Supply chain disruption and precautionary industrial policy*

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Abstract

The paper analyzes the design of industrial policies to improve the efficiency of a local input when there is a risk of international supply chain disruption. We first establish a case for research subsidies in a monopolistic setting: private investment to improve the inferior technology is lower than the socially optimal one. Then, considering several market environments differing in size, structure and appropriability of the innovation, we analyze private and welfare-maximizing investments and optimal transfers. Subsidies are always optimal with both monopolies and research joint-ventures, whereas under some circumstamces (notably, when there is high appropriability of an innovation and investment costs are sufficiently low) a tax might be optimal under duopoly. Research joint-ventures in an integrated market or a public reseach lab socially outperform the other environments since they benefit from a larger integrated market and a wider circulation of the innovation while preserving competition.

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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, a claim that can be extended to most industrialized areas after two decades of globalization. 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 was probably the most important legislative initiative of the Biden administration in this respect. The recent tariff initiatives of the second Trump administration are justified on similar grounds. In the EU, both the Council and the European Commission commissioned high-profile reports with the task of proposing plans and policies 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 of scale economies; however, they share some ambiguity towards the role of competition, mentioning the positive role of competition, while at the same time stating the need for market consolidation (achieved through weaker enforcement of merger control) which would allegedly allow EU

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

[2] Similar concerns have been raised reganding 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 the European Commission: Letta (2024) and Draghi (2024).

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 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 by supporting domestic innovation, 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, in the case we focus on, 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 in R&D.

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 in industries subject to geo-political risks but which suffer from an efficiency gap?[6] 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 an upstream and a downstream monopolist operate in the home country and the input supplier, which procures the efficient input if trade is open, can invest to develop an efficient local technology in case of trade disruption. In the first stage, the government chooses a R&D transfer (subsidy or tax), then the upstream firm decides R&D investments and finally, after knowing whether there is a supply-chain shock and once the research ac-

[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.

[6]In an extension, we consider the same question — is there scope for subsidising local production? — within a model with learning-by-doing where the cost of producing the input may decrease with greater local production

tivity has been (successfully or unsuccessfully) concluded, the downstream monopolist buys the input according to the most efficient technology available (and under efficient contracts with the upstream monopolist) and serves the market.

We show that, absent any transfer, the domestic input monopolist will invest. However, private investment is insufficient from a social welfare perspective, as the upstream monopolist does not internalize the negative effects of the shock on consumers and on downstream profits.[7] This implies that there is room for public intervention in the form of a 'precautionary subsidy' to enhance the 'investment in resilience'.

Section 3 analyses the same issue considering different market environments in terms of size, structure and appropriability of the innovation. We analyze a market that can sustain two production and research units (we also assume for simplicity that each firm is vertically integrated, unlike the previous section), 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 merger to (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 may range from nil to complete, depending on the enforcement of property rights and other factors affecting the possibility of imitation.

Maintaining the three-stage framework of the benchmark case, we derive and characterize the profit-maximizing and welfare-maximizing equilibrium R&D investments for the different market configurations, 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.

Equilibrium investments increase in the probability of disruption and shrink with the decreasing returns to innovation. It is the variation, rather than the level, of payoffs (profits and welfare) due to innovation that affects the equilibrium investments. This incremental payoff, 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 transfers that align the two. In our setting, the welfare maximizing transfer is always positive (a subsidy) when research efforts are coordinated (research joint-venture and merger to monopoly), whereas in a duopoly private investment may be higher than the social one (in particular, when appropriability of the investment is high, and business-stealing effects are more significant), requiring a tax, in some circumstances.

Section 4 then turns to a comparison of the equilibrium outcomes in the dif-

[7] Insufficient private investment occurs also when the two units are vertically integrated. In this case, however, it is driven only by the failure of internalisation of consumer surplus.

ferent market environments, deriving the results in the general framework (we shall also show two applications with Bertrand and Cournot competition with homogeneous products). We perform three comparisons among market environments looking at the highest score in terms of profit-maximizing investment, welfare-maximizing investment and social welfare evaluated at the socially optimal investment. Notice that these comparisons are not trivial, since the ranking in investments depend on the incremental payoffs (profits or welfare) from innovation whereas the ranking in social welfare at the optimal investment is based on the level of welfare in the different states.

We first identify, across market environments, the ranking of profit-maximizing investment absent subsidies. 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.

Focusing 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 increase in profits of the duopolists participating in the joint-venture, weakening private incentives. 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 low, the innovating duopolist, retaining most of the extra-profits from innovation, has a larger incentive to innovate than the monopolist, recalling the Arrow replacement effect, and the duopoly dominates in terms of investment. The opposite occurs when spillovers are significant.

To understand this result, consider that when spillovers are sufficiently high there is a positive investment externality occurring between 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-ventures score at the top in terms of investment, contrary to what happens with private investments. They are larger than under monopoly, since the increase in welfare that boosts investment is larger in a more competitive market. And investments are also larger than in the duopoly case since the research joint-venture allows to spread the innovation to both firms, increasing the social incentive to innovate.

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, by combining the highest investment and social benefit of a competitive market.

Section 5 presents some extensions. In Subsection 5.1 we consider — within the benchmark monopoly case — an alternative tool to promote domestic efficiency, namely local content requirements or subsidies to local production. When production generates learning-by-doing or dynamic economies of scale, producing locally (part of the input) allows to reduce the costs over time. We show that 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 push 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 Subsection 5.2 we analyze the case where the expected benefits of the innovation increase — for instance due to a higher probability of disruption or a larger technology gap that can be filled through R&D — up to a point where the symmetric investment solutions do not exist and the welfare maximizing investment entails concentrating all the research activity in one lab. With a sufficiently large benefit, decreasing returns to R&D do not prevent from investing in a single very large lab. Research joint-ventures outperform the other cases even in this case, requiring the concentration of all the research activity in a single lab while keeping the product markets competitive.

Finally, in Subsection 5.3 we explore the case when funding subsidies generates distortions, showing that with a positive public cost of funding the level of subsidies and the socially optimal level of investment shrink.

Overall, our results show some support for industrial policies in the shape of R&D (or output) subsidies, subject of course to the well-known caveats against subsidies, but do not 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 a joint-venture is preferable options. Moreover, when disruption is likely and the technology gap is significant, the policy prescription is to concentrate the research activity, even under public control, in a 'European Champion Lab' 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,[8] which is precisely

[8]Acemoglu and Tahbaz-Salehi (2024) study a general equilibrium model where firms endogenously form and maintain supply-customer relationships. They show that at equilibrium

the main focus of our work, and on which there is a small strand of literature. Grossman et al. (2023a) study a general equilibrium model and find, inter alia, conditions under which a subsidy for diversification of input would be optimal when cheaper foreign sourcing is riskier than local sourcing. Grossman et al. (2023b) studies, also in a general equilibrium framework, two (costly) mechanisms to increase resilience: one is investing resources to reduce the risk that a source is interrupted by choosing the less risky supplier, although more costly; the other is to diversify the sources of supply, so as to reduce the dependence on one or a small set of suppliers which may fail. Similar mechanisms are also analysed in Elliott et al. (2022), where firms invest to reduce the fragility of the supply chain. Traiberman and Rotemberg (2023) study trade policy in a situation where, facing a shock, a country might not be able to reach its full potential because of 'rustiness' in the production. Compared with Grossman et al (2023b), in our paper firms can improve the efficiency of home production by sinking resources, within a partial equilibrium model that involves using foreign inputs when the markets are open, and local inputs in case of trade disruption. Moreover, and more importantly, we consider different market environments in terms of size, structure, appropriability of the innovation, and the nature of strategic interaction.

Geopolitical shocks are not the only sources of fragility for an economy. For instance, energy outages might cause similar problems, and both firms and national governments might want to invest so as to increase the resilience of the system relative to the possible instability of electricity supply. Fried and Lagakos (2023) formalise a framework where firms might have access to generators and could rely on them in case of outages (this is not dissimilar to our model, where firms can invest to avoid the consequences of a shock) and quantify the long-run economic consequences of such outages. A similar pattern can be observed at the level of the entire electricity system. With the decarbonization policies and the expansion of renewable energy supply, the electricity systems experience an increasing role of discontinuous and unpredictable energy sources (solar and wind) and the need of back-up capacity to maintain the system balanced. This led to the introduction of capacity mechanisms subsidizing gas-fired power plants that remain idle for most of the time, the more so the larger the renewable share of total installed capacity. Hence, a relationship between the likelihood of supply shortages and the size of the investment in resilience can be observed in this case.[9]

From a more practical perspective, Arjona et al. (2023) develop a methodology aimed at identifying industries subject to the risk of supply-chain disruption,

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the system is inherently fragile, in the sense that small shocks create discontinuities in production. They analyse the macroeconomic consequences but do not study possible policy responses.

[9]See, e.g., Fabra (2018). In her paper, if demand exceeds capacity, a blackout would occur with some probability, with extreme negative consequences on welfare. Investment is therefore necessary to avoid such imbalances, and hence the possibility of outages. In a sense, therefore, this literature treats the shock as endogenous (the investment might even eliminate it) whereas in our framework the shocks are completely exogenous and the issue is how to 'insure' against such occurrences.

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 consider a monopoly supply chain composed of one upstream stage, which supplies the input to a downstream one, which transforms one-to-one input into output and sells it. If the two stages are run by independent firms, we assume they contract efficiently and use a two-part tariff: the upstream firm sells each unit of input at marginal cost c but receives a share $\alpha \in (0,1)$ of the downstream profits. If, instead, $\alpha = 1$ the two units can be thought of as parts of a vertically integrated firm.

Upstream stage. There are two technologies to produce the input: an efficient technology with marginal cost 0, that is available in the foreign markets, and a domestic inefficient technology with marginal cost $\bar{c} > 0$ which is locally feasible. Moreover, the upstream firm/unit can invest $x \in [0,1]$ in one lab[10] by sinking a cost

$$C(x) = \frac{\beta}{2}x^2$$

to develop locally with a probability x the efficient technology 0.[11]

If the international markets are open, which occurs with probability $1-\mu$, the upstream firm/unit procures the input according to the efficient technology at a marginal cost 0 (it may import the input from a foreign subsidiary or it may buy it from a competitive fringe of foreign firms to resell it downstream). In the event of a supply chain disruption, which occurs with probability μ, if the research activity is successful, the upstream firm/unit can supply the input at a marginal cost of 0; otherwise, if the research fails, the input is supplied at a marginal cost of $\bar{c}$. Hence, the marginal cost of the input can take two values: $c = 0$ if the international markets are open or, in case of supply chain

[10] We assume that the upstream firm runs only one R&D lab. This might be because market size is not sufficiently large, given fixed costs in production and research, to sustain more than one lab.

