Online Appendix for “Heterogeneous Innovations and Growth under Imperfect Technology Spillovers” (NOT FOR PUBLICATION)

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A Baseline Model

A.1 Illustration of Firm Innovation Decisions

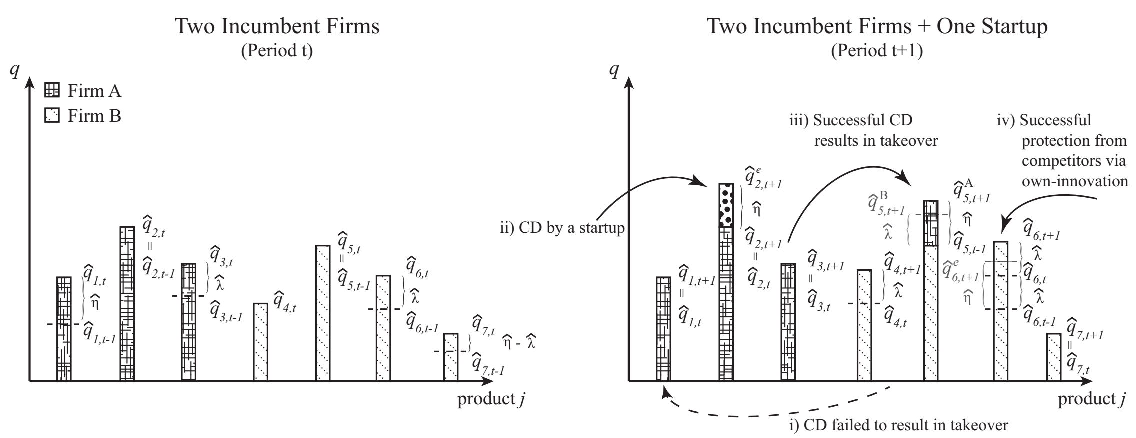

Figure 1: Firms’ Innovation and Product Quality Evolution Example

Figure 1 illustrates the following set of examples of firm innovation decisions.[1] Suppose firm A

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[1]The bar indicates log product quality $\widehat{q}_{j,t} \equiv \log(q_{j,t})$ with $\widehat{\eta} \equiv \log(\eta)$.

owns products 1,2,3, and firm B owns products 4,5,6,7.

• i) Failed product takeover with coin-tossing (product 1): firm A without successful own-innovation (at t) gets $q^A_{1,t+1} = \eta q_{1,t-1}$, while firm B with successful creative destruction (CD) (at t) obtains $q^B_{1,t+1} = \eta q_{1,t-1}$. A coin is tossed, and firm A keeps the product.

• ii) Successful product takeover w/o technology gap (product 2): A potential startup with successful creative destruction (at t) can take over the market from firm A with no successful own-innovations (at both $t-1$ and t) as $q^e_{2,t+1} = \eta q_{2,t-1} > q^A_{2,t+1} = q_{2,t-1}$

• iii) Failed market protection w/o technological gap (product 5): firm A can take it over through successful creative destruction, despite concurrently successful own-innovation by firm B as $\eta q_{5,t-1} > \lambda q_{5,t-1}$

• iv) Successful market protection with a technology gap (product 6): firm B obtains $q^B_{6,t+1} = \lambda^2 q_{6,t-1}$ with consecutively successful own-innovations from $t-1$. Rivals can only innovate up to $q^e_{6,t+1} = \eta q_{6,t-1}$, which makes firm B successfully protect the market.

A.2 Product Quality Evolution

Outsider Firms Let z^ℓ_j denote the own-innovation intensity for product line j and Δ^ℓ_j denote its technology gap. Since outside firms can only learn the lagged level of technology $q_{j,-1} = q_j/\Delta^\ell_j$, the evolution of product quality in $t+1$ occurs probabilistically as follows: for $\Delta_j = \Delta^1$, q'_j is equal to $\lambda q_{j,-1}$ with prob. $(1-\overline{x})z^1_j$, $q_{j,-1}$ with prob. $(1-\overline{x})(1-z^1_j)$, and $\eta q_{j,-1}$ with prob. $\overline{x}$; for Δ^2, q'_j is equal to $\lambda^2 q_{j,-1}$ with prob. z^2_j, $\lambda q_{j,-1}$ with prob. $(1-\overline{x})(1-z^2_j)$, and $\eta q_{j,-1}$ with prob. $\overline{x}(1-z^2_j)$; for Δ^3, q'_j is equal to $\lambda\eta q_{j,-1}$ with prob. z^3_j, $\eta q_{j,-1}$ with prob. $(1-\overline{x})(1-z^3_j) + \frac{1}{2}\overline{x}(1-z^3_j)$, and $\eta q_{j,-1}$ with prob. $\frac{1}{2}\overline{x}(1-z^3_j)$; and for Δ^4, q'_j is equal to $\lambda\frac{\eta}{\lambda}q_{j,-1}$ with prob. $(1-\overline{x})z^4_j + \frac{1}{2}\overline{x}z^4_j$, $\frac{\eta}{\lambda}q_{j,-1}$ with prob. $(1-\overline{x})(1-z^4_j)$, and $\eta q_{j,-1}$ with prob. $\overline{x}(1-z^4_j) + \frac{1}{2}\overline{x}z^4_j$.

A.3 Value Function and Optimal Innovation Decisions

The conditional expectation in the value function considers the success/failure of own-innovation and creative destruction, the arrival of the creative destruction shock, outcomes of coin-tosses (c-t), the distribution of current period product quality q, and the distribution of the current period technology gap Δ^ℓ. Thus, $\mathbb{E}\big[V\big(\Phi^{f\prime}\big|\Phi^f\big)\big|\{z_j\}_{j\in\mathcal{J}^f}, x\big] = \sum_{I^{\overline{x}}_1,\ldots,I^{\overline{x}}_{n_f}=0}^{1} \sum_{I^z_1,\ldots,I^z_{n_f}=0}^{1} \sum_{\text{c-t}_1,\ldots,\text{c-t}_{n_f}=\text{win}}^{\text{lose}} \sum_{I^x=0}^{1} \Big[$

$\prod_{i=1}^{n_f} \overline{x}^{I_i^{\overline{x}}}(1-\overline{x})^{1-I_i^{\overline{x}}} z_i^{I_i^z}(1-z_i)^{1-I_i^z}\big] \times \big[x^{I^x}(1-x)^{1-I^x}\big]\left(\frac{1}{2}\right)^{n_f}\mathbb{E}_{q,\Delta}V\big(\big[\bigcup_{i=1}^{n_f}\big[\big\{(\Delta'_{j_i}q_{j_i},\Delta'_{j_i})\big|(q_{j_i},\Delta_{j_i}), I_i^{\overline{x}}, I_i^z, \text{c-t}_i\big\}\setminus\{\mathbf{0}\}\big]\big]\bigcup\big[\big\{\big(\frac{\eta}{\Delta_{-j}}I^x q_{-j}, \frac{\eta}{\Delta_{-j}}I^x\big)\big\}\setminus\{\mathbf{0}\}\big]\big)$. Note that the first term in the value function (before $\bigcup$) is the subsets of possible realizations for $\Phi^{f\prime}$ from own-innovation, creative destruction, and coin-toss. The second term in the value function (after $\bigcup$) shows the subsets of possible realizations for $\Phi^{f\prime}$ from creative destruction, where $\{q'_{j_i}\} = \{\Delta'_{j_i}q_{j_i}\}\setminus\{0\}$, and $\{q'_{-j}\} = \{\frac{\eta}{\Delta_{-j}}I^x q_{-j}\}\setminus\{0\}$. If $\Delta'_{j_i} = 0$, then firm f loses product line j_i and $\{(q'_{j_i},\Delta'_{j_i})\}\setminus\{\mathbf{0}\} = \{\mathbf{0}\}\setminus\{\mathbf{0}\} = \emptyset$.

A.4 Technology Gap Portfolio Composition Distribution Transition

The range of $\widetilde{k}^1$ can be determined as follows: i) for $0 \leq \widetilde{k} \leq \min\{n_f - k, k\}$, the two combinations preceding the term in brackets are well defined for any $\widetilde{k}^1 \in [0,\widetilde{k}]\cap\mathbb{Z}$ and describe all possible cases; ii) if $n_f - k \geq k$, then $\tilde{k} > k$, $0 \leq \widetilde{k} - \widetilde{k}^1$, and $0 \leq \widetilde{k}^1 \leq n_f - k$ is satisfied. This gives $\widetilde{k} - k \leq \widetilde{k}^1 \leq \widetilde{k}$; and iii) if $k \geq n_f - k$, then $\widetilde{k} > n_f - k$, $0 \leq \widetilde{k} - \widetilde{k}^1$, and $0 \leq \widetilde{k}^1 \leq n_f - k$ is satisfied. Thus, $\max\{0, \widetilde{k} - k\} \leq \widetilde{k}^1 \leq n_f - k$.

By using $\widetilde{\mathbb{P}}(n_f, \widetilde{k}|n_f, k)$, the probability of $\mathcal{N} = \widetilde{\mathcal{N}}(n_f, k)$ transitioning to $\mathcal{N}' = \widetilde{\mathcal{N}}(n_f - h, \widetilde{k})$ for any $h \geq 0$ without considering creative destruction can be defined as follows: Take out h^1 numbers of product lines with $\Delta = \Delta^1$, and $h - h^1$ numbers of product lines with $\Delta = \Delta^2$ from $\widetilde{\mathcal{N}}(n_f, k)$, then compute the probability of $\widetilde{\mathcal{N}}(n_f - h, k - (h - h^1))$ transitioning to $\widetilde{\mathcal{N}}(n_f - h, \widetilde{k})$ with $\widetilde{\mathbb{P}}\big(n_f - h, \widetilde{k}|n_f - h, k - (h - h^1)\big)$ for all feasible h^1. Then, for $0 \leq h < n_f$, $n_f \geq 1$, $0 \leq \widetilde{k} \leq n_f - h$, and $0 \leq k \leq n_f$, $\widetilde{\mathbb{P}}\big(n_f - h, \widetilde{k}|n_f, k\big) = \sum_{h^1=\max\{0,h-k\}}^{\min\{h,n_f-k\}}\Big[\begin{pmatrix} n_f - k \\ h^1 \end{pmatrix}\begin{pmatrix} k \\ h - h^1 \end{pmatrix}\overline{x}^h(1 - z^2)^{h-h^1}\widetilde{\mathbb{P}}\big(n_f - h, \widetilde{k}|n_f - h, k - (h - h^1)\big)\Big]$; for $h = n_f \geq 1$, $\widetilde{k} = 0$, and $0 \leq k \leq n_f$, $\widetilde{\mathbb{P}}\big(n_f - h, \widetilde{k}|n_f, k\big) = \overline{x}^{n_f}(1 - z^2)^k$; and 0 otherwise. The range for h^1 is defined from above, ensuring $0 \leq h - h^1 \leq k$ and $0 \leq h^1 \leq n_f - k$ for any h^1.

