs asymmetrically, or even shut down one of them. See also Section 6.

[13] Hence, our analysis is focussed on investments that develop a public good, i.e. an advancement in knowledge that might be applicable to all plants. Although we may imagine some externalities from one investment in physical infrastructures to another, the issue of spillovers seems less relevant in this latter case.

disruption: $(0,0)$ if both firms innovate, $(\bar{c},\bar{c})$ if no innovation is developed, and $(0,\lambda^k\bar{c})$ if only one firm successfully completes its R&D project.

In case of two independent firms, parameter λ^D can be interpreted as the degree of appropriability of the innovation: a low value of λ^D corresponds to low appropriability and a high involuntary spillover (and vice versa, a high λ^D corresponds to high appropriability). If instead the two firms merge or participate in a research joint-venture, parameters λ^M and λ^J capture the specificity of lab i's innovation to i's production unit. If the merged entity or the research joint-venture are able to transfer to a large extent the innovation between its units/firms, the values of λ^M and λ^J are low. Although we develop our preliminary analysis for any λ^M and λ^J, our working assumption in the comparison of economic environments will be that the research joint-venture and the merged entity are able to completely transfer the innovation to both plants/firms, that is $\lambda^M = \lambda^J = 0$.

The degree of involuntary and voluntary technology transfer may depend on firm's governance, partial IPR protection, imperfect effectiveness of industrial secrets, ability to imitate, contacts of engineers between and within organizations, compatibility in the technology of production units or organizational frictions.[14]

Finally, by appropriately setting parameter λ^k we can also represent an environment in which the social planner directly sets the investment and transfers the results, if any, to firms ($\lambda^k = 0$), corresponding to a second-best solution, as well as an environment in which the social planner delegates R&D to the firms, indirectly affecting their investment through the subsidies, but without affecting the degree of transferabiliy of the innovation in environment k (the value of λ^k).

Summing up, the two key parameters that describe the possible states of the technologies in market $k = \{D, M, J\}$ are $\bar{c}$, referred to the technology gap of the status-quo vs. the best-practice technology, and λ^k, that is inversely related to the (voluntary or involuntary) transferability of the innovation to the non-innovating plant/firm.

Timing. The timing is as follows: given the market environment D, M, J, that is common knowledge,

- at stage 1 the social planner chooses a rate $s_i \in [-1, 1]$ for unit $i = 1, 2$ proportional to the research costs;
- at stage 2, having observed the rates s_i and s_j, with $i, j = 1, 2, i \neq j$, a firm chooses the investment $x_i \geq 0$ in lab i bearing a cost $(1-s_i)\beta x_i^2/2$ and developing the best-practice technology 0 with probability x_i; in this latter case, if lab j does not reach any innovation, it has access to a technology $c_j = \lambda^k\bar{c}$, where $\lambda^k \in [0, 1]$ for $k = \{D, M, J\}$;

[14] More generally, it might be reasonable to suppose that $0 \leq \lambda^M \leq \lambda^J \leq \lambda^D$. Further, notice that the nature of the innovation will usually affect the degree of transferability between units.

- at stage 3 disruption occurs or not; each firm chooses the more efficient technology available and sets the market strategy.

We now solve the game by backward induction, looking for subgame perfect equilibria.

4.1 Stage 3: product market equilibria

Since in a research joint-venture the firms compete non-cooperatively in the product market, the two relevant states of the product market in stage 3 are D and M. Since firms are symmetric, the equilibrium profits depend only on the technologies adopted (c_i^k, c_j^k), where each firm adopts the most efficient technology available among $\{0, \lambda^k \bar{c}, \bar{c}\}$. We denote $\Pi_i^k(c_i^k, c_j^k)$, $k = D, M$, the equilibrium profit of firm (plant) i when producing with costs c_i^k and the other firm (plant) j is endowed with technology c_j. In case of a research joint-venture, $\Pi_i^J(c_i^J, c_j^J) = \Pi^D(c_i^J, c_j^J)$. Furthermore, we denote, for $k = M, J$,

$$\Pi^k(c_i^k, c_j^k) = \Pi_i^k(c_i^k, c_j^k) + \Pi_i^k(c_i^k, c_j^k) \tag{9}$$

the joint equilibrium profits of the research joint-venture or the merged entity, which matter when choosing the investment.

Each of the market allocations, indexed to the market structure $k = D, M$ and the cost realizations, is associated to a level of welfare $W^k(c_i^k, c_j^k)$ and consumer surplus $CS^k(c_i^k, c_j^k)$. In case of research joint-venture, $W^J(c_i^J, c_j^J) = W^D(c_i^J, c_j^J)$ and $CS^J(c_i^J, c_j^J) = CS^D(c_i^J, c_j^J)$. We assume the following:

Assumption 1: For any market structure $(k = D, M)$, mode of competition in duopoly, and technologies of the two firms/plants $\{(0,0), (\bar{c}, \bar{c}), (0, \lambda^k \bar{c})\}$ there is a unique equilibrium in the product market. The associated welfare, consumer surplus and profits are proportional to the market size n.[15]

We further introduce the following assumptions on the ranking of profits and welfare in the different cost configurations:

Assumption 2: For $\lambda^k \in (0,1)$, $k = D, M$:

$$\begin{aligned} \Pi_i^D(0, \lambda^D \bar{c}) &> \Pi_i^D(0,0) \geq \Pi_i^D(\bar{c}, \bar{c}) \geq \Pi_i^D(\lambda^D \bar{c}, 0), \\ \Pi^M(0,0) &> \Pi^M(\lambda^M \bar{c}, 0) = \Pi^M(0, \lambda^M \bar{c}) > \Pi^M(\bar{c}, \bar{c}). \end{aligned}$$

Assumption 3: For $\lambda^k \in (0,1)$, $k = D, M$:

$$W^k(0,0) > W^k(\lambda^k \bar{c}, 0) = W^k(0, \lambda^k \bar{c}) > W^k(\bar{c}, \bar{c}).$$

[15] Proportionality implies that the demand is proportional to the number of consumers served and the costs are linear in production: $D_i(p;n) = n \cdot D_i(p;1)$ and $C_i(D_i;n) = c \cdot D_i(p;n)$, such that $\Pi_i(p;n) = n\,[p-c]\,D_i(p;1)$. Similar properties hold for aggregate profits, consumer surplus and welfare.

Assumption 2 states that the profits of the innovator (the laggard) are decreasing (increasing) in the degree of imitation and that the profits in symmetric cost configurations are (weakly) decreasing in the level of costs. If the firms merge, the profits are decreasing in the costs of the less efficient plant. Assumption 3 displays the ranking in terms of welfare, which is maximal when both firms/production units adopt the efficient technology and decreases in the cost of the less efficient plant.

Next, let us introduce the following notation:

$$\Delta\bar{\Pi}_i^D(\lambda^D) \equiv \Pi_i^D(0, \lambda^k\bar{c}) - \Pi_i^D(\bar{c}, \bar{c}) > 0, \tag{10}$$

$$\Delta\underline{\Pi}_i^D(\lambda^D) \equiv \Pi_i^D(0, 0) - \Pi_i^D(\lambda^k\bar{c}, 0) \geq 0, \tag{11}$$

that measure the incremental profit of duopolist i when innovating while facing, respectively, a rival endowed with the inefficient ($\Delta\bar{\Pi}_i^k$) or the best-practice ($\Delta\underline{\Pi}_i^k$) technology. Similarly, for aggregate profits and $k = M, J$:

$$\Delta\bar{\Pi}^k(\lambda^k) \equiv \Pi_i^k(0, \lambda^k\bar{c}) + \Pi_j^k(\lambda^k\bar{c}, 0) - 2\Pi_i^k(\bar{c}, \bar{c}),$$

$$\Delta\underline{\Pi}^k(\lambda^k) \equiv 2\Pi_i^k(0, 0) - \Pi_i^k(\lambda^k\bar{c}, 0) - \Pi_j^k(0, \lambda^k\bar{c}),$$

where the joint profits $\Pi^k(.)$ are given by (9).

Furthermore, we define for $k = D, M, J$ the corresponding expressions in terms of welfare:

$$\Delta\bar{W}^k(\lambda^k) \equiv W^k(0, \lambda^k\bar{c}) - W^k(\bar{c}, \bar{c}), \tag{12}$$

$$\Delta\underline{W}^k(\lambda^k) \equiv W^k(0, 0) - W^k(\lambda^k\bar{c}, 0). \tag{13}$$

We can notice that when there is perfect imitation ($\lambda^k = 0$) the non-innovating firm/unit has full access to the efficient technology, and $\Delta\underline{\Pi}^k = \Delta\underline{W}^k = 0$. Similarly, when profits with symmetric cost configurations do not depend on the level of marginal costs, as in Bertrand with homogenous products or Hotelling with covered market, $\Delta\bar{\Pi}_i^D(0) = 0$.

Then, the following assumptions hold:

Assumption 4: $\Delta\bar{\Pi}_i^k(\lambda^k) - \Delta\underline{\Pi}_i^k(\lambda^k) \geq 0$ for $\lambda^k \in [0, 1]$ for $k = D, M, J$ with strict inequality for $\lambda > 0$.