[11] Hence, by investing x the firm can catch-up but it cannot leapfrog the foreign technology.

disruption, if R&D is successful, and $c = \bar{c}$ when the international provision is unfeasible and research fails to develop the efficient technology.[12]

Downstream stage. We assume away any production cost other than the cost of the input. Hence, the downstream firm/unit produces at marginal cost $c \in \{0, \bar{c}\}$. It sells in the home market (subscript H) and in a foreign market (subscript F), making profits, respectively, $\Pi_H(c)$, and $\Pi_F(c)$. We denote the (gross) total industry profits for a given cost realization c as:

$$\Pi(c) = \Pi_H(c) + \Pi_F(c). \tag{1}$$

If the two units correspond to independent monopolists, given the two-part tariff contract, the upstream firm earns a share $\alpha \in (0, 1)$ of the total profits, and the downstream firm retains the fraction $1 - \alpha$ of them. The (gross) total industry welfare for given cost realization is

$$W(c) = \Pi(c) + CS(c), \tag{2}$$

where $CS(c)$ is domestic consumer surplus and $\Pi(c)$ includes the profits realized in the domestic and foreign markets.[13]

Social planner. The social planner can affect the firm's decision on the research investment x through a unit transfer s on the research costs. If $s > 0$ the subsidy is financed through lump-sum taxes, whereas a tax $s < 0$ is similarly rebated on consumers.[14] We further assume that, in a second best perspective, the social planner cannot dictate the market decisions of the firm.

Timing. The timing is as follows:

- at time 1 the social planner chooses a transfer rate $s \leq 1$ applied to the research costs $C(x)$ of the upstream firm/unit;
- at time 2, having observed the transfer rate, the upstream firm/unit chooses the investment x bearing a cost $(1 - s)\beta x^2/2$ and develops the efficient technology 0 with probability $x \leq 1$;
- at time 3 nature determines whether disruption occurs or not; then, the upstream unit supplies the most efficient technology available to the downstream unit, and market realisations take place.

[12]We can describe our setting also in terms of different supply chains, with the network *foreign fringe-upstream monopolist-downstream monopolist* when the markets are open, and *upstream monopolist-downstream monopolist* when trade is interrupted.

[13]One might think of an extreme situation where the input coming from abroad cannot be replaced at all. Our setting can accommodate this case, which would amount to having $\bar{c} \to \infty$, and the associated profits $\Pi(\bar{c}) = 0$. The key expressions below, $\Delta\Pi$ and ΔW, would continue to hold, and the results we shall obtain would not be affected. However, to avoid having to consider a multiplicity of cases, in the specific functional form examples throughout the paper we assume that the difference in costs is non-drastic, which amounts to assuming that $\bar{c}$ has an upper bound.

[14]Hence, when there is no cost of public funds all that matters for welfare is the total cost of research, no matter how it is covered by the firm or the public budget. The case of distortionary public funding will be discussed in Section 5.3.

2.1 Equilibrium

In what follows we shall describe the analysis as referring to the case of two independent monopolists: $\alpha \in (0,1)$. All the results extend to the vertical integration case ($\alpha = 1$)

The market outcome at time 3 depends on the most efficient technology available to the upstream — and hence also the downstream — firm, $c \in \{0, \overline{c}\}$. The expected profit of the upstream firm at stage 2 when choosing the investment x is

$$\pi(x) = (1-\mu)\alpha\Pi(0) + \mu\alpha\left\{\Pi(\overline{c}) + x\Delta\Pi\right\} - \frac{(1-s)\beta}{2}x^2, \tag{3}$$

where $\Pi(\cdot)$ is given by (1) and

$$\Delta\Pi \equiv \Pi(0) - \Pi(\overline{c}) > 0 \tag{4}$$

is the increase in profits, realized in the domestic and foreign market, allowed by the innovation. The profit-maximizing investment is therefore[15]

$$\hat{x}(s) = \frac{\mu\alpha\Delta\Pi}{(1-s)\beta}. \tag{5}$$

The expected total welfare given the investment $\hat{x}(s)$ is:

$$w(\hat{x}(s)) = (1-\mu)W(0) + \mu\left\{W(\overline{c}) + \hat{x}(s)\Delta W\right\} - \frac{\beta}{2}\hat{x}(s)^2 \tag{6}$$

where

$$\Delta W \equiv W(0) - W(\overline{c}) > 0 \tag{7}$$

measures the increase in welfare when adopting the innovative technology 0. Then, the optimal subsidy solves $\frac{dw}{ds} = \frac{dw}{dx}\frac{d\hat{x}(s)}{ds} = 0$. Since $\frac{d\hat{x}(s)}{ds} > 0$, it is analytically equivalent and convenient to look for the socially optimal investment that solves

$$\frac{dw}{dx} = \mu\Delta W - \beta x = 0, \tag{8}$$

obtaining

$$\tilde{x} = \frac{\mu\Delta W}{\beta}. \tag{9}$$

Then, equating $\hat{x}(s) = \tilde{x}$ and solving for s we get the welfare maximizing subsidy:

$$\tilde{s} = \frac{\Delta W - \alpha\Delta\Pi}{\Delta W} \in [0,1], \tag{10}$$

where $\tilde{s} = 0$ in the extreme case where both the downstream is able to extract all the consumer surplus, say thanks to perfect price discrimination, and the

[15] The SOC is $\frac{d^2\pi}{dx^2} = -(1-s)\beta < 0$. Note that the FOC and SOC do not change if the downstream firm purchases directly on the international market the input at 0, making the first term in (3) nil.

upstream firm's share of the industry profit is equal to 1. At the other extreme, $\tilde{s} = 1$ in case the upstream firm is unable to extract any profit from the donwstream firm.

It is interesting to notice that the welfare maximizing subsidy $\tilde{s}$ is equal to the deviation ratio between the welfare-maximizing investment $\tilde{x}$ and the profit maximizing investment absent subsidies, $\hat{x}(0)$:

$$\Delta x \equiv \frac{\tilde{x} - \hat{x}(0)}{\tilde{x}} = \frac{\Delta W - \alpha \Delta \Pi}{\Delta W} = \frac{\Delta CS + (1-\alpha)\Delta \Pi}{\Delta W}, \tag{11}$$

where $\Delta CS \equiv CS(0) - CS(\bar{c})$.[16] Hence, the private investment is lower than the socially optimal one, because the upstream firm under-invests, since it calibrates the investment only to its private profit $\alpha\Delta\Pi$ and it internalizes neither the effect of the investment on consumers, (ΔCS), nor on the downstream firm's profits $(1-\alpha)\Delta\Pi$. Indeed, the latter source for divergence between private and social investment decreases with α, the share of profits appropriated by the upstream firm, and vanishes in case of vertical intergration ($\alpha = 1$), but under-investment still remains due to the firm not considering the benefits of the innovation on consumers' surplus.

We summarize the discussion as follows:

Lemma 1 (Under-investment) *When the supply chain involves a monopolist both upstream and downstream, there is under-investment in case of a positive probability of disruption compared with the socially efficient level. Under-investment still holds, although to a lesser extent, also in case of vertical integration, as the firm does not internalize the effect on consumer surplus. If the social planner subsidizes the firm setting (10) it will implement the socially optimal investment (9).*

Example 1: Vertically-integrated monopoly In this and the following examples we assume that the firm is vertically integrated ($\alpha = 1$), it sells only in the domestic market ($\Pi_f(c) = 0$). The demand function $Q = n(1-p)$, where n is the size of the market. We also assume non-drastic innovation, i.e. $\bar{c} < 1/2$.

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

[16] Note that the existence of profits from exports does not qualitatively change the results: foreign and domestic profits enter the above expression in the same way: what matters are the profits made by domestic firms, whether on the domestic or the foreign market is immaterial.

- The optimal subsidy in case of monopoly will therefore be:

$$s = \frac{1}{3}.$$

3 Precautionary transfers and market environments

In the previous Section we established an argument in support of public transfers, in the form of subsidies to research, when a monopolistic industry faces the risk of supply chain disruption. Subsidies, by reducing the marginal cost of research, increase the private investment to the socially optimal level, which aims at providing social insurance against supply chain disruption.

We want now to explore the design of precautionary transfers under different market environments. To keep the analysis simple, we exclude features such as vertical separation and exports, that we considered in the previous section and that do not affect qualitatively the results, focussing on the case of vertically integrated firms and no foreign sales. Moreover, we mainly focus on symmetric interior equilibria, the precise conditions for their existence being specified in the proofs. We shall discuss the case of corner solutions in subsection 5.2.

Market environments. The market can sustain two production and research units covering any production and research fixed cost.[17] We consider three different cases depending on how the labs and the production units are run. In a duopoly (D) each (vertically integrated) firm manages independently one lab and competes non-cooperatively in the product market. The mode of competition may range from Bertrand to full collusion and is summarized, in reduced form, through the corresponding equilibrium profits. In a research joint-venture (J) the firms manage cooperatively the research labs, sharing the results achieved, but compete in the product market as duopolists.[18] Finally, in a merger to monopoly (M), the merged entity runs two labs[19] and two plants, transferring the innovation to both downstream units if research is successful, and 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, which we denote by the marginal cost c_i.

[17] One might interpret this market as the integration of two domestic markets like the one analysed in the previous Section.

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

[19] 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 5.2.

Costs, innovation and spillovers. As in the previous section, there are two technologies available: an efficient foreign technology with marginal cost 0, that the firm(s) can adopt in case of no supply chain disruption, and a local inefficient technology with marginal cost $\bar{c} > 0$. Disruption occurs with probability μ. Moreover, each lab can run a research process and develop locally the efficient technology with probability $x_i \in [0, 1]$ at total cost $C(x_i) = \frac{\beta}{2}x_i^2$, which can in part be covered though public subsidies.

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 imitated also by plant j.[20] More precisely, when in market environment $k = D, J, M$ only one lab develops the innovation, the non-innovating firm/lab j has access to a technology $c_j^k = \lambda^k \bar{c}$, where $\lambda^k \in [0, 1]$. Parameter λ^k can be interpreted as the degree of appropriability of the innovation: a low value of λ^k corresponds to low appropriability and a high spillover.

The degree of imitation may differ across market environments, since in a duopoly the firms are independent and spillovers, if any, are involuntary, while a merged entity and a research joint-venture may intentionally pursue a transfer of technology across plants/firms.[21] In order to stress this difference we introduce the following:

Assumption 1: $\lambda^D \in [0, 1]$, $\lambda^J = \lambda^M = 0$.

Hence, we assume that in case of a merger or research joint venture, if the research is successful in at least one lab, the innovation is fully transferred to both plants/firms. The case of full technology transfer may also apply to a public lab run by the social planner, who directly sets the investment and, if successful, transfers the results to all firms.[22]

Conversely, in a duopoly, when only one lab develops the innovation, the non-innovating firm/lab j has access to a technology $c_j^D = \lambda^D \bar{c}$, where $\lambda^D \in [0, 1]$. The degree of involuntary technology transfer may depend on firm's governance, partial IPR protection, ineffective protection of industrial secrets, ability to imitate, contacts of engineers between organizations, compatibility in the technology of production units or organizational frictions.

Given Assumption 1, the state of the technologies depend on two key parameters, $\bar{c}$ and λ^D**.** In a merger to monopoly or in a joint-venture two states

[20] 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.

[21] For simplicity, we assume away any spillovers from the foreign technology to the domestic firms.

[22] The case of partial transfer of the innovation in case of a merger to monopoly or a research joint-venture could be easily analyzed in our framework, but is omitted for simplicity. Note that assuming that a joint venture and a merged entity are able to seamlessly transfer an innovation across units biases the results in favour of these market structures over an independent duopoly.

of the technology may occur, $\{(0,0),(\bar{c},\bar{c})\}$, where the first term corresponds to the case when at least one lab successfully develops the efficient technology, and the second when both labs fail. In a duopoly three states of the technology may occur, $\left\{(0,0),(\bar{c},\bar{c}),(0,\lambda^D\bar{c})\right\}$, where the third term refers to the case when only one lab innovates and the rival partially benefits from the innovation.