With $\widetilde{\mathbb{P}}\big(n_f - h, \widetilde{k}|n_f, k\big)$, other possible cases can be described for each case. For example, the probability of $\mathcal{N} = (n_f, n_f - k, k, 0, 0)$ to $\mathcal{N}' = (n_f - h, n_f - h - \widetilde{k}, \widetilde{k}, 0, 0)$ for $h \geq -1$ is defined as $\mathbb{P}\big(n_f - h, n_f - h - \widetilde{k}, \widetilde{k}, 0, 0\,\big|n_f, n_f - k, k, 0, 0\big) = \widetilde{\mathbb{P}}\big(n_f - h, \widetilde{k}\big|n_f, k\big)(1 - x\overline{x}_{\text{takeover}}) + \widetilde{\mathbb{P}}\big(n_f - h - 1, \widetilde{k}\big|n_f, k\big)\mu(\Delta^3)\frac{1}{2}x(1 - z^3) + \widetilde{\mathbb{P}}\big(n_f - h - 1, \widetilde{k} - 1\big|n_f, k\big)\mu(\Delta^4)x\left(1 - \frac{1}{2}z^4\right)$. The first term is the probability of $\mathcal{N}$ transitioning to $\mathcal{N}'$ directly via the change in the firm's existing technology gap portfolio composition with unsuccessful creative destruction. The second term is the probability of $\mathcal{N}$ to $\widetilde{\mathcal{N}}(n_f - h - 1, \widetilde{k})$, where successful creative destruction adds one product line with $\Delta' = \Delta^1$. Since the next period technology gap of product line j from successful creative destruction is $\Delta'_j = \frac{q'_j}{q_j} = \frac{\eta q_{j,-1}}{\Delta_j q_{j,-1}} = \frac{\eta}{\Delta_j}$, firm needs to take over a product line with a technology gap of $\Delta = \Delta^3 = 1 + \eta$ to have a product line with a technology gap of Δ^1 in the next period. The third term is the probability of $\mathcal{N}$ to $\widetilde{\mathcal{N}}(n_f - h - 1, \widetilde{k} - 1)$, where successful creative destruction adds one product line with $\Delta' = \Delta^2$ by taking over a product line with a technology gap of $\Delta = \Delta^4$. For $h = -1$, the first term becomes zero by the definition of $\widetilde{\mathbb{P}}(\cdot|\cdot)$. Thus this probability is well defined for any $h \geq -1$.

With the computed probabilities of transitions between technology gap portfolio compositions, we can now define the inflows and outflows of a given technology gap portfolio. Let $\mathcal{F}$ denote the total mass of firms in the economy and $\mu(\mathcal{N})$ represent the share of firms with technology gap portfolio $\mathcal{N}$. Thus, $\widetilde{\mu}(\mathcal{N}) = \mathcal{F}\mu(\mathcal{N})$. Then, for example, inflows and outflows for $\mathcal{N} = (n_f, n_f - k, k, 0, 0)$ can be described as follows: for $\mathcal{N} = (n_f, n_f - k, k, 0, 0)$ with $n_f \geq 2$, any firm whose next period technology gap portfolio is not $\mathcal{N}$ is counted as outflows, followed by $\mathit{outflow}(n_f, n_f - k, k, 0, 0) = [1 - \mathbb{P}(n_f, n_f - k, k, 0, 0 \big| n_f, n_f - k, k, 0, 0)] \times \mathcal{F}\mu(n_f, n_f - k, k, 0, 0)$. Any firm with a total number of product lines $n \geq n_f - 1$ can have a technology gap portfolio composition equal to $\mathcal{N}$ through the combinations of own-innovation and creative destructions. Thus, for the maximum number of product lines $\bar{n}_f$, $\mathit{inflow}(n_f, n_f - k, k, 0, 0) = \mathcal{F}\sum_{n=n_f-1}^{\overline{n}_f} \sum_{\widetilde{k}=0}^{n} \big[\mu(n, n - \widetilde{k}, \widetilde{k}, 0, 0)\mathbb{P}(n_f, n_f - k, k, 0, 0 \big| n, n - \widetilde{k}, \widetilde{k}, 0, 0) + \mu(n, n - 1 - \widetilde{k}I_{\{n>1\}}, \widetilde{k}I_{\{n>1\}}, 1, 0)\mathbb{P}(n_f, n_f - k, k, 0, 0 \big| n, n - 1 - \widetilde{k}I_{\{n>1\}}, \widetilde{k}I_{\{n>1\}}, 1, 0) + \mu(n, n - 1 - \widetilde{k}I_{\{n>1\}}, \widetilde{k}I_{\{n>1\}}, 0, 1)\mathbb{P}(n_f, n_f - k, k, 0, 0 \big| n, n - 1 - \widetilde{k}I_{\{n>1\}}, \widetilde{k}I_{\{n>1\}}, 0, 1)\big] - \mathcal{F}\mu(n_f, n_f - k, k, 0, 0)\mathbb{P}(n_f, n_f - k, k, 0, 0 \big| n_f, n_f - k, k, 0, 0)$.[2]

B Simple Three-Period Heterogeneous Innovation Model

To analyze firms' innovation incentives and derive testable predictions, we examine a three-period economy with two product markets and three firms. In period 0, the economy starts with two product markets, market 1 and 2, with initial market-specific technologies $q_{1,0}$, and $q_{2,0}$, respectively. There are two firms in play, firm A and B. Firm A starts with product market 1 and an initial own-innovation probability $z_{1,0}$. Firm B, on the other hand, starts only with an initial creative

[2]Descriptions for other cases are available upon request.

destruction probability $x_{2,0}$, and can operate and produce in period 1 (but not in period 0). If creative destruction fails, firm B still keeps market 2 but produces with initial quality $q_{2,0}$. Thus, at the beginning of period 1, product qualities in the two markets are $q_{1,1} = \lambda q_{1,0}$ with probability $z_{1,0}$, $q_{1,1} = q_{1,0}$ with probability $1 - z_{1,0}$, $q_{2,1} = \eta q_{2,0}$ with probability $x_{2,0}$, and $q_{2,0}$ with probability $1 - x_{2,0}$, where $\lambda^2 > \eta > \lambda > 1$ represent innovation step sizes.

In period 1, the focal period, an outside firm engages in creative destruction to potentially take over the two product markets in period 2. The success of the outside firm in creative destruction is determined by the probability x_1^e for each product market. Additionally, there is a news shock in period 1 concerning the profit for period 2, possibly including an increase in foreign demand. Subsequently, the two incumbents utilize their given technologies to produce and invest in own-innovation and creative destructions. At the beginning of period 2, all innovation outcomes are realized, and then technological competition in each product market takes place. Only the firm with the highest technology in each product market continues producing. The economy ends after period 2.

In period 1, incumbent firm $i \in \{A, B\}$ invests $R_{j,1}^{\text{in}}$ in own-innovation for $j \in \{1, 2\}$, achieving a success probability of $z_{j,1}$. The R&D production function is $z_{j,1} = \left(R_{j,1}^{\text{in}} / \widehat{\chi} q_{j,1}\right)^{0.5}$. Successful own-innovation increases next-period product quality by $\lambda > 1$. Thus, the period 2 product quality for firm i becomes $q_{j,2}^i = \lambda q_{j,1}$ with prob. $z_{j,1}$, and $q_{j,2}^i = q_{j,1}$ with prob. $1 - z_{j,1}$. Similarly, firm i invests $R_{-j,1}^{\text{ex}}$ to learn the period 0 technology used by firm $-i \neq i$ and improve it, which determines the success probability of creative destruction $x_{-j,1}$. The R&D production function is $x_{-j,1} = \left(R_{-j,1}^{\text{ex}} / \widetilde{\chi} q_{-j,0}\right)^{0.5}$, where $-j$ is owned by $-i$. Successful creative destruction enhances product quality relative to the lagged-period quality by $\eta > 1$. Thus, product $-j$'s quality in period 2 for firm i is $q_{-j,2}^i = \eta q_{-j,0}$ with prob. $x_{-j,1}$, and $q_{-j,2}^i = \emptyset$ with prob. $1 - x_{-j,1}$, where the symbol $\emptyset$ means firm i failed to acquire the production technology for product $-j$.

Optimal Innovation Decisions and Theoretical Predictions Assume that in a given product market j and period t, firms receive an instantaneous profit of $\pi_{j,t} q_{j,t}$ where $q_{j,t}$ is the product quality and $\pi_{j,t}$ is a market-period-specific constant known to firms before each period begins. Because there are only two products, incumbents and the outside firm can perform creative destruction on the same product. For simplicity in the model, we further assume that the outside firm can engage in creative destruction only if an incumbent fails to do so, following Garcia-Macia et al. (2019). Then the profit maximization problem for firm i in product market j with quality $q_{j,1}$ in period 1 can be written as $V(q_{j,1}) = \max_{\{z_{j,1},x_{-j,1}\}} \big\{\pi_{j,1}q_{j,1} - \widehat{\chi}(z_{j,1})^2 q_{j,1} - \widetilde{\chi}(x_{-j,1})^2 q_{-j,0} + (1-x_{j,1})(1-x_1^e)\big[(1-z_{j,1})\pi_{j,2}q_{j,1} + z_{j,1}\pi_{j,2}\lambda q_{j,1}\big] + (x_{j,1}+(1-x_{j,1})x_1^e)\big[z_{j,1}\pi_{j,2}\lambda q_{j,1}\mathcal{I}_{\{\lambda q_{j,1}>\eta q_{j,0}\}} + \frac{1}{2}(1-z_{j,1})\pi_{j,2}q_{j,1}\mathcal{I}_{\{q_{j,1}=\eta q_{j,0}\}}\big] + x_{-j,1}\big[(1-z_{-j,1})\pi_{-j,2}\eta q_{-j,0}\mathcal{I}_{\{\eta q_{-j,0}>q_{-j,1}\}} + z_{-j,1}\pi_{-j,2}\eta q_{-j,0}\mathcal{I}_{\{\eta q_{-j,0}>\lambda q_{-j,1}\}} + \frac{1}{2}(1-z_{-j,1})\pi_{-j,2}\eta q_{-j,0}\mathcal{I}_{\{\eta q_{-j,0}=q_{-j,1}\}} + \frac{1}{2}z_{-j,1}\pi_{-j,2}\eta q_{-j,0}\mathcal{I}_{\{\eta q_{-j,0}=\lambda q_{-j,1}\}}\big]\big\}$, where $\mathcal{I}_{\{\cdot\}}$ is an indicator function that captures the possible relationships between the technologies of the three firms in period 2 within a given market. The first three terms show the period 1 profit net of total R&D cost.

The first bracket represents the incumbent's expected profit from market j if neither the incumbent nor the outside firm succeeds in creative destruction in market j. The second bracket represents the expected profit from market j if either the other incumbent or the outside firm succeeds in creative destruction in market j. The third bracket represents the expected profit from market $-j$ if firm i succeeds in creative destruction in market $-j$. The terms following $\frac{1}{2}$ account for scenarios where two firms could potentially produce the same quality product, triggering a coin-toss tiebreaker rule.

The interior solutions to this problem are: for $q_{j,1} = q_{j,0}$, $z^*_{j,1} = \frac{\pi_{j,2}}{2\widehat{\chi}}(\lambda-1)(1-x^*_{j,1})(1-x^e_1)$; for $q_{j,1} = \lambda q_{j,0}$, $z^*_{j,1} = \frac{\pi_{j,2}}{2\widehat{\chi}}\big[\lambda - (1-x^*_{j,1})(1-x^e_1)\big]$; for $q_{j,1} = \eta q_{j,0}$, $z^*_{j,1} = \frac{\pi_{j,2}}{2\widehat{\chi}}\big[\lambda - \frac{1}{2} - \frac{1}{2}(1-x^*_{j,1})(1-x^e_1)\big]$; for $q_{-j,1} = q_{-j,0}$, $x^*_{-j,1} = \frac{\eta\pi_{-j,2}}{2\widetilde{\chi}}$; for $q_{-j,1} = \lambda q_{-j,0}$, $x^*_{-j,1} = \frac{\eta\pi_{-j,2}}{2\widetilde{\chi}}(1-z^*_{-j,1})$; and for $q_{-j,1} = \eta q_{-j,0}$, $x^*_{-j,1} = \frac{\eta\pi_{-j,2}}{2\widetilde{\chi}}\frac{1}{2}(1-z^*_{-j,1})$, which maximize the firm profit considering the technology gap of its own and others, as well as the potential outcomes of own-innovation and creative destruction by all firms involved.

