

Internet Appendix for
Technological Obsolescence

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A.1. Using Annual Citations To Capture Technology Evolution

Knowledge itself ages. The scientific value and relevance of a technology usually experiences a hump-shaped dynamic. The scientific relevance usually increases in the early years as the new technology starts to diffuse and is adopted; it later decays as the technology fails to stay at the frontier and becomes replaced by newer generations of technology. This conceptual idea has been discussed in many classic works on innovation (Pakes and Schankerman, 1984; Caballero and Jaffe, 1993).

Annual citations received by each patent capture knowledge aging.²⁰ We start by presenting two motivating facts. In Figure 2, we plot the age distribution of patents that a new patent cites as its prior art. This figure shows that new patents rely heavily on patents that are less than twenty years old. In fact, half or more of the cited patents in a new technology are within ten years old. A small number of patents have quite long-lasting impacts and may be influential even after 50 years, suggesting heterogeneity in the speed of aging.

In Figure A.1, we perform the reverse exercise to show the same point. In panel (a), we study the forward citations each patent receives through its life cycle. Because of the right-truncation problem of patent citations, we produce the citation dynamic curve by cohorts of patent filing years. Patents keep obtaining citations even after one or two decades, after the first few years of the “climbing up” period. In Figure A.1 panel (b), we show heterogeneity in this citation pattern. In this graph, we divide patents from the same early cohort of 1990 into three groups based on the ratio of firms’ five years’ citations in the total number of citations to date. The early bloomers (orange line) collect significantly more patents in their earlier life than the late-bloomers (dark navy line), but they also age more quickly.

If we summarize this difference in forward citation dynamics using one statistic, that is the half life of a technology—the time it takes for each patent to collect half of its total citations (Machlup, 1962). The median half lives for the early-bloomer group and the later-bloomer group are 8 years and 17 years, respectively. Figure A.2 shows the distribution of patent-level half lives for the sample of patents granted prior to 2000. We again observe a very robust heterogeneity. The half lives of patents also vary across different industries and different technology spaces. Figure A.3 shows the

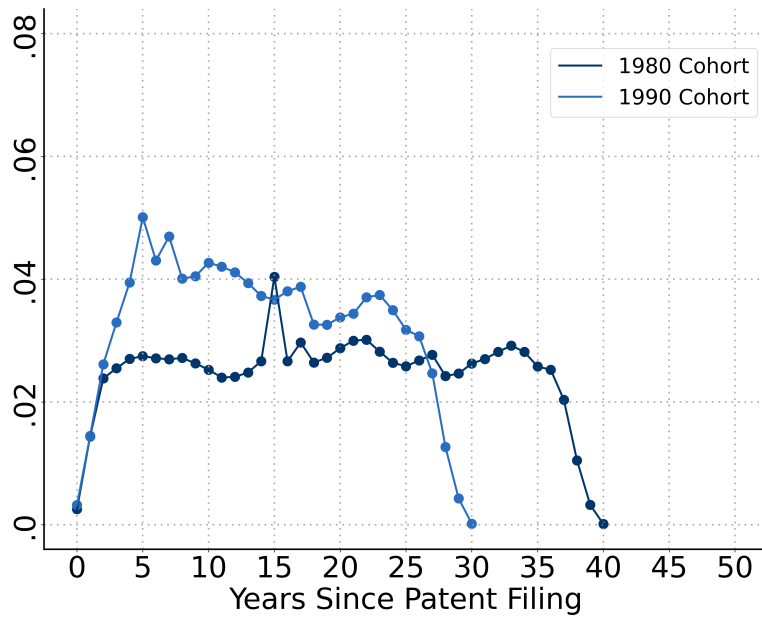
²⁰This intuition is also used in bibliometrics and scientometrics, which use citation patterns of patents and papers to track technology evolution.

half lives of patents summarized by the Fama-French 48 industries, and in Appendix Figure A.4 we show those differences across different technological fields categorized by the International Patent Classification (IPC).

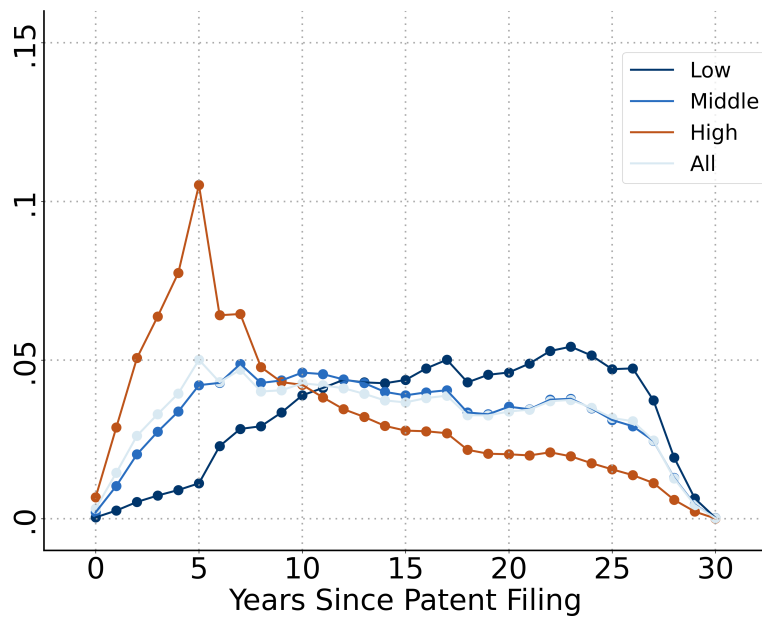
One caveat is that the process of citing patents could be noisy (Roach and Cohen, 2013). Most noticeably, a large portion of citations are so-called examiner-citations, which are inserted by patent examiners but not the patent applicants or their hired professionals (Alcácer, Gittelman, and Sampat, 2009). This could affect both the construction of technology bases and citations they receive. Since the technology obsolescence measure is a within-firm change, those concerns should not introduce too strong of a systematic error into our analysis. Just to make sure this issue does not affect our measure, for the post-2002 sample in which we could observe citation sources, i.e. examiner-citations vs. applicant ones, we find that the correlation of the two versions of obsolescence with and without examiner patents is 0.94.

Do the citations made by each patent signal the technological evolution and innovation quality? We find evidence consistent with this conjecture. A patent's backward citation is informative of the quality and innovativeness of the patent itself. We show this in our context and also lean on the literature that explores a similar question. If we simply repeat Figure 2 and check if breakthrough innovative patents (as identified using Kelly et al. (2021)) cite past patents of different ages, we do see a sharp difference, as shown in Figure A.5.

When we look deeper, we see that the more innovative patents cite past patents that are less obsolete, while the less innovative patents cite patents that are more obsolete. Specifically, we find that more innovative patents cite patents when these cited patents are on their upward citation trend. For example, in Figure A.6, we find that the more innovative patents cite patents that on average experience an increase in citations in the previous year, and have a low obsolescence score (as constructed using the same logic in the paper but at a patent level).



(a) Average Forward Citation Dynamic



(b) Heterogeneity in Forward Citation Dynamic

Figure A.1. Dynamics of Citations Received By Each Patent

Notes. This figure presents the dynamics of citations received by patents and its heterogeneities. Panel (a) presents the annual citation received by patents organized by the 1980 and the 1990 cohort. Panel (b) presents the annual citation received by patents of the 1990 cohort depending on whether they are early- or late-bloomers, defined based on the ratio of firms' five years' citations in the total number of citations to date. Panel (b) presents the histogram of a patent's half-life using all patents applied and granted before 2000.

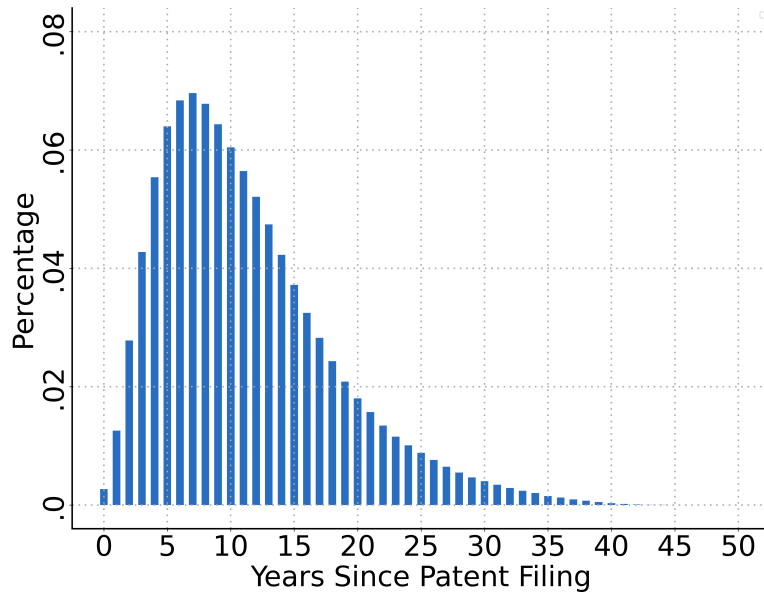


Figure A.2. Distribution of Patents' Half-Lives

Notes. This figure presents the histogram of a patent's half-life using all patents applied and granted before 2000. The half-life is defined as the number of years it takes for a patent to receive half of the total citations received by the patent to date.