This implies that

$$\begin{aligned}\Delta\bar{\Pi}^k(\lambda^k) - \Delta\underline{\Pi}^k(\lambda^k) &= 2\left[\Pi_i^k(0, \lambda^k\bar{c}) + \Pi_j^k(\lambda^k\bar{c}, 0) - \Pi_i^k(\bar{c}, \bar{c}) - \Pi_i^k(0, 0)\right] \\ &= 2\left[\Delta\bar{\Pi}_i^k(\lambda^k) - \Delta\underline{\Pi}_i^k(\lambda^k)\right] \geq 0.\end{aligned}$$

Assumption 5: $\Delta\bar{W}^k(\lambda^k) > \Delta\underline{W}^k(\lambda^k)$ for $\lambda^k \in [0, 1]$ and $k = D, M, J$.

Assumption 4 states that the equilibrium profits of a firm/lab increase more when it leads than when it catches up, and it implies that the same property holds for total profits, while assumption 5 claims the same property holds true for total welfare. These assumptions are met in a number of oligopoly models including Bertrand and Cournot with homogeneous and differentiated products.

4.2 Stage 2: investment

We distinguish the equilibrium investment in the two labs in case the research activity is run independently by the two firms, as in a duopoly, or is coordinated to maximize the joint profits as in a merger to monopoly or a research joint-venture. In this section we focus on interior equilibria, focussing on the case when parameter β is sufficiently high. In an online Appendix we consider the case when the interior allocation is an unstable equilibrium or a saddle point, while the equilibrium solution is asymmetric. This case will be briefly commented in Section 6.

4.2.1 Non-cooperative investment: duopoly

The expected profit for firm i is

$$\begin{aligned}\Pi_i^D(x_i, x_j; \lambda^D) \quad = \quad & (1-\mu)\Pi_i^D(0,0) + \mu \left\{x_i x_j \Pi_i^D(0,0)\right. \\ & + x_i(1-x_j)\Pi_i^D(0, \lambda^D \bar{c}) + (1-x_i)x_j \Pi_i^D(\lambda^D \bar{c}, 0) \\ & \left. + \left[(1-x_i)(1-x_j)\right] \Pi_i^D(\bar{c}, \bar{c})\right\} \\ & - \frac{(1-s_i)\beta}{2} x_i^2. \end{aligned} \tag{14}$$

The investment best replies[16] are

$$\hat{x}_i(x_j; \lambda^D) = \max\left\{0, \min\left\{\frac{\mu\Delta\bar{\Pi}_i^D(\lambda^D)}{(1-s_i)\beta} - \frac{\mu\left[\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\underline{\Pi}_i^D(\lambda^D)\right]}{(1-s_i)\beta} x_j, 1\right\}\right\}. \tag{15}$$

The term $-\mu\left[\Delta\bar{\Pi}_i^D(\lambda) - \Delta\underline{\Pi}_i^D(\lambda)\right]$, which is negative under Assumption 4, captures the negative externality on firm i's marginal return on investment of a marginal increase in the rival's investment x_j. Given Assumption 2, firm i's profits are higher when competing with a laggard than with a front-runner. When the rival slightly increases its investment, it becomes more likely that firm i will compete with a rival endowed with the efficient technology, reducing firm i's marginal return from investment. Assumption 4 also implies that the best reply (15) is downward sloping, that is competition in investments is in strategic substitutes.

The following proposition decribes the investment equilibria in a duopoly.

Proposition 3 (Equilibrium investments: duopoly) *If*

$$\beta > \hat{\beta}^D(s_i; \lambda^D) \equiv \frac{\mu\left(\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\underline{\Pi}_i^D(\lambda^D)\right)}{(1-s_i)} \tag{16}$$

[16]The SOCs are satisfied since $\frac{\partial^2 \Pi_i^D}{\partial x_i^2} = -(1-s_i)\beta < 0$.

for both firms there exists a unique stable equilibrium

$$\hat{x}_i^D(s_i, s_j; \lambda^D) = \min\left\{ \frac{\mu\Delta\bar{\Pi}_i^D(\lambda^D)\left[(1-s_i)\beta - \mu\left(\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\underline{\Pi}_i^D(\lambda^D)\right)\right]}{(1-s_i)(1-s_j)\beta^2 - \mu^2\left(\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\underline{\Pi}_i^D(\lambda^D)\right)^2}, 1 \right\}. \tag{17}$$

Proof: See Appendix.

In all the equilibria the investment is (weakly) increasing in the subsidy and in the probability of disruption and decreasing in the convexity of the research costs. Moreover, a higher spillover (a lower λ^D) reduces the investment.

4.2.2 Coordinated investment: Research joint-venture and Merger to monopoly.

We now turn to the case where the investment in the two labs is chosen cooperatively, as in a merger to monopoly or a research joint-venture, to maximize the joint profits. Given (9), the expected joint profits for $k = M, J$ are therefore

$$\begin{aligned} \Pi^k(x_i, x_j; \lambda^k) &= (1-\mu)\Pi^k(0,0) + \mu\left\{x_i x_j \Pi^k(0,0)\right. \\ &\quad + (x_i + x_j - 2x_i x_j)\Pi^k(0, \lambda^k \bar{c}) \\ &\quad \left. + (1-x_i)(1-x_j)\Pi^k(\bar{c}, \bar{c})\right\} \\ &\quad - \frac{\beta}{2}\left[(1-s_i)x_i^2 + (1-s_j)x_j^2\right]. \end{aligned} \tag{18}$$

The following proposition identifies the optimal investment that maximizes the expected joint profits.

Proposition 4 (Equilibrium investment: joint-profit maximization) *If*

$$\beta > \hat{\beta}^k(s_i, s_j; \lambda^k) \equiv \frac{\mu\left[\Delta\bar{\Pi}^k(\lambda^k) - \Delta\underline{\Pi}^k(\lambda^k)\right]}{\left[(1-s_i)(1-s_j)\right]^{\frac{1}{2}}} \tag{19}$$

for $k = M, J$, the optimal investment of the merged entity or research joint-venture is

$$\hat{x}_i^k(s_i, s_j; \lambda^k) = \min\left\{ \frac{\mu\Delta\bar{\Pi}^k(\lambda^k)\left[(1-s_i)\beta - \mu\left(\Delta\bar{\Pi}^k(\lambda^k) - \Delta\underline{\Pi}^k(\lambda^k)\right)\right]}{(1-s_i)(1-s_j)\beta^2 - \mu^2\left(\Delta\bar{\Pi}^k(\lambda^k) - \Delta\underline{\Pi}^k(\lambda^k)\right)^2}, 1 \right\}. \tag{20}$$

Proof: See Appendix.

The comparative statics with respect to the subsidy, the probability of disruption, the decreasing returns to R&D and the (aggregate) profits differentials are the same as in the non-cooperative duopoly equilibrium investment.

Corollary 5 (Investment with symmetric subsidies) *If $s_i = s_j = s$ and conditions (16) and (19) are met, the equilibrium in the three market environments is symmetric:*

$$\hat{x}_i^D(s,s;\lambda^D) = \min\left\{\frac{\mu\Delta\bar{\Pi}_i^D(\lambda^D)}{(1-s)\beta+\mu\left(\Delta\bar{\Pi}_i^D(\lambda^D)-\Delta\underline{\Pi}_i^D(\lambda^D)\right)},1\right\}, \quad (21)$$

$$\hat{x}_i^k(s,s;\lambda^k) = \min\left\{\frac{\mu\Delta\bar{\Pi}^k(\lambda^k)}{(1-s)\beta+\mu\left(\Delta\bar{\Pi}^k(\lambda^k)-\Delta\underline{\Pi}^k(\lambda^k)\right)},1\right\}, \quad (22)$$

where $k = M, J$.

When the research activity is coordinated in the two labs (research joint–venture and merger to monopoly), we shall focus on the case when the innovation, if discovered, is fully transferred to both firms/plants, that is $\lambda^J = \lambda^M = 0$. In this case, $\Delta\underline{\Pi}^k(0) = 0$ and

$$\hat{x}_i^k(s,s;0) = \min\left\{\frac{\mu\Delta\bar{\Pi}^k(\lambda^k)}{(1-s)\beta+\mu\Delta\bar{\Pi}^k(\lambda^k)},1\right\} \quad (23)$$

for $k = M, J$.

4.3 Stage 1: Welfare maximizing investment and optimal subsidies

We now turn to stage 1, where the social planner sets the optimal subsidies. Recall that, as mentioned in the previous section, we focus on interior solutions, i.e., we are assuming values of β which are sufficiently high (corner solutions are dealt with in an online Appendix) and we first derive the welfare-maximizing levels of investment and then the subsidies that implement them in the Nash equilibrium (duopoly) or in the merged entity and research joint-venture optimal choices. It is important to keep in mind that the welfare-maximizing level of investment is chosen independently from the issue of implementing it through subsidies, since this latter step does not exert a constraint on the design of the policy, as we show in the following. The expected welfare for given levels of investment x_i and x_j given the market structure $k = D, M, J$ and Assumption 3 is:

$$\begin{aligned} W^k(x_i,x_j;\lambda^k) = {} & (1-\mu)W^k(0,0)+\mu\left\{x_ix_jW^k(0,0)\right. \\ & \left.+(x_i+x_j-2x_ix_j)W^k(0,\lambda^k\bar{c})+(1-x_i)(1-x_j)W^k(\bar{c},\bar{c})\right\} \\ & -\frac{\beta}{2}(x_i^2+x_j^2). \end{aligned} \quad (24)$$

Let us define the following threshold for $k = D, M$:[17]

$$\tilde{\beta}^k(\lambda^k) \equiv \mu \left[\Delta\bar{W}^k(\lambda^k) - \Delta\underline{W}^k(\lambda^k)\right] \tag{25}$$

Proposition 6 (Welfare-maximizing investments) *Given the market structure $k = D, M$, if*

$$\beta > \tilde{\beta}^k(\lambda^k)$$

the welfare-maximizing investment is symmetric and equal to

$$\tilde{x}_i^k = \tilde{x}_j^k = \tilde{x}^k(\lambda^k) = \frac{\mu\Delta\bar{W}^k(\lambda^k)}{\beta + \mu(\Delta\bar{W}^k(\lambda^k) - \Delta\underline{W}^k(\lambda^k))} \leq 1. \tag{26}$$

Proof: See Appendix.