Proposition B.1. *For each $q_{j,1}$ and for $\lambda^2 > \eta > \lambda > 1$, we can order own-innovation intensities as $z^*_{j,1}\big|_{q_{j,1}=\lambda q_{j,0}} > z^*_{1,1}\big|_{q_{j,1}=\eta q_{j,0}} > z^*_{j,1}\big|_{q_{j,1}=q_{j,0}}$. Furthermore, $\frac{\partial z^*_{j,1}}{\partial x^e_1}\big|_{q_{j,1}=\lambda q_{j,0}} > \frac{\partial z^*_{j,1}}{\partial x^e_1}\big|_{q_{j,1}=\eta q_{j,0}} > 0 > \frac{\partial z^*_{j,1}}{\partial x^e_1}\big|_{q_{j,1}=q_{j,0}}$.*

Proof. The first part is straightforward with simple algebra. The second part is proved as follows. For $q_{j,1} = q_{j,0}$, we have $\frac{\partial z_{j,1}}{\partial x^e_1} = -\frac{\pi_{j,2}}{2\widehat{\chi}}(\lambda-1)\big[(1-x_{j,1}) + (1-x^e_1)\frac{\partial x_{j,1}}{\partial x^e_1}\big]$, and $\frac{\partial x_{j,1}}{\partial x^e_1} = 0$. Thus, the following is obtained: $\frac{\partial z_{j,1}}{\partial x^e_1} = -\frac{\pi_{j,2}}{2\widehat{\chi}}(\lambda-1)(1-x_{j,1}) < 0$. For $q_{j,1} = \lambda q_{j,0}$, we have $\frac{\partial z_{j,1}}{\partial x^e_1} = \frac{\pi_{j,2}}{2\widehat{\chi}}\big[1 - x_{j,1} + (1-x^e_1)\frac{\partial x_{j,1}}{\partial x^e_1}\big]$ and $\frac{\partial x_{j,1}}{\partial x^e_1} = -\frac{\eta\pi_{j,2}}{2\widetilde{\chi}}\frac{\partial z_{j,1}}{\partial x^e_1}$. Thus, the following holds: $\frac{\partial z_{j,1}}{\partial x^e_1} = (1-x_{j,1})\big[\frac{2\widehat{\chi}}{\pi_{j,2}} + \frac{\eta\pi_{j,2}}{2\widetilde{\chi}}(1-x^e_1)\big]^{-1} > 0$, hence $\frac{\partial x_{j,1}}{\partial x^e_1} = -\frac{\eta\pi_{j,2}}{2\widetilde{\chi}}\frac{\partial z_{j,1}}{\partial x^e_1} < 0$. For $q_{j,1} = \eta q_{j,0}$, we have

$\frac{\partial z_{j,1}}{\partial x_1^e} = \frac{\pi_{j,2}}{2\widetilde{\chi}}\frac{1}{2}\left[1 - x_{j,1} + (1 - x_1^e)\frac{\partial x_{j,1}}{\partial x_1^e}\right]$, and $\frac{\partial x_{j,1}}{\partial x_1^e} = -\frac{\eta\pi_{j,2}}{2\widetilde{\chi}}\frac{1}{2}\frac{\partial z_{j,1}}{\partial x_1^e}$. This gives $\frac{\partial z_{j,1}}{\partial x_1^e} = (1 - x_{j,1})\left[\frac{4\widehat{\chi}}{\pi_{j,2}} + \frac{\eta\pi_{j,2}}{4\widetilde{\chi}}(1 - x_1^e)\right]^{-1} > 0$, hence $\frac{\partial x_{j,1}}{\partial x_1^e} = -\frac{1}{2}\frac{\eta\pi_{j,2}}{2\widetilde{\chi}}\frac{\partial z_{j,1}}{\partial x_1^e} < 0$ holds. With $x_{j,1}^*$ and $\frac{\eta\pi_{j,2}}{2\widetilde{\chi}} \in (0, 1)$, along with the restriction $4\widehat{\chi} > \pi_{j,2}$, the following holds: $\frac{4\widehat{\chi}}{\pi_{j,2}} + \frac{\eta\pi_{j,2}}{4\widetilde{\chi}}(1 - x_1^e) > \frac{2\widehat{\chi}}{\pi_{j,2}} + \frac{\eta\pi_{j,2}}{2\widetilde{\chi}}(1 - x_1^e)$. Therefore, we get $\frac{\partial z_{j,1}^*}{\partial x_1^e}\Big|_{q_{j,1}=\lambda q_{j,0}} > \frac{\partial z_{j,1}^*}{\partial x_1^e}\Big|_{q_{j,1}=\eta q_{j,0}}$ □

The second part of proposition B.1 suggests that firms without a technology gap decrease their own-innovation when facing a higher probability of creative destruction in their own markets. This is because they cannot enhance their product protection through own-innovation. Conversely, firms with a significant technological advantage do not substantially increase their own-innovation in response to creative destruction from outsiders, as the risk of losing their own product market is minimal. In intermediate cases, firms intensify their own-innovation response to creative destruction from outsiders to reduce the probability of losing their market.

Higher innovation in period 0 increases the probability of achieving a high technology gap in period 1, thereby aiding firms in market protection. To understand how past innovation intensity influences the firm's current decision on own-innovation when facing a higher probability of encountering a competitor, x_1^e, we define the expected value of own-innovation intensity in period 1 as $\bar{z}_1^* = z_{1,1}^*\big|_{q_{1,1}=q_{1,0}}\frac{1}{2}(1 - z_{1,0}) + z_{2,1}^*\big|_{q_{2,1}=q_{2,0}}\frac{1}{2}(1 - x_{2,0}) + z_{1,1}^*\big|_{q_{1,1}=\lambda q_{1,0}}\frac{1}{2}z_{1,0} + z_{2,1}^*\big|_{q_{2,1}=\eta q_{2,0}}\frac{1}{2}x_{2,0}$, where $\frac{1}{2}$ accounts for the two products. Proposition B.1 provides the following result:

Corollary B.1 (Market-Protection Effect)**.** *The impact of period 0 innovation intensities, $z_{1,0}$ and $x_{2,0}$, on expected own-innovation in period 1 can be characterized as follows: $\frac{\partial \bar{z}_1^*}{\partial x_1^e \partial z_{1,0}} > 0$, and $\frac{\partial \bar{z}_1^*}{\partial x_1^e \partial x_{2,0}} > 0$.*

Proof. From $\bar{z}_1^*$, we know that $\frac{\partial \bar{z}_1^*}{\partial z_{1,0}} = \frac{1}{2}\left(z_{1,1}^*\big|_{q_{1,1}=\lambda q_{1,0}} - z_{1,1}^*\big|_{q_{1,1}=q_{1,0}}\right) > 0$ and $\frac{\partial \bar{z}_1^*}{\partial x_{2,0}} = \frac{1}{2}\left(z_{2,1}^*\big|_{q_{2,1}=\eta q_{2,0}} - z_{2,1}^*\big|_{q_{2,1}=q_{2,0}}\right) > 0$, where the signs can be derived from proposition B.1. The results follow from proposition B.1. □

Corollary B.1 suggests that intensive innovation in the previous period prompts firms to increase own-innovation in response to higher competitive pressure. As indicated by the optimal decision rule, firms' decisions regarding creative destruction also depend on the past innovation decisions of other firms, which is outlined in the following proposition.

Proposition B.2. *For each $q_{j,1}$ and for $\lambda^2 > \eta > \lambda > 1$, we can order creative destruction intensities as follows: $x^*_{j,1}\big|_{q_{j,1}=q_{j,0}} > x^*_{j,1}\big|_{q_{j,1}=\lambda q_{j,0}} > x^*_{j,1}\big|_{q_{j,1}=\eta q_{j,0}}$. Furthermore, $\frac{\partial x^*_{j,1}}{\partial x^e_1}\big|_{q_{j,1}=q_{j,0}} = 0$, $\frac{\partial x^*_{j,1}}{\partial x^e_1}\big|_{q_{j,1}=\lambda q_{j,0}} < 0$, and $\frac{\partial x^*_{j,1}}{\partial x^e_1}\big|_{q_{j,1}=\eta q_{j,0}} < 0$. Proof: See the proof for Proposition B.1*

Proposition B.2 implies that firms decrease creative destruction if incumbents hold a higher technology advantage, as it becomes more difficult to displace them in the market through creative destruction. In markets where there is a technological barrier (technology gap > 1), firms also reduce their creative destruction in response to increased creative destruction by outside firms. This is because incumbents in these markets respond defensively by increasing own-innovation (proposition B.1). To understand how the past innovation intensity of other firms influences a firm's current decision on creative destruction, define the expected value of creative destruction intensity in period 1 as $\overline{x}^*_1 = x^*_{1,1}\big|_{q_{1,1}=q_{1,0}}\frac{1}{2}(1-z_{1,0}) + x^*_{2,1}\big|_{q_{2,1}=q_{2,0}}\frac{1}{2}(1-x_{2,0}) + x^*_{1,1}\big|_{q_{1,1}=\lambda q_{1,0}}\frac{1}{2}z_{1,0} + x^*_{2,1}\big|_{q_{2,1}=\eta q_{2,0}}\frac{1}{2}x_{2,0}$. Then, the first part of proposition B.2 implies the following:

Corollary B.2 (Technological Barrier Effect)**.** *Given technology $q_{j,1}$ and period 0 innovation intensities $z_{1,0}$ and $x_{2,0}$, $\frac{\partial \overline{x}^*_1}{\partial z_{1,0}} < 0$ and $\frac{\partial \overline{x}^*_1}{\partial x_{2,0}} < 0$ hold.*

Proof. $\frac{\partial \overline{x}^*_1}{\partial z_{1,0}} = \frac{1}{2}\left(x^*_{1,1}\big|_{q_{1,1}=\lambda q_{1,0}} - x^*_{1,1}\big|_{q_{1,1}=q_{1,0}}\right) < 0$, and $\frac{\partial \overline{x}^*_1}{\partial x_{2,0}} = \frac{1}{2}\left(x^*_{2,1}\big|_{q_{2,1}=\eta q_{2,0}} - x^*_{2,1}\big|_{q_{2,1}=q_{2,0}}\right) < 0$, where the signs follow from proposition B.2 □

Corollary B.2 indicates that higher technology levels in other markets, resulting from previous innovation, act as effective technological barriers, making it challenging for outside firms to take over those product markets. This reduces firms' incentives for creative destruction. Lastly, because innovation is forward-looking, changes in future profits π' are crucial factors influencing the current period's innovation. Proposition B.3 summarizes this:

Proposition B.3 (Ex-post Schumpeterian Effect)**.** *Given the expected profit $\pi_{j,2}$ in period 2, we obtain $\frac{\partial z^*_{j,1}}{\partial \pi_{j,2}} > 0\ \forall q_{j,1}$ and $\frac{\partial x^*_{j,1}}{\partial \pi_{j,2}} > 0$ for $q_{j,1} = q_{j,0}$. The signs for $\frac{\partial x^*_{j,1}}{\partial \pi_{j,2}}$ for other technology gaps remain ambiguous.*

Proof. For $q_{j,1} = q_{j,0}$, we have $\frac{\partial z_{j,1}}{\partial \pi_{j,2}} = \frac{1}{2\widehat{\chi}}(\lambda-1)(1-x_{j,1})(1-x^e_1) - \frac{\pi_{j,2}}{2\widehat{\chi}}(\lambda-1)(1-x^e_1)\frac{\partial x_{j,1}}{\partial \pi_{j,2}}$ and $\frac{\partial x_{j,1}}{\partial \pi_{j,2}} = \frac{\eta}{2\widehat{\chi}}$. Thus, $\frac{\partial z_{j,1}}{\partial \pi_{j,2}} = \frac{1}{2\widehat{\chi}}(\lambda-1)(1-2x_{j,1})(1-x^e_1) > 0$ iff $x_{j,1} < \frac{1}{2}$. For $q_{j,1} = \lambda q_{j,0}$, we get $\frac{\partial z_{j,1}}{\partial \pi_{j,2}} > 0$ unambiguously. For $q_{j,1} = \eta q_{j,0}$, $\frac{\partial z_{j,1}}{\partial \pi_{j,2}} = \frac{1}{2\widehat{\chi}}\left[\lambda - \frac{1}{2} - \frac{1}{2}(1-x_{j,1})(1-x^e_1)\right] + \frac{\pi_{j,2}}{2\widehat{\chi}}\frac{1}{2}(1-x^e_1)\frac{\partial x_{j,1}}{\partial \pi_{j,2}}$

and $\frac{\partial x_{j,1}}{\partial \pi_{j,2}} = \frac{\eta}{2\widetilde{\chi}}\frac{1}{2}(1 - z_{j,1}) - \frac{\eta \pi_{j,2}}{2\widetilde{\chi}}\frac{1}{2}\frac{\partial z_{j,1}}{\partial \pi_{j,2}}$ are obtained, and we get $\frac{\partial z_{j,1}}{\partial \pi_{j,2}} = \left[\lambda - \frac{1}{2} - \frac{1}{2}(1 - 2x_{j,1})(1 - x_1^e)\right]\left[2\widehat{\chi} + \frac{\eta(\pi_{j,2})^2}{2\widetilde{\chi}}\frac{1}{4}(1 - x_1^e)\right]^{-1} > 0$. The sign for $\frac{\partial x_{j,1}}{\partial \pi_{j,2}}$ remains ambiguous. □

