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On the strategic choice of innovation type

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Abstract

This note studies the strategic choice between product and process innovation under hard budget constraints. Firms cannot invest in both dimensions, so innovation choices are shaped by strategic interaction as well as private returns. We show that when quality-enhancing innovation becomes sufficiently effective, firms coordinate on a symmetric profile in which both adopt product innovation, even though social welfare is maximized by asymmetric specialization. A minimal ex ante subsidy, targeted to the direction of innovation, is enough to implement the welfare-optimal asymmetric allocation without distorting market competition. The results highlight how simple, directional incentives can correct strategic misalignment in resource-constrained innovation environments.

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1 Introduction

Firms constantly face trade-offs when allocating scarce R&D resources. While innovation is crucial to remain competitive, the decision of *how* to innovate is often constrained by limited budgets, capabilities, or policy frameworks. In many settings, firms must choose between improving product quality— *product innovation*—and enhancing production efficiency—*process innovation*.

These two forms of innovation are conceptually distinct and entail different economic effects. Product innovation aims to raise consumers' willingness to pay, as in the introduction of new automobile models with enhanced features or smartphones with improved camera systems. In contrast, process innovation—such as adopting more efficient assembly techniques or automating production lines—reduces marginal costs without altering the perceived quality of the product.

Hard budget constraints often make these innovation choices mutually exclusive. Historical and recent evidence provides clear examples. Ford's early focus on process innovation through the assembly line contrasted with General Motors' strategy of frequent product upgrades, illustrating how firms facing financial constraints may prioritize one direction over the other. Toyota's post–WWII development of the Toyota Production System similarly reflected a strategic emphasis on process improvements under severe capital shortages. More recently, LEGO's 2004–2006 restructuring involved a deliberate shift away from ambitious product diversification toward operational simplification and cost efficiency.

When firms must choose between innovation types, their decisions are shaped not only by internal returns but also by strategic considerations. In markets where firms interact, the profitability of a given innovation strategy depends on the rival's choice. If one firm invests in product innovation while the other cuts costs, their competitive positions become structurally different, potentially softening price or quantity competition and altering equilibrium outcomes.

This note develops a simple theoretical model to study such strategic interactions. We consider a duopoly in which firms can invest in either product or process innovation, but not both. The effectiveness of product innovation is captured by a parameter α governing horizontal differentiation. We show that when α is small, firms may specialize in different innovation directions, giving rise to asymmetric equilibria. However, when product innovation becomes sufficiently effective, firms coordinate on a symmetric profile in which both choose product innovation. This privately optimal outcome is not socially efficient: total welfare is maximized when firms adopt different innovation strategies, with one improving quality and the other reducing costs.

We then show how a simple ex-ante subsidy—granted to one firm conditional on choosing process innovation—can restore the asymmetric allocation as the unique equilibrium when α is large. The intervention is minimal, affects only the first-stage choice, and does not require monitoring outcomes or altering the second-stage market game. Yet it is sufficient to overcome the strategic misalignment that prevents specialization.

Finally, the analysis highlights how targeted innovation support can address coordination failures in strategic environments. When innovation is exclusive and competition is intense, firms may adopt symmetric strategies that are privately optimal but socially inefficient. A small directional subsidy can restore the welfare-maximizing allocation without distortions in marginal decisions or total R&D effort.

2 Related Literature

The strategic allocation of R&D between product and process innovation has been widely studied in the economics of innovation. A substantial body of research has explored how market structure, firm incentives, and public policies affect firms' innovation strategies and outcomes.

Capuano and Grassi (2019) develop a theoretical framework in which product innovation creates technological spillovers, and cooperation in R&D becomes a rational response to weak intellectual property protection. Their model emphasizes how strategic interaction and the nature of spillovers jointly determine investment outcomes. Extending this line of work, Capuano and Grassi (2020, 2022) show how licensing agreements can strengthen cooperative incentives, allowing firms to internalize externalities and increase investment.

On the empirical side, Cantabene and Grassi (2019) investigate the determinants of R&D cooperation using firm-level data from Italy. They find that both public incentives and strategic complementarities play a role in shaping cooperative behavior. Cantabene and Grassi (2024) examine the link between cooperation and firm performance, showing that its impact depends on firm-level characteristics and the type of innovation pursued.

These studies complement broader theoretical contributions on the joint or alternative use of product and process innovation. In duopoly settings, Rosenkranz (2003) analyzes simultaneous investment decisions when consumers value product variety, while Mantovani (2006) models complementarity between innovation types in a monopolistic framework. Lin and Saggi (2002) emphasize how the nature of market competition affects R&D direction, and Lambertini (2003) explores optimal R&D portfolios in environments with asymmetric returns.