The symmetric welfare-maximizing investment $\tilde{x}^k(\lambda^k)$ is increasing in the probability of disruption and decreasing in the marginal cost of R&D, as we already observed for the private investment. When the innovation is completely transferable ($\lambda^k = 0$), as we assume in the cases of merger to monopoly and research joint-venture, there is no welfare or profit gain from catching up since the laggard has already full access to the innovation, and $\Delta\underline{W}^k(0) = \Delta\underline{\Pi}^k(0) = 0$. In this case $\tilde{\beta}^k(0) = \mu\Delta\bar{W}^k(0)$ and the symmetric solution is $\tilde{x}^k(0) < \frac{1}{2}$ for $\beta > \tilde{\beta}^k(0)$. (The case of moderate decreasing returns ($\beta \leq \tilde{\beta}^k(\lambda^k)$) is considered in an online Appendix and discussed in Section 6.)

Once identified the symmetric investment patterns that the social planner would like to obtain, we have to find the subsidies that implement them through the choice of the firm(s): $\hat{x}_i^k(s_i.s_j;\lambda^k) = \tilde{x}_i^k(\lambda^k)$. Lemma 7 identifies the subsidies that allow the social planner to implement, through the choice of the firm(s), the welfare-maximizing level of investment in the different market environments.

Lemma 7 (Optimal subsidies) *If conditions (25) and, for $s_i = s_j$, (16) and (19) are met, the optimal subsidies in market $k = D, M, J$ are:*

$$\tilde{s}_i^k(\lambda^k) = \tilde{s}_j^k(\lambda^k) = 1 - \frac{\Delta\bar{\Pi}^k(.)}{\Delta\bar{W}^k(.)} - \frac{\mu\left[\Delta\bar{W}^k(.)\Delta\underline{\Pi}^k(.) - \Delta\bar{\Pi}^k(.)\Delta\underline{W}^k(.)\right]}{\beta\Delta\bar{W}^k(.)}. \tag{27}$$

[17] Notice that, according to Assumption 3, $W^J(c_i, c_j) = W^D(c_i, c_j)$. Hence, for given level of spillover the welfare maximizing investment has the same expression both in duopoly and research joint-venture in the different cost configurations. The optimal investment from the social planner standpoint, therefore, may differ in the two cases only if the level of spillover is not the same. For this reason we focus in the following proposition on the welfare-maximizing investment in duopoly and merger to monopoly.

As already observed in Section 2, the profit maximizing equilibrium investments without subsidies fall short of the welfare-maximizing ones, requiring some subsidy to be set to increase the R&D activity. In case of research joint-venture and merger to monopoly ($\lambda^J = \lambda^M = 0$), $\Delta \underline{W}^k(0) = \Delta \underline{\Pi}^k(0) = 0$ and the optimal subsidies become:

$$\tilde{s}_i^k(0) = \tilde{s}_j^k(0) = 1 - \frac{\Delta \bar{\Pi}^k(0)}{\Delta \bar{W}^k(0)}; \tag{28}$$

The subsidies in case of merger to monopoly and research joint-venture are always lower than 1 if $\bar{\Pi}^k(0) = 2\left[\Pi_i(0,0) - \Pi_i(\bar{c},\bar{c})\right] > 0$. If, however, the equilibrium profits are constant in the marginal cost when common to both firms, as it happens in the Bertrand or in the Hotelling duopoly with covered market, $\Delta \bar{\Pi}^D(0) = 0$. In a research joint-venture, then, the firms do not gain if investing, since the profits do not change if the investment is successful while a positive investment erodes the net profits. In order to implement the welfare maximizing investment, then, the planner has to fully subsidy the investment and to set the level of investment $\tilde{x}^J(0)$. The following corollary states this result.

Corollary 8 (Public research lab) *Suppose the equilibrium profits in the duopoly are invariant to the marginal costs $c \in \{0, \bar{c}\}$ in a symmetric cost configuration, that is $\Pi_i^D(0,0) = \Pi_i^D(\bar{c},\bar{c})$, as in the Bertrand model and in the Hotelling model with covered market. Then, in case of joint-ventures in order to implement the welfare-maximizing investment $\tilde{x}^J$ the social planner has to fully cover the research costs and fix the level of investment, equivalently to managing directly the research labs.*

5 Comparison of market environments

Having analyzed the equilibrium investments in the different market environments, we can now address two related issues. First of all we are interested in comparing the ranking of investments in the four cases from a private and social point of view, thereby identifying potential tensions between profit and welfare maximizing incentives. Secondly, looking at social welfare we can find the market environment that generates the highest performance.

There are two issues that the debate on industrial policy in Europe currently addresses, motivated by evidence that European productivity and competitiveness is lagging behind the US and China's, as stressed in the Letta (2024) and Draghi (2024) Reports. The first is that a deeper market integration among European member states could promote firms' productivity. The second is whether it would be better to relax competition in order to create 'European champions' which supposedly would be more efficient and better able to compete in the international markets.

In terms of our model, the first question can be addressed by comparing the outcomes of segmented vs. integrated markets for a given market structure. To this end, we shall compare the equilibria under two segmented monopolies (S) and a single monopoly operating in the market which is the union of the two (M). The second question will be addressed by taking the enlarged size of the (integrated) market as given and comparing equilibria arising from the duopoly, research joint-venture and merger to monopoly.

5.1 Comparison of private and social investments

We start by comparing across the different market environments the profit maximizing investment absent subsidies with the investment that maximizes welfare. We have already observed that the divergence between the two may be dealt with by properly designing subsidies.

The focus on investment levels is of independent interest given the argument that Europe is lagging behind the US and China in many sectors, and that an acceleration in investments is needed, as the recent Draghi Report strongly argues.

We derive first a useful result that allows to take into account the different market size in a simple way.

Lemma 9 (Market size and differential values) *Given Assumption* 1*, we have:* $2\Delta\Pi^S(n) = \Delta\bar{\Pi}^M(\lambda^M = 0, 2n)$ *and* $2\Delta W^S(n) = \Delta\bar{W}^M(\lambda^M = 0, 2n)$*.*

Proof: see Appendix.

An implication of Lemma 9 refers to the optimal subsidies in segmented markets and in a merger to monopoly in an integrated market as stated in Lemma 7. It turns out that the level of subsidy for each individual firm/plant is the same in the two environments:

$$\tilde{s}_i^M(0) = \tilde{s}_j^M(0) = 1 - \frac{\Delta\bar{\Pi}^M(0)}{\Delta\bar{W}^M(0)} = \tilde{s}^S,$$

although the transfer is financed by each government in case of industrial policies implemented by member countries, and through a central budget when markets are integrated.

In what follows, we focus on interior symmetric equilibria, since we are first of all interested in situations like those that motivate this paper, where investments are significantly below the level desired by the social planner.

5.1.1 Profit-maximizing investment

Several factors may potentially affect the comparison in private investments in the three market environments. First, the integrated market is larger than the segmented ones, and this tends to increase the investment. Second, as already observed, in a duopoly each firm's investment exerts a negative externality on the return from investment of the other, an effect that does not arise in segmented monopolies and that is internalized when investments are coordinated.

Third, the incentive to invest does not depend on the level of profits but on the increase in profits when innovating relative to the status quo technology. This differential effect is captured by the Arrow replacement effect, which in general is different in a duopoly and in a monopoly. Finally, in a duopoly involuntary spillovers reduce incentives to invest, whereas spillovers are of course immaterial in segmented monopolies and, by assumption, they are fully transferred within a merged entity or among research joint-venture partners. In what follows, we identify and discuss these effects within our general framework and provide two applications to Bertrand and Cournot competition with homogeneous products.

The following proposition finds sufficient conditions to compare the equilibrium investments when firms choose them with no subsidy in place.

Proposition 10 (Ranking of profit-maximizing investment) *Consider the market environments S, D, M and J. Suppose there are no subsidies in all cases and the innovation is perfectly transferable in the merger to monopoly and research joint-venture cases ($\lambda^M = \lambda^J = 0$). If the condition (16) for a stable symmetric equilibrium in the integrated duopoly and the condition (19) for an interior symmetric equilibrium in case of cooperative investment are satisfied, then:*

- *The investment of the merged entity in each lab is always larger than that of the segmented monopolists: $\hat{x}^M(0, 2n) > \hat{x}^S(n)$.*
- *In an integrated market:*
  - *The investment in case of a research joint-venture is never higher than that of a merger to monopoly: $\hat{x}_i^J(0) \leq \hat{x}_i^M(0)$.*
  - *If the Arrow replacement effect is positive, there exists a threshold $\hat{\lambda} \in (0, 1)$ such that the investment $\hat{x}^D(\lambda^D)$ in the integrated duopoly is higher (lower) than the investment $\hat{x}^M(0)$ of the merged entity in each lab when $\lambda^D > \hat{\lambda}$ ($\lambda^D < \hat{\lambda}$);*
  - *If, instead, the Arrow replacement effect is negative, we cannot rank in general the investment in the duopoly and in the merger to monopoly.*

Proof: see Appendix.