Timing. The timing is as follows: given the market environment $k = D, J, M$, the degree of innovation appropriability λ^k, and the probability of supply-chain disruption μ, that are common knowledge:

- at time 1, the social planner chooses a transfer rate $s_i \leq 1$ for lab $i = 1, 2$ proportional to the research costs;
- at time 2, having observed the rates s_1 and s_2, firm i 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;
- at time 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.

3.1 Time 3: product market equilibria

We summarize the market equilibrium in the third stage through reduced form expressions of the relevant payoffs (profits, consumers' surplus and welfare), which depend on the technologies adopted (c_i^k, c_j^k) by firm/plant i and j in market environment $k = D, J, M$, where each firm/plant adopts the most efficient technology available, and, in the duopoly, on the mode of competition. We then assume the following:

Assumption 2: For market structure $k = D, J, M$ and for any cost realizations and mode of competition in duopoly, there is a unique corresponding equilibrium in the product market. The associated welfare, consumer surplus and profits are proportional to the market size n.[23]

We introduce the following notation. In a duopoly and research joint-venture we denote firm i's equilibrium profits as:

$$\Pi_i^k(c_i^k, c_j^k), \tag{12}$$

[23]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.

for $k = D, J$, where $\Pi_i^J(c_i^J, c_j^J) = \Pi^D(c_i^J, c_j^J)$. In a research joint-venture and in a monopoly we further denote the industry profits as:

$$\Pi^k(c_i^k, c_j^k) = \Pi_i^k(c_i^k, c_j^k) + \Pi_j^k(c_i^k, c_j^k) \quad \text{for} \quad k = J, M. \tag{13}$$

For a given state of the technology (c_i^k, c_j^k), each of the equilibrium market allocations $k = D, J, M$ is associated to a level of welfare $W^k(c_i^k, c_j^k)$ and consumer surplus $CS^k(c_i^k, c_j^k)$, where $W^J(c_i^J, c_j^J) = W^D(c_i^J, c_j^J)$ and $CS^J(c_i^J, c_j^J) = CS^D(c_i^J, c_j^J)$.

We further introduce the following assumptions on the ranking of payoffs in the different cost configurations:

Assumption 3: The firm and industry profits are ranked as follows:

$$\begin{aligned}
\Pi_i^D(0, \lambda^D \bar{c}) &> \Pi_i^D(0,0) \geq \Pi_i^D(\bar{c}, \bar{c}) \geq \Pi_i^D(\lambda^D \bar{c}, 0) \quad \text{for} \quad \lambda^D \in (0,1) \\
\Pi^J(0,0) &\geq \Pi^J(\bar{c}, \bar{c}) \\
\Pi^M(0,0) &> \Pi^M(\bar{c}, \bar{c}).
\end{aligned}$$

Assumption 4: Welfare and consumer surplus are ranked as follows: :

$$\begin{aligned}
CS^D(0,0) &> CS^D(\lambda^D \bar{c}, 0) = CS^D(0, \lambda^D \bar{c}) > CS^D(\bar{c}, \bar{c}) \quad \text{for} \quad \lambda^D \in (0,1) \\
CS^k(0,0) &> CS^k(\bar{c}, \bar{c}) \quad \text{for} \quad k = J, M, \\
W^D(0,0) &> W^D(\lambda^D \bar{c}, 0) = W^D(0, \lambda^D \bar{c}) > W^D(\bar{c}, \bar{c}) \quad \text{for} \quad \lambda^D \in (0,1), \\
W^k(0,0) &> W^k(\bar{c}, \bar{c}) \quad \text{for} \quad k = J, M.
\end{aligned}$$

Assumption 3 states that in a duopoly 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. In a merger to monopoly or in a research joint-venture, the profits are decreasing in the symmetric costs. Assumption 4 displays the ranking in terms of welfare and consumers' surplus, which are maximal when both firms/production units adopt the efficient technology, and decrease in the cost of the less efficient plant.

To make the notation compact, let us denote $\Phi^k(c_i^k, c_j^k)$ as the payoff (profit, consumer surplus or total welfare) in market enviroment $k = D, J, M$ when the corresponding state of the technology is (c_i^k, c_j^k). When we refer to firms, the payoff is the profit and $\Phi_i^D(\cdot) = \Pi_i^D(c_i^D, c_j^D)$ in a duopoly and $\Phi^k(\cdot) = \Pi^k(c_i^k, c_j^k)$, $k = J, M$ in research joint-ventures and merger to monopoly, where the industry profit matters for the investment decisions. When, instead, we refer to consumers or total welfare, then, respectively, $\Phi^k(\cdot) = CS^k(c_i^k, c_j^k)$ and $\Phi^k(\cdot) = W^k(c_i^k, c_j^k)$, for $k = D, J, M$.

Then, let the *incremental payoff* when an innovation is developed in a lab be:

$$\begin{aligned}
\Delta\bar{\Phi}^k(\lambda^k) &\equiv \Phi^k(0, \lambda^k \bar{c}) - \Phi^k(\bar{c}, \bar{c}) > 0, \qquad (14) \\
\Delta\underline{\Phi}^k(\lambda^k) &\equiv \Phi^k(0,0) - \Phi^k(\lambda^k \bar{c}, 0) \geq 0, \qquad (15)
\end{aligned}$$

for $k = D, J, M$ and λ^k defined in Assumption 1. $\Delta\bar{\Phi}^k(\lambda^k)$ measures the incremental payoff in market environment k when the innovation is developed in one lab while the other fails, potentially benefitting from the other lab's innovation according to the parameter λ^k. For instance, in a duopoly the incremental profit when only firm i innovates is $\Delta\bar{\Pi}_i^D(\lambda^D) \equiv \Pi^D(0, \lambda^D\bar{c}) - \Pi^D(\bar{c}, \bar{c})$.[24] Similarly, $\Delta\underline{\Phi}^k(\lambda^k)$ corresponds to the incremental payoff when lab i innovates and the other one is successful as well. In the duopoly, the incremental profit is $\Delta\underline{\Pi}_i^D(\lambda^D) \equiv \Pi_i^D(0,0) - \Pi_i^D(\lambda^D\bar{c}, 0)$. We can notice that when there is complete technology transfer, as in research joint-ventures, merger to monopoly, and in the limiting case $\lambda^D = 0$ in a duopoly, the incremental payoff of a second innovation is nil. Then, $\Delta\bar{\Phi}^k(0) \geq \Delta\underline{\Phi}^k(0) = 0$. When, instead, in the duopoly case, $\lambda^D \in (0, 1]$ we introduce the following:

Assumption 5: $\Delta\bar{\Pi}_i^D(\lambda^D) > \Delta\underline{\Pi}_i^D(\lambda^D)$ and $\Delta\bar{W}(\lambda^D) > \Delta\underline{W}(\lambda^D)$ for $\lambda^D \in (0, 1]$; $\Delta\bar{C}S(\lambda^D) > \Delta\underline{C}S(\lambda^D)$ for $\lambda^D < \bar{\lambda} < 1$.

Assumption 5 states that in a duopoly the equilibrium profits of a firm/lab and total welfare, increase more when the innovating firm leads rather than when it catches up. The same property does not apply to consumer surplus in general, since the ranking in the incremental CS depends on the degree of spill-over: when it is small (λ^D large) the cost of the inefficient firm (and the equilibrium prices) falls down moderately when only the rival innovates, whereas, when the firm catches up the innovating rival, the costs of both firms are efficient (and the prices are low). In this case, therefore, $\Delta\bar{C}S(\lambda^D) < \Delta\underline{C}S(\lambda^D)$. With spill-over high enough (low λ^D), instead, the opposite holds true.

This set of assumptions is met in a number of oligopoly models including Cournot and Bertrand with differentiated products.[25]

3.2 Time 2: investment

In this section we focus on (symmetric-transfers) interior equilibria, what requires parameter β to be sufficiently high.[26]

We can distinguish the duopoly, where the two firms set the investment independently, from the cooperative investment decision that takes place in the research joint-venture and merger to monopoly cases. There are two differences we have to take into account. First, in a duopoly each firm maximizes its profit, whereas in the cooperative case the investment is chosen to maximize joint profits. Second, according to our assumptions on the cooperative environments, the innovation, if developed, is fully transfered to all firms/units, whereas in a

[24] When there is complete spillover in a duopoly ($\lambda^D = 0$) and 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, $\Delta\bar{\Pi}_i^D(0) = 0$.

[25] See, e.g., Amir et al. (2014) for a proof that Assumptions 3 and 4 hold in a general setting.

[26] In Appendix II we consider the general case including asymmetric subsidies and interior or corner investments. We explicitly specify there the expressions of the thresholds on β that generates the interior vs. corner equilibria.

duopoly involuntary spillover imply partial imitation according to the parameter $\lambda^D \in [0,1]$.

The expected profits in a duopoly are therefore:

$$\begin{aligned}\pi_i^D(x_i, x_j; \lambda^D) &= (1-\mu)\Pi_i^D(0,0) + \mu\left\{x_i x_j \Pi_i^D(0,0)\right. \\ &\quad + x_i(1-x_j)\Pi_i^D(0,\lambda^D \overline{c}) + (1-x_i)x_j\Pi_i^D(\lambda^D\overline{c},0) \\ &\quad \left. + \left[(1-x_i)(1-x_j)\right]\Pi_i^D(\overline{c},\overline{c})\right\} \\ &\quad -\frac{(1-s_i)\beta}{2}x_i^2. \end{aligned} \tag{16}$$

The FOC[27] can be written as

$$\hat{x}_i^D(x_j;\lambda^D) = \max\left\{0, \frac{\mu\Delta\bar{\Pi}_i^D(\lambda^D)}{(1-s_i)\beta} - \frac{\mu\left[\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\underline{\Pi}_i^D(\lambda^D)\right]}{(1-s_i)\beta}x_j\right\}. \tag{17}$$

The term $-\mu\left[\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\underline{\Pi}_i^D(\lambda^D)\right] < 0$ under Assumption 5, implies that the best reply (17) is downward sloping, that is competition in investments is in strategic substitutes. This term captures the negative externality of a marginal increase in the other firm's investment x_j on firm i's marginal return of investment. Given Assumption 5, firm i's increase in profits when innovating is higher when competing with a laggard than with a front-runner. When the other firm 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.

In the research joint-venture and merger to monopoly case the investment is chosen to maximize joint profits anticipating the full transfer of innovation if research in either lab is successful. Hence, the profits, for $k = J, M$, are:

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

where $\Pi^k(.,.)$ are the industry profits (13).

Focussing on the case of symmetric (non discriminatory) transfers $s_i = s_j = s$, the equilibrium investment in the different market environments is described in the following proposition.