Empirical evidence points to potential complementarities. Jaumandreu and Mairesse (2016) find that product and process innovation jointly shape demand and cost structures, though disentangling their effects remains challenging. Bianchini et al. (2018), Calvino (2019), and Miravete and Pernías (2006) all report positive interactions between innovation types in firm-level data. Related survey-based evidence is offered by Cozzarin (2017) and Kamutando and Tregenna (2024), among others.

Finally, a growing literature addresses how public policy can shape not just the amount, but also the direction of innovation. Seminal work by Aghion et al. (2005) and Acemoglu et al. (2012) connects competition and innovation policy, while Hall and Lerner (2010) discuss the broader landscape of R&D financing. More recent contributions such as Cabon-Dhersin and Gibert (2019), Le and Jaffe (2017), and Grassi and Martina (2026) focus specifically on the design of effective subsidies, including those aimed at inducing cooperation or specific innovation outcomes.

3 The Model

We consider a duopoly in which two symmetric firms, indexed by $i = 1, 2$, compete in quantities on a linear market. Each firm has the opportunity to invest in either product innovation (Z), which increases consumers' willingness to pay, or process innovation (P), which reduces marginal production costs. However, due to a hard budget constraint, each firm can invest in only one type of innovation.

Timing of the Game:

Stage 1 Each firm simultaneously chooses whether to invest in product innovation ($I_{Z,i} > 0$ and $I_{P,i} = 0$) or in process innovation ($I_{P,i} > 0$ and $I_{Z,i} = 0$).

Stage 2 Given the chosen innovation types, firms observe each other's strategy and compete à la Cournot in the product market.

Demand and Cost Structure:

Let $A > 0$ denote the market size and $c > 0$ the initial marginal cost. If firm i invests in product innovation, it increases its demand by shifting the intercept through the term $\alpha I_{Z,i}$, where $\alpha \in (0, 1)$ measures the effectiveness of product innovation. If it invests in process innovation, it reduces its marginal cost linearly by $I_{P,i}$. Investments are costly and convex: the cost is $\frac{I_{P,i}^2}{2}$ or $\frac{I_{Z,i}^2}{2}$.

The inverse demand function faced by firm i is:

$$p_i = A - q_i - q_j + \alpha I_{Z,i}. \tag{1}$$

Equation 1 can be derived from a standard quasi–linear utility specification with vertical differentiation, where product innovation increases the willingness to pay for the innovating firm's variety. In this framework, firm i's investment in product innovation $I_{Z,i}$ shifts the intercept of its own demand curve, but does not directly alter the rival's demand. This assumption reflects the idea that quality improvements are firm–specific and do not generate demand–side spillovers. Similar formulations are widely used in the industrial–organization literature on product and process innovation; see, for example, Mantovani (2006), where product innovation raises consumers' valuation of a firm's output while process innovation affects only marginal costs.[1]

Firm i's total cost is:

$$C_i = (c - I_{P,i})q_i + \frac{I_{P,i}^2}{2} + \frac{I_{Z,i}^2}{2}. \tag{2}$$

Profit function:

$$\pi_i = (A - q_i - q_j + \alpha I_{Z,i})q_i - (c - I_{P,i})q_i - \frac{I_{P,i}^2}{2} - \frac{I_{Z,i}^2}{2}. \tag{3}$$

We solve the game by backward induction. First, we characterize the Cournot equilibrium quantities conditional on innovation levels. Then we derive optimal investment choices for the four possible innovation configurations.

[1] One could alternatively allow the rival's investment $I_{Z,j}$ to affect the demand faced by firm i by modifying substitutability across varieties. However, introducing such cross–effects would add an additional channel of strategic interaction that is not essential for the mechanism studied here and would prevent closed–form solutions. Our specification isolates the role of the budget constraint in shaping innovation direction while maintaining analytical tractability.

3.1 Second Stage: Quantity Competition

Maximizing π_i (equation 3) with respect to q_i, the best response function is:

$$q_i = \frac{1}{2}\left(A - c + I_{P,i} + \alpha I_{Z,i} - q_j\right).$$

Solving the system, the equilibrium quantities are:

$$q_i^* = \frac{1}{3}\left(A - c + 2I_{P,i} - I_{P,j} + 2\alpha I_{Z,i} - \alpha I_{Z,j}\right). \tag{4}$$

3.2 First Stage: Innovation Choices and Optimal Investments

We substitute the equilibrium quantities from the second-stage Cournot game, obtained in Equation (4), into the profit function and let each firm choose its innovation investment optimally at the first stage. Since firms can invest in only one type of innovation, we solve four separate optimization problems corresponding to the possible innovation profiles. The resulting investment levels and profits for each scenario are reported below.