Proposition 10 first of all establishes that the investment in segmented markets is always lower than that in a unified market. This holds true when we compare segmented monopolies and a merger to monopoly in the integrated market. The larger investment of the merged entity is driven by the ability to transfer the innovation developed in one lab to all production units, exploiting this way the larger market served. Moving to the different market structures in the integrated market, the investment in case of a joint-venture is not higher than that in a merger to monopoly since in both cases the innovation is fully transferred to both units/firms ($\lambda^M = \lambda^J = 0$), with an increase in profits that is higher for the merged entity than for the partner duopolists in the joint-venture. Furthermore, the investment of duopolists is larger than that of the merged entity if two effects play together. If the Arrow replacement effect is positive, the duopolist's incentives to invest are stronger than that of the merger entity, since the increase in profits when an innovation is introduced is larger. Moreover, this positive effect is not weakened by the imitation of the non-innovating firm when spillovers are limited (λ^D is sufficiently high). When these two effects are satisfied, the highest level of investment is realized in an integrated duopoly market. When, instead, the Arrow replacement effect is positive but spillover are substantial, the investment of the merged entity dominates. Finally, when the Arrow replacement effect is negative, we cannot sign the ranking in investment in duopoly and merger to monopoly without putting more structure into the model.

Example 2: Comparison of profit maximizing investments: integrated vs. segmented monopoly Consider the case where there is a monopolistic firm which owns two units and faces a demand function $Q = 2\bar{n}(1-p)$, where $\bar{n}$ is the size of one of the two equal-sized markets that are integrated. By applying (20) we obtain one unit's optimal investment under integrated monopoly absent subsidies as:

$$\hat{x}^M = \frac{2\mu\bar{n}(2-\bar{c})\bar{c}}{4\beta - \mu\bar{n}(2-\bar{c})\bar{c}}.$$

It is immediate to check that $\hat{x}^M$ is bigger than $\hat{x}^S = \frac{\mu\bar{n}(2-\bar{c})\bar{c}}{4\beta}$, which is the investment made by one of the two monopolies in each market of size $\bar{n}$.

Example 3: Comparison of profit maximizing investment: price competition We have already found the equilibrium investment under integrated monopoly. Let us turn to the duopoly case under Bertrand competition and homogeneous products. Setting the population size of the integrated market as $n \equiv 2\bar{n}$, market demand is $Q = n(1-p)$, where p is the lower price set. The equilibrium prices for given combination of marginal costs are $p_i^D(0,0) = 0$, $p_i^D(0,\bar{c}) = p_j^D(\bar{c},0) = p_i^D(\bar{c},\bar{c}) = \bar{c} < 1/2$, since we assume a non-drastic difference in costs. Letting $\lambda^D = \lambda$ and $\lambda^M = \lambda^J = 0$, the equilibrium profits are $\Pi^D(0,0) = \Pi^D(0,0) = \Pi^D(\bar{c},\bar{c}) = \Pi^D(\lambda\bar{c},0) = 0$ and $\Pi^D(0,\lambda\bar{c}) = n\lambda\bar{c}(1-\lambda\bar{c})$. The incremental profits, therefore, are:

$$\begin{aligned} \Delta\bar{\Pi}^D &= \Pi^D(0,\lambda\bar{c}) - \Pi^D(\bar{c},\bar{c}) = n\lambda\bar{c}(1-\lambda\bar{c}) \\ \Delta\underline{\Pi}^D &= \Pi^D(0,0) - \Pi^D(\lambda\bar{c},0) = 0. \end{aligned}$$

Absent subsidies, the condition for an interior stable solution is $\beta > \mu n\lambda\bar{c}(1-\lambda\bar{c})$ and the symmetric equilibrium investments in case of duopoly are:

$$\hat{x}_i^D = \frac{\mu n\lambda\bar{c}(1-\lambda\bar{c})}{\beta + \mu n\lambda\bar{c}(1-\lambda\bar{c})}.$$

Since $\hat{x}_i{}^M = \frac{\mu n(2-\bar{c})\bar{c}}{4\beta-\mu n(2-\bar{c})\bar{c}}$, one can check that $\hat{x}_i^D > \hat{x}_i^M$ for $\lambda^D > 1/2$ and vice versa. In other words, if the spillovers are sufficiently high ($\lambda < 1/2$) duopolistic investments are hindered by lack of appropriability, and a merger would internalise the externality among the firms and promote investments. Otherwise, if spillovers are small, investments are higher under competition.

Finally, since in a research joint-venture the innovation is fully transferred to each firm, $\Delta\bar{\Pi}^J(0) = \hat{x}_i^J(0) = 0$. Each firm knows that if its innovation is successul and it obtains zero cost, it would have to fully share it with the rival yielding zero profits, thereby taking away any incentive to invest.

Example 4: Comparison of profit maximizing investment: quantity competition In the same setting of Example 3, let us consider quantity (Cournot) competition. The monopoly solution does not change. As for the duopoly case, standard derivations give:

$$\Pi^D(0,0) = \frac{n}{9};\ \Pi^D(0,\lambda\bar{c}) = \frac{n(1+\lambda\bar{c})^2}{9};\ \Pi^D(\lambda\bar{c},0) = \frac{n(1-2\lambda\bar{c})^2}{9};\ \Pi^D(\bar{c},\bar{c}) = \frac{n(1-\bar{c})^2}{9};$$

$$\Delta\bar{\Pi}^D(\lambda) = \frac{n\bar{c}(1+\lambda)\left[2-\bar{c}(1-\lambda)\right]}{9};\ \ \Delta\underline{\Pi}^D(\lambda) = \frac{4n\bar{c}\lambda(1-c\lambda)}{9}. \tag{29}$$

We can then use (21) to find the equilibrium investment (for $s_i = s_j = 0$):

$$\hat{x}^D = \frac{n\bar{c}\mu(1+\lambda)\left[2-\bar{c}(1-\lambda)\right]}{9\beta+\bar{c}n\mu\left[2-2\lambda-\bar{c}(1-5\lambda^2)\right]}.$$

Finally, one can check that $\hat{x}^D \geq \hat{x}^M$ iff:

$$\left[4\bar{c}\beta - n\bar{c}\mu(2-\bar{c})(5+\bar{c})\right]\lambda^2 + 8\beta\lambda - 2(2-\bar{c})\left[5\beta+n\bar{c}\mu(2-\bar{c})\right] \geq 0,$$

which can only hold if λ and $\bar{c}$ are sufficiently high, as Figure 1 shows. (Recall that β must be high enough for the interior stable equilibrium to exist.)

Turning to research joint-venture with full transferability of innovations, we have:

$$\Delta\underline{\Pi}^J(\lambda^J=0) = 0;\ \ \Delta\bar{\Pi}^J(\lambda^J=0) = \Pi^D(0,0) - \Pi^D(\bar{c},\bar{c}) = \frac{2n\bar{c}(2-\bar{c})}{9}.$$

By applying (22) we have:

$$\hat{x}^J = \frac{2n\bar{c}\mu(2-\bar{c})}{9\beta+2n\bar{c}\mu(2-\bar{c})}.$$

One can then check that $\hat{x}^M > \hat{x}^J$ amounts to:

$$\frac{2n\bar{c}\mu(2-\bar{c})}{\left[9\beta+2n\bar{c}\mu(2-\bar{c})\right]\left[4\beta+n\bar{c}\mu(2-\bar{c})\right]} > 0,$$

and it is therefore satisfied for any admissible parameter value, thereby confirming the general result obtained above. Further, $\hat{x}^D \geq \hat{x}^J$ for $\lambda \geq (3 + \sqrt{9 - 16\bar{c} + 8\bar{c}^2})/(6\bar{c})$. The intuition is the same as for the comparison between merger and duopoly: it is only when spillovers are sufficiently high that it is better to have a cooperative solution rather than competing in the investment decision.

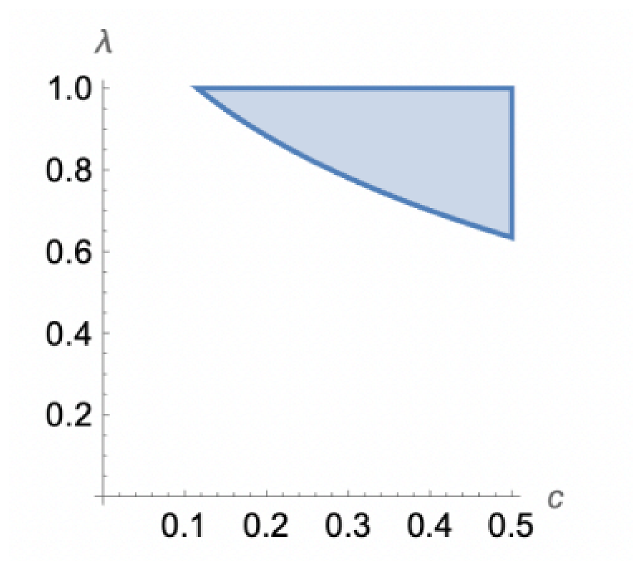

Figure 1: Region where $\hat{x}^D \geq \hat{x}^M$. Figure drawn for $\beta = 1/2$, $\mu = 1/4$, $n = 1$.

Welfare effects of private investments: Comparisons The level of investments is an important dimension in the comparisons between different market structures, but not the unique one of interest. In particular, one might be interested in whether, for instance, the higher investment that might be attained by the merged entity outweighs the market power effect created in the absence of competition. By replacing the equilibrium investments obtained in the different configurations, i.e., for $k = D, M, J$ into (24) we obtain the welfare levels under private investments at equilibrium.