Proposition 2 (Investment with non-discriminatory transfers) *Suppose $s_i = s_j = s$:*

- *the unique symmetric equilibrium investment in the duopoly is:*

$$\hat{x}_i^D(s,s;\lambda^D) = \frac{\mu\Delta\bar{\Pi}_i^D(\lambda^D)}{(1-s)\beta + \mu\left(\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\underline{\Pi}_i^D(\lambda^D)\right)} \tag{19}$$

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

for $i = 1, 2$;

- *the unique symmetric equilibrium investment in the merger to monopoly and research joint-venture is*

$$\hat{x}_i^k(s,s) = \frac{\mu \Delta \bar{\Pi}^k}{(1-s)\beta + \mu \Delta \bar{\Pi}^k} \tag{20}$$

for $i = 1, 2$, where $k = J, M$.

Proof: See Appendix I.

The symmetric equilibrium investment in all environments is increasing in the transfer, in the probability of disruption, and in the incremental profits when the innovation is realized. It is instead decreasing in the steepness of the R&D marginal cost. Notice that in a research joint-venture the profit maximizing investment is positive only if $\Delta\bar{\Pi}^J = \Pi^D(0,0) - \Pi^D(\bar{c},\bar{c}) > 0$. If, however, the equilibrium mark-up over marginal costs is constant when firms have the same marginal cost, as it happens in the Bertrand with homogeneous producgs or in the Hotelling duopoly with covered market, the duopolists do not gain from running the R&D together and then sharing the innovation, that is $\Delta\bar{\Pi}^J = 0$, since the profits, given by a fixed mark-up over common marginal costs, do not change if the investment is successful, while a positive investment erodes the net profits. In this case, then $\hat{x}_i^J(s,s) = 0$.

3.3 Time 1: Welfare-maximizing investment and optimal transfers

We now turn to time 1, where the social planner sets the optimal transfers. As already discussed in Section 2, when there is no distortionary cost of public funds, we can represent the problem of the social planner as directly picking the welfare-maximizing level of investment and then setting the transfer such that the private firms implement those investments.[28]

The expected welfare as a function of investment x_i^k and x_j^k in the market environment $k = D, J, M$ is:

$$\begin{aligned} w^k(x_i^k, x_j^k; \lambda^k) \quad = \quad & (1-\mu)W^k(0,0) + \mu\left\{x_i^k x_j^k W^k(0,0)\right. \\ & + (x_i^k + x_j^k - 2x_i^k x_j^k)W^k(0, \lambda^k \bar{c}) + (1-x_i^k)(1-x_j^k)W^k(\bar{c},\bar{c})\left.\right\} \\ & -\frac{\beta}{2}\left(\left(x_i^k\right)^2 + \left(x_j^k\right)^2\right). \end{aligned} \tag{21}$$

[28] We remove this assumption in subsection 5.3. Note that this solution method does not apply when public funds are costly.

Proposition 3 (Welfare-maximizing investments) *The symmetric welfare maximizing investment in a duopoly is:*

$$\tilde{x}_i^D = \tilde{x}_j^D = \tilde{x}^D(\lambda^D) = \frac{\mu\Delta\bar{W}^D(\lambda^D)}{\beta + \mu(\Delta\bar{W}^D(\lambda^D) - \Delta\underline{W}^D(\lambda^D))}, \tag{22}$$

whereas in a research joint-venture or merger to monopoly we have:

$$\tilde{x}^k = \frac{\mu\Delta\bar{W}^k}{\beta + \mu\Delta\bar{W}^k} \tag{23}$$

for $k = J, M$.

Proof: See Appendix I.

The symmetric welfare-maximizing investment in all environments is increasing in the probability of disruption and in the welfare gain from innovating, and decreasing in the marginal cost of R&D, as we already observed for the private investment.

Implementation. The following proposition identifies the transfers 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.

Proposition 4 (Optimal transfers) *In the different market environments the optimal transfers that implement the welfare maximizing investment are:*

- *in the **research joint venture and merger to monopoly**, a subsidy:*

$$\tilde{s}_i^k = \tilde{s}_j^k = 1 - \frac{\Delta\bar{\Pi}^k}{\Delta\bar{W}^k} \in (0,1) \tag{24}$$

  for $k = J, M$;

- *in a **duopoly**, a transfer:*

$$\tilde{s}_i^D(\lambda^D) = \tilde{s}_j^D(\lambda^D) = 1 - \frac{\Delta\bar{\Pi}_i^D(\cdot)}{\Delta\bar{W}^D(\cdot)} - \frac{\mu\left[\Delta\bar{W}^D(\cdot)\Delta\underline{\Pi}_i^D(\cdot) - \Delta\bar{\Pi}_i^D(\cdot)\Delta\underline{W}^D(\cdot)\right]}{\beta\Delta\bar{W}^D(\cdot)} \gtreqless 0. \tag{25}$$

- *sufficient conditions for a subsidy in duopoly are:*

- $\Delta\bar{C}S^D - (\Pi_i^D(0, \lambda^D\bar{c}) - \Pi_i^D(\lambda^D\bar{c}) > 0$ *or*

$$\Delta\bar{W}^D(\Delta\bar{\Pi}_i^D - \Delta\bar{\Pi}_i^D) + \left(\Delta\bar{W}^D - \Delta\underline{W}^D\right)\left[\Delta\bar{C}S^D - (\Pi_i^D(0, \lambda^D\bar{c}) - \Pi_i^D(\lambda^D\bar{c})\right] > 0; \tag{26}$$

- *the transfer is, instead, a tax if β is sufficiently low (still consistent with the equilibrium conditions) and (26) is negative.*

Proof: See Appendix I.

Proposition 4 shows that with a research joint-venture or a merger to monopoly, there is under-investment, requiring the social planner to subsidize research, since firms do not interalize the social benefits of innovation, namely the increase in consumers' surplus. Given assumption 3, the subsidies in a monopoly are always positive and lower than 1.

We already observed that in a research joint-venture the profit maximizing investment may be nil if the firms gains a constant mark-up over a common marginal costs (e.g. Bertrand with homogeneous products or Hotelling duopoly). The following corollary covers this case.

Corollary 5 (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 withhomogeneous products 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 ($\tilde{s}_i^J = 1$) and fix the level of investment ($x_i^J = \tilde{x}^J$), equivalent to managing directly the research labs.*

In a duopoly, instead, we may have over- or under-investment compared with the socially optimal level. From (25) we observe that when β is sufficiently large, the third term becomes negligible and the transfer is positive (a subsidy). When, however, β is low, still meeting the conditions for an interior solution, and the expression in squared brackets is positive, the optimal transfer may be a tax. Looking at the condition (26), the term $\Delta\bar{C}S^D(\lambda^D) - \left[\Pi_i^D(0,\lambda^D\bar{c}) - \Pi_i^D(\lambda^D\bar{c},0)\right]$ can be positive or negative. If positive, the condition is met and the social planner opts for a subsidy. When, instead, it is negative and sufficiently large in absolute value, (26) may fail, implying a tax for sufficiently low β. This expression has a clear economic interpretation that links the private and social incentives to innovate.

When setting the profit maximizing investment, each firm takes into account the incremental profits when it innovates while the other lags behind, compared with the opposite outcome when only the rival is successful, $\Pi_i^D(0,\lambda^D\bar{c}) - \Pi_i^D(\lambda^D\bar{c},0)$. This difference is labelled in different ways (e.g. competitive effect, strategic innovation differential) in the innovation literature[29] and plays a key role in the incentives to gain leadership through innovation. If this difference is large, it boosts the private investment. The welfare maximizing investment, in turn, is driven by the incremental consumers' surplus when only one firm innovates $\Delta\bar{C}S^D(\lambda^D) = CS^D(0,\lambda^D\bar{c}) - CS^D(\bar{c},\bar{c})$.

Consider the case when the spillovers are high, corresponding to a low λ^D, and only one firm innovates. Also the non-innovating firm is able to implement a low cost $\lambda^D\bar{c}$ through imitation, pushing down the equilibrium prices.

[29]See Aghion et al. (2005).

Then, the increase in consumer surplus is large while the incremental profits when innovating vs. not innovating is moderate. In this case, therefore, $\Delta\bar{C}S^D(\lambda^D) - \left[\Pi_i^D(0, \lambda^D\bar{c}) - \Pi_i^D(\lambda^D\bar{c}, 0)\right] > 0$, (26) is met and the private incentives fall short of the social ones, requiring a subsidy. Conversely, when the involuntary spill-overs are limited (high λ^D), the non-innovating firm remains inefficient, the innovator experiences a strong business stealing effect on the laggard, and the private incentives are strong while the benefits of innovation transferred to consumers through low prices are small. In this case, the firms over-invest and it is socially optimal to tax research to reduce private investment.[30]

4 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. 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 consider 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.

4.1 Comparison of private and social investments

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

Let us first consider the effect of market size on investment. Since, by Assumption 2, the market size affects proportionally the level of profits and welfare in any cost configuration, the differential profits and welfare are proportional to

[30] See also the analysis of optimal taxes vs. subsidies in Grossman et al. (2024), who also find that the optimal policy might be a tax, due to a similar 'business stealing' argument.

the market size as well. Comparing the benchmark case of separate monopoly markets of size n, analyzed in Section 2, that we relabel now for convenience with superscript S (separated monopoly), and that of an integrated market of double the size, we prove in the Appendix I, Lemma 10 the following:

$$\begin{aligned} \Delta\bar{\Pi}^M(2n) &= 2\Delta\Pi^S(n) \\ \Delta\bar{W}^M(2n) &= 2\Delta W^S(n). \end{aligned}$$

where $\Delta\Pi^S(n) \equiv \Pi(0;n) - \Pi(\bar{c};n)$ and $\Pi(\cdot)$ is given by (1).

Similarly, $\Delta W^S(n) \equiv W(0;n) - W(\bar{c};n)$ and $W(\cdot)$ is given by (2). In other words, when the market size doubles, the increase in profits and welfare when the innovation is realized doubles as well. Consequently, the optimal subsidies in segmented markets and in a merger to monopoly are the same: $\tilde{s}_i^M = 1 - \frac{\Delta\bar{\Pi}^M}{\Delta\bar{W}^M} = \tilde{s}^S$, 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.

4.1.1 Ranking of profit-maximizing investments

Several factors may potentially affect the comparison in private investments in the different 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 in an integrated market. Third, in all cases 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 suggests that the incentive to innovate is larger in a duopoly.[31] Finally, in a duopoly involuntary spillovers reduce the incentives to invest, whereas spillovers are of course immaterial in segmented monopolies and, by assumption, they are complete within a merged entity or among research joint-venture partners. In what follows, we identify and discuss these effects within our reduced form framework and provide two applications to Bertrand and Cournot competition with homogeneous products.

In the following proposition we compare the (interior) equilibrium investments that the firm(s) choose when no subsidy is in place.

Proposition 6 (Ranking of profit-maximizing investment) *Consider the market environments S, D, J and M, where the segmented market is of size n and the integrated market of size $2n$. Suppose there are* ***no transfers*** *in all cases. Then:*

[31] The Arrow replacement effect (Arrow, 1962) says that the incentives to innovate are stronger in a competitive market than in a monopoly one. It is based on the comparison of the increase in profits when a firm adopts a cost-reducing innovation vs. when it does not innovate. In our notation, $\Pi_i^D(0,\bar{c}) - \Pi_i^D(\bar{c},\bar{c}) > \Pi^M(0,0) - \Pi^M(\bar{c},\bar{c})$, or $\Delta\bar{\Pi}_i^D(1) > \Delta\bar{\Pi}^M$.