(1) Both firms choose process innovation Each firm sets $I_{Z,i} = 0$. The FOC with respect to $I_{P,i}$ gives:

$$I_{P,i} = \frac{4}{5}(A - c). \tag{5}$$

$$\pi_i^{PP} = \frac{(A-c)^2}{25}. \tag{6}$$

(2) Both firms choose product innovation Each firm sets $I_{P,i} = 0$. The FOC with respect to $I_{Z,i}$ yields:

$$I_{Z,i} = \frac{4\alpha(A-c)}{9 - 4\alpha^2}. \tag{7}$$

Profits:

$$\pi_i^{ZZ} = \frac{(A-c)^2(9 - 8\alpha^2)}{(9 - 4\alpha^2)^2}. \tag{8}$$

(3) Firm 1 chooses product, Firm 2 chooses process innovation Set $I_{P,1} = I_{Z,2} = 0$. The FOCs yield:

$$I_{Z,1} = \frac{4(A-c)(4\alpha^2 - 3)}{8\alpha^2 - 3}, \qquad I_{P,2} = \frac{4\alpha(A-c)}{8\alpha^2 - 3}. \tag{9}$$

Profits:

$$\pi_1^{PZ} = \frac{(A-c)^2(3 - 4\alpha^2)^2}{(8\alpha^2 - 3)^2}. \tag{10}$$

$$\pi_2^{PZ} = \frac{(A-c)^2(9 - 8\alpha^2)}{(8\alpha^2 - 3)^2}. \tag{11}$$

(4) Firm 1 chooses process, Firm 2 chooses product innovation

$$\pi_1^{ZP} = \pi_2^{PZ}, \qquad \pi_2^{ZP} = \pi_1^{PZ}. \tag{12}$$

Tables 1 and 2 summarize, respectively, the innovation choices with optimal investment levels and the associated profit outcomes.

Table 1: Optimal Innovation Investments Under Each Strategy Profile

Scenario	Firm 1 Investment	Firm 2 Investment
PP (Process, Process)	$I_{P,1} = \frac{4}{5}(A-c),\ \ I_{Z,1} = 0$	$I_{P,2} = \frac{4}{5}(A-c),\ \ I_{Z,2} = 0$
ZZ (Product, Product)	$I_{P,1} = 0,\ \ I_{Z,1} = \frac{4\alpha(A-c)}{9-4\alpha^2}$	$I_{P,2} = 0,\ \ I_{Z,2} = \frac{4\alpha(A-c)}{9-4\alpha^2}$
PZ (Product, Process)	$I_{P,1} = 0,\ \ I_{Z,1} = \frac{4(A-c)(4\alpha^2-3)}{8\alpha^2-3}$	$I_{P,2} = \frac{4\alpha(A-c)}{8\alpha^2-3},\ \ I_{Z,2} = 0$
ZP (Process, Product)	$I_{P,1} = \frac{4\alpha(A-c)}{8\alpha^2-3},\ \ I_{Z,1} = 0$	$I_{P,2} = 0,\ \ I_{Z,2} = \frac{4(A-c)(4\alpha^2-3)}{8\alpha^2-3}$

Table 2: Profit Outcomes Across Innovation Scenarios

Scenario	Firm 1 Profit	Firm 2 Profit
PP (Process, Process)	$\frac{(A-c)^2}{25}$	$\frac{(A-c)^2}{25}$
ZZ (Product, Product)	$\frac{(A-c)^2(9-8\alpha^2)}{(9-4\alpha^2)^2}$	$\frac{(A-c)^2(9-8\alpha^2)}{(9-4\alpha^2)^2}$
PZ (Product, Process)	$\frac{(A-c)^2(3-4\alpha^2)^2}{(8\alpha^2-3)^2}$	$\frac{(A-c)^2(9-8\alpha^2)}{(8\alpha^2-3)^2}$
ZP (Process, Product)	$\frac{(A-c)^2(9-8\alpha^2)}{(8\alpha^2-3)^2}$	$\frac{(A-c)^2(3-4\alpha^2)^2}{(8\alpha^2-3)^2}$

These expressions allow us to compare profits across configurations and derive equilibrium outcomes depending on the value of α. In the next section, we show how these strategic interactions lead to inefficient outcomes when left unregulated.