Proposition B.3 implies that any factor that affects future profits may influence firms' own-innovation and creative destruction. Specifically, an increase in expected profit from one's own market encourages firms to intensify their own-innovation efforts. However, the impact of an increase in expected profit in other markets on firms' decisions regarding creative destruction is ambiguous when the local technology gap exceeds 1. This ambiguity arises because incumbents in these markets tend to increase their own-innovation efforts in response to higher expected profits, thereby allowing them to protect their markets. In cases where the local technology gap equals 1, incumbents cannot protect their markets through own-innovation alone. Consequently, an increase in expected future profit unambiguously stimulates creative destruction in such scenarios. These findings highlight the diverse factors influencing own-innovation, creative destruction, and overall innovation levels.

C Extension: Stochastic Innovation Step Size

In this section, we extend our baseline model by relaxing the constant innovation step size assumption. We demonstrate that the predictions of our baseline model remain robust without assuming that $\lambda^2 > \eta$. Thus, $\lambda^2 > \eta$ is an innocuous simplifying assumption serving only to clarify the exposition of the main mechanism and reduce computational burden. Following Garcia-Macia et al. (2019), we let firms draw innovation step sizes from probability distributions. Successful innovation improves product quality by a step size drawn from a distribution. For own-innovation, $\lambda \sim \widehat{\mu}(\lambda)$, where $\lambda \in [\lambda_L, \lambda_U]$ with mean $\overline{\lambda}$; for creative destruction, $\eta \sim \widetilde{\mu}(\eta)$, where $\eta \in [\eta_L, \eta_U]$ with mean $\overline{\eta}$. Here, $\lambda_L \geq 1$ and $\eta_L \geq 1$ hold. To be consistent with our empirical findings in Section 3.2, we assume $\overline{\eta} \geq \overline{\lambda}$. Under this setup, the technology gap is continuous, taking values $\Delta \in [1, \eta_U]$.

Innovation by Incumbents Consider firm A, which owns product 1 with quality q_{1t} and technology gap Δ_{1t}, where $q_{1t} = \Delta_{1t} q_{1t-1}$, and $\Delta_{1t} \in [1, \eta_U]$. For simplicity, assume firms exit the economy in $t+1$ after receiving profits from their products. If firm A retains product 1 in $t+1$, it receives a profit of πq_{1t+1} and zero otherwise. Furthermore, if firm A succeeds in taking over product 2 owned by firm B, it receives a profit of πq_{2t+1}. The value function of firm A in t is then $V(q_{1t}, \Delta_{1t}) = \max_{z_{1t}, x^A_{2t}} \{\pi\Delta_{1t}q_{1t-1} - \widehat{\chi}z_{1t}^{\widehat{\psi}}\Delta_{1t}q_{1t-1} - \widetilde{\chi}(x^A_{2t})^{\widetilde{\psi}}q_{2t-1} + \widetilde{\beta}\mathbb{E}_{\{\lambda_{jt},\eta_{jt}\}_{j=1}^2}\big[(1-z_{1t})(1-x^B_{1t}+x^B_{1t}Pr(\Delta_{1t} \geq \eta_{1t}))\pi\Delta_{1t}q_{1t-1} + z_{1t}(1-x^B_{1t}+x^B_{1t}Pr(\Delta_{1t}\lambda_{1t} \geq \eta_{1t}))\pi\Delta_{1t}\lambda_{1t}q_{1t-1} + x^A_{2t}(z_{2t}Pr(\eta_{2t} > \Delta_{2t}\lambda_{2t}) + (1-z_{2t})Pr(\eta_{2t} > \Delta_{2t}))\pi\eta_{2t}q_{2t-1}\big]\}$. The first three terms represent current period profits net of R&D costs for own-innovation ($\widehat{\chi}z_{1t}^{\widehat{\psi}}\Delta_{1t}q_{1t-1}$) and creative destruction ($\widetilde{\chi}(x^A_{2t})^{\widetilde{\psi}}q_{2t-1}$). The terms inside the expectation operator correspond to the expected profits from the existing product (product 1) and that from taking over product 2 through creative destruction. Here, z_{2t}, x^B_{1t}, and Δ_{2t} represent firm B's respective counterparts for own-innovation and creative destruction intensities, and technology gap.

Taking the first-order conditions with respect to z_{1t} and x^A_{2t} yields firm A's optimal own-innovation decision $z^*_{1t} = \big(\widetilde{\beta}\pi/\widehat{\chi}\widehat{\psi}\big)^{1/(\widehat{\psi}-1)}\big[(\overline{\lambda}-1)(1-x^B_{1t}) + x^B_{1t}\mathbb{E}_{\lambda_{1t},\eta_{1t}}\{\lambda_{1t}Pr(\Delta_{1t}\lambda_{1t} \geq \eta_{1t})\} - x^B_{1t}\mathbb{E}_{\eta_{1t}}\{Pr(\Delta_{1t} \geq \eta_{1t})\}\big]^{1/(\widehat{\psi}-1)}$, and optimal creative destruction decision $x^{A*}_{2t} = \big(\widetilde{\beta}\pi/\widetilde{\chi}\widetilde{\psi}\big)^{1/(\widetilde{\psi}-1)}$ $\big[z_{2t}\mathbb{E}_{\lambda_{2t},\eta_{2t}}\{\eta_{2t}Pr(\eta_{2t} > \Delta_{2t}\lambda_{2t})\} + (1-z_{2t})\mathbb{E}_{\eta_{2t}}\{\eta_{2t}Pr(\eta_{2t} > \Delta_{2t})\}\big]^{1/(\widetilde{\psi}-1)}$. The following proposition shows that the changes in firms' own-innovation decisions in response to increasing competition mirror those in the baseline model. To prove this analytically, we assume that the two step sizes are drawn from uniform distributions, $\mathcal{U}(\cdot,\cdot)$.

Proposition F.1 (Market-Protection Effect)**.** *Suppose $\lambda \sim \mathcal{U}(\lambda_L, \lambda_U)$ and $\eta \sim \mathcal{U}(\eta_L, \eta_U)$, with $\overline{\eta} \geq \overline{\lambda}$, $\lambda_U > \eta_L$, and equal variances. Then, $\frac{\partial z^*_{1t}(x^B_{1t},\Delta_{1t})}{\partial x^B_{1t}}$ is hump-shaped with respect to the technology gap Δ_{1t} and is positive over a region that includes $[\frac{\eta_L}{\lambda_L}, \eta_U)$ when $\frac{\lambda_U}{\lambda_L} \in (1,4)$. Additionally, $\frac{\partial z^*_{1t}(x^B_{1t},\Delta_{1t})}{\partial x^B_{1t}}\Big|_{\Delta_{1t}=\eta_U} = 0$, while the sign of $\frac{\partial z^*_{1t}(x^B_{1t},\Delta_{1t})}{\partial x^B_{1t}}\Big|_{\Delta_{1t}=1}$ remains ambiguous.*

Proof. The sign of $\frac{\partial z^*_{1t}(x^B_{1t},\Delta_{1t})}{\partial x^B_{1t}}$ follows the sign of $** = -(\overline{\lambda}-1) - \mathbb{E}_{\eta_{1t}}\{Pr(\Delta_{1t} \geq \eta_{1t})\} + \mathbb{E}_{\lambda_{1t},\eta_{1t}}\{\lambda_{1t}Pr(\Delta_{1t}\lambda_{1t} \geq \eta_{1t})\}$. Depending on the value of Δ_{1t}, there are three cases to consider: Case 1, where $\Delta_{1t}\lambda_L < \eta_L$; Case 2, where $\Delta_{1t}\lambda_L \in [\eta_L, \eta_U)$; and Case 3, where $\Delta_{1t}\lambda_L = \eta_U$. Without loss of generality, we normalize $\lambda_L = 1$. In Case 1, we have $\mathbb{E}_{\eta_{1t}}\{Pr(\Delta_{1t} \geq \eta_{1t})\} = 0$, and $\mathbb{E}_{\lambda_{1t},\eta_{1t}}\{\lambda_{1t}Pr(\Delta_{1t}\lambda_{1t} \geq \eta_{1t})\} = \frac{\Delta_{1t}\lambda_U - \eta_L}{6\Delta^2_{1t}(\eta_U-\eta_L)(\lambda_U-\lambda_L)}(2\Delta^2_{1t}\lambda^2_U - \Delta_{1t}\lambda_U\eta_L - \eta^2_L)$. Then, we can show that $\frac{\partial **}{\partial \Delta_{1t}} > 0$ as $\lambda_U > \eta_L > \Delta_{1t} \geq 1$, and $\frac{\partial^2 **}{\partial \Delta^2_{1t}} > 0$. Thus, $**$ is an increasing and convex function of Δ_{1t}. Furthermore, $** \,|_{\Delta_{1t}\nearrow\eta_L/\lambda_L} > 0$ when $\frac{\lambda_U}{\lambda_L} \in (1,4)$. The sign of $\frac{\partial **}{\partial \Delta_{1t}}\big|_{\Delta_{1t}=1}$ is ambiguous. In Case 2, we have $\mathbb{E}_{\eta_{1t}}\{Pr(\Delta_{1t} \geq \eta_{1t})\} = \frac{\Delta_{1t}-\eta_L}{\eta_U-\eta_L}$, and $\mathbb{E}_{\lambda_{1t},\eta_{1t}}\{\lambda_{1t}Pr(\Delta_{1t}\lambda_{1t} \geq \eta_{1t})\} = \frac{1}{2(\eta_U-\eta_L)(\lambda_U-\lambda_L)}\big[\lambda^2_U(\eta_U-\eta_L) + \lambda^2_L\eta_L - \frac{1}{3\Delta^2_{1t}}(2\Delta^3_{1t}\lambda^3_L + \eta^3_U)\big]$. Then, we can show that $\frac{\partial^2 **}{\partial \Delta^2_{1t}} < 0$, $\frac{\partial **}{\partial \Delta_{1t}}\big|_{\Delta_{1t}=\eta_L/\lambda_L} > 0$, $\frac{\partial **}{\partial \Delta_{1t}}\big|_{\Delta_{1t}\nearrow\eta_U} < 0$, and $**\,\big|_{\Delta_{1t}\nearrow\eta_U} = 0$. Thus, $**$ is a concave function of Δ_{1t}, achieving a maximum at $\Delta_{1t}^{*} \in (\eta_L/\lambda_L, \eta_U)$. Since $**\big|_{\Delta_{1t}\nearrow\eta_U} = 0$, it follows that $**\big|_{\Delta_{1t}=\Delta_{1t}^{*}} > 0$. As in Case 1, $**\,|_{\Delta_{1t}=\eta_L/\lambda_L} > 0$ when $\frac{\lambda_U}{\lambda_L} \in (1, 4)$. In Case 3, we have $\mathbb{E}_{\eta_{1t}}\{Pr(\Delta_{1t} \geq \eta_{1t})\} = 1$ and $\mathbb{E}_{\lambda_{1t},\eta_{1t}}\{\lambda_{1t}Pr(\Delta_{1t}\lambda_{1t} \geq \eta_{1t})\} = \overline{\lambda}$. Therefore, $** = 0$. $\square$

The condition $\lambda_U/\lambda_L \in (1, 4)$ implies that the average quality improvement ranges from 0% to 150%. Thus, this condition is most likely satisfied in the real application. Furthermore, $\frac{\partial z_{1t}^{*}(x_{1t}^{B},\Delta_{1t})}{\partial x_{1t}^{B}} > 0$ in a region near $\Delta_{1t} = \eta_U$, even without imposing this condition. Although the sign of $\frac{\partial **}{\partial \Delta_{1t}}\big|_{\Delta_{1t}=1}$ is ambiguous, numerical analysis shows that it is negative as long as η_L and λ_L is not significantly different. For example, in our baseline model calibration, we have $\overline{\lambda} = 1.04$ and $\overline{\eta} = 1.075$, which implies $\frac{\eta_L}{\lambda_L} = 1.034$, and $\frac{\lambda_U}{\lambda_L} = 1.08$. These values satisfy $\frac{\partial **}{\partial \Delta_{1t}}\big|_{\Delta_{1t}=1} < 0$.