- *The investment made by the merged entity in each lab in the integrated market is always larger than that of the segmented monopolists in each individual market:* $\hat{x}^M(2n) > \hat{x}^S(n)$.

- *In an integrated market:*

  - *The investment in case of a research joint-venture is never higher than that of a merger to monopoly:* $\hat{x}_i^J \leq \hat{x}_i^M$.
  - *If the Arrow replacement effect holds, that is* $\Delta\bar{\Pi}_i^D(1) - \Delta\bar{\Pi}^M > 0$, *there exists a threshold* $\hat{\lambda} \in (0,1)$ *such that the investment* $\hat{x}^D(\lambda^D)$ *of each duopolist is higher (lower) than the investment* $\hat{x}^M$ *of the merged entity in each lab when* $\lambda^D > \hat{\lambda}$ $(\lambda^D < \hat{\lambda})$.
  - *If, instead, the Arrow replacement effect does not hold, we cannot rank in general the investment in the duopoly and in the merger to monopoly.*

Proof: see Appendix I.

Proposition 6 first of all establishes that, keeping constant the market environment, market size boosts private investment. More precisely, this holds when we compare segmented monopolies and a merger to monopoly in the integrated market. The larger investment of the merged entity in each of its labs 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, with an increase in profits that is higher for the merged entity than for the partner duopolists in the joint-venture, which always compete with symmetric costs.

In case of duopoly, instead, asymmetric cost configurations may arise if there are only limited spillovers, providing an incentive to invest. Indeed, the investment of duopolists is larger than that of the merged entity if imitation is limited. If the Arrow replacement effect holds, the incentives to innovate of a duopolist when no spill-over occurs is stronger than that of the merged entity. This positive effect still prevails if imitation is limited (λ^D sufficiently high). Hence, for high enough λ^D, the highest level of investment is realized in an integrated duopoly market. When, instead, the Arrow replacement effect holds but spillovers are substantial, the investment of the merged entity dominates.

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 $Q = 2n(1-p)$, where n is the size of one of the two equal-sized markets that are integrated. By applying (20) and (5) we obtain one unit's optimal investment under integrated monopoly absent subsidies and the optimal investment of the local monopolist:

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

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, maintaining the same demand curve as in the previous example. The equilibrium prices for given combination of marginal costs are $p_i^D(0,0) = 0$, $p_i^D(0,\lambda\bar{c}) = p_j^D(\lambda\bar{c},0) = \lambda\bar{c}$ and $p_i^D(\bar{c},\bar{c}) = \bar{c} < 1/2$, since we assume a non-drastic difference in costs. The equilibrium profits are $\Pi^D(0,0) = \Pi^D(\bar{c},\bar{c}) = \Pi^D(\lambda\bar{c},0) = 0$ and $\Pi^D(0,\lambda\bar{c}) = 2n\lambda\bar{c}(1-\lambda\bar{c})$. The incremental profits, therefore, are:

$$\begin{aligned} \Delta\bar{\Pi}^D &= \Pi^D(0,\lambda\bar{c}) - \Pi^D(\bar{c},\bar{c}) = 2n\lambda\bar{c}(1-\lambda\bar{c}) \\ \Delta\underline{\Pi}^D &= \Pi^D(0,0) - \Pi^D(\lambda\bar{c},0) = 0. \end{aligned}$$

The symmetric equilibrium investments in case of duopoly are:

$$\hat{x}_i^D(\lambda) = \frac{2\mu n\lambda\bar{c}(1-\lambda\bar{c})}{\beta + 2\mu n\lambda\bar{c}(1-\lambda\bar{c})}.$$

Since $\hat{x}_i{}^M = \frac{\mu n(2-\bar{c})\bar{c}}{2\beta+\mu n(2-\bar{c})\bar{c}}$, one can check that $\hat{x}_i^D > \hat{x}_i^M$ for $\lambda > 1/2$ 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, $\Delta\bar{\Pi}^J = \hat{x}_i^J = 0$. Each firm knows that if its innovation is successful 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:

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

$$\Delta\bar{\Pi}^D(\lambda) = \frac{2n\bar{c}(1+\lambda)\left[2-\bar{c}(1-\lambda)\right]}{9}; \quad \Delta\underline{\Pi}^D(\lambda) = \frac{8n\lambda\bar{c}(1-\lambda\bar{c})}{9}. \tag{27}$$

We can then use (19) to find the equilibrium investment (for $s_i = s_j = 0$):

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

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

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

which can only hold if λ and $\bar{c}$ are sufficiently high, as Figure 1 shows.

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

$$\Delta\underline{\Pi}^J = 0; \quad \Delta\bar{\Pi}^J = \Pi^D(0,0) - \Pi^D(\bar{c},\bar{c}) = \frac{4n\bar{c}(2-\bar{c})}{9}.$$

By applying (20) we have:

$$\hat{x}^J = \frac{4n\bar{c}\mu(2-\bar{c})}{9\beta + 4n\bar{c}\mu(2-\bar{c})}.$$

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

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

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.

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 profit-maximizing investments obtained in the different configurations, i.e., for $k = D, M, J$ into (21) 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.

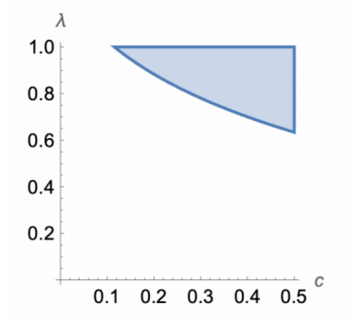

Figure 1: Region where $\hat{x}^D \geq \hat{x}^M$. Figure drawn for $\beta = 1/2$, $\mu = 1/4$, $n = 1$.

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 in a joint-venture. As one can see, this occurs when λ is sufficiently high, namely when the appropriability of the investment is sufficiently strong. 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.

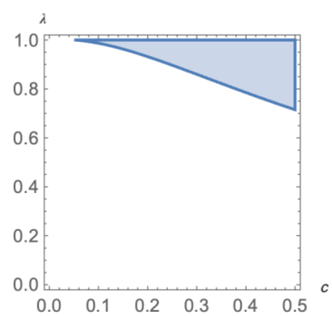

Figure 2: Region of (c, λ) where, absent subsidies, welfare is higher under duopoly than the research joint venture. Figure drawn for $\beta = 1$, $\mu = 1/4$, $n = 1$.

4.1.2 Ranking of welfare-maximizing investments

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

Proposition 7 (Ranking of welfare-maximizing investment) *Comparing the symmetric socially optimal investment in the different market environments:*

- *the welfare-maximizing investment of the merged entity in each lab is always larger than that of the segmented monopolists:* $\tilde{x}^M(2n) > \tilde{x}^S(n)$*;*
- *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.*

Proof: see Appendix I.

Proposition 7 shows the ranking in investment driven by welfare maximization. It is important to recall that what ultimately matters in affecting the comparison of welfare-maximizing investments in all market environments is not the ranking in the *level* of welfare, but in its *increase* when innovating. 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, making consumers and firms better off. 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, when only one R&D project is successful, the innovator retains at least some cost advantage compared with the laggard.

Comparing the results in Proposition 6 and 7, 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 striking 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 By making use of the expressions derived above and applying (23) and (22) we obtain:

$$\begin{aligned}
\tilde{x}^M &= \frac{3\mu\bar{c}n(2-\bar{c})}{8\beta+3\mu\bar{c}n(2-\bar{c})}, \\
\tilde{x}^D(\lambda^D) &= \frac{\mu\bar{c}n(2-\bar{c}-2\bar{c}\left(\lambda^D\right)^2)}{2\beta+\mu\bar{c}n(2-\bar{c}-2\bar{c}\left(\lambda^D\right)^2)}, \\
\tilde{x}^J &= \frac{\mu\bar{c}n(2-\bar{c})}{2\beta+\mu\bar{c}n(2-\bar{c})}
\end{aligned} \tag{28}$$

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

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

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^D. 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 $\lambda^D > .88$.

Example 4. Comparisons of welfare maximizing investments: quantity competition Let us consider now the case when firms choose quantities. First, note that the optimal public investments for the merged entity are already given by expression (28). By inserting the expressions given by (27) into (23) and (22) we obtain the social planner's investment choice for duopoly and a joint-venture when firms compete in quantities, as:

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

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

4.2 Welfare ranking of market environments

Although a ranking of market environments with respect to private and social investments is of independent interest in a policy perspective, a comprehensive comparison requires to look at the expected welfare computed at the socially optimal investment in all cases, $w^k(\tilde{x}^k, \tilde{x}^k)$ for $k = D, J, M$. In particular, we want to analyze whether research joint-ventures yield not only the highest level

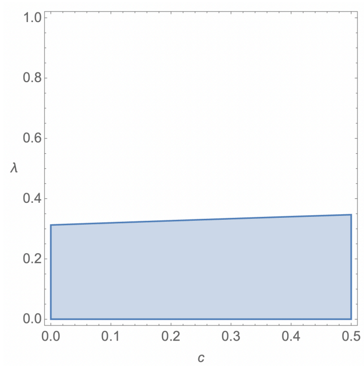

Figure 3: Region where $\tilde{x}^D \geq \tilde{x}^M$. Figure drawn for $\beta = 1/2$, $\mu = 1/5$, $n = 1$.

of welfare-maximizing investment, but also the best performance in terms of welfare compared with the other market environments. The following proposition confirms this conjecture.

Proposition 8 (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.*

Proof: see Appendix I.

Hence, the ranking in welfare maximizing investment is replicated also when considering the expected welfare associated, in each market environment, to these investments. Interestingly, while the ranking in social investment is driven by the increase in welfare due to innovation, the ranking of expected welfare depends on its level in the different cost realizations. The overall ranking of expected welfare at the socially optimal investment, therefore, derives from the interaction of increase and level of welfare in the different environments and cost realizations.

We started this Section mentioning two proposals at the core of the current industrial policy debate in Europe. The first is that a deeper market integration among European member states could promote firms' productivity. We have indeed found that the equilibria outcomes in an integrated market economy would dominate those obtained in two segmented economies.

The second one consists in calling for a relaxation of competition so as to create 'European champions' better able to compete in the international markets. Focusing on an integrated market and comparing the different environments for given level of investment, we found that research joint ventures welfare-dominate duopolies, allowing a complete technology transfer, and are also superior to a merger to monopoly since they promote 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.

If we limited our attention to a comparison between duopoly and merger — for instance under merger control — the results are ambiguous. Even under the favourable assumption that laboratories of the merged entity would fully share their innovations, a merger would lead to higher investment only if technological spillovers among independent duopolists are high enough. However, even in this case one should recall that investment levels are just one dimension to assess, and that a merger would affect negatively consumer surplus. To sum up, our results do not support a relaxation of merger control, but they do support a favourable approach of R&D cooperative agreements.

5 Extensions

In this section we discuss three extensions of our analysis that are relevant in the current debate. First, we discuss local content requirement policies. They consist of measures aimed at stimulating an improvement of the efficiency of domestic productions, based on the condition that at least a fraction of inputs used to assemble the final products are produced in the home country. They have been adopted among others in the US Inflation Reduction Act. Secondly, we consider the case where the size of the technology gap to be filled, and/or the likelihood of trade disruption, is so large to make it desirable to concentrate all research activities in a single lab. Finally, we introduce the cost of public funds.