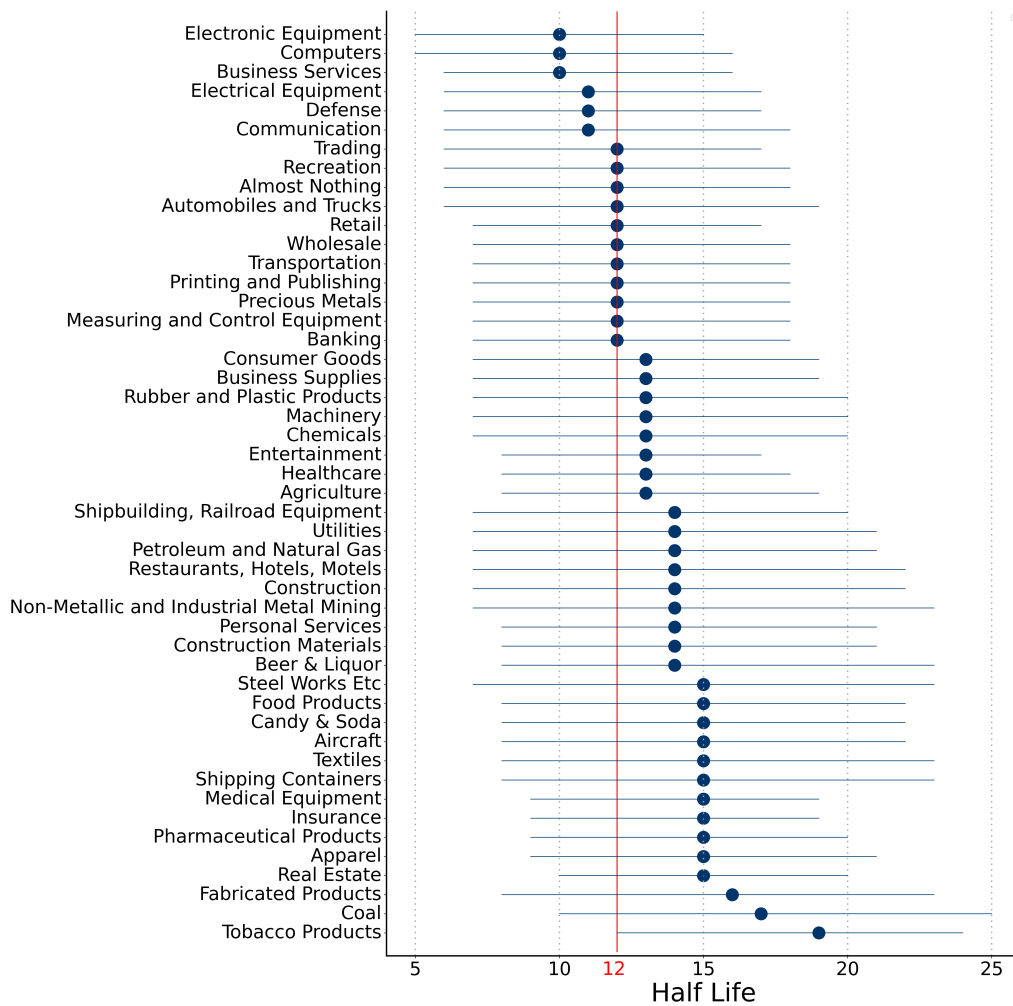


Figure A.3. Dynamics of Citations Received By Each Patent—Heterogeneity

Notes. This figure plots the half-lives of patents produced by firms from different industries. The sample of patents is restricted to the pre-2000 cohort to allow adequate time to realize the half-life of patents.

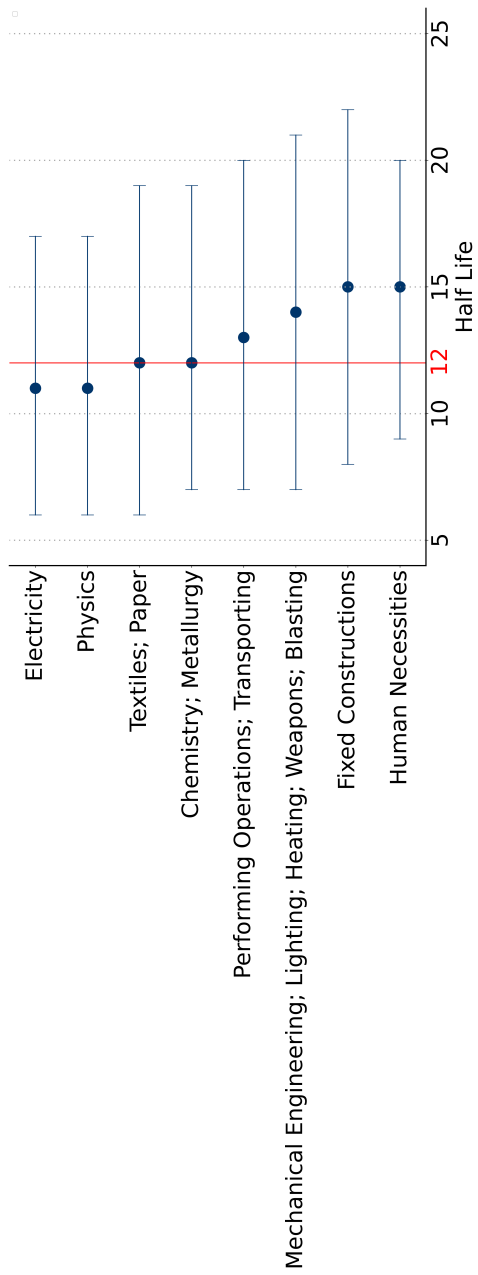


Figure A.4. Patent Citation Half-Lives By International Patent Classification Categories

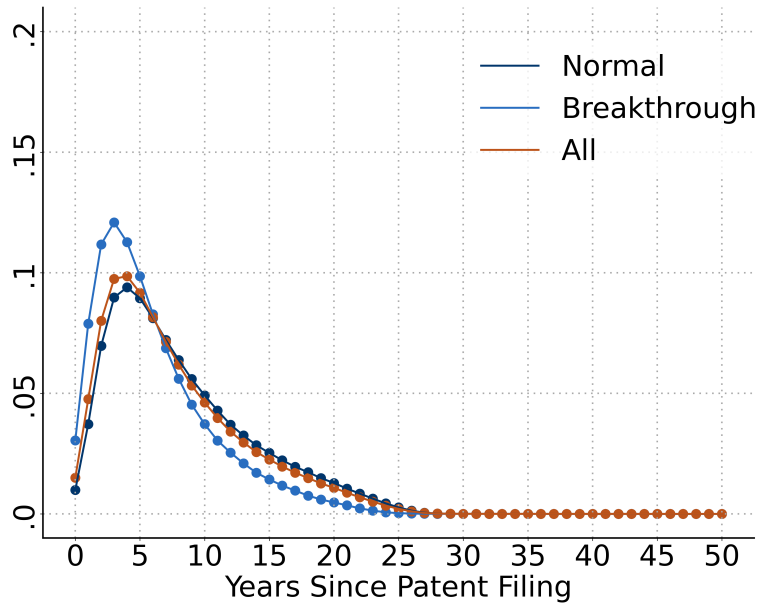


Figure A.5. Heterogeneity in Backward Citation Dynamics

Notes. This figure presents the heterogeneity in backward citation dynamics. The “breakthrough” patents are obtained from Kelly et al. (2021), which is available for patents filed up to 2002. The patent sample contains those patents filed before 2002 with at least 10 backward citations and no more than 1000 backward citations.