The resulting expressions being fairly long and involved, it is difficult to solve the associated inequalities analytically. However, numerical solutions (where parameters are chosen so that there are interior solutions) show that the welfare under multi-product monopoly is dominated by both the duopoly and the joint venture.

Figure 2 shows the region where, absent subsidies, competition on both investment and quantity gives rise to a higher welfare level than when investment decisions are taken cooperatively. As one can see, this occurs when λ is sufficiently high, namely when the appropriability of the investment is sufficiently high. In this case, each duopolist exerts a negative externality on the research effort of the rival. This negative externality is internalized in the research joint-venture, leading to a lower investment.

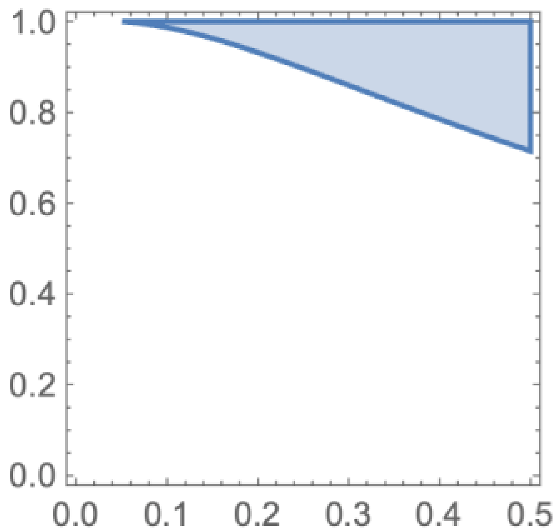

Figure 2: Region of (c, λ) where, absent subsidies, welfare is higher under duopoly than the research joint venture. Figure drawn for $\beta = 1$, $\mu = 1/4$, $n = 1$.

5.1.2 Welfare-maximizing investments

We now compare the optimal investment levels for the social planner in the different market environments.

Proposition 11 (Ranking of welfare-maximizing investment) *Suppose the condition (25) is satisfied for $k = S, D, M, J$, implying that there exists a welfare-maximizing interior symmetric investment both in all market environments.*

- *The welfare-maximizing investment of the merged entity in each lab is always larger than that of the segmented monopolists: $\tilde{x}^M(0, 2n) > \tilde{x}^S(n)$.*
- *In the integrated market the welfare-maximizing investment is higher in the research joint-venture than in duopoly (for any $\lambda^D > 0$) and merger to monopoly.*

Proposition 11 shows the ranking in investment driven by welfare maximization. First of all, segmented monopolies are always dominated, also from a social perspective, by a merger to monopoly in an integrated market. In the comparison, the merged entity is able to transfer across production units the innovation, exploiting the larger integrated market. Focussing on an integrated market, the innovation is perfectly transferable across firms or production units both in research-joint-venture and merger to monopoly. The welfare-maximizing investment is higher in the research joint-venture, that preserves some form of competition in the product market, since the increase in welfare when the innovation is widely adopted is larger in a duopoly than in a monopoly. Finally, the only difference between research joint-venture and duopoly is in the level of transferability of the innovation across firms. The joint-venture, then, dominates since it allows to transfer the innovation perfectly, whereas in a duopoly the innovator retains at least some cost advantage compared with the laggard.

Comparing the results in Proposition 10 and 11, research joint-ventures generate the highest welfare-maximizing investment while the larger profit-maximizing investment occurs either in the duopoly or in the merger to monopoly. This stricking contrast is driven by two interacting effects, namely the different degree of innovation's diffusion and the differential payoff when innovation is realized. These two effects differ from a social or private perspective and across market environments, leading to a different ranking in the level of investments. Indeed, the combination of coordination and diffusion of innovation with competition in the product market, that characterizes joint-ventures, is detrimental to profits and private incentives whereas it magnifies the social incentives to invest. Circulating the innovation once discovered spreads the benefits to all productions and generates a higher welfare increase the more competitive is the market. At the same time, the poor private incentives require subsidies to replicate the socially desirable investments.

Example 3. Comparisons of welfare maximizing investments: price competition In what follows, we compare the socially optimal investments if firms are choosing prices. By making use of the expressions derived above and applying (26) we obtain:

$$\begin{aligned} \tilde{x}^M &= \frac{3\mu\bar{c}n(2-\bar{c})}{8\beta+3\mu\bar{c}n(2-\bar{c})}, \\ \tilde{x}^D &= \frac{\mu\bar{c}n(2-\bar{c}-\bar{c}\lambda^2)}{2\beta+\mu\bar{c}n(2-\bar{c}-\bar{c}\lambda^2)}, \\ \tilde{x}^J &= \frac{\mu\bar{c}n(2-\bar{c})}{2\beta+\mu\bar{c}n(2-\bar{c})} \end{aligned} \tag{30}$$

It turns out that $\tilde{x}^J > \max\left\{\tilde{x}^D, \tilde{x}^M\right\}$ and:

$$\tilde{x}^D \geq \tilde{x}^M \quad for \quad \lambda \in \left[0, \frac{\sqrt{2\beta(2-\bar{c})}}{\sqrt{\bar{c}(8\beta - 3\mu\bar{c}n(2-\bar{c}))}}\right]$$

Note that for $\bar{c}$ small enough, the inequality holds for any value of λ. For high values of $\bar{c}$, $\tilde{x}^M > \tilde{x}^D$ for sufficiently high values of λ. For instance, normalising $n = 1$ and setting $\mu = 1/5$, $\beta = 2$ and $c = 1/2$, we have $\tilde{x}^M > \tilde{x}^D$ for $\lambda > .88$.

Two effects are at play here. On the one hand, competition implies that one extra unit of investment (and hence expected lower costs) will have a stronger impact on consumer surplus than under (two-product) monopoly. On the other hand, recall we are assuming perfect transferability within the merged entity, whereas under competition transferability is imperfect. When λ is very high, spillovers among competitors are almost nil, which decreases the value of having one extra unit of investment.

Example 4. Comparisons of welfare maximizing investments: quantity competition Let s consider now the case when firms choose quantities. First, note that the optimal public investments for the merged entity are already given by expression (30). By inserting the expressions given by (29) into (26) we obtain the social planner's investment choice for duopoly and a joint-venture when firms compete in quantities, as:

$$\tilde{x}^D(\lambda) = \frac{n\bar{c}\mu(16 - 8\bar{c} - 8\lambda + 11\bar{c}\lambda^2)}{2\left[9\beta + n\bar{c}\mu(8 - 4\bar{c} - 8\lambda + 11\bar{c}\lambda^2)\right]}; \quad \tilde{x}^J = \frac{4n\bar{c}\mu(2-\bar{c})}{9\beta + 4n\bar{c}\mu(2-\bar{c})}.$$

Then, $\tilde{x}^J > \max\left\{\tilde{x}^D(\lambda), \tilde{x}^M\right\}$ for any $\lambda > 0$ and $\tilde{x}^D(\lambda) > \tilde{x}^M$ for λ sufficiently low, as Figure 3 shows..

5.2 Comparison of maximal welfare in the market environments

Although a ranking of cases with respect to investment is of independent interest in a policy perspective, a comprehensive comparison of market environments requires to look at the expected welfare computed at the socially optimal investment in all cases. In particular, we want to analyze whether research joint-ventures yield not only the highest level of investment but also the best performance in terms of welfare compared with the other market environments. The following proposition confirms this conjecture.

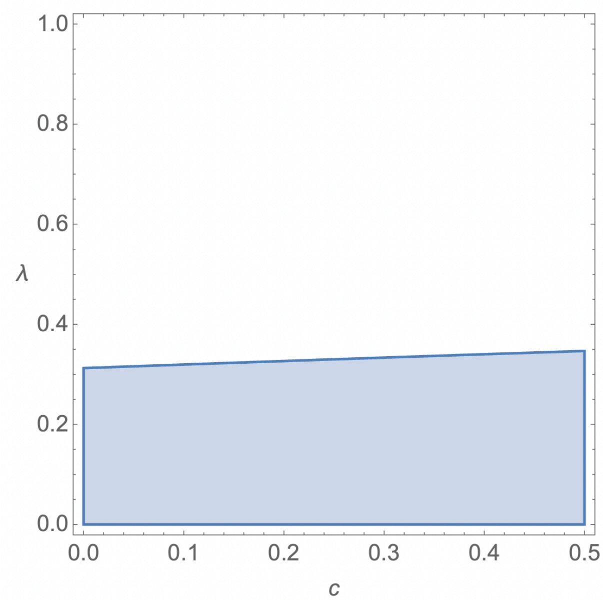

Figure 3: Region where $\tilde{x}^D \geq \tilde{x}^M$. Figure drawn for $\beta = 1/2$, $\mu = 1/5$, $n = 1$.

Proposition 12 (Welfare maximizing market environment) *When, in each market environment, the investment is chosen at the socially optimal level, the expected welfare reaches the highest performance in an integrated market with research joint-ventures.*

Hence, the ranking in welfare maximizing investment is replicated also when considering the expected welfare associated, in each market environment, to these investments. The integrated market monopoly dominates the segmented ones since the innovation is fully transferred to the two plants when only one lab is successful, while the unsuccessful segmented monopoly would lag behind. Turning to the integrated market and compering the different environments for given level of investment, research joint ventures welfare-dominate duopolies, allowing a complete technology transfer, while it is superior to a merger to monopoly since it promotes a higher increase in welfare by preserving competitive markets. These advantages are further enhanced by the fact that the investment is higher with research joint ventures than in the other cases.