5.1 Learning effects and local content requirements

Let us consider, in the framework of the benchmark local monopoly, the case where the improvement in the production technologies derives from learning by doing in production rather than from an investment in research.[32] We can adapt our analysis referring to a two-period setting. The firm can initially 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 local production x.[33] A fraction s of costs arising from producing x in the inefficient

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

[33] More precisely, by producing an amount x in the first period in the inefficient plant at total cost $C(x_1) = \beta x^2/2$, with probability x 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).

local plant is covered through a public subsidy to local production. Alternatively, the social planner may impose a minimum level of local production x to receive the subsidy (local content requirement: LCR). This same outcome may also be implemented imposing to the firm a minimum level of LCR rather than recurring to a subsidy, shifting the burden from the public budget to the private profits. In Appendix II we fully develop the analysis, that here we summarize in the following lemma.

Lemma 9 (Subsidy to local production) *The results of the R&D model extend to the case of intertemporal scale economies. In particular, a subsidy to domestic production would achieve the optimal level of domestic production in the first period. Equivalently, the imposition of a local content production equal to (9) 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 mitigate the risk of 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.

5.2 Significant technology gaps and research concentration

So far we have derived the comparison of market environments focussing on interior symmetric equilibria, with both firms/labs investing. When research is managed cooperatively, as in the joint-venture and merger cases, this solution has an advantage and a cost. On the positive side, it limits the amount of investment on each lab, which is efficient when there are significant decreasing returns from the lab size. On the negative side, however, running parallel research processes might imply a wasteful duplication, since with positive probability the innovation is developed in both labs. Then, the choice to concentrate research in a single large lab or splitting it into separate units is affected by the degree of decreasing returns in research activity. This trade-off, in turn, must be assessed compared with the benefits of developing the innovation, which depend on the expected efficiency improvements realized through the innovation by closing the gap with the best practice technology when trade disruption occurs.

All these factors may be identified if, for instance, we consider the conditions for a symmetric solution in the research joint-venture case, which outperforms the other market enviroments. The condition for a symmetric solution of the social planner's problem is

$$\beta > \mu \left[W^D(0,0) - W^D(\bar{c},\bar{c}) \right]. \tag{29}$$

Given the expected social benefits of innovation, summarized in the expression on the RHS, we need a steeply increasing marginal cost of research (a sufficiently high β) to induce the social planner to keep active two parallel and smaller labs ($\tilde{x}^J < \frac{1}{2}$) notwithstanding the cost of duplication, and developing the innovation with a probability $\tilde{x}^J(2-\tilde{x}^J)^2$ that is lower than 1.

However, the term on the RHS is increasing with the probability of disruption and the size of the technology gap filled by the innovation. Hence, when the probability of disruption and/or the technology gap are substantial, it may be socially efficient to concentrate all the research in a single large lab. In Appendix III we fully characterize this case.

Summarizing the main results, when the conditions for a welfare maximizing symmetric interior solution are 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 ($\tilde{x}^J = 1$) and shutting down the other, with an overall increase in the probability of discovery (equal to 1 in our setting[34]). Research joint-ventures, even with asymmetric solutions, welfare-dominate a duopoly market environment: in this latter environment the imperfect transfer of the innovation leads the social planner to keep open a second lab at a smaller scale, even if investment in the larger one allows to develop the efficient technology with certainty in one firm. While total investment in a duopoly exceeds that in a research joint-venture, the spread of innovation is higher in the latter. Similarly, comparing the research joint venture with a merger to monopoly, in both cases the social planner induces an investment that reaches the success with probability 1, but the more competitive market outcome with research joint-ventures welfare dominates the merger to monopoly.

The asymmetric investment outcome is implemented by applying symmetric subsidies that the joint-venture cashes in only for the activity of the running lab, since the subsidy does not entirely cover the cost of research. The lower the cost parameter, β, and/or the higher the technology gap $\Delta\bar{W}^D$, the lower the subsidies needed, up to a point where there is no need of public subsidies to implement the socially optimal outcome.

Our result, therefore, suggests that, when the technology gap is significant and the probability of disruption substantial, promoting the socially efficient policy prescribes to support joint-ventures and concentrating research in a single 'European Lab Champion', while preserving competition in the product market.

5.3 Cost of public funds

Our final extension, based on the benchmark case of a monopolistic supply chain developed in Section 2, considers the case where transferring funds to the private

[34] 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.

firm (or financing a public lab) entails a distortionary unit cost $t > 0$. In this case, the private and social costs of R&D diverge, the latter being $\frac{\beta(1+st)x^2}{2}$. The optimal subsidy satisfies the FOC $\frac{dw}{ds} = \frac{dw}{dx}\frac{d\hat{x}(s)}{ds} - stx = 0$, and therefore $\frac{dw}{dx} > 0$ at the optimal social investment: with a cost of public funding, the social planner desires to implement a lower level of investment.[35]

To find the optimal subsidy and investment explicitly, let us consider social welfare:

$$w(\hat{x}(s)) = (1-\mu)W(0) + \mu\left\{W(\overline{c}) + \hat{x}(s)\Delta W\right\} - \frac{\beta(1+st)}{2}\hat{x}(s)^2,$$

where $\hat{x}(s)$ is given by (5). Then, the welfare maximizing subsidy is equal to:

$$\tilde{s}(t) = \frac{2\Delta W - (2+t)\,\alpha\Delta\Pi}{2\Delta W + t\alpha\Delta\Pi},$$

implementing the welfare maximizing investment

$$\tilde{x}(t) = \hat{x}(\tilde{s}(t)) = \frac{\mu\,(2\Delta W + t\alpha\Delta\Pi)}{2\beta\,(1+t)},$$

where both the subsidy and the investment are decreasing in the cost of public funds.[36]

6 Conclusions

The debate on the resilience of the European economy to supply chain disruptions 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 efficient local inputs, by offering a local alternative to imports 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, we find that an integrated internal market allows to boost investments, a wider diffusion of innovation and a higher social welfare. Therefore, our results strongly support the claim made in some policy reports that a deeper market integration among European member states would promote firms' productivity.

[35] This point is noticed also in Juhasz et al (2024), p. 14. A distortion might occur, in either direction, also in case the objective of the social planner is not social welfare.

[36] If $t > \frac{2(\Delta W - \alpha\Delta\Pi)}{\alpha\Delta\Pi}$ the social planner does not intervene, that is $\tilde{s}(t) = 0$.

Fourth, comparing different environments 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. If we ignore cooperation in R&D and we just compared duopoly and merger equilibria, mergers would lead to higher investments only if R&D spillovers among independent duopolists were large. But even in that case, welfare would not necessarily increase because of the negative effects on consumer surplus. Therefore, we find no support for the claim made by some commentators and policymakers that relaxing competition and favouring market consolidation would foster the productivity of European firms by making them more efficient and better able to compete in the international markets.

Fifth, when the net benefit from R&D is larger (due to lower costs of investment, 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.[37]

We also think it is appropriate to remind the reader of the usual arguments which caution against too naive reliance on public subsidies. They include not only the cost of public funding, as analysed formally above, but also, among the others: the risk of over-compensating firms, namely subsidising them for investment they would do anyhow, in particular when the costs and benefits of research activity are not fully observed by the public authorities;[38] the possible distortions in the internal market occurring when some member states have weaker public budget constraints and hence can subsidise domestic firms significantly more than other states;[39] and the well-known arguments that underline that governments might choose to protect particular sectors (or even firms) for political economy reasons that have nothing to do with the existence of externalities and market failures such as those discussed in this paper.[40]

Finally, we would like to stress some of the possible limitations of our approach. In this respect, our analysis is based on a partial equilibrium model, which inevitably does not allow us to consider some important aspects such as the macroeconomic consequences of the shocks,[41] or the fact that supply

[37]Antitrust authorities have warned of the possibility that research joint-ventures might sometimes provide rivals with a forum where to discuss product market strategies. To the extent that collusion might be a by-product of cooperation in R&D, one might consider a public R&D firm as a preferable alternative.

[38]To this purpose, in its state aid control enforcement, the European Commission routinely looks for the 'incentive effect' of state aid.

[39]For this reason, it would be desirable if in the EU subsidies were decided at the supranational level by the European Commission, rather than being distributed by each member state to its domestic firms.

[40]In this perspective, we find particularly useful the work done by Arjona et al. (2023), who develop objective criteria to identify industries subject to the risk of supply-chain disruption.

[41]The reader might refer to the general equilibrium models mentioned in the literature

chain failures might lead to input distortions and hence create potential other sources of inefficiency.[42] Further, we focus on some particular policy responses to exogenous shocks, notably R&D subsidies, the promotion of R&D cooperative agreements, the creation of public research firms, and local content requirement policies. But of course other possible policy instruments might be foreseen. These might include, for instance, international sourcing diversification (it might be less costly to rely on suppliers from countries with uncorrelated geopolitical risk than produing inputs locally) or stockpiling (in particular for some inputs with relatively low storage cost).

Additionally, we develop our analysis assuming that R&D costs and outcomes are perfectly observed by the enforcer. Adding asymmetric information would enrich the analysis but also make it more complex, and it is left to future research.

We should also note that in our paper we focus on a completely exogenous geopolitical risk which might affect imports. However, there might be risks of supply chain disruption which have a different, not necessarily foreign, origin. Think for instance of electricity outages, natural disasters, or cyberattacks. Our analysis might help understand possible policy responses for those disruptive events too.[43]

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review in the Introduction.

[42]See e.g., Fried and Lagakos (2023)

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7 Appendix I: Proofs

Proof of Proposition 2. Let us consider the case of symmetric subsidies: $s_i = s_j = s$. If the market environment is a duopoly and $\beta > \frac{\mu\left(\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\underline{\Pi}_i^D(\lambda^D)\right)}{(1-s)}$, the best reply for firm i is

$$\hat{x}_i(x_j;\lambda) = \max\left\{0, \min\left\{\frac{\mu\Delta\bar{\Pi}_i^D(\lambda^D)}{(1-s)\beta} - \frac{\mu\left[\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\underline{\Pi}_i^D(\lambda^D)\right]}{(1-s)\beta}x_j, 1\right\}\right\}. \quad (30)$$

and the Nash equilibrium is symmetric and stable at (19). Moreover, since the best replies are linear, they never intersect out of the equilibrium, establishing uniqueness.

If the market environment is J or M, the investment is chosen cooperatively and the innovation fully transferred, implying $\lambda^k = 0 = \Delta\underline{\Pi}^k(\lambda^k)$. If $\beta > \frac{\mu\Delta\bar{\Pi}^k}{1-s}$, with symmetric subsidies the FOC and SOC are

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

The SOC for an interior maximum are met if $\beta > \frac{\mu\Delta\bar{\Pi}^k}{1-s}$. The two conditions on β ensure that the equilibrium investments are interior. ■

Proof of Proposition 3.

Suppose the market environment is a duopoly. If $\beta > \mu\left[\Delta\bar{W}^D(\lambda^D) - \Delta\underline{W}^D(\lambda^D)\right]$, the optimal interior solution from the social planner's standpoint in case of a duopoly is identified by the FOC's and SOC's:

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

The inequality in the third line, given Assumption 5, can be rewritten as $\beta > \mu\left[\Delta\bar{W}^D(\lambda^D) - \Delta\underline{W}^D(\lambda^D)\right]$. If it holds, the social planner is willing to implement the symmetric level of investment (22).