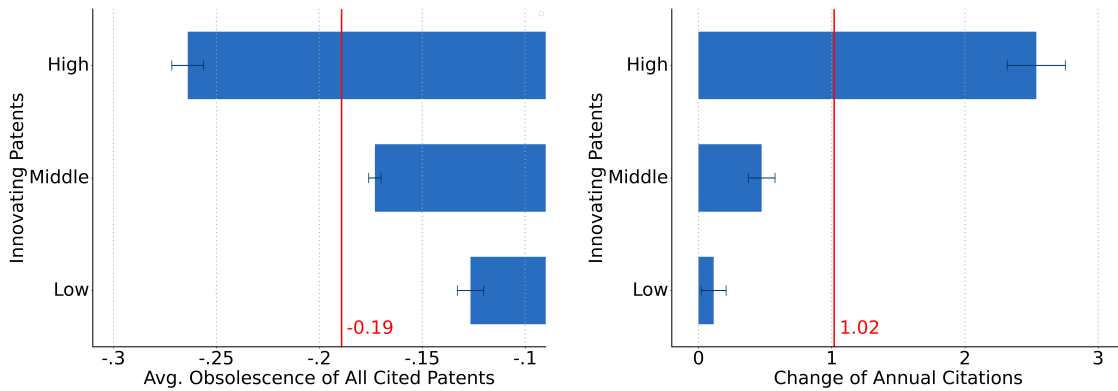


Figure A.6. Characteristics of Patents’ Backward Citations

Notes. This figure plots the characteristics of patents cited by patents categorized based on their own innovativeness (based on within-cohort forward citations). The left panel plots the average level of obsolescence at the time the new patents cite the old patents, and the right panel plots the change of annual citations at the time of citing.

A.2. Mathematical Formulation of the *Obsolescence* Measure

In this Appendix, we provide a mathematical formulation of the *Obsolescence* measure, and we use the co-citation matrix as an important tool for this formalization.

Here we define the *Obsolescence* measure in the matrix form. Suppose there are N patents in the world to date, and they are numbered 1, 2, ... N —they cite each other in these inventions. There are M patenting firms, and they are indexed as 1, 2, ..., M .

We can define three important matrices:

- **The citation matrix:** Let $\mathbb{C}_\tau = [c_{p_1, p_2}]$ denote the $N \times N$ matrix in which each element c_{p_1, p_2} indicates whether patent p_1 cites p_2 in the patent.
- **The ownership matrix:** Let $\mathbb{F} = [f_1, f_2, \dots, f_N]'$ denote the $N \times 1$ vector in which each element f_p represents the assignee of the patent p
- **The timing matrix:** For each patent p , it is filed at year t_p by its assignee firm f_p . Let $\mathbb{T} = [t_1, t_2, \dots, t_N]'$ denote the $N \times 1$ vector in which its p -th element represents the filing year of patent p .

Our objective is to represent the *Obsolescence* in the matrix form. Note that the measure for each firm f at year t , with obsolescence horizon ω , is defined as:

$$Obsolescence_{f,t}^\omega = - [\ln(1 + Cit_t(TechBase_{f,t-\omega})) - \ln(1 + Cit_{t-\omega}(TechBase_{f,t-\omega}))], \quad (A4)$$

where $Cit_t(TechBase_{f,t-\omega})$ is the number of citations received at year t by the patents in the technology base of firm f in year t_b , where the technology base is defined as all the cited patents by a firm's own patents. For now—we will ignore the restrictions that exclude the focal firm's own patents from the base and exclude the focal firm's own citations to the base. This will simplify the exposition of the idea and will be introduced later.

Transforming to Matrix Form: An alternative way to think about the above $Cit_{t/t-\omega}(TechBase_{f,t-\omega})$ operation—namely citations to a firm's technology base—is that we essentially need to calculate the “co-citations” between (i) a firm's past innovation up to $t - \omega$ and (ii) the concurrent innovation that happens in year t or $t - \omega$.

$$Cit_t(TechBase_{f,t-\omega}) = \underbrace{\mathbb{1}(\mathbb{F} = f \ \& \ \mathbb{T} \leq t - \omega)'}_{\text{Patents owned by firm } f \text{ at } t - \omega} \cdot \mathbb{C}\mathbb{C}' \cdot \underbrace{\mathbb{1}(\mathbb{T} = t)}_{\text{Concurrent innovation in year } t}, \quad (\text{A5})$$

where $\mathbb{1} : \mathbb{R}^N \rightarrow \mathbb{R}^N$ is the matrix element-wise indicator operator. To understand Equation (A5), first note that $\mathbb{C}\mathbb{C}'$ is the co-citation matrix in which each element (p_1, p_2) represents the number of patents cited by the two patents p_1 and p_2 . The indicator function $\mathbb{1}(\mathbb{T} = t)$ represents all the patents filed in year t and $\mathbb{1}(\mathbb{F} = f \ \& \ \mathbb{T} \leq t - \omega)$ represents the patents filed by firm f up to year $t - \omega$. Thus, $Cit_t(TechBase_{f,t-\omega})$ captures the number of co-citations made by the patents at year t and the patents filed by firm f up to year $t - \omega$. We can similarly define

$$Cit_{t-\omega}(TechBase_{f,t-\omega}) = \underbrace{\mathbb{1}(\mathbb{F} = f \ \& \ \mathbb{T} \leq t - \omega)'}_{\text{Patents owned by firm } f \text{ at } t - \omega} \cdot \mathbb{C}\mathbb{C}' \cdot \underbrace{\mathbb{1}(\mathbb{T} = t - \omega)}_{\text{Concurrent innovation in year } t - \omega}, \quad (\text{A6})$$

However, as mentioned above, the definition in Eq. (A5) is slightly different from the one we used in the paper, which included a few restrictive adjustments.

1. **Exclude focal firms' own patents from the base:** First we do not consider the co-citations to firms' own patents in the technology base in the paper. Thus, we need to drop those citations in the citation matrix. To do this, we need to use a modified version of the co-citation matrix, $\mathbb{C}[\mathbb{C} \odot (\mathbb{J}_N \cdot \mathbb{1}(\mathbb{F} \neq f)')]'$, where \odot is the Hadamard product operator and \mathbb{J}_N is the $N \times 1$ matrix of ones. Here, the Hadamard product operation drops all the co-citations to firms' own patents in the technology base.
2. **Exclude focal firms' own citation to the base:** In the paper, we also do not consider the co-citations from firms' own patents. Thus, we need to drop those firms' own patents filed in year t by using $\mathbb{1}(\mathbb{F} \neq f \ \& \ \mathbb{T} = t)$.

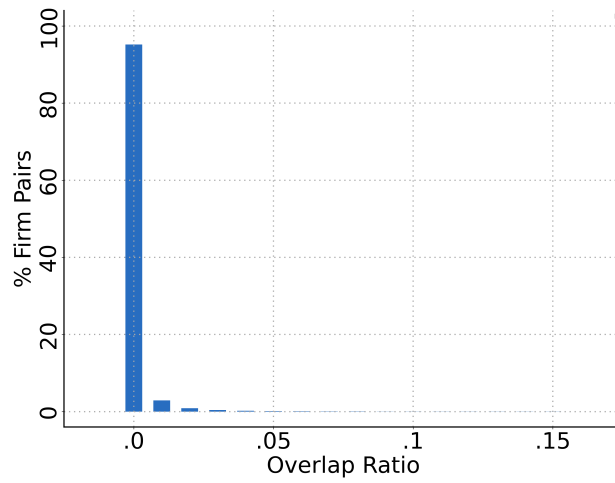
Therefore, after considering the adjustments in the first two points, we have a modified version of $Cit_t(TechBase_{f,t-\omega})$:

$$Cit_t(TechBase_{f,t-\omega}) = \mathbb{1}(\mathbb{F} = f \ \& \ \mathbb{T} \leq t - \omega)' \cdot \mathbb{C}[\mathbb{C} \odot (\mathbb{J}_N \cdot \mathbb{1}(\mathbb{F} \neq f)')] \cdot \mathbb{1}(\mathbb{F} \neq f \ \& \ \mathbb{T} = t). \quad (\text{A7})$$

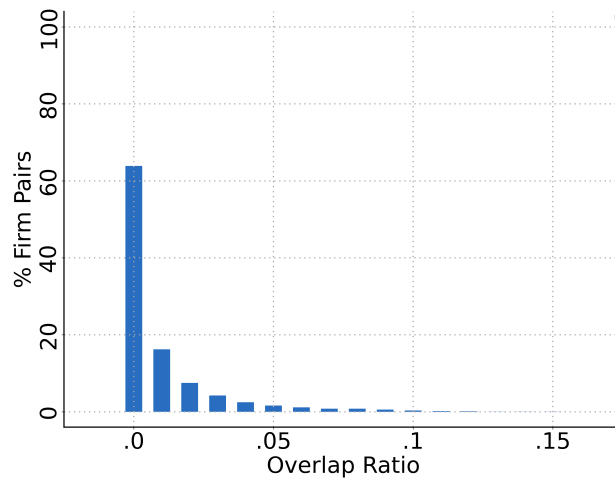
Plugging Equation (A7) into Equation (A4), we obtain the *Obsolescence* measure with duplicated technology base, which is the one we use in Table A.16.

Finally, the *Obsolescence* measure in the original formulation uses a de-duplicated technology base. That is, if multiple firms' patents cite the same patent, we only consider it once in the technology base. However, the matrix form of the *Obsolescence* measure double counts the co-citations to those patents and we have no good way to deal with this under the matrix form.