The next proposition shows that this extended model also has the technological barrier effect.

Proposition F.2 (Technological Barrier Effect)**.** *High own-innovation intensity by an incumbent (z_{2t}) as well as a high technological barrier in the target market (Δ_{2t}) both discourage creative destruction by rival firms. Formally,* $\frac{\partial x_{2t}^{A}(z_{2t},\Delta_{2t})}{\partial z_{2t}} < 0$, *and* $\frac{\partial x_{2t}^{A}(z_{2t},\Delta_{2t})}{\partial \Delta_{2t}} < 0$.

Proof. Since $\lambda_{2t} \geq 1$ and $\eta_{2t} \geq 1$, we have $\mathbb{E}_{\eta_{2t}}\{\eta_{2t}Pr(\eta_{2t} > \Delta_{2t})\} > \mathbb{E}_{\eta_{2t},\lambda_{2t}}\{\eta_{2t}Pr(\eta_{2t} > \Delta_{2t}\lambda_{2t})\}\ \forall\ \Delta_{2t} \geq 1$. Thus, $\frac{\partial x_{2t}^{A}(z_{2t},\Delta_{2t})}{\partial z_{2t}} < 0$. Furthermore, $\mathbb{E}_{\eta_{2t},\lambda_{2t}}\{\eta_{2t}Pr(\eta_{2t} > \Delta_{2t}\lambda_{2t})\}$ is a decreasing function of Δ_{2t}. Thus, $\frac{\partial x_{2t}^{A}(z_{2t},\Delta_{2t})}{\partial \Delta_{2t}} < 0$. $\square$

D Extension: Multi-Creative Destruction

By allowing firms to do multiple creative destructions, all remain the same except for firm innovation decisions and aggregate variables.

D.1 Optimal Innovation Decision

Following Klette and Kortum (2004) and several follow-on studies, we model firms' creative destruction decisions based on the number of products they produce (n_f). Creative destruction can be viewed as a spin-off derived from each firm's existing products. Consider product j firm f owns with quality q_j and technology gap Δ_j^{ℓ}. In the subsequent period, the evolution of this product can result in six cases: firm f i) loses product j and business takeover (through creative destruction) fails, ii) loses product j and takeover succeeds, iii) keeps product j while both own-innovation and takeover fail, iv) keeps product j while own-innovation fails, but takeover succeeds, v) keeps product j with successful own-innovation, but takeover fails, and vi) keeps product j with successful own-innovation and takeover. Denoting the product-technology gap pair for a product that firm f acquires through successful business takeover in the next period as $\{(q', \Delta')\}$, we can write down the evolution of the product portfolio stemming from $\Phi^f = \{(q_j, \Delta_j^\ell)\}$ for $\ell \in \{1, 2, 3, 4\}$ for each of the six cases. For example, for $\Delta_j^\ell = \Delta^2$, $\Phi_j^{f\prime} = \emptyset \cup \emptyset$ with prob. $\overline{x}(1 - z^2)(1 - x\overline{x}_{\text{takeover}})$, $\Phi_j^{f\prime} = \emptyset \cup \{(q', \Delta')\}$ with prob. $\overline{x}(1 - z^2)(x\overline{x}_{\text{takeover}})$, $\Phi_j^{f\prime} = \{(q_j, \Delta^1)\} \cup \emptyset$ with prob. $(1 - \overline{x})(1 - z^2)(1 - x\overline{x}_{\text{takeover}})$, $\Phi_j^{f\prime} = \{(q_j, \Delta^1)\} \cup \{(q', \Delta')\}$ with prob. $(1 - \overline{x})(1 - z^2)(x\overline{x}_{\text{takeover}})$, $\Phi_j^{f\prime} = \{(\Delta^2 q_j, \Delta^2)\} \cup \emptyset$ with prob. $z^2(1 - x\overline{x}_{\text{takeover}})$, and $\Phi_j^{f\prime} = \{(\Delta^2 q_j, \Delta^2)\} \cup \{(q', \Delta')\}$ with prob. $z^2(x\overline{x}_{\text{takeover}})$.[3]

If the value function is additively separable with respect to each product a firm produces, we only need to solve it at the product level and aggregate it to the firm level. For product j with $\Phi_j^f = \{(q_j, \Delta^\ell)\}$, the value function is given by $V(\Phi_j^f) = \max_{z_j, x_j} \{\pi q_j - \widehat{\chi} z_j^{\widehat{\psi}} q_j - \widetilde{\chi} x_j^{\widetilde{\psi}} \overline{q} - F\overline{q} + \widetilde{\beta}\mathbb{E}\big[V'\big(\Phi_j^{f\prime}\big)|\Phi_j^f, z_j, x_j\big]\}$, where $F\overline{q}$ represents fixed operating costs.[4] The value function for firm f with a portfolio of product quality and technology gap is then: $\Phi^f = \big\{\Phi_j^f\big\}_{j\in\mathcal{J}^f}$ is $V\big(\Phi_j^f\big) = \sum_{j\in\mathcal{J}^f} V\big(\Phi_j^f\big)$. The following proposition derives analytic expressions for firms' decision rules.[5]

Proposition F.1. *Given a technology gap distribution $\big\{\mu\big(\Delta^\ell\big)\big\}_{\ell=1}^4$, a fixed cost of operation equal to $F\overline{q} = \widetilde{\beta}B(1 + g)\overline{q}$, and the exit value for a product given by $V(\emptyset) = \frac{B\overline{q}}{1 - x\overline{x}_{\text{takeover}}}$, the value function of firm f with a product quality and technology gap portfolio of $\Phi^f \equiv \big\{(q_j, \Delta_j)\big\}_{j\in\mathcal{J}^f}$ is: $V(\Phi^f) = \sum_{\ell=1}^4 A_\ell\big(\sum_{j\in\mathcal{J}^f|\Delta_j=\Delta^\ell} q_j\big) + n_f B\overline{q}$, where $A_1 = \pi - \widehat{\chi}(z^1)^{\widehat{\psi}} + \widetilde{\beta}\big[A_1(1 - \overline{x})(1 - z^1) + \lambda A_2(1 - \overline{x})z^1\big]$, $A_2 = \pi - \widehat{\chi}(z^2)^{\widehat{\psi}} + \widetilde{\beta}\big[A_1(1 - \overline{x})(1 - z^2) + \lambda A_2 z^2\big]$, $A_3 = \pi - \widehat{\chi}(z^3)^{\widehat{\psi}} + \widetilde{\beta}\big[A_1\big(1 - \frac{1}{2}\overline{x}\big)(1 - z^3) + \lambda A_2 z^3\big]$, $A_4 = \pi - \widehat{\chi}(z^4)^{\widehat{\psi}} + \widetilde{\beta}\big[A_1(1 - \overline{x})(1 - z^4) + \lambda A_2\big(1 - \frac{1}{2}\overline{x}\big)z^4\big]$, and $B = \big[x\widetilde{\beta}A_{\text{takeover}} - \widetilde{\chi}x^{\widetilde{\psi}}\big]/\big[1 - \widetilde{\beta}(1 + g)x\overline{x}_{\text{takeover}}\big]$, and the optimal innovation probabilities are $z^1 = \big[\widetilde{\beta}\big[(1 - \overline{x})\lambda A_2 - (1 - \overline{x})A_1\big]/\big[\widehat{\psi}\widehat{\chi}\big]\big]^{\frac{1}{\widehat{\psi}-1}}$, $z^2 = \big[\big[\widetilde{\beta}\big[\lambda A_2 - (1 - \overline{x})A_1\big]/\big[\widehat{\psi}\widehat{\chi}\big]\big]^{\frac{1}{\widehat{\psi}-1}}$, $z^3 = \big[\big[\widetilde{\beta}\big[\lambda A_2 - \big(1 - \frac{1}{2}\overline{x}\big)A_1\big]/\big[\widehat{\psi}\widehat{\chi}\big]\big]^{\frac{1}{\widehat{\psi}-1}}$, $z^4 = \big[\big[\widetilde{\beta}\big[\lambda\big(1 - \frac{1}{2}\overline{x}\big)A_2 - \big(1 - \overline{x}\big)A_1\big]/\big[\widehat{\psi}\widehat{\chi}\big]\big]^{\frac{1}{\widehat{\psi}-1}}$, and $x = \big[\big[\widetilde{\beta}\big[A_{\text{takeover}} + \overline{x}_{\text{takeover}}B(1 + g)\big]/\big[\widetilde{\psi}\widetilde{\chi}\big]\big]^{\frac{1}{\widetilde{\psi}-1}}$, where g is the average product quality growth*

[3] For simplicity, we use the unconditional probability of business takeover $x\overline{x}_{\text{takeover}}$ abusively.

[4] This is commonly assumed for tractability (Akcigit and Kerr, 2018; De Ridder, 2024; Argente et al., 2024)

[5] The analytic expression for startup decisions remains unchanged.

rate in the economy, A_{takeover} *is the ex-ante value of a product line obtained from successful takeover, defined as* $A_{\text{takeover}} \equiv \frac{1-z^3}{2} A_1 \mu(\Delta^3) + \left(1 - \frac{z^4}{2}\right) A_2 \lambda \mu(\Delta^4) + A_3 \eta \mu(\Delta^1) + (1-z^2) A_4 \frac{\eta}{\lambda} \mu(\Delta^2)$*, and* $\overline{x}_{\text{takeover}} = \mu(\Delta^1) + (1-z^2)\mu(\Delta^2) + \frac{1}{2}(1-z^3)\mu(\Delta^3) + \left(1 - \frac{1}{2}z^4\right)\mu(\Delta^4)$.