6 Large markets and significant technology gaps

So far we have derived the comparison of market environments focussing on symmetric welfare maximizing investments, requiring sufficiently high decreasing returns to R&D. Consider, for example, the research joint-venture case, which outperforms the other market enviroments. From (25), the definition of $\Delta\bar{W}^J(\lambda^J)$ and $W^J(\lambda^J)$ and the condition $\lambda^J = 0$, the condition for a symmetric solution of the social planner's problem is

$$\beta > \mu n \left[W^D(0,0;1) - W^D(\bar{c},\bar{c};1)\right], \tag{31}$$

where n is the market size and $W^D(0,0;1) - W^D(\bar{c},\bar{c};1)$ is the increase in welfare in a market of size 1 when the technology gap is filled. Given the social benefits of innovation, summarized in the expression on the RHS, we need a steeply increasing marginal cost of research to induce the social planner keeping active two parallel and smaller labs ($\tilde{x}^J(0) < \frac{1}{2}$) notwithstanding the cost of duplication, and developing the innovation with a probability $2\tilde{x}^J(0) - \tilde{x}^J(0)^2$ that is lower than 1.

However, the term on the RHS is increases with the probability of disruption, the market size and the welfare gains from innovation and the social benefits of the innovation. Hence, there are relevant economic enviroments, as large markets with significant technology lags, in which the condition for a symmetric pattern of social investment is not satisfied. In the online Appendix we fully characterize this case.

Summarizing the main results, when (31) is not met, research joint-ventures still welfare-dominate the other cases. In this environment, the social planner is willing to implement an asymmetric solution by fully investing in one lab ($\tilde{x}^J(0) = 1$) and shutting down the other, with an overall increase in the probability of discovery (equal to 1 in our setting[18]). This outcome is implemented, for increasing benefits from innovation, by progressively reducing the subsidy, up to a point where the private incentives induce the asymmetric outcome with no need of a subsidy.

Our result, therefore, suggests that creating a large internal market when the technology gap is significant generates the incentives for a large investment in research that matches the social target. In this case, the best solution in a social perspective is a research joint venture that concentrates the innovation

[18] A more realistic case is when, even investing at a very high rate, the innovation is developed at most with a probability $\phi < 1$. The results, however, do not change in the comparison of the market environments and the symmetric or asymmetric solutions.

activity in a single center and distributes the innovation to all participants in a competitive enviroment.

7 Conclusions

The debate on the resilience of the European economy to supply chain disruption has posed a number of issues to policymakers, public institutions and academics. This paper provides a simple framework to address some of the relevant matters, offering a set of preliminary answers.

First, we argue that subsidies that stimulate investment in resilience, by offering a local alternative to imports of key inputs in case of disruption, might be justified, since private incentives fall short of the desired level of investment in a public perspective.

Second, we show that temporary subsidies to inefficient domestic production may be desirable if dynamic economies of scale and learning by doing improve the efficiency of local producers, reaching similar results as with subsidies to research.

Third, our result strongly support the claim that an integrated internal market allows to boost investments, a wider diffusion of innovation and a higher social welfare.

Fourth, comparing different structures in an integrated market, research joint ventures perform better in terms of investment and welfare than duopoly and merger to monopoly. Hence, coordination in research provides the most desirable effects when combined with competition in the product market. In some cases the optimal investment can be implemented only through a public research center.

Fifth, when the benefit from R&D is larger (due to lower costs of investment, larger market size, or a bigger technology improvement), it is optimal to concentrate all the research activity in a single large lab and distribute the outcomes of research to all firms, maintaining a competitive market. Hence, even when it is convenient to concentrate investment, concentration should be in research activities, not at the level of the product market.

References

[1] Arjona,R., Connell,W., Herghelegiu,C. (2023), An enhanced methodology to monitor the EU's strategic dependencies and vulnerabilities, Single Market Economics WP2023/14, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (EuropeanCommission)

[2] d'Aspremont C. and Jacquemin A., (1988), Cooperative and Non-Cooperative R&D in Duopoly with Spillovers, *American Economic Review,* 78: 1133-1137.

[3] Bourreau M., Jullien B. and Yassine Lefouili (2024), “Horizontal Mergers and Incremental Innovation”, *The RAND Journal of Economics*, forthcoming.

[4] Denicolò V. and Polo M., (2018), Duplicative Research, Mergers and Innovation, , *Economics Letters*, 166: 56-59.

[5] Denicolò V. and Polo M., (2021), Mergers and Innovation Sharing, *Economics Letters*, 202: 1-4.

[6] Draghi M. (2024), *The Future of European Competitiveness*, Report for the European Commission.

[7] Fabra, N., Motta M and Peitz M. (2022), Learning from electricity markets: How to design a resilience strategy, Energy Policy, 168, 113116.

[8] Federico G., Langus G. and Valletti T., (2018), Horizontal Mergers and Product Innovation, *International Journal of Industrial Organization,* 59:1-23.

[9] Grossman G., Helpman E. and Sabal A. (2023), Resilience in Vertical Supply Chains, NBER Working Paper No. 31739.

[10] Juhász R., Lane N. and Rodrik D. (2024) The New Economics of Industrial Policy, Annual Review of Economics, Volume 16.

[11] Letta E. (2024), *Much More than a Market*, Report for the European Commission.

[12] Motta M. and Tarantino E. (2021) The Effects of Horizontal Mergers when Firms Compete in Prices and Investment, *International Journal of Industrial Organization, 78*

[13] Piechucka J., Sauri-Romero L. and Smulders B., (2024), Competition and Industrial Policies: Complementary Action for EU Competitiveness, *Journal of Competition Law&Economics,* 1-25.

[14] Schwellnus C., Haramboure A., Samek L., Chiapin Pechansky R. and Cadestin C. (2023), *Global value chain dependencies under the magnifying glass*, OECD Report.

[15] Tagliapietra, S. and Veugelers, R. (eds.) (2023). Sparking Europe’s new industrial revolution: A policy for net zero, growth and resilience. Brussles: Bruegel.

8 Appendix: Proofs

Proof of Proposition 3.

The best replies (15) intersect at (17). If the slope of the best reply (15) in a neighborhood of (17) is lower than 1 in absolute value for both firms, that is condition (16) is met, the equilibrium is stable. Moreover, since the best replies are linear, they never intersect out of the equilibrium, establishing uniqueness. ■

Proof of Proposition 4. The FOC's and SOC's for a maximum in the joint profits maximization problem for $i = 1, 2$ are:

$$\begin{aligned}
\frac{\partial \Pi^k}{\partial x_i} &= \mu \Delta \bar{\Pi}^k(\lambda^k) - \mu \left(\Delta \bar{\Pi}^k(\lambda^k) - \Delta \underline{\Pi}^k(\lambda^k) \right) x_j - (1 - s_i)\beta x_i = 0, \\
\frac{\partial^2 \Pi^k}{\partial x_i^2} &= -(1 - s_i)\beta < 0, \\
\det H &= (1 - s_i)(1 - s_j)\beta^2 - \mu^2 \left[\Delta \bar{\Pi}^k(\lambda^k) - \Delta \underline{\Pi}^k(\lambda^k) \right]^2 > 0.
\end{aligned}$$

If condition (19) is met, the maximum is interior at (20). ■

Proof of Proposition 6.

The optimal interior solution from the social planner's standpoint for $k = D, M$ is identified by the FOC's and SOC's:

$$\begin{aligned}
\frac{\partial W^k}{\partial x_i} &= \mu \Delta \bar{W}^k(\lambda^k) - \mu \left[\Delta \bar{W}^k(\lambda^k) - \Delta \underline{W}^k(\lambda^k \right] x_j - \beta x_i = 0, \\
\frac{\partial^2 W^k}{\partial x_i^2} &= -\beta < 0, \\
\det H &= \beta^2 - \mu^2 \left[\Delta \bar{W}^k(\lambda^k) - \Delta \underline{W}^k(\lambda^k) \right]^2 > 0.
\end{aligned}$$

The inequality in the third line, given Assumption 5, can be rewritten as (25). If it holds, the social planner is willing to implement the symmetric level of investment (26). ■

Proof of Lemma 9. Let $\Phi = \Pi, W$ denote profits or welfare. From (2) and (5) including explicitly the market size n of the segmented monopolies: $2\Delta\Phi^S(n) \equiv 2\left[\Phi^S(0; n) - \Phi^S(\bar{c}; n)\right]$. Then, $2\Phi^S(c; n) = \Phi^S(c; 2n) = \Phi^M(c, c; 2n)$ for $c \in \{0, \bar{c}\}$, from the multiplicative effect of market size on profits and welfare – Assumption 1 –, where the second term is the equilibrium profit/welfare in a segmented monopoly of size $2n$ and the third is the equilibrium profit/welfare of a monopoly (or a merged entity) in the integrated market that produces with two plants of marginal cost c. Then, $\Delta\Phi^S(c; 2n) = \Delta\Phi^M(c, c; 2n) = \Delta\bar{\Phi}^M(\lambda^M)$ for $\lambda^M = 0$. ■

Proof of Proposition 10. We compare the equilibrium investment in the market environments S, D, M and J when there is no subsidy.