A.3. Additional Results



(a) All Firms with Patents



(b) Firms with > 100 Patents

Figure A.7. Overlap Ratio of Technology Base Between Within-Industry Firms

Notes. This figure plots the pair-wise overlap of technology bases among firms in the same SIC3 industry-year. The overlap of firm i and j 's bases are calculated as the ratio between the size of their intersections (numerator) and the size of their unions (denominator). Panel (a) uses all firms with a patent, while panel (b) focuses on firms with at least 100 patents.

Table A.1. Decomposition of the *Obsolescence* Measure

	Decomposition (1)		Decomposition (2)	
	Variation	% of total variation	Variation	% of total variation
Total	3,869.92	100	3,869.92	100
Between industries	385.01	9.95	385.01	9.95
Within industries	1,087.92	28.11	1,126	29.10
Within firm	2,397	61.94		
Within industries \times year			2,358.92	60.96

Notes. This table shows variations of the *Obsolescence* (abbreviated as *Obs* here for compact notation) measure from different sources. The first decomposition decomposes *Obsolescence* into across-industry, across firms within an industry, and within a firm (over time):

$$\begin{aligned}
\sum_i \sum_j \sum_t \left(Obs_{ijt} - \overline{\overline{Obs}} \right)^2 &= \sum_i \sum_j \sum_t \left[(Obs_{ijt} - \overline{Obs}_{ij.}) + (\overline{Obs}_{ij.} - \overline{\overline{Obs}}_{.j}) + (\overline{\overline{Obs}}_{.j} - \overline{\overline{Obs}}) \right]^2 \\
&= \sum_i \sum_j \sum_t (Obs_{ijt} - \overline{Obs}_{ij.})^2 \quad \text{within firm} \\
&= \sum_i \sum_j \sum_t (\overline{Obs}_{ij.} - \overline{\overline{Obs}}_{.j})^2 \quad \text{within industries} \\
&= \sum_i \sum_j \sum_t (\overline{\overline{Obs}}_{.j} - \overline{\overline{Obs}})^2 \quad \text{between industries}
\end{aligned}$$

where Obs_{ijt} is the *Obsolescence* for firm j in industry i in year t , $\overline{Obs}_{ij.}$ is the within-firm mean for firm i , $\overline{\overline{Obs}}_{.j}$ is the industry mean for industry j , and $\overline{\overline{Obs}}$ is the grand mean.

The second decomposition decomposes *Obsolescence* into across across-industry, within-industry across different years, and within industry-year across different firms:

$$\begin{aligned}
\sum_i \sum_j \sum_t \left(Obs_{ijt} - \overline{\overline{Obs}} \right)^2 &= \sum_i \sum_j \sum_t \left[(Obs_{ijt} - \overline{Obs}_{.jt}) + (\overline{Obs}_{.jt} - \overline{\overline{Obs}}_{.j}) + (\overline{\overline{Obs}}_{.j} - \overline{\overline{Obs}}) \right]^2 \\
&= \sum_i \sum_j \sum_t (Obs_{ijt} - \overline{Obs}_{.jt})^2 \quad \text{within industry} \times \text{year} \\
&= \sum_i \sum_j \sum_t (\overline{Obs}_{.jt} - \overline{\overline{Obs}}_{.j})^2 \quad \text{within industries} \\
&= \sum_i \sum_j \sum_t (\overline{\overline{Obs}}_{.j} - \overline{\overline{Obs}})^2 \quad \text{between industries}
\end{aligned}$$

where $\overline{Obs}_{.jt}$ is the within-industry-year mean for industry j in year t .

Table A.2. Robustness: Technological Obsolescence and Firm Growth - Without Keeping the Same Observations Across Different Horizons

Time Horizon =	$t + 1$	$t + 2$	$t + 3$	$t + 4$	$t + 5$
Profits					
<i>Obsolescence_t</i>	-0.011*** (0.003)	-0.017*** (0.004)	-0.021*** (0.007)	-0.025*** (0.009)	-0.031*** (0.011)
R^2	0.214	0.239	0.246	0.246	0.250
Observations	29,319	27,562	25,980	23,685	21,605
Output					
<i>Obsolescence_t</i>	-0.010*** (0.003)	-0.017*** (0.005)	-0.022*** (0.008)	-0.026** (0.010)	-0.032** (0.013)
R^2	0.171	0.192	0.199	0.201	0.206
Observations	30,846	28,972	27,296	24,830	22,621
Capital					
<i>Obsolescence_t</i>	-0.012*** (0.002)	-0.023*** (0.005)	-0.033*** (0.007)	-0.043*** (0.010)	-0.052*** (0.012)
R^2	0.160	0.182	0.189	0.195	0.199
Observations	31,579	29,655	27,921	25,353	23,037
Labor					
<i>Obsolescence_t</i>	-0.006*** (0.002)	-0.012*** (0.004)	-0.017** (0.007)	-0.018** (0.009)	-0.019* (0.010)
R^2	0.151	0.160	0.164	0.169	0.177
Observations	31,494	29,564	27,847	26,182	23,818
TFP					
<i>Obsolescence_t</i>	-0.008*** (0.003)	-0.012*** (0.004)	-0.014*** (0.005)	-0.015*** (0.005)	-0.014** (0.007)
R^2	0.200	0.262	0.304	0.323	0.334
Observations	23,781	22,246	20,957	19,109	17,443

Notes. This table examines the relation between *Obsolescence* and firm growth and productivity using the model below (equation (2)) in the paper):

$$\log Y_{f,t+\tau} - \log Y_{f,t} = \beta_{\tau} \cdot \text{Obsolescence}_{f,t} + \theta_{\tau} \cdot X_{f,t} + \delta_{I \times t} + \varepsilon_{f,t+\tau}.$$

The outcome variables, Y , include firm profits, output, capital, employment, and TFP, all defined and described in Table 1. The table presents results estimated using up to five years from t . Controls include the level $\log Y_{f,t}$, the log value of the capital stock, the log number of employees, the log number of patents granted up to year t , the log value of the firm age, and the firm's idiosyncratic volatility. All right-hand-side variables are standardized to unit standard deviation to facilitate magnitude interpretations. The model includes industry (SIC3)-by-year fixed effects. Standard errors are clustered by firm and year, and they are shown in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A.3. Robustness of Obsolescence Measure - Horizons $\omega = 1$

Time Horizon =	$t + 1$	$t + 2$	$t + 3$	$t + 4$	$t + 5$
Profits ($N = 21,274$)					
<i>Obsolescence_t</i>	-0.006* (0.003)	-0.013*** (0.004)	-0.018*** (0.005)	-0.021*** (0.007)	-0.022*** (0.009)
<i>Citation-Weighted Patents_t</i> (CW)	0.003 (0.005)	0.007 (0.008)	0.011 (0.011)	0.010 (0.014)	0.013 (0.016)
<i>Patent Value_t</i> (SM)	0.017** (0.007)	0.027** (0.011)	0.036*** (0.014)	0.046*** (0.016)	0.055*** (0.018)
R^2	0.253	0.272	0.271	0.265	0.258
Output ($N = 22,358$)					
<i>Obsolescence_t</i>	-0.009*** (0.003)	-0.014*** (0.004)	-0.022*** (0.006)	-0.024*** (0.007)	-0.031*** (0.010)
<i>Citation-Weighted Patents_t</i> (CW)	-0.004 (0.004)	-0.004 (0.007)	-0.006 (0.010)	-0.006 (0.012)	-0.005 (0.015)
<i>Patent Value_t</i> (SM)	0.014** (0.006)	0.022** (0.011)	0.030** (0.014)	0.036* (0.019)	0.047** (0.020)
R^2	0.202	0.212	0.213	0.211	0.212
Capital ($N = 22,873$)					
<i>Obsolescence_t</i>	-0.011*** (0.002)	-0.017*** (0.004)	-0.021*** (0.005)	-0.026*** (0.007)	-0.035*** (0.009)
<i>Citation-Weighted Patents_t</i> (CW)	-0.009*** (0.002)	-0.011*** (0.004)	-0.012* (0.006)	-0.010 (0.009)	-0.011 (0.010)
<i>Patent Value_t</i> (SM)	0.017*** (0.004)	0.029*** (0.008)	0.037*** (0.012)	0.043*** (0.016)	0.051*** (0.018)
R^2	0.184	0.202	0.206	0.205	0.202
Labor ($N = 23,511$)					
<i>Obsolescence_t</i>	-0.006*** (0.002)	-0.011*** (0.003)	-0.014*** (0.005)	-0.019*** (0.006)	-0.023*** (0.008)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005 (0.003)	-0.006 (0.005)	-0.007 (0.007)	-0.009 (0.010)	-0.012 (0.011)
<i>Patent Value_t</i> (SM)	0.011*** (0.004)	0.018** (0.007)	0.023** (0.009)	0.029** (0.012)	0.034** (0.014)
R^2	0.173	0.182	0.185	0.184	0.184
TFP ($N = 16,639$)					
<i>Obsolescence_t</i>	-0.003 (0.003)	-0.004 (0.003)	-0.007** (0.004)	-0.011** (0.004)	-0.015*** (0.005)
<i>Citation-Weighted Patents_t</i> (CW)	0.001 (0.003)	0.007 (0.006)	0.010 (0.007)	0.007 (0.008)	0.007 (0.009)
<i>Patent Value_t</i> (SM)	0.015* (0.008)	0.019 (0.012)	0.024** (0.011)	0.030*** (0.011)	0.033*** (0.010)
R^2	0.238	0.295	0.331	0.346	0.350

Notes. This table examines the relation between *Obsolescence* and firm growth and productivity after adding measures of new innovation, the stock market-based patent value from Kogan et al. (2017), and citation-weight patent counts. The design follows that in Table 4.