4 Equilibrium Analysis and Inefficiency

We now characterize the equilibrium outcomes in the first stage. Since each firm can invest in only one type of innovation, and the game is symmetric, there are four possible strategy profiles: both firms choose process innovation (PP), both choose product (ZZ), or one chooses product and the other process (PZ or ZP).

Each firm compares its expected profit under each scenario. Because the game is symmetric, it suffices to analyze Firm 1's best response for different values of the effectiveness parameter α.

Equilibrium Characterization

Let us focus on the case in which Firm 2 invests in process innovation. Then Firm 1 compares

$$\pi_1^{ZP} = \frac{(A-c)^2(9-8\alpha^2)}{(8\alpha^2-3)^2},$$
$$\pi_1^{PP} = \frac{(A-c)^2}{25}.$$

Firm 1 prefers Product to Process whenever

$$\pi_1^{ZP} > \pi_1^{PP} \qquad \iff \qquad \frac{9-8\alpha^2}{(8\alpha^2-3)^2} > \frac{1}{25}.$$

Solving this inequality shows that it holds for all $\alpha \in (0,1)$. Hence, we can state the following proposition:

Proposition 1 (No process–process equilibrium) *For all $\alpha \in (0,1)$, the best response to* Process *is* Product. *As a consequence, the strategy profile* (Process, Process) *is never a Nash equilibrium.*

Let us now consider the case in which Firm 2 invests in product innovation. Then Firm 1 compares

$$\pi_1^{PZ} = \frac{(A-c)^2(3-4\alpha^2)^2}{(8\alpha^2-3)^2},$$
$$\pi_1^{ZZ} = \frac{(A-c)^2(9-8\alpha^2)}{(9-4\alpha^2)^2}.$$

Firm 1 prefers Product to Process whenever

$$\pi_1^{ZZ} > \pi_1^{PZ} \qquad \iff \qquad \frac{9-8\alpha^2}{(9-4\alpha^2)^2} > \frac{(3-4\alpha^2)^2}{(8\alpha^2-3)^2}.$$

Solving this inequality, we can state the following proposition:

Proposition 2 (Best reply to product) *Let Firm 2 choose* Product. *Then there exists a unique threshold $\alpha^* \approx 0.7788$, such that:*

- *if $0 < \alpha < \alpha^*$, Firm 1 prefers* Process *to* Product*;*
- *if $\alpha > \alpha^*$, Firm 1 prefers* Product *to* Process.

Combining Propositions 1 and 2, we can characterize the set of Nash equilibria of the innovation game as follows:

Proposition 3 (Equilibrium innovation patterns) *There exists a unique threshold $\alpha^* \approx 0.7788$ such that:*

- *If* $0 < \alpha < \alpha^*$, *the game admits two asymmetric Nash equilibria:*

$$(\textsc{Product}, \textsc{Process}) \quad \textit{and} \quad (\textsc{Process}, \textsc{Product}).$$

- *If* $\alpha > \alpha^*$, PRODUCT *is a strictly dominant strategy for both firms, and the unique Nash equilibrium is the symmetric profile:*

$$(\textsc{Product}, \textsc{Product}).$$

These results highlight a simple but important insight. When horizontal differentiation is sufficiently strong (i.e., when α is large), product innovation becomes the dominant strategic choice: improving quality shifts the firm's own demand and generates a strong competitive advantage, so that both firms choose PRODUCT in equilibrium. For lower values of α, instead, no firm has an incentive to match the rival's quality improvement, because the induced competitive response raises investment costs without generating a sufficiently large demand shift. As a consequence, the equilibrium set contains only asymmetric profiles, in which one firm specializes in product innovation while the other invests in process innovation.

Social Welfare Comparison

While private incentives lead to asymmetric equilibria when $\alpha < \alpha^*$ and to a symmetric outcome when $\alpha > \alpha^*$, the social planner may prefer strategic asymmetry irrespective of the strength of horizontal differentiation. To assess this, we define social welfare as:

$$W = \pi_1 + \pi_2 + CS. \tag{13}$$

where $CS = \frac{1}{2}(q_1^2 + q_2^2)$ under linear demand.

Table 3 reports closed-form expressions for total welfare under each scenario. These follow from the explicit profit functions and the consumer-surplus formula under linear demand.