Suppose, then, that the market environment is $k = J, M$ and that $\beta > \mu\Delta\bar{W}^k$. Since the innovation is fully transferable, $\Delta\underline{W}^k = 0$. The FOC's and SOC's are:

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

If $\beta > \mu\Delta\bar{W}^k$ the maximum is interior and symmetric at ((23)). ■

Proof of Proposition 4. Consider market environments $k = J, M$. The conditions for an interior solution $\hat{x}^k(s)$ in the profit maximization investment is $(1-s)\beta > \mu\Delta\bar{\Pi}^k$. Setting $\hat{x}^k(s) = \tilde{x}^k$ and solving for the subsidy we get $\tilde{s}^k = 1 - \frac{\Delta\bar{\Pi}^k}{\Delta\bar{W}^k}$. Substituting in the previous condition: $(1-\tilde{s}^k)\beta > \mu\Delta\bar{\Pi}^k$ we obtain $\beta > \mu\Delta\bar{W}^k$ which guarantees that an interior symmetric solution $\tilde{x}^k$ in the social planner problem exists. Finally, we observe that $\tilde{s}^k \in (0,1)$.

Let us move now to the duopoly case. The conditions for a stable symmetric Nash equilibrium $\hat{x}^D(s,\lambda^D)$ is $(1-s)\beta > \mu\left[\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\underline{\Pi}_i^D(\lambda^D)\right]$. Equating $\hat{x}^D(s,\lambda^D) = \tilde{x}^D$ and solving for the subsidy we obtain (skipping the reference to λ^D)

$$\tilde{s}^D = 1 - \frac{\Delta\bar{\Pi}_i^D}{\Delta\bar{W}^D} - \frac{\mu\left[\Delta\bar{W}^D\Delta\underline{\Pi}_i^D - \Delta\underline{W}^D\Delta\bar{\Pi}_i^D\right]}{\beta\Delta\bar{W}^D}.$$

Then, substituting in the previous expression we obtain the condition

$$\beta > \frac{\Delta\bar{\Pi}_i^D\left(\Delta\bar{W}^D + \Delta\underline{W}^D\right) - 2\Delta\bar{W}^D\Delta\underline{\Pi}_i^D}{\Delta\bar{\Pi}_i^D} \equiv \hat{\beta}^D,$$

which ensures that a stable Nash equilibrium $\hat{x}^D(\tilde{s}^D,\lambda^D)$ exists at the optimal subsidy $\tilde{s}^D$. Further, to ensure a welfare maximazing symmetric interior solution $\tilde{x}^D$ exists, the condition $\beta > \mu\left(\Delta\bar{W}^D - \Delta\underline{W}^D\right) \equiv \tilde{\beta}^D$ must be met. Hence, the optimal subsidy is $\tilde{s}^D$ if $\beta > \max\left\{\hat{\beta}^D, \tilde{\beta}^D\right\}$. Simple algebra shows that $\tilde{\beta}^D > \hat{\beta}^D$ if and only if $\Delta\bar{W}^D\Delta\underline{\Pi}_i^D - \Delta\underline{W}^D\Delta\bar{\Pi}_i^D > 0$.

Turning to the sign of the transfer $\tilde{s}^D$, it is positive for

$$\beta > \frac{\mu\left[\Delta\bar{W}^D\Delta\underline{\Pi}_i^D - \Delta\underline{W}^D\Delta\bar{\Pi}_i^D\right]}{(\Delta\bar{W}^D - \Delta\bar{\Pi}_i^D)} \equiv \beta^+,$$

where the denominator is positive while in general we cannot sign the numerator. If $\Delta\bar{W}^D\Delta\underline{\Pi}_i^D - \Delta\underline{W}^D\Delta\bar{\Pi}_i^D \leq 0$ the transfer is positive (subsidy) for any value of β, including those that ensure that the equilibrium solution exists in the firms' and social planner's problems. If, instead, $\Delta\bar{W}^D\Delta\underline{\Pi}_i^D - \Delta\underline{W}^D\Delta\bar{\Pi}_i^D > 0$, we cannot exclude that the optimal transfer is a tax ($\tilde{s}^D < 0$). More precisely, when

$\Delta\bar{W}^D\Delta\underline{\Pi}_i^D - \Delta\underline{W}^D\Delta\bar{\Pi}_i^D > 0$ the conditions for the existence of the equilibrium are met if $\beta > \tilde{\beta}^D$, since this conditions ensures that also the stable Nash equilibrium condition holds true. Then, if $\tilde{\beta}^D < \beta^+$, for $\beta \in \left(\tilde{\beta}^D, \beta^+\right)$ the optimal transfer $\tilde{s}^D$ exists and is a tax. If, instead, $\tilde{\beta}^D \geq \beta^+$, the social planner always opts for a subsidy. The condition $\tilde{\beta}^D \geq \beta^+$ can be rewritten as

$$\Delta\bar{W}^D\Delta\underline{\Pi}_i^D - \Delta\underline{W}^D\Delta\bar{\Pi}_i^D < (\Delta\bar{W}^D - \Delta\bar{\Pi}_i^D)\left(\Delta\bar{W}^D - \Delta\underline{W}^D\right)$$

or

$$\begin{aligned} & \Delta\bar{W}^D(\Delta\bar{\Pi}_i^D - \Delta\bar{\Pi}_i^D) + \left(\Delta\bar{W}^D - \Delta\underline{W}^D\right)(\Delta\bar{W}^D - 2\Delta\bar{\Pi}_i^D) \\ = \;& \Delta\bar{W}^D(\Delta\bar{\Pi}_i^D - \Delta\bar{\Pi}_i^D) + \left(\Delta\bar{W}^D - \Delta\underline{W}^D\right)\left[\Delta\bar{C}S^D - (\Pi_i^D(0, \lambda^D\bar{c}) - \Pi_i^D(\lambda^D\bar{c})\right] > 0. \end{aligned}$$

Then, if the expression in the last line is positive the transfer is always a subsidy. Since the first term is positive by Assuption 5, a sufficient condition for a subsidy is that the term in squared brackets is positive. ■

Lemma 10 (Market size and differential values) *Given Assumption* 2*, we have:* $2\Delta\Pi^S(n) = \Delta\bar{\Pi}^M(2n)$ *and* $2\Delta W^S(n) = \Delta\bar{W}^M(2n)$*.*

Proof. Let $\Phi = \Pi, W$ denote profits or welfare. From (4) and (7), using superscript S for the benchmarke segmented monopoly and M for the integrated monopoly and including explicitly the market size n of the segmented monopoly and $2n$ of the integrated one: $2\Delta\Phi^S(n) \equiv 2\left[\Phi^S(0; n) - \Phi^S(\bar{c}; n)\right]$. 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 2 −, 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 6. 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 of size n with the **merger to monopoly in an integrated market** M of size $2n$. The equilibrium level of investment is larger in each lab in the integrated merger to monopoly than in each segmented monopolist's lab if

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

Given Lemma 10 we can rewrite it as

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

which corresponds to

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

Hence, when $\beta > \mu\Delta\bar{\Pi}^M(2n)$, ensuring a symmetric investment $\hat{x}^M(2n)$, the merged entity, absent subsidies, 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** in an **integrated market** (we drop therefore the reference to the market size $2n$). In what follows we assume that the conditions for an interior stable solution in the D, J, M market environments are met, that is $\beta > \mu \max\left\{\Delta\bar{\Pi}_i^D(\lambda) - \Delta\underline{\Pi}_i^D(\lambda), \Delta\bar{\Pi}^k\right\}$, $k = J, M$.

M **vs.** J**:** The investment in case of joint venture (20), is increasing in $\Delta\bar{\Pi}^D = \Pi^D(0,0) - \Pi^D(\bar{c},\bar{c})$, which, in turn, is 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

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

After rearranging we obtain:

$$\beta\left[\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\bar{\Pi}^M\right] > -\mu\Delta\underline{\Pi}_i^D(\lambda^D)\Delta\bar{\Pi}^M. \tag{31a}$$

Depending on the degree of appropriability $\lambda^D \in [0,1]$, we have

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

and $\Delta\underline{\Pi}_i^D(\lambda^D) \in \left[0, \Pi_i^D(0,0) - \Pi_i^D(\bar{c},0)\right]$. Hence, $\Delta\bar{\Pi}_i^D(\lambda^D)$ and $\Delta\underline{\Pi}_i^D(\lambda^D)$ 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 (31a) is negative and the RHS is zero, implying that the inequality does not hold and $\hat{x}^D(0) \leq \hat{x}^M$, 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 expression of the Arrow replacement effect. If the Arrow effect holds, that is it is positive, (31a) 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 $\beta\left[\Delta\bar{\Pi}_i^D(\hat{\lambda})-\Delta\bar{\Pi}^M\right]=-\mu\Delta\underline{\Pi}_i^D(\hat{\lambda})\Delta\bar{\Pi}^M$. For $\lambda^D\leq\hat{\lambda}$ (31a) is not satisfied and $\hat{x}^D(\lambda^D)\leq\hat{x}^M$, while the duopoly investment is larger than the monopolist otherwise. If instead the Arrow replacement effect does not hold, when $\lambda^D=1$ both terms in (31a) 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 7. We start by comparing the welfare-maximizing investment in the segmented monopolies (superscript S) and in the merger to monopoly (superscript M) in an integrated market.

S **vs.** M**:** Suppose $\beta>\mu\Delta\bar{W}^M$. Then, in the merger to monopoly there is a unique symmetric welfare-maximizing interior solution (23), while the welfare-maximizing investment in local monopolies is (9). After rearranging and using Lemma 10 we get:

$$\tilde{x}^M=\frac{\mu\Delta\bar{W}^M}{\beta+\mu\Delta\bar{W}^M}>\tilde{x}^S=\frac{\mu\Delta W^S}{\beta}$$
$$\frac{\mu\Delta\bar{W}^M}{\beta+\mu\Delta\bar{W}^M}>\frac{\mu\Delta W^M}{2\beta}$$
$$\beta>\mu\Delta\bar{W}^M.$$

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. Suppose $\beta>\mu\Delta\bar{W}^k$ for $k=M,J$. The welfare-maximizing investment is given by (23), with $\Delta\bar{W}^k=W^k(0,0)-W^k(\bar{c},\bar{c})$. Further, given Assumption 4, $\Delta\bar{W}^J=W^D(0,0)-W^D(\bar{c},\bar{c})$ that is increasing in the intensity of competition. Moreover, $\Delta\bar{W}^J=\Delta\bar{W}^D(\lambda^D)$ with $\lambda^D=0$. Finally, $\tilde{x}^k$ is increasing in $\Delta\bar{W}^k$. Then,

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

since $\Delta\bar{W}^D(0)\geq\Delta\bar{W}^M$, 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. We can write:

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

that corresponds to:

$$\beta\left[\Delta\bar{W}^D(0)-\Delta\bar{W}^D(\lambda^D)\right]>\mu\Delta\underline{W}^D(\lambda^D)\Delta\bar{W}^D(0) \tag{32}$$

since $\beta>\mu\Delta\bar{W}^D(0)>0$ and $\beta>\mu\left[\Delta\bar{W}^D(\lambda^D)-\Delta\underline{W}^D(\lambda^D)\right]>0$ at 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 (32) can be rewritten as

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

which holds true for $\beta>\mu\Delta\bar{W}^D(0)$ and $\lambda^D>0$, since the term in square brackets is positive given Assumption 4.