Table A.4. Robustness of Obsolescence Measure—Horizons $\omega = 3$

Time Horizon =	$t + 1$	$t + 2$	$t + 3$	$t + 4$	$t + 5$
Profits ($N = 21,274$)					
<i>Obsolescence_t</i>	-0.010*** (0.003)	-0.018*** (0.004)	-0.021*** (0.006)	-0.024*** (0.008)	-0.023** (0.009)
<i>Citation-Weighted Patents_t</i> (CW)	0.003 (0.005)	0.006 (0.008)	0.010 (0.011)	0.009 (0.014)	0.012 (0.016)
<i>Patent Value_t</i> (SM)	0.017** (0.007)	0.027** (0.011)	0.035*** (0.014)	0.046*** (0.016)	0.055*** (0.018)
R^2	0.254	0.272	0.272	0.265	0.258
Output ($N = 22,358$)					
<i>Obsolescence_t</i>	-0.008*** (0.003)	-0.015*** (0.005)	-0.021*** (0.007)	-0.024*** (0.009)	-0.027*** (0.010)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005 (0.004)	-0.005 (0.007)	-0.006 (0.010)	-0.007 (0.012)	-0.006 (0.014)
<i>Patent Value_t</i> (SM)	0.014** (0.006)	0.022** (0.010)	0.029** (0.014)	0.035* (0.019)	0.047** (0.019)
R^2	0.202	0.213	0.213	0.211	0.212
Capital ($N = 22,873$)					
<i>Obsolescence_t</i>	-0.012*** (0.002)	-0.019*** (0.004)	-0.028*** (0.007)	-0.038*** (0.009)	-0.046*** (0.011)
<i>Citation-Weighted Patents_t</i> (CW)	-0.009*** (0.002)	-0.012*** (0.004)	-0.013** (0.006)	-0.012 (0.008)	-0.012 (0.010)
<i>Patent Value_t</i> (SM)	0.016*** (0.004)	0.029*** (0.008)	0.036*** (0.012)	0.042*** (0.015)	0.050*** (0.018)
R^2	0.184	0.202	0.207	0.207	0.203
Labor ($N = 23,511$)					
<i>Obsolescence_t</i>	-0.006*** (0.002)	-0.011*** (0.004)	-0.015** (0.006)	-0.019** (0.008)	-0.021** (0.009)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005* (0.003)	-0.007 (0.005)	-0.008 (0.007)	-0.009 (0.009)	-0.013 (0.011)
<i>Patent Value_t</i> (SM)	0.011*** (0.003)	0.018** (0.007)	0.023** (0.009)	0.028** (0.012)	0.033** (0.014)
R^2	0.173	0.182	0.185	0.184	0.184
TFP ($N = 16,639$)					
<i>Obsolescence_t</i>	-0.005* (0.003)	-0.008** (0.004)	-0.011** (0.005)	-0.015*** (0.005)	-0.016*** (0.005)
<i>Citation-Weighted Patents_t</i> (CW)	0.001 (0.003)	0.007 (0.006)	0.009 (0.007)	0.006 (0.008)	0.006 (0.009)
<i>Patent Value_t</i> (SM)	0.015* (0.008)	0.019 (0.012)	0.024** (0.011)	0.030*** (0.011)	0.033*** (0.010)
R^2	0.239	0.296	0.331	0.346	0.350

Notes. This table examines the relation between *Obsolescence* and firm growth and productivity after adding measures of new innovation, the stock market-based patent value from Kogan et al. (2017), and citation-weight patent counts. The design follows that in Table 4.

Table A.5. Technological Obsolescence and Firm Distress and Failure

Time Horizon =	$t + 1$	$t + 2$	$t + 3$	$t + 4$	$t + 5$
$Obsolescence_t$	0.0001 (0.0003)	0.0007 (0.0006)	0.0016* (0.0010)	0.0021* (0.0013)	0.0022 (0.0015)
R^2	0.1575	0.1330	0.1286	0.1285	0.1308
Observations	30,013	30,013	30,013	30,013	30,013

Notes. This table examines the relation between *Obsolescence* and firm bankruptcy (Chapter 11) using the same design as in Table 4 in the main text.

Table A.6. Technological Obsolescence and Growth, Isolating Variations in *Obsolescence*

Time Horizon =	$t + 1$	$t + 2$	$t + 3$	$t + 4$	$t + 5$
Profits ($N = 21,274$)					
<i>Obsolescence_t</i>	-0.016*** (0.003)	-0.027*** (0.006)	-0.030*** (0.008)	-0.032*** (0.010)	-0.029** (0.012)
<i>Citation-Weighted Patents_t</i> (CW)	0.002 (0.004)	0.004 (0.008)	0.008 (0.011)	0.006 (0.014)	0.010 (0.016)
<i>Patent Value_t</i> (SM)	0.016** (0.007)	0.025** (0.011)	0.034** (0.013)	0.044*** (0.016)	0.054*** (0.018)
R^2	0.255	0.273	0.272	0.266	0.258
Output ($N = 22,358$)					
<i>Obsolescence_t</i>	-0.009*** (0.003)	-0.020*** (0.006)	-0.026*** (0.009)	-0.033*** (0.011)	-0.034** (0.014)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005 (0.004)	-0.006 (0.007)	-0.008 (0.009)	-0.008 (0.012)	-0.008 (0.014)
<i>Patent Value_t</i> (SM)	0.013** (0.005)	0.021** (0.010)	0.028** (0.013)	0.034* (0.019)	0.045** (0.019)
R^2	0.202	0.213	0.213	0.211	0.212
Capital ($N = 22,873$)					
<i>Obsolescence_t</i>	-0.012*** (0.003)	-0.022*** (0.005)	-0.031*** (0.008)	-0.038*** (0.011)	-0.043*** (0.014)
<i>Citation-Weighted Patents_t</i> (CW)	-0.010*** (0.002)	-0.013*** (0.004)	-0.014** (0.006)	-0.013 (0.008)	-0.014 (0.010)
<i>Patent Value_t</i> (SM)	0.016*** (0.004)	0.028*** (0.008)	0.035*** (0.012)	0.041*** (0.015)	0.048*** (0.018)
R^2	0.184	0.202	0.207	0.206	0.202
Labor ($N = 23,511$)					
<i>Obsolescence_t</i>	-0.006** (0.003)	-0.011** (0.005)	-0.017** (0.007)	-0.021** (0.009)	-0.021* (0.011)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005* (0.003)	-0.007 (0.005)	-0.009 (0.007)	-0.010 (0.009)	-0.014 (0.011)
<i>Patent Value_t</i> (SM)	0.011*** (0.003)	0.017** (0.007)	0.022** (0.009)	0.027** (0.012)	0.032** (0.014)
R^2	0.173	0.182	0.185	0.184	0.184
TFP ($N = 16,639$)					
<i>Obsolescence_t</i>	-0.009*** (0.003)	-0.015*** (0.005)	-0.019*** (0.006)	-0.021*** (0.006)	-0.019*** (0.007)
<i>Citation-Weighted Patents_t</i> (CW)	0 (0.003)	0.005 (0.006)	0.007 (0.007)	0.004 (0.008)	0.005 (0.009)
<i>Patent Value_t</i> (SM)	0.014* (0.008)	0.019 (0.012)	0.023** (0.011)	0.029*** (0.011)	0.032*** (0.010)
R^2	0.239	0.296	0.332	0.347	0.350

Notes. This table examines the relation between *Obsolescence* and firm growth and productivity using a new construction. Specifically, this approach reconstructs the *Obsolescence* measure with one modification: when tracking changes in citations between $t - \tau$ and t , we impute the citations changes to be zero for patents in the base that experienced a growth of citations over this time window. The table design follows that in Table 6.