S **vs.** M**:** Let us consider first the comparison of **segmented monopolies** S and **merger to monopoly in an integrated market** M. The equilibrium level of investment is larger in the merger to monopoly if

$$\hat{x}^M(0, 2n) = \frac{\mu \Delta \bar{\Pi}^M(0, 2n)}{\beta + \mu \Delta \bar{\Pi}^M(0, 2n)} > \hat{x}^S(n) = \frac{\mu \Delta \Pi^S(n)}{\beta}.$$

Given Lemma 9 we can rewrite it as

$$\frac{\mu\Delta\bar{\Pi}^M(0,2n)}{\beta+\mu\Delta\bar{\Pi}(0,2n)} > \frac{\mu\Delta\Pi^M(0,2n)}{2\beta}$$

which corresponds to

$$\beta > \mu\Delta\bar{\Pi}^M(0,2n) \equiv \hat{\beta}^M(0).$$

Hence, when (19) holds the merged entity invests in each lab more than each monopolist in its segmented market.

Since the investment in local monopoly is always lower than that of the merged entity in an integrated market, the relevant comparison is between the **duopoly,** the **research joint-venture** and **merger to monopoly** (with perfect transferability of the innovation across production units in both cases) in an **integrated market** (we drop therefore the reference to the market size $2n$).

M **vs.** J**:** The term $\Delta\underline{\Pi}^M(0) = \Delta\underline{\Pi}^J(0)$ is nil when $\lambda^M = \lambda^J = 0$, and the investment in case of joint venture, as stated in Corollary 5 is increasing in $\Delta\bar{\Pi}^M(0) = \Pi^M(0,0) - \Pi^M(\bar{c},\bar{c})$ and decreasing in the intensity of competition, being 0 in case of Bertrand and $\Delta\bar{\Pi}^M$ under perfect collusion. Hence, the investment in research joint-venture is never higher than that in case of a merger to monopoly.

D **vs.** M**:** Focussing, therefore, on the comparison of duopoly and merger to monopoly, the former is larger than that of the merged entity in each lab if

$$\hat{x}_i^D(\lambda^D) = \frac{\mu\Delta\bar{\Pi}_i^D(\lambda^D)}{\beta+\mu\left(\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\underline{\Pi}_i^D(\lambda^D)\right)} > \hat{x}^M(0) = \frac{\mu\Delta\bar{\Pi}^M(0)}{\beta+\mu\Delta\bar{\Pi}^M(0)}.$$

After rearranging we obtain:

$$\beta\left[\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\bar{\Pi}^M(0)\right] > -\Delta\underline{\Pi}_i^D(\lambda^D)\hat{\beta}^M(0) \tag{32a}$$

where $\hat{\beta}^M(0)$ is defined in (19).

$$\Delta\bar{\Pi}_i^D(\lambda^D) \in \left[\Pi_i^D(0,0) - \Pi_i^D(\bar{c},\bar{c}), \Pi_i^D(0,\bar{c}) - \Pi_i^D(\bar{c},\bar{c})\right]$$

and $\Delta\underline{\Pi}_i^D(\lambda^D) \in \left[0, \Pi_i^D(0,0) - \Pi_i^D(\bar{c},0)\right]$ are both non-negative and increasing in λ^D. When $\lambda^D = 0$, $\Delta\underline{\Pi}_i^D(0) = 0$ and $\Delta\bar{\Pi}_i^D(0) \in \left[0, \Delta\bar{\Pi}_i^M(0)/2\right]$, where the two extremes correspond to Bertrand competition and full collusion. Hence, when $\lambda^D = 0$ the LHS in the inequality (32a) is negative and the RHS is zero, implying that the inequality does not hold and $\hat{x}^D(0) < \hat{x}^M(0)$, where the equality sign holds true only in case of full collusion. When λ^D increases, the LHS increases and the RHS becomes negative and decreases. For $\lambda^D = 1$, $\Delta\underline{\Pi}_i^D(1) > 0$ and

$$\Delta\bar{\Pi}_i^D(1) - \Delta\bar{\Pi}^M(0) = \left[\Pi_i^D(0,\bar{c}) - \Pi_i^D(\bar{c},\bar{c})\right] - \left[\Pi^M(0,0) - \Pi^M(\bar{c},\bar{c})\right]$$

corresponding to the Arrow replacement effect. If the Arrow effect is positive, (32a) is satisfied and the duopolists' investment is larger than the investment in each lab of the merged entity. Then, there exists a $\hat{\lambda}$ such that $\beta\left[\Delta\bar{\Pi}_i^D(\hat{\lambda}) - \Delta\bar{\Pi}^M(0)\right] = -\Delta\underline{\Pi}_i^D(\hat{\lambda})\hat{\beta}^M(0)$. For $\lambda^D < \hat{\lambda}$ (32a) is satisfied and $\hat{x}^D(\lambda^D) < \hat{x}^M(0)$. If instead the Arrow replacement effect is negative, when $\lambda^D = 1$ both terms in (32a) are negative, and the ranking of investments in the two market structures cannot be established in general, depending on the nature of market competition and the structural parameters of the market.

■

Proof of Proposition 11. We start by comparing the welfare-maximizing investment in the segmented monopolies and in the merger to monopoly in an integrated market.

S **vs.** M**:** Suppose $\beta > \tilde{\beta}^M(0)$ as defined in (25). Then, in the merger to monopoly there is a unique symmetric welfare-maximizing interior solution (26) for $k = M$, while the welfare-maximizing investment in local monopolies is (4). After rearranging and using Lemma 9 we get:

$$\tilde{x}^M(0) = \frac{\mu\Delta\bar{W}^M(0)}{\beta + \mu\Delta\bar{W}^M(0)} > \tilde{x}^S(n) = \frac{\mu\Delta W^S(n)}{\beta}$$

$$\frac{\mu\Delta\bar{W}^M(0)}{\beta + \mu\Delta\bar{W}^M(0)} > \frac{\mu\Delta W^M(0,2n)}{2\beta}$$

$$\beta > \mu\Delta\bar{W}^M(0) \equiv \tilde{\beta}^M(0).$$

Hence, the socially optimal investment is larger in an integrated market.

M **vs.** J**:** Secondly, in an integrated market we compare the investment in a merger to monopoly and in a research joint-venture when the innovation is perfectly transferable in both cases, that is $\lambda^M = \lambda^J = 0$. The welfare-maximizing investment for $k = M, J$ is given by (26), with $\Delta\underline{W}^k(0) = 0$ and $\Delta\bar{W}^k(0) = W^k(0,0) - W^k(\bar{c},\bar{c})$. Further, given Assumption 3, $\Delta\bar{W}^J(0) = W^D(0,0) - W^D(\bar{c},\bar{c})$, that is increasing in the intensity of competition. Finally, $\tilde{x}^k(0)$ is increasing in $\Delta\bar{W}^k(0)$. Then,

$$\tilde{x}^J(0) = \frac{\mu\Delta\bar{W}^D(0)}{\beta + \mu\Delta\bar{W}^D(0)} \geq \tilde{x}^M(0) = \frac{\mu\Delta\bar{W}^M(0)}{\beta + \mu\Delta\bar{W}^M(0)}$$

since $\Delta\bar{W}^D(0) \geq \Delta\bar{W}^M(0)$, with the strict inequality holding for any duopoly equilibrium except full collusion.

J **vs.** D**:** We have therefore to compare the investment in a duopoly and in a research joint-venture. Taking into account that $\Delta\underline{W}^J(0) = 0$ we can write:

$$\tilde{x}^D(\lambda^D) = \frac{\mu\Delta\bar{W}^D(\lambda^D)}{\beta + \mu(\Delta\bar{W}^D(\lambda^D) - \Delta\underline{W}^D(\lambda^D))} < \tilde{x}^J(0) = \frac{\mu\Delta\bar{W}^D(0)}{\beta + \mu\Delta\bar{W}^D(0)}$$

that corresponds to:

$$\beta\left[\Delta\bar{W}^D(0)-\Delta\bar{W}^D(\lambda^D)\right]>\Delta\underline{W}^D(\lambda^D)\tilde{\beta}^J(0) \tag{33}$$

where $\beta>\tilde{\beta}^J(0)\equiv\mu\Delta\bar{W}^D(0)>0$ and

$$\beta>\tilde{\beta}^D(\lambda^D)\equiv\mu\left[\Delta\bar{W}^D(\lambda^D)-\Delta\underline{W}^D(\lambda^D)\right]>0$$

in the interior welfare-maximizing investment. Since $\Delta\bar{W}^D(0)=W^D(0,0)-W(\bar{c},\bar{c})$, $\Delta\bar{W}^D(\lambda^D)=W^D(0,\lambda^D\bar{c})-W(\bar{c},\bar{c})$ and $\Delta\underline{W}^D(\lambda^D)=W^D(0,0)-W(\lambda^D\bar{c},0)$, condition (33) can be rewritten as

$$\beta\left[W^D(0,0)-W^D(0,\lambda^D\bar{c})\right]>\tilde{\beta}^J(0)\left[W^D(0,0)-W^D(0,\lambda^D\bar{c})\right]$$

which holds true for $\beta>\tilde{\beta}^J(0)$ and $\lambda^D>0$, since the term in square brackets is positive given Assumption 3.

■

Proof of Proposition 12. Let us consider the welfare evaluated at the welfare maximizing investment in the different market environments.