Proof. Suppose the value function is additively separable with respect to each product a firm produces. Then, we can rewrite the expected future value term for each technology gap case as follows: for Δ^1, $\mathbb{E}\left[V'\left(\Phi^{f\prime}\right)|\Phi^f, z^1, x\right] = (1-\overline{x})(1-z^1)V'\left(\left\{(q_j, \Delta^1)\right\}\right) + (1-\overline{x})z^1 V'\left(\left\{(\Delta^2 q_j, \Delta^2)\right\}\right) + x\mathbb{E}V'\left(\left\{(q', \Delta')\right\}\right) + \overline{x}(1 - x\overline{x}_{\text{takeover}})V'(\emptyset)$; for Δ^2, $\mathbb{E}\left[V'\left(\Phi^{f\prime}\right)|\Phi^f, z^2, x\right] = (1-\overline{x})(1-z^2)V'\left(\left\{(q_j, \Delta^1)\right\}\right) + z^2 V'\left(\left\{(\Delta^2 q_j, \Delta^2)\right\}\right) + x\mathbb{E}V'\left(\left\{(q', \Delta')\right\}\right) + \overline{x}(1-z^2)(1 - x\overline{x}_{\text{takeover}})V'(\emptyset)$, for Δ^3, $\mathbb{E}\left[V'\left(\Phi^{f\prime}\right)|\Phi^f, z^3, x\right] = \left(1 - \frac{1}{2}\overline{x}\right)(1-z^3)V'\left(\left\{(q_j, \Delta^1)\right\}\right) + z^3 V'\left(\left\{(\Delta^2 q_j, \Delta^2)\right\}\right) + x\mathbb{E}V'\left(\left\{(q', \Delta')\right\}\right) + \frac{1}{2}\overline{x}(1-z^3)(1 - x\overline{x}_{\text{takeover}})V'(\emptyset)$; and for Δ^4, $\mathbb{E}\left[V'\left(\Phi^{f\prime}\right)|\Phi^f, z^4, x\right] = (1-\overline{x})(1-z^4)V'\left(\left\{(q_j, \Delta^1)\right\}\right) + \left(1 - \frac{1}{2}\overline{x}\right)z^4 V'\left(\left\{(\Delta^2 q_j, \Delta^2)\right\}\right) + x\mathbb{E}V'\left(\left\{(q', \Delta')\right\}\right) + \overline{x}\left(1 - \frac{1}{2}z^4\right)(1 - x\overline{x}_{\text{takeover}})V'(\emptyset)$.

Using the guessed value function $V(\left\{(q_j, \Delta^\ell)\right\}) = A_\ell q_j + B\overline{q}$, solving for the FONCs with respect to z^ℓ and x, and applying the suggested forms for fixed costs and the exit value, we obtain the analytic expressions for the optimal innovation decisions. For example, if $\Delta^\ell = \Delta^1$, we get $A_1 q_j + B\overline{q} = \pi q_j - \widehat{\chi} z_j^{\widehat{\psi}} q_j - \widetilde{\chi} x_j^{\widetilde{\psi}} \overline{q} + \widetilde{\beta}\Big[(1-\overline{x})(1-z^1)A_1 q_j + (1-\overline{x})z^1 A_2 \Delta^2 q_j + x_j \left[A_{\text{takeover}} + \overline{x}_{\text{takeover}}(1+g)B\right]\overline{q}\Big]$, as the fixed cost of operation and the exit value cancel out some terms associated with B. The FONC with respect to z_j is $\frac{\partial}{\partial z_j} = \widehat{\psi}\widehat{\chi} z_j^{\widehat{\psi}-1} = \widetilde{\beta}\Big[(1-\overline{x})A_2\Delta^2 - (1-\overline{x})A_1\Big]$. This equation provides the optimal own-innovation decision for Δ^1 case, which only depends on the technology gap. The FONC with respect to x_j is $\frac{\partial}{\partial x_j} = \widetilde{\psi}\widetilde{\chi} x_j^{\widetilde{\psi}-1} = \widetilde{\beta}\left[A_{\text{takeover}} + \overline{x}_{\text{takeover}}(1+g)B\right]$. This equation provides the optimal creative destruction x, which is independent of both product quality and technology gap. Collecting terms with q_j gives us the expression for A_1, which only depends on the technology gap, and collecting terms with $\overline{q}$ gives us the expression for B, which is independent of both product quality and technology gap. The remaining three technology gap cases follow the same process. These results confirm the additive separability of the value function with respect to each product-technology gap pair. □

D.2 Technology Gap Distribution Transition

From the quality evolution for incumbents (in the main text) and outsiders (Section A.2) the inflows and outflows for technology gap distribution ($\mu(\Delta^\ell)$) are defined as follows: for Δ^1, inflow is $(1-z^2)(1-\overline{x})\mu(\Delta^2)+(1-z^3)\mu(\Delta^3)+(1-z^4)(1-\overline{x})\mu(\Delta^4)$ and outflow is $(\overline{x}+z^1(1-\overline{x}))\mu(\Delta^1)$; for Δ^2, inflow is $z^1(1-\overline{x})\mu(\Delta^1)+z^3\mu(\Delta^3)+(z^4+(1-z^4)\overline{x})\mu(\Delta^4)$ and outflow is $(1-z^2)\mu(\Delta^2)$; for Δ^3, inflow is $\overline{x}\mu(\Delta^1)$ and outflow is $\mu(\Delta^3)$; and for Δ^4, inflow is $(1-z^2)\overline{x}\mu(\Delta^2$ and outflow is $\mu(\Delta^4)$.

D.3 Aggregate Variables

Aggregate Creative Destruction Arrival Rate Firms do creative destruction for each product they own simultaneously. Given the unit mass of products, there is a unit mass of creative destruction trials by incumbent firms each period. Defining $s_d = \mathcal{F}_d/\mathcal{F}$ as the share (the total mass) of domestic products and $s_o = \mathcal{F}_o/\mathcal{F}$ as the outside counterpart, we can write the aggregate creative destruction arrival rate as $\overline{x} = s_d x + \mathcal{E}_d x_e + \underbrace{s_o x + \mathcal{E}_o}_{\equiv \overline{x}_o}$, where $\mathcal{E}_o$ is the total mass of potential outside entrants with successful creative destruction. As we assume the symmetry between domestic and outside firms, the outsiders' creative destruction intensity is also x. As $s_d + s_o = 1$, we can rewrite $\overline{x}$ as $\overline{x} = x + \mathcal{E}_d x_e + \mathcal{E}_o$.

Aggregate Productivity Growth Decomposition The total mass of domestic creative destruction trials is the share of products owned by domestic firms s_d, given the unit mass assumption. Thus, we can replace the mass of domestic firms ($\mathcal{F}_d$) with s_d and obtain the following decomposition as in the single creative destruction setup:

$$
\begin{aligned}
g = & \underbrace{\left(\Delta^2 - 1\right) s_d \left[(1-\overline{x})z^1\mu(\Delta^1) + z^2\mu(\Delta^2) + z^3\mu(\Delta^3) + (1-\overline{x}/2)\, z^4\mu(\Delta^4)\right]}_{\text{own-innovation by domestic incumbents}} \\
& + \underbrace{\left(\Delta^2 - 1\right)(1-s_d) \left[(1-\overline{x})z^1\mu(\Delta^1) + z^2\mu(\Delta^2) + z^3\mu(\Delta^3) + (1-\overline{x}/2)\, z^4\mu(\Delta^4)\right]}_{\text{own-innovation by foreign firms}} \\
& + \underbrace{\left(\overline{\Delta^{\text{ex}}} - 1\right) s_d x \mu(\overline{\Delta^{\text{ex}}})}_{\text{creative destr. by domestic incumbents}} + \underbrace{\left(\overline{\Delta^{\text{ex}}} - 1\right) \mathcal{E}_d x_e \mu(\overline{\Delta^{\text{ex}}})}_{\text{creative destr. by domestic startups}} + \underbrace{\left(\overline{\Delta^{\text{ex}}} - 1\right) \overline{x}_o \mu(\overline{\Delta^{\text{ex}}})}_{\text{creative destr. by foreign firms}} .
\end{aligned}
$$

Aggregate Domestic R&D Expenses Similarly, the aggregate domestic R&D expenses can be rephrased as $R_d = \widehat{\chi} \sum_{\ell=1}^{4} \left[\int_0^1 q_j \mathcal{I}_{\{\Delta_j = \Delta^\ell, j\in\mathcal{D}\}} dj\right] (z^\ell)^{\widehat{\psi}} + s_d \widetilde{\chi}\overline{q} x^{\widetilde{\psi}} + \mathcal{E}_d \widetilde{\chi}_e (x_e)^{\widetilde{\psi}_e}\overline{q}$.

Aggregate Consumption Households own both final goods and domestic intermediate producers. They fund the R&D expenses of domestic potential startups and pay the exit value to domestic incumbents. The households earn labor income from final goods producer (wL), operating fixed costs from intermediate producers ($s_d F\overline{q}$), as well as profits from both producers ($\Pi = 0$ and $\sum_{j\in\mathcal{D}} \pi q_j > 0$). Intermediate producers' profits include the exit value if their product is taken over and their own creative destruction fails. Thus, the household budget constraint is $wL + s_d F\overline{q} + \int j \in \mathcal{D}\{\pi q_j - F\overline{q}\} + (1 - x\overline{x}_{\text{takeover}})V(\emptyset) = C + \mathcal{E}_d \widetilde{\chi}_e(x_e)^{\widetilde{\psi}_e}\overline{q} + (1 - x\overline{x}_{\text{takeover}})V(\emptyset)$. With the final goods producers' profit function $\Pi = Y - \int_{j\in\mathcal{D}} p_j y_j dj - \int_{j\notin\mathcal{D}} p_j y_j dj - wL$, the aggregate consumption is $C = Y - \int_{j\notin\mathcal{D}} p_j y_j dj - Y_d - R_d$.

E Solution Algorithm

In the model, $\{z^\ell\}_{\ell=1}^4$ are functions of $\overline{x}$; g is a function of $\overline{x}$, $\{z^\ell\}_{\ell=1}^4$, and $\{\mu(\Delta^\ell)\}_{\ell=1}^4$; x is a function of $\overline{x}$ and $\{\mu(\Delta^\ell)\}_{\ell=1}^4$; x_e is a function of $\overline{x}$ and $\{\mu(\Delta^\ell)\}_{\ell=1}^4$; and $\overline{x}$ is a function of x, and x_e. Therefore, we can solve for an equilibrium of the model by iterating over the value for the aggregate creative destruction arrival rate $\overline{x}$.

For the extended model with multiple creative destruction: i) Guess values for $\overline{x}$, g and the technology gap distribution $\{\mu(\Delta^\ell)\}_{\ell=1}^4$; ii) Using the guess of $\overline{x}$, compute $\{A_\ell\}_{\ell=1}^4$, and $\{z^\ell\}_{\ell=1}^4$; iii) Using the guess of $\overline{x}$, g, and $\{\mu(\Delta^\ell)\}_{\ell=1}^4$, compute B, x, x_e. Next, compute the stationary $\{\mu_\infty(\Delta^\ell)\}_{\ell=1}^4$, based on the guess of $\{\mu_\infty(\Delta^\ell)\}_{\ell=1}^4$, innovation decision rules, and the following law of motion $\mu_{n+1}(\Delta^\ell) = \mu_n(\Delta^\ell) + \mathit{inflow}_n(\Delta^\ell) - \mathit{outflow}_n(\Delta^\ell)$ for each $\ell \in \{1, 2, 3, 4\}$. Lastly, compute g_∞ with $\{\mu_\infty(\Delta^\ell)\}_{\ell=1}^4$; iv) Compute $\overline{x}' = x + \mathcal{E}_d x_e + \mathcal{E}_o$; v) If $\overline{x} \neq \overline{x}'$, set $\overline{x} = \overline{x}'$, $g = g_\infty$, and $\{\mu(\Delta^\ell)\}_{\ell=1}^4 = \{\mu_\infty(\Delta^\ell)\}_{\ell=1}^4$, use them as new guess, and return to ii); vi) Repeat ii) through v) until the convergence of $\overline{x}$; and vii) Simulate the model over 10,000 products for 1,200 years and compute the moments averaged across the last 150 years.