Table A.7. Heterogeneity Across Different Firm and Industry Characteristics, Controlling For Innovation Measures

Heterogeneity	Core Patents		Product/Process Patents		Competition	
	Core	Non-Core	Product	Process	High	Low
Profits						
<i>Obsolescence_t</i>	-0.019*** (0.007)	-0.005 (0.007)	-0.023*** (0.007)	-0.008 (0.005)	-0.021*** (0.007)	-0.024 (0.015)
<i>Citation-Weighted Patents_t</i> (CW)	0.009 (0.011)	0.011 (0.011)	0.009 (0.011)	0.011 (0.011)	0.007 (0.014)	0.014 (0.017)
<i>Patent Value_t</i> (SM)	0.035*** (0.014)	0.036*** (0.014)	0.035*** (0.014)	0.036*** (0.014)	0.037** (0.015)	0.047*** (0.013)
R^2	0.272	0.271	0.272	0.271	0.246	0.391
Observations	21,274	21,274	21,274	21,274	15,513	5,761
Output						
<i>Obsolescence_t</i>	-0.020*** (0.008)	-0.004 (0.007)	-0.020*** (0.008)	-0.007 (0.005)	-0.022** (0.009)	-0.015 (0.012)
<i>Citation-Weighted Patents_t</i> (CW)	-0.007 (0.009)	-0.006 (0.010)	-0.007 (0.009)	-0.006 (0.010)	-0.015 (0.011)	0.030** (0.012)
<i>Patent Value_t</i> (SM)	0.029** (0.014)	0.030** (0.014)	0.029** (0.014)	0.030** (0.014)	0.031** (0.015)	0.039*** (0.012)
R^2	0.213	0.212	0.213	0.212	0.192	0.360
Observations	22,358	22,358	22,358	22,358	16,564	5,794
Capital						
<i>Obsolescence_t</i>	-0.028*** (0.007)	-0.014** (0.006)	-0.032*** (0.008)	-0.009* (0.006)	-0.036*** (0.009)	-0.013 (0.010)
<i>Citation-Weighted Patents_t</i> (CW)	-0.014** (0.006)	-0.012* (0.006)	-0.014** (0.006)	-0.012* (0.006)	-0.017*** (0.007)	-0.007 (0.013)
<i>Patent Value_t</i> (SM)	0.036*** (0.012)	0.037*** (0.012)	0.036*** (0.012)	0.037*** (0.012)	0.038*** (0.012)	0.039*** (0.013)
R^2	0.208	0.205	0.208	0.205	0.191	0.306
Observations	22,873	22,873	22,873	22,873	17,022	5,851
Labor						
<i>Obsolescence_t</i>	-0.012** (0.006)	-0.005 (0.006)	-0.017** (0.007)	-0.005 (0.005)	-0.016** (0.008)	-0.005 (0.010)
<i>Citation-Weighted Patents_t</i> (CW)	-0.008 (0.007)	-0.008 (0.007)	-0.009 (0.007)	-0.008 (0.007)	-0.012* (0.008)	0.006 (0.015)
<i>Patent Value_t</i> (SM)	0.023** (0.009)	0.024** (0.009)	0.023** (0.009)	0.023** (0.009)	0.025** (0.010)	0.025*** (0.009)
R^2	0.184	0.184	0.185	0.184	0.159	0.312
Observations	23,511	23,511	23,511	23,511	17,525	5,986
TFP						
<i>Obsolescence_t</i>	-0.011*** (0.004)	-0.006 (0.004)	-0.011** (0.004)	-0.007* (0.004)	-0.013** (0.005)	-0.005 (0.008)
<i>Citation-Weighted Patents_t</i> (CW)	0.009 (0.007)	0.010 (0.007)	0.008 (0.007)	0.010 (0.007)	0.002 (0.008)	0.022*** (0.008)
<i>Patent Value_t</i> (SM)	0.024** (0.011)	0.024** (0.011)	0.024** (0.011)	0.024** (0.011)	0.027** (0.013)	0.011* (0.006)
R^2	0.331	0.331	0.331	0.331	0.306	0.478
Observations	16,639	16,639	16,639	16,639	12,804	3,835

Notes. This table examines the relation between *Obsolescence* and firm growth and productivity in different subsamples. This is the same design as in Table 7 in the main text, after adding new innovation measures SM and CW. The core vs. non-core (peripheral) patents are defined as the top technology class(es) that populate 50% of all the firm's patents. The product (disembodied) vs. process (embodied) innovation is defined using the textual description of patents based on [Bena and Simintzi \(2019\)](#). The product market competition is categorized into high vs. low based on the SIC3 HHI. The empirical design follows that in Table 4, only the $t + 3$ horizon is reported.

Table A.8. Technological Obsolescence and Growth, 20-Year Rolling Window for the Technology Base

Time Horizon =	$t + 1$	$t + 2$	$t + 3$	$t + 4$	$t + 5$
Profits ($N = 21,274$)					
<i>Obsolescence_t</i>	-0.012*** (0.003)	-0.020*** (0.005)	-0.023*** (0.008)	-0.026*** (0.009)	-0.026** (0.011)
<i>Citation-Weighted Patents_t</i> (CW)	0.002 (0.005)	0.005 (0.008)	0.009 (0.011)	0.007 (0.014)	0.011 (0.016)
<i>Patent Value_t</i> (SM)	0.017** (0.007)	0.026** (0.011)	0.035*** (0.013)	0.045*** (0.016)	0.054*** (0.018)
R^2	0.254	0.272	0.272	0.265	0.258
Output ($N = 22,358$)					
<i>Obsolescence_t</i>	-0.008** (0.004)	-0.016*** (0.006)	-0.021** (0.009)	-0.026** (0.011)	-0.030** (0.014)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005 (0.004)	-0.006 (0.007)	-0.007 (0.009)	-0.008 (0.012)	-0.008 (0.014)
<i>Patent Value_t</i> (SM)	0.014** (0.006)	0.021** (0.010)	0.029** (0.014)	0.035* (0.019)	0.046** (0.019)
R^2	0.202	0.213	0.213	0.211	0.212
Capital ($N = 22,873$)					
<i>Obsolescence_t</i>	-0.012*** (0.003)	-0.021*** (0.005)	-0.030*** (0.008)	-0.039*** (0.010)	-0.046*** (0.012)
<i>Citation-Weighted Patents_t</i> (CW)	-0.010*** (0.002)	-0.013*** (0.004)	-0.014** (0.006)	-0.013 (0.008)	-0.014 (0.010)
<i>Patent Value_t</i> (SM)	0.016*** (0.004)	0.028*** (0.008)	0.036*** (0.012)	0.041*** (0.015)	0.049*** (0.018)
R^2	0.185	0.203	0.208	0.207	0.203
Labor ($N = 23,511$)					
<i>Obsolescence_t</i>	-0.006** (0.002)	-0.010** (0.004)	-0.015** (0.007)	-0.017** (0.009)	-0.018* (0.010)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005* (0.003)	-0.007 (0.005)	-0.009 (0.007)	-0.010 (0.009)	-0.014 (0.011)
<i>Patent Value_t</i> (SM)	0.011*** (0.003)	0.018** (0.007)	0.023** (0.009)	0.028** (0.012)	0.033** (0.014)
R^2	0.173	0.182	0.185	0.184	0.184
TFP ($N = 16,639$)					
<i>Obsolescence_t</i>	-0.005* (0.003)	-0.008* (0.004)	-0.012*** (0.005)	-0.016*** (0.005)	-0.015** (0.006)
<i>Citation-Weighted Patents_t</i> (CW)	0 (0.003)	0.006 (0.006)	0.008 (0.007)	0.005 (0.008)	0.006 (0.009)
<i>Patent Value_t</i> (SM)	0.015* (0.008)	0.019 (0.012)	0.023** (0.011)	0.030*** (0.011)	0.033*** (0.010)
R^2	0.239	0.296	0.331	0.346	0.350

Notes. This table examines the relation between *Obsolescence* and firm growth and productivity. The design follows that in Table 4.