Let us start from the two separate monopolies, each of which generates an expected welfare (3) evaluated at the optimal investment $\tilde{x}^S$. Taking into account Lemma 9 and the fact that the two research activities are statistically independent, the total welfare generated by the sum of the two separate monopolies is:

$$\begin{aligned}W_1^S(\tilde{x}^S)+W_2^S(\tilde{x}^S) &= (1-\mu)2W^S(0)+\mu\left\{\left(\tilde{x}^S\right)^2 2W^S(0)\right.\\ &\quad \left.+(1-\tilde{x}^S)^2 2W^S(\bar{c})+2\tilde{x}^S(1-\tilde{x}^S)(W^S(\bar{c})+W^S(0))\right\}\\ &\quad -\beta\left(\tilde{x}^S\right)^2\\ &= (1-\mu)W^M(0,0)+\mu\left\{\left(\tilde{x}^S\right)^2 W^M(0,0)\right.\\ &\quad \left.+(1-\tilde{x}^S)^2W^M(\bar{c},\bar{c})+2\tilde{x}^S(1-\tilde{x}^S)W^M(0,\bar{c})\right\}\\ &\quad -\beta\left(\tilde{x}^S\right)^2.\end{aligned}$$

The expected welfare in the different market enviroments of the integrated market is, instead, given by (24) evaluated at (26) for $\lambda^D\in[0,1]$, $\lambda^M=\lambda^J=0$.

Then,

$$\begin{aligned}W^M(\tilde{x}^M)-W_1^S(\tilde{x}^S)-W_2^S(\tilde{x}^S) &= \mu\left\{\left[2\tilde{x}^M-\left(\tilde{x}^M\right)^2-\left(\tilde{x}^S\right)^2\right]W^M(0,0)\right.\\ &\quad +\left[(1-\tilde{x}^M)^2-\left(1-\tilde{x}^S\right)^2\right]W^M(\bar{c},\bar{c})\\ &\quad \left.-2\tilde{x}^S(1-\tilde{x}^S)W^M(0,\bar{c})\right\}-\beta\left[\left(\tilde{x}^M\right)^2-\left(\tilde{x}^S\right)^2\right].\end{aligned}$$

Then, evaluating the difference if the integrated monopolist applies the investment of the local monopolists, that is $x^M = \tilde{x}^S$, we get:

$$W^M(\tilde{x}^S) - W_1^S(\tilde{x}^S) - W_2^S(\tilde{x}^S) = \mu 2\tilde{x}^S(1-\tilde{x}^S)\left(W^M(0,0) - W^M(0,\bar{c})\right) > 0.$$

Hence, at $x^M = \tilde{x}^S$ the expected welfare in the integrated monopoly is higher than the sum of the expected welfare in the two segmented monopolies. Since the expected welfare in the segmented monopolies is at its maximum while it is not in the integrated monopoly, the difference in expected welfare is even larger, confirming that market integration welfare-dominates the segmented environment.

Turning to the comparison of integrated market environments, we apply the same method as in the previous case. Taking as a reference the research joint-venture, the difference in expected welfare between J and $k = D, M$ when both expressions are evaluated at the welfare maximizing investment $\tilde{x}^k$ is:

$$W^J(\tilde{x}^k) - W^k(\tilde{x}^k) = \mu\left\{2\tilde{x}^k(1-\tilde{x}^k)\left[W^D(0,0) - W^k(0,\lambda^k\bar{c}\right]\right\},$$

that, taking into account Assumption 3, yields in case of duopoly

$$W^J(\tilde{x}^D) - W^D(\tilde{x}^D) = \mu\left\{2\tilde{x}^D(1-\tilde{x}^D)\left[W^D(0,0) - W^D(0,\lambda^D\bar{c}\right]\right\} > 0$$

for $\lambda^D > 0$, whereas in case of monopoly we have

$$W^J(\tilde{x}^M) - W^M(\tilde{x}^M) = \mu\left\{2\tilde{x}^M(1-\tilde{x}^M)\left[W^D(0,0) - W^M(0,0\right]\right\} > 0$$

if in duopoly the firms do not perfectly collude. Hence, research joint-ventures dominate the other market environments not only in terms of investment but also in terms of expected welfare. ■

9 Online Appendix : Corner solutions

In this online Appendix we derive the relevant results when the conditions for an interior solution are not met, either because in a duopoly the interior equilibrium is unstable or because, when investment decisions are coordinated, the interior allocation is a saddle point. We first derive the equilibrium profit-maximizing investment in the non-cooperative and cooperative cases, then the welfare-maximizing ones and the optimal subsidies that align the two decisione.

Proposition 13 (Private investment: non cooperative corner equilibria) *If, for given s_i, $\beta \leq \hat{\beta}^D(s_i;\lambda^D) \equiv \frac{\mu\left(\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\underline{\Pi}_i^D(\lambda^D)\right)}{(1-s_i)}$ for firm i, the equilibrium (17) is unstable, and there exists a stable equilibrium at a corner solution:*

$$\hat{x}_i^D(s_i,s_j) = 1 \tag{34}$$

$$\hat{x}_j^D(s_j,s_i;\lambda^D) = \min\left\{\frac{\mu\Delta\underline{\Pi}_i^D(\lambda^D)}{(1-s_i)\beta}, 1\right\} \geq 0. \tag{35}$$

Proof of Proposition 13. If $\beta \leq \hat{\beta}^D(s_i;\lambda^D)$ for firm i, the best reply at (17) has a slope higher than 1 in absolute value. Hence, it is an unstable equilibrium and there is a stable asymmetric equilibrium at a corner solution. One firm fully invests. Substituting $x_i = 1$ in (15) we get (35). ∎

Proposition 14 (Private investment: cooperative corner solutions) *If, for given s_i and s_j, $\beta \leq \hat{\beta}^k(s_i, s; \lambda^k) \equiv \frac{\mu\left[\Delta\bar{\Pi}^k(\lambda^k) - \Delta\underline{\Pi}^k(\lambda^k)\right]}{[(1-s_i)(1-s_j)]^{\frac{1}{2}}}$ for $k = M, J$, the optimal investment is at a corner solution*

$$\hat{x}_i^k = 1 \tag{36}$$

$$\hat{x}_j^k(s_j;\lambda^k) = \min\left\{\frac{\mu\Delta\underline{\Pi}^k(\lambda^k)}{(1-s_j)\beta}, 1\right\} > 0. \tag{37}$$

Proof of Proposition 14. If $\beta \leq \hat{\beta}^k(s_i, s; \lambda^k)$, (20) is a saddle point and the merged entity chooses the corner solution, where (37) is obtained from the FOC when the investment in the other lab is 1. ∎

Proposition 15 (Welfare-maximizing asymmetric solutions) *If*

$$\beta \leq \tilde{\beta}^k(\lambda^k) \equiv \mu\left[\Delta\bar{W}^k(\lambda^k) - \Delta\underline{W}^k(\lambda^k)\right]$$

for $k = D, M, J$, the social planner chooses a corner solution

$$\tilde{x}_i^k = 1 \tag{38}$$

$$\tilde{x}_j^k(\lambda^k) = \min\left\{\frac{\mu\Delta\underline{W}^k(\lambda^k)}{\beta}, 1\right\}. \tag{39}$$

Proof of Proposition 15.

If $\beta \leq \tilde{\beta}^k(\lambda^k)$, (26) is a saddle point and the optimal investment is at the corner solution (38) and (39), where the second one is obtained from the FOC setting $x_i^k = 1$. ∎

Proposition 15 and 14 claim that, when the research activity of the labs is coordinated and the innovation is fully transferred to all firms/plants, as it happens in research joint-ventures and merger to monopoly, all the research activity is concentrated in one lab pushing up the investment to obtain the innovation with certainty. Then, there is no need to duplicate the research effort in a second lab. When, instead, research is run by the two firms separately, as in a duopoly, and the diffusion of innovation is not complete, there is an incentive for the social planner to keep open, although at a smaller scale, a second lab to insure that innovation is developed and adopted in the firm when imitation fails.

Hence, the total investment in duopoly is larger than when research is coordinated, but the probability of adopting the innovation in both plants is lower. This immediately suggests that, in terms of expected welfare, duopoly performs worse than joint-ventures. Similarly, monopoly is welfare dominated by joint-ventures since the level of investment is the same but the welfare increase due to the innovation is larger when the market is more competitive.

Focussing on research joint ventures, when $\beta \leq \tilde{\beta}^J(0)$ the social planner is willing to implement the corner solution $\tilde{x}_i^J = 1$ and $\tilde{x}_j^J = 0$. Notice that this is also the equilibrium outcome when the joint-venture chooses the investment if $\beta \leq \hat{\beta}^J(s_i, s_j; 0)$. Hence, if the subsidy is set at

$$s_i = s_j = s(\beta) = \max\left\{1 - \frac{\mu\Delta\bar{\Pi}^D(0)}{\beta}, 0\right\} \tag{A7}$$

then $\hat{\beta}^J(s(\beta), s(\beta); 0) = \beta$ for $\beta \leq \tilde{\beta}^J(0)$ and the joint-venture chooses the same corner solution $\hat{x}_i^J = 1$ and $\hat{x}_j^J = 0$. Notice also that the subsidy is increasing in β and equal to 0 for $\beta = \mu\Delta\bar{\Pi}^J(0) = \hat{\beta}^J(0,0;0)$. Hence, in the interval $\beta \in \left[\hat{\beta}^J(0,0;0), \tilde{\beta}^J(0)\right]$ the social planner sets a symmetric subsidy (A7) that is received only in one lab, which runs the research activity at full scale. For $\beta < \hat{\beta}^J(0,0;0)$ the asymmetric outcome is chosen by the research joint-venture with no need of any subsidy. We summarize the discussion in the following:

Proposition 16 (Welfare dominant equilibrium) *If* $\beta \leq \tilde{\beta}^J(0) = \mu\Delta\bar{W}^D(0)$ *the social planner implements an asymmetric investment* $\hat{x}_i^J = 1$ *and* $\hat{x}_j^J = 0$ *by setting* $\tilde{s}_i = \tilde{s}_j = \tilde{s}(\beta)$ *equal to (A7).*