Table E1: Changes in Innovation Values

Description	Variables	Before	After	% Change
Innovation Values	A_1	0.160	0.158	-1.1%
	A_2	0.173	0.172	-1.0%
	A_3	0.182	0.180	-1.0%
	A_4	0.165	0.163	-1.1%
	B	0.011	0.011	-2.6%

Table E2: Aggregate Growth Rate Decomposition

Description	Before	After	% Change
Average productivity growth (g, %)	2.229	2.242	0.6%
Growth by outside firms (g_o, %)	0.312	0.510	63.3%
Growth by domestic firms (g_d, %)	1.888	1.680	-11.0%
Growth from domestic own-innovation (%)	1.047	0.927	-11.4%
Growth from domestic creative destruction (%)	0.656	0.571	-13.0%
Growth from domestic startups (%)	0.186	0.182	-1.7%

Table E3: Aggregate Growth Rate Decomposition, Holding Mass Fixed

Description	Before	After	% Change
Average productivity growth by domestic firms (%)	1.888	1.875	-0.7%
Growth from domestic own-innovation (%)	1.047	1.048	0.1%
Growth from domestic creative destruction (%)	0.656	0.645	-1.7%
Growth from domestic startups (%)	0.186	0.182	-1.7%

Table E4: Changes in Firm Innovation in High Creative Destruction Cost Economy

Description	Variables	Before	After	% Change
Creative destruction arrival rate by outside firms	$\overline{x}_o$	1.361	2.406	76.8%
Aggregate creative destruction arrival rate	$\overline{x}$	8.966	9.636	7.5%
Prob. of own-innovation ($\Delta^1 = 1$)	z^1	20.581	20.300	-1.4%
Prob. of own-innovation ($\Delta^2 = \lambda$)	z^2	50.357	51.024	1.3%
Prob. of own-innovation ($\Delta^3 = \eta$)	z^3	36.483	36.744	0.7%
Prob. of own-innovation ($\Delta^4 = \frac{\eta}{\lambda}$)	z^4	35.469	35.662	0.5%
Prob. of creative destruction, incumbents	x	0.380	0.363	-4.6%
Prob. of creative destruction, potential startups	x_e	7.285	6.954	-4.6%

Table E5: Aggregate Growth Decomposition, Low Creativity Economy, Holding Mass Fixed

Description	Before	After	% Change
Average productivity growth by domestic firms (%)	1.397	1.378	-1.4%
Growth from domestic own-innovation (%)	0.991	0.994	0.3%
Growth from domestic creative destruction (%)	0.017	0.016	-5.3%
Growth from domestic startups (%)	0.388	0.368	-5.3%

F Other Theoretical Results

G Counterfactual: Competitive Pressure by Domestic Startups

We increase the mass of potential domestic startups ε_d by 15.2%, which raises the creative destruction arrival rate $\overline{x}$ from 21.5% to 21.9% (1.51% increase, equivalent to the main counterfactual exercise). Table F1 and Panel A in Table F2 present the results. The firm-level responses remain the same as before, while the total mass of domestic incumbents and startups increases. Thus, the moments related to the number of domestic firms and startups help identify the source behind the increased competitive pressure (domestic startups vs outside firms). Also, Panel B in Table F2 displays the growth decomposition, where the aggregate growth increases (unlike the main exercise), but domestic creative destruction decreases as before.

Table F1: Changes in Firm Innovation: Economy with More Potential Startups

Description	Variables	Before	After	% Change
Creative destruction arrival rate by outside firms	$\overline{x}_o$	3.30	3.04	-7.94%
Aggregate creative destruction arrival rate	$\overline{x}$	21.53	21.85	1.51%
Prob. of own-innovation ($\Delta^1 = 1$)	z^1	16.87	16.80	-0.42%
Prob. of own-innovation ($\Delta^2 = \lambda$)	z^2	57.83	57.95	0.20%
Prob. of own-innovation ($\Delta^3 = \eta$)	z^3	39.66	39.72	0.14%
Prob. of own-innovation ($\Delta^4 = \frac{\eta}{\lambda}$)	z^4	37.35	37.37	0.06%
Prob. of creative destruction, incumbents	x	16.76	16.54	-1.35%
Prob. of creative destruction, potential startups	x_e	4.02	3.97	-1.35%

Table F2: Aggregate Moment Change: Economy with More Potential Startups

Description	Before	After	% Change
Panel A: Changes in the Aggregate Moments			
Total mass of domestic firms	0.386	0.416	7.6%
Total mass of domestic startups	0.029	0.033	13.4%
R&D to sales ratio (%)	4.579	4.512	-1.5%
Avg. number of products	2.290	2.164	-5.5%
Panel B: Changes in the Aggregate Growth and Decomposition			
Average productivity growth by domestic firms (%)	1.89	1.93	2.3%
Growth from domestic own-innovation (%)	1.05	1.07	1.8%
Growth from domestic creative destruction (%)	0.66	0.65	-0.1%
Growth from domestic startups (%)	0.19	0.21	13.2%

H Data Appendix

H.1 Summary Statistics

Table G1 and G2 present summary statistics.

H.2 Real Effect of Firm Innovation with Alternative Measures

We replicate the findings using an alternative set of measures for creative destruction and own-innovation. Specifically, creative destruction is explicitly defined by the count of patents with a zero self-citation ratio, while own-innovation is measured by patents with a self-citation above 0% or 10%. This more direct measure of creative destruction and own-innovation exhibits consistent and even more pronounced effects, as presented in Table G3.

H.3 Parallel Pre-trend Assumption

We test the parallel pre-trends assumption, a key identifying assumption for the Diff-in-Diff model. We estimate (29) for the two seven-year periods preceding the policy change, 1984-1991 and 1992-1999. Table G4 supports the validity of the assumption, where the coefficient estimates are smaller and statistically insignificant.

Table G1: The Whole Universe of Patenting Firms vs. Regression Sample in 1992

	All patenting firms	Regression sample
Average number of patents	6.15	8.86
	(19.46)	(24.10)
Average self-citation rate	0.0434	0.0540
	(0.0899)	(0.0941)
Innovation intensity	0.055	0.093
	(0.25)	(0.33)
Number of industries operating	2.34	5.43
	(3.67)	(6.94)
Employment	511.7	1988.0
	(1869.0)	(3835.0)
Patent stock	6.45	35.22
	(26.61)	(64.37)
Employment growth	0.07	0.06
	(0.60)	(0.40)
Firm age	12.33	15.65
	(6.76)	(9.42)
7yr patent growth		-0.854
		(1.312)
7yr self-citation ratio growth		0.356
		(1.322)
Number of firms	26,500	3,100

Note: Innovation intensity in 2000 is 0.183(0.58), the seven-year patent growth in 2000 is -1.07(1.207), and the seven-year self-citation ratio growth in 2000 is 0.282(1.304).

Table G2: Foreign Competition Shock Related Measures

	NTR gap	Dnstream NTR g.	Upstream NTR g.	NTR rate	Non-NTR r.
Mean	0.291	0.138	0.203	0.027	0.303
(Std. dev.)	(0.127)	(0.060)	(0.073)	(0.022)	(0.134)
cov(, NTR gap)		0.485	0.434	0.412	0.969
cov(, Up. NTR g.)		0.204			

H.4 Other Robustness Test

Furthermore, we perform several robustness checks as follows. First, we replace the baseline firm-level NTR gaps with the industry-level NTR gaps based on the primary industry (with the

Table G3: Real Effect of Innovation on Productivity Growth, Product Added, and Product Concentration (Alternative Innovation Measures)

	ΔTFPR	#prod. add	ΔHHI	ΔTFPR	#prod. add	ΔHHI
#patents (self-cite=0)	0.118**	0.358**	-0.124**	0.129**	0.354***	-0.120**
	(0.055)	(0.085)	(0.055)	(0.052)	(0.081)	(0.052)
#patents (self-cite>0.10)	-0.027	-0.274***	0.134**	-0.055	-0.317***	0.152**
	(0.053)	(0.102)	(0.063)	(0.056)	(0.118)	(0.067)
Observations	5,700	5,700	5,700	5,700	5,700	5,700
Fixed effects	jt	jt	jt	jt	jt	jt
Own innov cutoffs	0%	0%	0%	10%	10%	10%

Notes: Creative destruction is defined by the number of patents with a zero self-citation ratio, and own-innovation is defined by the number of patents with a self-citation above a certain cutoff. In the first three columns, the cutoff is set at zero, whereas in the last three columns, it is set at 10%. The baseline set of controls along with firm payroll, the number of operating industries and products are included. The estimates for industry (j) and the year (t) fixed effects, and the coefficient associated with the binary indicator are suppressed due to disclosure restrictions. Robust standard errors adjusted for clustering at the firm-level are displayed below each coefficient. Observations are unweighted. Observation counts are rounded due to Census Bureau disclosure avoidance procedures. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table G4: Parallel Pre-trend Test

	ΔPatents	ΔPatents	ΔSelf-cite	ΔSelf-cite
NTR gap	-0.397	-0.380	-0.554	-0.546
	(0.487)	(0.488)	(0.403)	(0.402)
$\times$ Innovation intensity		-0.195		-0.058
		(0.162)		(0.395)
NTR gap $\times$ $\mathcal{I}_{\{1992\}}$	0.523	0.500	0.252	0.259
	(0.355)	(0.362)	(0.294)	(0.290)
$\times$ Innovation intensity		0.092		-0.113
		(0.243)		(0.491)
Observations	5,000	5,000	5,000	5,000
Fixed effects	j, p	j, p	j, p	j, p
Controls	baseline	baseline	baseline	baseline

Notes: The baseline set of controls is included. The estimates for industry (j) and the period (p) fixed effects, and the coefficient associated with the binary indicator are suppressed due to disclosure restrictions, and the constant is dropped as well. Robust standard errors adjusted for clustering at the level of the firms' major industries are displayed below each coefficient. Observations are unweighted. Observation counts are rounded due to Census Bureau disclosure avoidance procedures. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

largest employment size) in which firms operate.[6] See Table G5. Second, we include upstream and

[6]The baseline measure uses the employment-share weighted average of the industry-level NTR gaps, where the employment share is measured at the start year of each period and averaged across the firm's operating industries.

downstream competitive pressure shocks as covariates to control the effect of trade shocks through firms' I-O networks.[7] See Table G6. The third test addresses a potential sampling bias using the inverse propensity score weights.[8,9] See Table G7. The fourth test adjusts the level of standard error clustering to the firm level.[10] See Table G8. The fifth test considers the potential correlation between the innovation intensity measure and firm size or age (e.g., Acemoglu et al., 2018), which may blur the effect of technological barriers. To address this concern, we control additional terms that interact innovation intensity with firm age and size. Moreover, we use an alternative measure based on the inverse of the innovation intensity gap relative to the industry frontier, averaged over the past five years, as the level of technological advantage. See Tables G9 and G10. The sixth test confirms the robustness of alternative measures for creative destruction and own-innovations. Creative destruction is directly measured by the number of new product added, and own-innovation is directly measured by the number of patents with a self-citation ratio above 0% or 10%. Also, we examine the impact on within-firm product market concentration. See Tables G11, G12, and G13. Lastly, we include additional controls (such as the cumulative number of patents, firm payroll, the number of industries or products, industry-level skill and capital intensities, as well as dummies for importers and exporters) beyond the baseline set to eliminate potential alternative interpretations. See Tables G14 and G15.

[7]The upstream (downstream) measure captures the effect of trade shocks propagating upstream (downstream) from an industry's buyers (suppliers). Using the 1992 BEA input-output table, we construct upstream and downstream competitive pressure shocks as the weighted averages of industry-level trade shocks. Following the approach in Pierce and Schott (2016), we assign I-O weights to zero for both upstream and downstream industries within the same three-digit NAICS broad industries for each six-digit NAICS industry.

[8]This issue can potentially arise from the selection of samples with a positive number of patents granted in the start year and in any of the last four years of each period in the regression analysis, which is inevitable to compute the self-citation ratio over two years for each period.

[9]To formulate the weights, we employ a logit regression on the entire universe of the LBD. The dependent variable is set to one if the firm belongs to the regression sample and zero otherwise. The independent variables include firm size, age, employment growth rate, industry, and a multi-unit status indicator.

[10]In our baseline analysis, we cluster the standard errors at the six-digit NAICS level as most variations in the firm-level NTR gap occur at the industry level.