Table A.9. Technological Obsolescence and Growth, Technology Base with Depreciation Rate of 0.9

Time Horizon =	$t + 1$	$t + 2$	$t + 3$	$t + 4$	$t + 5$
Profits ($N = 21,274$)					
<i>Obsolescence_t</i>	-0.013*** (0.003)	-0.021*** (0.005)	-0.024*** (0.008)	-0.027*** (0.009)	-0.027** (0.011)
<i>Citation-Weighted Patents_t</i> (CW)	0.002 (0.005)	0.005 (0.008)	0.008 (0.011)	0.007 (0.014)	0.011 (0.016)
<i>Patent Value_t</i> (SM)	0.017** (0.007)	0.026** (0.011)	0.035*** (0.013)	0.045*** (0.016)	0.054*** (0.018)
R^2	0.254	0.273	0.272	0.265	0.258
Output ($N = 22,358$)					
<i>Obsolescence_t</i>	-0.009** (0.004)	-0.017*** (0.006)	-0.022** (0.009)	-0.027** (0.011)	-0.031** (0.013)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005 (0.004)	-0.006 (0.007)	-0.007 (0.009)	-0.008 (0.012)	-0.007 (0.014)
<i>Patent Value_t</i> (SM)	0.013** (0.006)	0.021** (0.010)	0.029** (0.014)	0.035* (0.019)	0.046** (0.019)
R^2	0.202	0.213	0.213	0.211	0.212
Capital ($N = 22,873$)					
<i>Obsolescence_t</i>	-0.013*** (0.003)	-0.022*** (0.005)	-0.031*** (0.008)	-0.040*** (0.010)	-0.048*** (0.012)
<i>Citation-Weighted Patents_t</i> (CW)	-0.010*** (0.002)	-0.013*** (0.004)	-0.014** (0.006)	-0.013 (0.008)	-0.014 (0.010)
<i>Patent Value_t</i> (SM)	0.016*** (0.004)	0.028*** (0.008)	0.036*** (0.012)	0.041*** (0.015)	0.049*** (0.018)
R^2	0.185	0.203	0.208	0.207	0.204
Labor ($N = 23,511$)					
<i>Obsolescence_t</i>	-0.006*** (0.002)	-0.011** (0.004)	-0.015** (0.007)	-0.018** (0.008)	-0.019* (0.010)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005* (0.003)	-0.007 (0.005)	-0.009 (0.007)	-0.010 (0.009)	-0.014 (0.011)
<i>Patent Value_t</i> (SM)	0.011*** (0.003)	0.018** (0.007)	0.023** (0.009)	0.028** (0.012)	0.033** (0.014)
R^2	0.173	0.182	0.185	0.184	0.184
TFP ($N = 16,639$)					
<i>Obsolescence_t</i>	-0.006* (0.003)	-0.009** (0.004)	-0.013*** (0.005)	-0.017*** (0.005)	-0.015** (0.006)
<i>Citation-Weighted Patents_t</i> (CW)	0 (0.003)	0.006 (0.006)	0.008 (0.007)	0.005 (0.008)	0.005 (0.009)
<i>Patent Value_t</i> (SM)	0.015* (0.008)	0.019 (0.012)	0.023** (0.011)	0.030*** (0.011)	0.033*** (0.010)
R^2	0.239	0.296	0.331	0.346	0.350

Notes. This table examines the relation between *Obsolescence* and firm growth and productivity. The design follows that in Table 4.

Table A.10. Technological Obsolescence and Growth, Deflated by Patents Per Capita

Time Horizon =	$t + 1$	$t + 2$	$t + 3$	$t + 4$	$t + 5$
Profits ($N = 21,274$)					
<i>Obsolescence_t</i>	-0.012*** (0.003)	-0.019*** (0.005)	-0.023*** (0.008)	-0.026*** (0.009)	-0.026** (0.011)
<i>Citation-Weighted Patents_t</i> (CW)	0.002 (0.005)	0.005 (0.008)	0.009 (0.011)	0.007 (0.014)	0.011 (0.016)
<i>Patent Value_t</i> (SM)	0.017** (0.007)	0.026** (0.011)	0.035*** (0.014)	0.045*** (0.016)	0.055*** (0.018)
R^2	0.254	0.272	0.272	0.265	0.258
Output ($N = 22,358$)					
<i>Obsolescence_t</i>	-0.008** (0.004)	-0.016*** (0.006)	-0.021** (0.009)	-0.026** (0.011)	-0.030** (0.013)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005 (0.004)	-0.006 (0.007)	-0.007 (0.009)	-0.008 (0.012)	-0.007 (0.014)
<i>Patent Value_t</i> (SM)	0.014** (0.006)	0.021** (0.010)	0.029** (0.014)	0.035* (0.019)	0.046** (0.019)
R^2	0.202	0.213	0.213	0.211	0.212
Capital ($N = 22,873$)					
<i>Obsolescence_t</i>	-0.012*** (0.003)	-0.021*** (0.005)	-0.030*** (0.008)	-0.039*** (0.010)	-0.045*** (0.012)
<i>Citation-Weighted Patents_t</i> (CW)	-0.010*** (0.002)	-0.013*** (0.004)	-0.014** (0.006)	-0.013 (0.008)	-0.014 (0.010)
<i>Patent Value_t</i> (SM)	0.016*** (0.004)	0.028*** (0.008)	0.036*** (0.012)	0.042*** (0.015)	0.049*** (0.018)
R^2	0.185	0.203	0.208	0.207	0.203
Labor ($N = 23,511$)					
<i>Obsolescence_t</i>	-0.006** (0.002)	-0.010** (0.004)	-0.015** (0.007)	-0.018** (0.009)	-0.019* (0.010)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005* (0.003)	-0.007 (0.005)	-0.009 (0.007)	-0.010 (0.009)	-0.014 (0.011)
<i>Patent Value_t</i> (SM)	0.011*** (0.003)	0.018** (0.007)	0.023** (0.009)	0.028** (0.012)	0.033** (0.014)
R^2	0.173	0.182	0.185	0.184	0.184
TFP ($N = 16,639$)					
<i>Obsolescence_t</i>	-0.006* (0.003)	-0.008* (0.004)	-0.012** (0.005)	-0.015*** (0.005)	-0.014** (0.006)
<i>Citation-Weighted Patents_t</i> (CW)	0 (0.003)	0.006 (0.006)	0.008 (0.007)	0.005 (0.008)	0.006 (0.009)
<i>Patent Value_t</i> (SM)	0.015* (0.008)	0.019 (0.012)	0.024** (0.011)	0.030*** (0.011)	0.033*** (0.010)
R^2	0.239	0.296	0.331	0.346	0.350

Notes. This table examines the relation between *Obsolescence* and firm growth and productivity after adding measures of new innovation, the stock market-based patent value from Kogan et al. (2017), and citation-weight patent counts. The design follows that in Table 4.

Table A.11. Technological Obsolescence and Growth, Firm FE ($t + 5$)

	(1)	(2)	(3)	(4)	(5)
	Profits _{$t+5$}	Output _{$t+5$}	Capital _{$t+5$}	Labor _{$t+5$}	TFP _{$t+5$}
<i>Obsolescence_{t}</i>	-0.026*** (0.009)	-0.016* (0.008)	-0.029*** (0.008)	-0.017** (0.008)	-0.008 (0.005)
R^2	0.964	0.970	0.976	0.965	0.640
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	17,927	17,974	17,946	17,868	15,792

Notes. This table examines the relation between *Obsolescence* and firm growth and productivity after adding measures of new innovation, the stock market-based patent value from [Kogan et al. \(2017\)](#), and citation-weight patent counts. The design follows that in [Table 4](#).

Table A.12. Technological Obsolescence and Growth—Dropping Competitors’ Patents

Time Horizon =	Drop Patents from Hoberg-Phillips Competitors			Drop Patents from SIC-3 Competitors		
	$t + 1$	$t + 3$	$t + 5$	$t + 1$	$t + 3$	$t + 5$
	Profits ($N = 21,274$)					
<i>Obsolescence_t</i>	-0.011*** (0.003)	-0.021*** (0.007)	-0.024** (0.010)	-0.012*** (0.003)	-0.021*** (0.007)	-0.025** (0.011)
<i>Citation-Weighted Patents_t</i> (CW)	0.002 (0.005)	0.009 (0.011)	0.011 (0.016)	0.002 (0.005)	0.009 (0.011)	0.011 (0.016)
<i>Patent Value_t</i> (SM)	0.017** (0.007)	0.035*** (0.013)	0.055*** (0.018)	0.017** (0.007)	0.035*** (0.014)	0.055*** (0.018)
R^2	0.254	0.272	0.258	0.254	0.272	0.258
	Output ($N = 22,358$)					
<i>Obsolescence_t</i>	-0.008** (0.004)	-0.019** (0.008)	-0.026** (0.013)	-0.008** (0.004)	-0.019** (0.008)	-0.027** (0.013)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005 (0.004)	-0.007 (0.009)	-0.007 (0.014)	-0.005 (0.004)	-0.007 (0.009)	-0.007 (0.014)
<i>Patent Value_t</i> (SM)	0.014** (0.006)	0.029** (0.013)	0.046** (0.019)	0.014** (0.006)	0.029** (0.014)	0.046** (0.019)
R^2	0.202	0.213	0.212	0.202	0.213	0.212
	Capital ($N = 22,873$)					
<i>Obsolescence_t</i>	-0.012*** (0.003)	-0.030*** (0.008)	-0.044*** (0.012)	-0.012*** (0.002)	-0.030*** (0.007)	-0.044*** (0.012)
<i>Citation-Weighted Patents_t</i> (CW)	-0.010*** (0.002)	-0.014** (0.006)	-0.014 (0.010)	-0.010*** (0.002)	-0.014** (0.006)	-0.014 (0.010)
<i>Patent Value_t</i> (SM)	0.016*** (0.004)	0.036*** (0.012)	0.049*** (0.018)	0.016*** (0.004)	0.036*** (0.012)	0.049*** (0.018)
R^2	0.184	0.208	0.203	0.185	0.208	0.203
	Labor ($N = 23,511$)					
<i>Obsolescence_t</i>	-0.005** (0.002)	-0.013* (0.007)	-0.013 (0.010)	-0.006** (0.002)	-0.013* (0.007)	-0.015 (0.010)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005* (0.003)	-0.008 (0.007)	-0.013 (0.011)	-0.005* (0.003)	-0.008 (0.007)	-0.014 (0.011)
<i>Patent Value_t</i> (SM)	0.011*** (0.003)	0.023** (0.009)	0.033** (0.014)	0.011*** (0.003)	0.023** (0.009)	0.033** (0.014)
R^2	0.173	0.184	0.183	0.173	0.185	0.183
	TFP ($N = 16,639$)					
<i>Obsolescence_t</i>	-0.006* (0.003)	-0.011** (0.004)	-0.011** (0.006)	-0.005 (0.003)	-0.010** (0.004)	-0.013** (0.006)
<i>Citation-Weighted Patents_t</i> (CW)	0 (0.003)	0.008 (0.007)	0.006 (0.009)	0.001 (0.003)	0.008 (0.007)	0.006 (0.009)
<i>Patent Value_t</i> (SM)	0.015* (0.008)	0.024** (0.011)	0.033*** (0.010)	0.015* (0.008)	0.024** (0.011)	0.033*** (0.010)
R^2	0.239	0.331	0.350	0.239	0.331	0.350