■

Proof of Proposition 8. Let us consider the welfare evaluated at the welfare maximizing investment in the different market environments.

Let us start from the two separate monopolies and consider the expected welfare (6) evaluated at the welfare maximizing investment (9). Taking into account Lemma 10 and the fact that the two research activities are statistically independent, the total expected welfare generated by the sum of the two separate monopolies is:

$$\begin{aligned}
w_1^S(\tilde{x}^S)+w_2^S(\tilde{x}^S) &= (1-\mu)2W^S(0)+\mu\left\{\left(\tilde{x}^S\right)^2 2W^S(0)\right.\\
&\quad\left.+(1-\tilde{x}^S)^2 2W^S(\bar{c})+2\tilde{x}^S(1-\tilde{x}^S)(W^S(\bar{c})+W^S(0))\right\}\\
&\quad-\beta\left(\tilde{x}^S\right)^2\\
&= (1-\mu)W^M(0,0)+\mu\left\{\left(\tilde{x}^S\right)^2 W^M(0,0)\right.\\
&\quad\left.+(1-\tilde{x}^S)^2 W^M(\bar{c},\bar{c})+2\tilde{x}^S(1-\tilde{x}^S)W^M(0,\bar{c})\right\}\\
&\quad-\beta\left(\tilde{x}^S\right)^2.
\end{aligned}$$

The difference with the expected welfare of the merger to monopoly in the integrated market, evaluated at a generic x^M, is:

$$\begin{aligned}
w^M(x^M)-w_1^S(\tilde{x}^S)-w_2^S(\tilde{x}^S) &= \mu\left\{\left[2x^M-\left(x^M\right)^2-\left(\tilde{x}^S\right)^2\right]W^M(0,0)\right.\\
&\quad+\left[(1-x^M)^2-\left(1-\tilde{x}^S\right)^2\right]W^M(\bar{c},\bar{c})\\
&\quad\left.-2\tilde{x}^S(1-\tilde{x}^S)W^M(0,\bar{c})\right\}-\beta\left[\left(x^M\right)^2-\left(\tilde{x}^S\right)^2\right].
\end{aligned} \tag{33}$$

Then, evaluating (33) 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 D when both expressions are evaluated at the duopoly welfare maximizing investment $\tilde{x}^D(\lambda^D)$ is:

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

given Assumption 4.

Comparing the research joint-venture and the merger to monopoly using the welfare maximizing investment in case of monopoly, $\tilde{x}^M$, we get:

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

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. ■

8 Appendix II: Learning by doing and Local Content Requirements

Let us assume that the firm is active for two periods. If the international markets are open, it can purchase the input at the efficient cost 0. Moreover, by producing a fraction x_1 of output locally with a cost $C(x_1) = \frac{\beta}{2}x_1^2$ in the first period it is able with probability x_1 to produce at the efficient marginal cost 0 in the second period in case of trade disruption. The timing of the game is as follows:

- period 0: the social planner chooses a transfer rate $s \leq 1$ to be applied to the production costs of 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

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

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

$$\pi(x_1) = \Pi_1(q_1, x_1; s) + (1-\mu)\Pi_2(0) + \mu\left[x_1\Pi_2(0) + (1-x_1)\Pi_2(\bar{c})\right] \tag{34}$$

Since total production q_1 in the first period affects only Π_1 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.[44]

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

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

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

The expected welfare can be written as

$$w(x_1) = W_1^S(q_1) - \beta x_1^2/2 + (1-\mu)W_2^S(0) + \mu\left[x_1 W_2^S(0) + (1-x_1)W_2^S(\bar{c})\right], \tag{35}$$

which is separable in q_1 and $x_{1,}$ implying the same solution as in the case of RD.

9 Appendix III: Private and social investments: asymmetric equilibria.

In the following we derive the optimal profit maximizing and welfare maximizing investment when transfers are asymmetric and when the solution is not interior. Recall that we assume full transferability of the innovation in case of research joint-venture and merger to monopoly, and partial unvoluntary spillovers in a duopoly, that is, for $k = J, M$ we have $\lambda^k = 0$, implying $\Delta\underline{\Pi}_i^k = \Delta\underline{W}^k = 0$, and $\lambda^D \in [0,1]$.

The following proposition decribes the investment equilibria in a duopoly when transfers are asymmetric.

[44] 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.

Proposition 11 (Non-cooperative duopoly investment) *Suppose the transfers are asymmetric ($s_i \neq s_j$). If*

$$\beta > \hat{\beta}^D(s_i;\lambda^D) \equiv \frac{\mu\left(\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\underline{\Pi}_i^D(\lambda^D)\right)}{(1-s_i)} \tag{36}$$

for both firms there exists a unique stable equilibrium

$$\hat{x}_i^D(s_i,s_j;\lambda^D) = \min\left\{\frac{\mu\Delta\bar{\Pi}_i^D(\lambda^D)\left[(1-s_i)\beta - \mu\left(\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\underline{\Pi}_i^D(\lambda^D)\right)\right]}{(1-s_i)(1-s_j)\beta^2 - \mu^2\left(\Delta\bar{\Pi}_i^D(\lambda^D) - \Delta\underline{\Pi}_i^D(\lambda^D)\right)^2}, 1\right\}. \tag{37}$$

If, for given s_i, $\beta \leq \hat{\beta}^D(.)$ for firm i, the equilibrium (37) is unstable, and there exists a stable equilibrium at a corner solution:

$$\hat{x}_i^D(s_i,s_j) = 1 \tag{38}$$

$$\hat{x}_j^D(s_j,s_i;\lambda^D) = \min\left\{\frac{\mu\Delta\underline{\Pi}_i^D(\lambda^D)}{(1-s_i)\beta}, 1\right\} \geq 0. \tag{39}$$

Proof. The best replies ((17)) intersect at (37). If the slope of the best reply ((17)) in a neighborhood of (37) is lower than 1 in absolute value for both firms, that is condition $\beta > \hat{\beta}^D(.)$ is met, the equilibrium is stable. Moreover, since the best replies are linear, they never intersect out of the equilibrium, establishing uniqueness. If $\beta \leq \hat{\beta}^D(.)$ for firm i, the best reply at (37) 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 (17) we get (39). ■

The following proposition covers the case of research joint-venture and merger to monopoly and identifies the optimal investment that maximizes the expected joint profits when transfers are asymmetric.

Proposition 12 (Joint-profit maximization investment) *Suppose the transfers are asymmetric ($s_i \neq s_j$). If*

$$\beta > \hat{\beta}^k(s_i,s_j) \equiv \frac{\mu\Delta\bar{\Pi}^k}{[(1-s_i)(1-s_j)]^{\frac{1}{2}}} \tag{40}$$

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

$$\hat{x}_i^k(s_i,s_j) = \min\left\{\frac{\mu\Delta\bar{\Pi}^k\left[(1-s_i)\beta - \mu\Delta\bar{\Pi}^k\right]}{(1-s_i)(1-s_j)\beta^2 - \mu^2\left(\Delta\bar{\Pi}^k\right)^2}, 1\right\}. \tag{41}$$

If, for given s_i and s_j, $\beta \leq \hat{\beta}^k(.)$ for $k = M, J$, the optimal investment is at a corner solution

$$\hat{x}_i^k = 1 \tag{42}$$

$$\hat{x}_j^k = 0. \tag{43}$$

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

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

If condition (40) is met, the maximum is interior at (41). If $\beta \leq \hat{\beta}^k(.)$, (41) is a saddle point and the merged entity chooses the corner solution, where (43) is obtained from the FOC when the investment in the other lab is 1. ■

Finally, in the following proposition we analyze the case when the welfare-maximizing investment is asymmetric.

Proposition 13 (Welfare-maximizing investment) *If the market is a duopoly and*

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

the social planner chooses a corner solution

$$\tilde{x}_i^D = 1 \tag{44}$$

$$\tilde{x}_j^D(\lambda) = \min \left\{ \frac{\mu \Delta \underline{W}^k(\lambda)}{\beta}, 1 \right\}. \tag{45}$$

If, instead, the market environment is $k = M, J$ and $\beta \leq \mu \Delta \bar{W}^k$ the social planner chooses the corner solution

$$\tilde{x}_i^k = 1 \tag{46}$$

$$\tilde{x}_j^k = 0. \tag{47}$$

Proof of Proposition 13.

The FOC's and SOC's for the maximization problem of the social planner when the market environment is a duopoly are:

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

If $\beta \leq \mu \left[\Delta \bar{W}^D(\lambda) - \Delta \underline{W}^D(\lambda)\right]$ the symmetric allocation is a saddle point and the optimal investment is at a corner solution with one investment equal to 1 and the other given by the FOC. Notice that in this case if spillovers are not complete ($\lambda^D > 0$) the social planner may prefer to keep open a second lab, even if the first one develops the innovation with probability 1, to ensure that also the second firm may innovate with some probability.

If $\beta \leq \mu\Delta\bar{W}^k$, the same argument applies for $k = J, M$. The FOC's and SOC's are

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

If $\beta \leq \mu\Delta\bar{W}^k$ the symmetric investment (23) is a saddle point and the optimal investment is at the corner solution (46) and (47). Notice that in this case the social planner keeps working only one lab, reaching the innovation with probability 1 and fully transferring the efficient technology to both plants/firms. ■

Finally, focussing on research joint-ventures, the optimal subsidy is described in the following lemma.

Lemma 14 (Optimal subsidy with asymmetric investment) *Consider the research joint-venture market environment. When $\beta \leq \mu\Delta\bar{W}^J$ the social planner implements the corner solution $\tilde{x}_i^J = 1$ and $\tilde{x}_j^J = 0$ by applying the symmetric subsidies*

$$s_i = s_j = s(\beta) = \max\left\{1 - \frac{\mu\Delta\bar{\Pi}^J}{\beta}, 0\right\} \tag{48}$$

which is positive and increasing in β for $\beta \in \left[\mu\Delta\bar{\Pi}^J, \mu\Delta\bar{W}^J\right]$ and zero for $\beta < \mu\Delta\bar{\Pi}^J$. The research joint venture runs only one lab at full scale and shuts down the other.

Proof. When $s_i = s_j = s(\beta)$ the asymmetric solution $\hat{x}_i^J = 1$ and $\hat{x}_j^J = 0$ is chosen also by the research joint-venture, since the condition for a corner solution in the joint-profit maximization problem is met. Although the subsidy is non-discriminatory, it is lower than 1 and the research joint-venture, therefore, cashes in it only for the running lab. The subsidy is increasing in β and equal to 0 for $\beta = \mu\Delta\bar{\Pi}^J$. Hence, in the interval $\beta \in \left[\mu\Delta\bar{\Pi}^J, \mu\Delta\bar{W}^J\right]$ the social planner sets a symmetric subsidy (48) that is used only in one lab, which runs the research activity at full scale. For $\beta < \mu\Delta\bar{\Pi}^J$ the asymmetric outcome is chosen by the research joint-venture with no need of any subsidy. ■