Table G5: Industry-level Tariff Measures

	ΔPatents	ΔPatents	ΔSelf-cite	ΔSelf-cite
NTR gap $\times$ Post	0.016	0.011	0.005	-0.001
	(0.249)	(0.249)	(0.261)	(0.261)
$\times$ Innovation intensity		-0.032		0.760***
		(0.229)		(0.272)
Observations	6,500	6,500	6,500	6,500
Fixed effects	j, p	j, p	j, p	j, p
Controls	baseline	baseline	baseline	baseline
Weights for tariffs	major industry	major industry	major industry	major industry

Notes: Table reports results of OLS generalized difference-in-differences regressions in which industry-level tariff measures are used. The baseline set of controls is included. The estimates for industry (j) and the period (p) fixed effects, and the coefficient associated with the binary indicator are suppressed due to disclosure restrictions, and the constant is dropped as well. Robust standard errors adjusted for clustering at the level of the firms' major industries are displayed below each coefficient. Observations are unweighted. Observation counts are rounded due to Census Bureau disclosure avoidance procedures. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table G6: Foreign Competition Shock through I-O Linkages

	ΔPatents	ΔPatents	ΔSelf-cite	ΔSelf-cite
NTR gap $\times$ Post	-0.111	-0.111	-0.296	-0.424
	(0.331)	(0.342)	(0.356)	(0.355)
$\times$ Innovation intensity		-0.001		0.824***
		(0.337)		(0.288)
Observations	6,500	6,500	6,500	6,500
Fixed effects	j, p	j, p	j, p	j, p
Controls	baseline+IO	baseline	baseline	baseline

Notes: The baseline set of controls is included along with the diff-in-diff terms for upstream and downstream sectors, respectively. The estimates for industry (j) and the period (p) fixed effects, and the coefficient associated with the binary indicator are suppressed due to disclosure restrictions, and the constant is dropped as well. Robust standard errors adjusted for clustering at the level of the firms' major industries are displayed below each coefficient. Observations are unweighted. Observation counts are rounded due to Census Bureau disclosure avoidance procedures. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table G7: Weighted by Inverse Propensity Score

	ΔPatents	ΔPatents	ΔSelf-cite	ΔSelf-cite
NTR gap $\times$ Post	0.003	0.039	-0.394	-0.603
	(0.475)	(0.484)	(0.509)	(0.512)
$\times$ Innovation intensity		-0.045		0.893***
		(0.282)		(0.294)
Observations	6,500	6,500	6,500	6,500
Fixed effects	j, p	j, p	j, p	j, p
Controls	baseline	baseline	baseline	baseline
Regression weights	inv. propens.	inv. propens.	inv. propens.	inv. propens.

Notes: Table reports results of OLS generalized difference-in-differences regressions in which observations are weighted by the inverse of the propensity scores from logit model (y = indicator for analysis sample). The baseline set of controls is included. The estimates for industry (j) and the period (p) fixed effects, and the coefficient associated with the binary indicator are suppressed due to disclosure restrictions. Robust standard errors adjusted for clustering at the level of the firms' major industries are displayed below each coefficient. Observation counts are rounded due to Census Bureau disclosure avoidance procedures. For the sake of space, only the main coefficients are presented. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table G8: Standard Error Clustering on Firms

	ΔPatents	ΔPatents	ΔSelf-cite	ΔSelf-cite
NTR gap $\times$ Post	0.067	0.071	0.045	-0.062
	(0.287)	(0.290)	(0.308)	(0.312)
$\times$ Innovation intensity		-0.054		0.795***
		(0.245)		(0.277)
Observations	6,500	6,500	6,500	6,500
Fixed effects	j, p	j, p	j, p	j, p
Controls	baseline	baseline	baseline	baseline
se. cluster	firmid	firmid	firmid	firmid

Notes: Table reports results of OLS generalized difference-in-differences regressions in which robust standard errors are adjusted for clustering at the firm-level. The baseline set of controls is included. The estimates for industry (j) and the period (p) fixed effects, and the coefficient associated with the binary indicator are suppressed due to disclosure restrictions. Observations are unweighted. Observation counts are rounded due to Census Bureau disclosure avoidance procedures. For the sake of space, only the main coefficients are presented. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table G9: Robustness Check for Innovation Intensity Measure (Firm Age, Size Effects)

	ΔPatents	ΔPatents	ΔSelf-cite	ΔSelf-cite
NTR gap × Post	-0.447	-0.342	0.805	0.292
	(0.645)	(0.691)	(0.668)	(0.641)
× Innovation intensity		-0.026		0.826***
		(0.239)		(0.284)
Observations	6,500	6,500	6,500	6,500
Fixed effects	j, p	j, p	j, p	j, p
Controls	baseline+	baseline+	baseline+	baseline+

Notes: The baseline set of controls is included along with additional controls for the set of interaction terms between innovation intensity and firm age, as well as innovation intensity and firm size, to check robustness for potential correlations between innovation intensity, firm age, and firm size. The estimates for industry (j) and the period (p) fixed effects, and the coefficient associated with the binary indicator are suppressed due to disclosure restrictions, and the constant is dropped as well. Observations are unweighted. Observation counts are rounded due to Census Bureau disclosure avoidance procedures. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table G10: Alternative Technology Barrier Measure

	ΔPatents	ΔPatents	ΔSelf-cite	ΔSelf-cite
NTR gap × Post	0.067	0.131	0.045	0.029
	(0.287)	(0.291)	(0.308)	(0.313)
× Innovation intensity		-0.058		0.066*
		(0.440)		(0.040)
Observations	6,500	6,500	6,500	6,500
Fixed effects	j, p	j, p	j, p	j, p
Controls	baseline	baseline	baseline	baseline

Notes: The baseline set of controls is included, with the innovation intensity measure replaced by the past 5-year average of the inverse of the within-industry innovation intensity gap from the frontier firm as a proxy for the accumulated level of technology barriers. The estimates for industry (j) and the period (p) fixed effects, and the coefficient associated with the binary indicator are suppressed due to disclosure restrictions, and the constant is dropped as well. Observations are unweighted. Observation counts are rounded due to Census Bureau disclosure avoidance procedures. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table G11: Alternative Creative Destruction Measure

	#products added	#products added	#products added
NTR gap × Post	-0.239***	-0.231***	-0.218***
	(0.068)	(0.067)	(0.063)
Observations	497,000	497,000	497,000
Fixed effects	j, p	j, p	j, p
Controls	baseline	baseline	baseline
Creative destruction measure	(innovation intensity)	(labor productivity)	(TFPR)

Notes: Creative destruction is directly measured by the number of products added and taken as the main dependent variable. The baseline set of controls (with a different measure for technological barriers) is included. Innovation intensity is the baseline measure as before in the first column. In the second and third columns, it is replaced by the inverse gap of the firm's labor productivity or TFPR from the frontier in its operating industry as an alternative way to measure the degree of technological barriers. Estimates for industry-period (jp) fixed effects as well as the constant are suppressed. Robust standard errors adjusted for clustering at the level of the firms' major industries are displayed below each coefficient. Observations are unweighted. Observation counts are rounded due to Census Bureau disclosure avoidance procedures. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table G12: Alternative Own-Innovation Measure

	ΔPatents (self-cite>0)	ΔPatents (self-cite>0)	ΔPatents (self-cite>10)	ΔPatents (self-cite>10)
NTR gap × Post	0.007	0.001	0.005	-0.008
	(0.004)	(0.004)	(0.004)	(0.005)
× Innovation intensity		0.100***		0.206***
		(0.033)		(0.077)
Observations	497,000	497,000	497,000	497,000
Fixed effects	j, p	j, p	j, p	j, p
Controls	baseline	baseline	baseline	baseline

Notes: Own-innovation is directly measured and taken as the main dependent variable. The first two columns measure it by the number of patents with a positive self-citation ratio (self-cite > 0), and the last two columns measure it by those with at least a 10% self-citation ratio (self-cite > 10). The baseline set of controls is included. Estimates for industry-period (jp) fixed effects as well as the constant are suppressed. Robust standard errors adjusted for clustering at the level of the firms' major industries are displayed below each coefficient. Observations are unweighted. Observation counts are rounded due to Census Bureau disclosure avoidance procedures. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table G13: The Effect on Product Concentration

	Δproduct HHI	Δproduct HHI
NTR gap $\times$ Post	-0.002	-0.019
	(0.042)	(0.012)
$\times$ Innovation intensity		0.262**
		(0.116)
Observations	497,000	497,000
Fixed effects	j, p	j, p
Controls	baseline	baseline

Notes: The main dependent variable is the product sales concentration within each firm. The baseline set of controls is included. Estimates for industry-period (jp) fixed effects as well as the constant are suppressed. Robust standard errors adjusted for clustering at the level of the firms' major industries are displayed below each coefficient. Observations are unweighted. Observation counts are rounded due to Census Bureau disclosure avoidance procedures. * p < 0.1, ** p $<$ 0.05, *** p < 0.01.

Table G14: Robustness Test for the Market-Protection Effect (Overall Innovation)

	ΔPatents	ΔPatents	ΔPatents	ΔPatents	ΔPatents	ΔPatents
NTR gap $\times$ Post	0.076	0.062	0.028	0.112	0.081	0.074
	(0.283)	(0.284)	(0.284)	(0.278)	(0.279)	(0.280)
$\times$ Innov. intensity	-0.055	-0.037	-0.051	0.058	-0.055	-0.029
	(0.242)	(0.242)	(0.239)	(0.243)	(0.240)	(0.231)
Observations	6,500	6,500	6,500	6,500	6,500	6,500
Fixed effects	j, p	j, p	j, p	j, p	j, p	j, p
Controls	base+	base+	base+	base+	base+	base+

Notes: All columns augment the baseline set of controls with additional variables. Specifically, column (1) includes the cumulative number of patents, column (2) includes firm payroll, column (3) includes the number of industries in which firms operate, column (4) includes the industry-level skill, capital intensities, column (5) includes the number of industries and the industry-level skill, capital intensities, and column (6) includes the number of industries, the industry-level skill, capital intensities, a dummy for firms with total imports > 0, and a dummy for firms with total exports > 0. The estimates for industry (j) and the period (p) fixed effects, and the coefficients associated with the binary indicators are suppressed due to disclosure restrictions, and the constant is dropped as well. Robust standard errors adjusted for clustering at the level of the firms' major industries are displayed below each coefficient. Observations are unweighted. Observation counts are rounded due to Census Bureau disclosure avoidance procedures. * p < 0.1, ** p $<$ 0.05, *** p < 0.01.

Table G15: Robustness Test for the Market-Protection Effect (Own-Innovation)

	ΔSelf-c.	ΔSelf-c.	ΔSelf-c.	ΔSelf-c.	ΔSelf-c.	ΔSelf-c.
NTR gap $\times$ Post	-0.078	-0.059	-0.026	0.007	0.042	0.063
	(0.290)	(0.291)	(0.289)	(0.287)	(0.285)	(0.285)
$\times$ Innov. intensity	0.798***	0.789***	0.792***	0.789***	0.787***	0.777***
	(0.278)	(0.278)	(0.280)	(0.277)	(0.279)	(0.268)
Observations	6,500	6,500	6,500	6,500	6,500	6,500
Fixed effects	j, p	j, p	j, p	j, p	j, p	j, p
Controls	base+	base+	base+	base+	base+	base+

Notes: All columns augment the baseline set of controls with additional variables. Specifically, column (1) includes the cumulative number of patents, column (2) includes firm payroll, column (3) includes the number of industries in which firms operate, column (4) includes the industry-level skill, capital intensities, column (5) includes the number of industries and the industry-level skill, capital intensities, and column (6) includes the number of industries, the industry-level skill, capital intensities, a dummy for firms with total imports > 0, and a dummy for firms with total exports > 0. The estimates for industry (j) and the period (p) fixed effects, and the coefficients associated with the binary indicators are suppressed due to disclosure restrictions, and the constant is dropped as well. Robust standard errors adjusted for clustering at the level of the firms' major industries are displayed below each coefficient. Observations are unweighted. Observation counts are rounded due to Census Bureau disclosure avoidance procedures. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

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