Table 3: Social Welfare Across Innovation Scenarios

Scenario	W (total welfare)
PP	$\frac{11}{25}(A-c)^2$
ZZ	$\frac{(A-c)^2(27-16\alpha^2)}{(9-4\alpha^2)^2}$
Asymmetric	$\frac{(A-c)^2(88\alpha^4-140\alpha^2+63)}{(8\alpha^2-3)^2}$

Proposition 4 (Socially optimal innovation pattern) *For all* $\alpha \in (0,1)$, *social welfare is maximized under the asymmetric configuration: one firm invests in* PRODUCT *innovation and the other in* PROCESS *innovation.*

This result reflects the planner's preference for strategic differentiation. Specialization allows one firm to reduce costs while the other enhances perceived value, jointly increasing total output and consumer surplus.

Remark. The privately optimal equilibrium diverges from the socially optimal outcome whenever $\alpha > \alpha^* \approx 0.7788$. In this region, firms coordinate on the symmetric profile (Product, Product) even though the planner strictly prefers the asymmetric allocation.

This divergence reflects a coordination failure: the asymmetric outcome is not stable without external incentives. In the next section, we introduce a simple policy mechanism to restore efficiency.

5 Policy Implications and Conclusion

The inefficiency highlighted above arises from a coordination failure: although the asymmetric allocation (PZ) maximizes welfare, it is not an equilibrium when $\alpha > \alpha^*$, because each firm has a unilateral incentive to choose Product. As a result, the game leads to the symmetric outcome (Product,Product), even though it is socially suboptimal.

A Minimal Subsidy Scheme

When $\alpha > \alpha^*$, the unique Nash equilibrium is the symmetric profile (Product, Product), whereas social welfare is maximized by an asymmetric allocation. To implement the socially optimal pattern, the planner can introduce a minimal ex ante subsidy $\epsilon > 0$ to one firm, conditional on choosing Process innovation. This policy shifts incentives in the first stage without distorting marginal costs or the second-stage Cournot game.

Suppose the planner aims to induce the asymmetric profile (Product, Process) and offers a transfer ϵ to Firm 2 if it chooses Process. Then Firm 2 compares the profit under symmetric product innovation, π_2^{ZZ}(Equation 8), with its profit under the asymmetric configuration, π_2^{PZ}(Equation 11) plus the transfer ϵ. Thus Process becomes a best reply whenever

$$\epsilon > \pi_2^{ZZ} - \pi_2^{PZ}.$$

Using the closed-form expressions in Equations (8) and (11), the minimum subsidy required to sustain the asymmetric allocation is

$$\epsilon(\alpha) = (A-c)^2 \left[\frac{9-8\alpha^2}{(9-4\alpha^2)^2} - \frac{(3-4\alpha^2)^2}{(8\alpha^2-3)^2} \right]. \tag{14}$$

The subsidy is positive if and only if $\alpha > \alpha^*$, and it decreases with α: as quality becomes more effective in shifting demand, a smaller transfer is needed to support specialization.[2] This constitutes a minimal intervention, since it affects only the first-stage innovation choice and leaves the second-stage market outcome unchanged.

[2] Because the transfer is paid ex ante and conditional only on the innovation type, it does not distort marginal production decisions, cannot induce predatory pricing or collusion, and leaves the Cournot stage unchanged. Hence no unintended strategic behavior arises.

Broader Implications

The analysis highlights a simple but important policy lesson. Even in the absence of R&D spillovers, technological complementarities, or cooperative agreements, innovation policy must take into account the strategic interaction generated by resource constraints. Firms may coordinate on symmetric innovation strategies that are privately stable but socially suboptimal, especially when quality improvements are highly effective.

Our results complement a broader literature on how public incentives shape innovation choices under competition. For instance, Capuano and Grassi (2019) and Cantabene and Grassi (2019) study how cooperation and knowledge spillovers affect R&D incentives, while Capuano and Grassi (2022) and Cantabene and Grassi (2024) examine how licensing, performance pressure, and institutional constraints interact with strategic investment. The mechanism identified here is distinct: even in a setting without spillovers or cooperative behavior, targeted subsidies may be required to offset strategic misalignment in innovation direction.

More generally, the results suggest that innovation policy should not only encourage higher R&D effort, but also consider the composition of innovation when firms face budget constraints. Designing simple directional incentives may be sufficient to restore alignment between private and social objectives.

Conclusion

When innovation choices are mutually exclusive, firms may coordinate on symmetric strategies that are privately optimal but socially inefficient. In our setting, the planner always prefers asymmetric specialization, yet this outcome fails to emerge when quality improvements are highly effective. A minimal, ex ante subsidy targeted to the direction of innovation is sufficient to restore efficiency without distorting market competition. Sometimes, effective policy requires not more subsidies, but better-targeted ones.

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