Notes. This table examines the relation between *Obsolescence* and firm growth and productivity. The design follows that in Table 4 with abbreviation. The key difference with Table 4 is that when constructing *Obsolescence*, the Technology Base excludes patents from industry competitors defined using both Hoberg-Phillips categorizations (Hoberg and Phillips, 2016) and competitors in the same 3-digit SIC industries.

Table A.13. Robustness of *Obsolescence* Measure—Only General Patents In the Base

Time Horizon =	High-Generality Patents			Low-Generality Patents		
	$t + 1$	$t + 3$	$t + 5$	$t + 1$	$t + 3$	$t + 5$
Profits ($N = 21,274$)						
<i>Obsolescence_t</i>	-0.011*** (0.003)	-0.021*** (0.007)	-0.025*** (0.009)	-0.006** (0.003)	-0.012** (0.006)	-0.014 (0.010)
<i>Citation-Weighted Patents_t</i> (CW)	0.003 (0.005)	0.010 (0.011)	0.012 (0.016)	0.003 (0.005)	0.011 (0.011)	0.013 (0.016)
<i>Patent Value_t</i> (SM)	0.017** (0.007)	0.035*** (0.013)	0.054*** (0.018)	0.017** (0.007)	0.035*** (0.014)	0.055*** (0.018)
R^2	0.254	0.272	0.258	0.253	0.271	0.257
Output ($N = 22,358$)						
<i>Obsolescence_t</i>	-0.006* (0.003)	-0.019** (0.008)	-0.025** (0.011)	-0.006** (0.003)	-0.012* (0.006)	-0.012 (0.010)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005 (0.004)	-0.007 (0.009)	-0.006 (0.014)	-0.005 (0.004)	-0.006 (0.010)	-0.005 (0.014)
<i>Patent Value_t</i> (SM)	0.014** (0.006)	0.029** (0.014)	0.046** (0.019)	0.014** (0.006)	0.030** (0.014)	0.047** (0.020)
R^2	0.202	0.213	0.212	0.202	0.213	0.211
Capital ($N = 22,873$)						
<i>Obsolescence_t</i>	-0.010*** (0.002)	-0.025*** (0.007)	-0.038*** (0.011)	-0.008*** (0.002)	-0.016*** (0.006)	-0.023*** (0.009)
<i>Citation-Weighted Patents_t</i> (CW)	-0.009*** (0.002)	-0.013** (0.006)	-0.012 (0.010)	-0.009*** (0.002)	-0.012** (0.006)	-0.011 (0.010)
<i>Patent Value_t</i> (SM)	0.016*** (0.004)	0.036*** (0.012)	0.049*** (0.018)	0.016*** (0.004)	0.037*** (0.012)	0.051*** (0.018)
R^2	0.184	0.207	0.203	0.183	0.206	0.201
Labor ($N = 23,511$)						
<i>Obsolescence_t</i>	-0.006** (0.002)	-0.015** (0.006)	-0.018** (0.009)	-0.005** (0.002)	-0.011** (0.005)	-0.012 (0.008)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005* (0.003)	-0.008 (0.007)	-0.013 (0.011)	-0.005* (0.003)	-0.008 (0.007)	-0.013 (0.011)
<i>Patent Value_t</i> (SM)	0.011*** (0.003)	0.023** (0.009)	0.033** (0.014)	0.011*** (0.003)	0.023** (0.009)	0.034** (0.014)
R^2	0.173	0.185	0.184	0.173	0.184	0.183
TFP ($N = 16,639$)						
<i>Obsolescence_t</i>	-0.007** (0.003)	-0.012*** (0.005)	-0.014*** (0.005)	-0.003 (0.002)	-0.007* (0.004)	-0.005 (0.005)
<i>Citation-Weighted Patents_t</i> (CW)	0 (0.003)	0.009 (0.007)	0.006 (0.009)	0.001 (0.003)	0.010 (0.007)	0.007 (0.009)
<i>Patent Value_t</i> (SM)	0.015* (0.008)	0.024** (0.011)	0.033*** (0.010)	0.015* (0.008)	0.024** (0.011)	0.033*** (0.010)
R^2	0.239	0.331	0.350	0.238	0.331	0.349

Notes. This table examines the relation between *Obsolescence* and firm growth and productivity in different subsamples. The technology base is constructed using patents that are of high- vs. low- generality, defined as in Hall, Jaffe, and Trajtenberg (2001). The empirical design follows that in Table 4, only the $t + 1$, $t + 3$, and $t + 5$ horizon is reported.

Table A.14. Robustness of *Obsolescence* Measure—Different Components of Technology Base

Time Horizon =	Foreign-Country Patents			Non-Corporation Patents			Standard Essential Patents		
	$t+1$	$t+3$	$t+5$	$t+1$	$t+3$	$t+5$	$t+1$	$t+3$	$t+5$
<i>Obsolescence_t</i>	-0.010*** (0.003)	-0.022*** (0.006)	-0.029*** (0.009)	-0.002 (0.003)	-0.004 (0.007)	-0.005 (0.009)	0.001 (0.004)	-0.016* (0.009)	-0.021* (0.012)
<i>Citation-Weighted Patents_t</i> (CW)	0.003 (0.005)	0.009 (0.011)	0.011 (0.016)	0.003 (0.005)	0.011 (0.011)	0.013 (0.016)	0.003 (0.005)	0.011 (0.011)	0.013 (0.016)
<i>Patent Value_t</i> (SM)	0.017*** (0.007)	0.035*** (0.013)	0.054*** (0.018)	0.017*** (0.007)	0.036*** (0.014)	0.055*** (0.018)	0.017*** (0.007)	0.036*** (0.014)	0.055*** (0.018)
R^2	0.254	0.272	0.258	0.253	0.271	0.257	0.253	0.271	0.257
Profits ($N=21,274$)									
<i>Obsolescence_t</i>	-0.007** (0.003)	-0.018** (0.007)	-0.027*** (0.011)	-0.004 (0.003)	-0.007 (0.007)	-0.006 (0.009)	-0.004 (0.004)	-0.019* (0.010)	-0.025* (0.014)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005 (0.004)	-0.007 (0.009)	-0.007 (0.014)	-0.005 (0.004)	-0.006 (0.010)	-0.005 (0.015)	-0.004 (0.004)	-0.006 (0.010)	-0.005 (0.015)
<i>Patent Value_t</i> (SM)	0.014*** (0.006)	0.029*** (0.014)	0.046*** (0.019)	0.014*** (0.006)	0.030*** (0.014)	0.047*** (0.020)	0.014*** (0.006)	0.030*** (0.014)	0.047*** (0.020)
R^2	0.202	0.213	0.212	0.202	0.212	0.211	0.202	0.212	0.211
Output ($N=22,358$)									
<i>Obsolescence_t</i>	-0.011*** (0.002)	-0.029*** (0.006)	-0.040*** (0.010)	-0.004** (0.002)	-0.013** (0.006)	-0.018** (0.009)	-0.004 (0.004)	-0.012 (0.009)	-0.023* (0.013)
<i>Citation-Weighted Patents_t</i> (CW)	-0.009*** (0.002)	-0.014** (0.006)	-0.013 (0.010)	-0.009*** (0.002)	-0.012** (0.006)	-0.011 (0.010)	-0.009*** (0.002)	-0.012* (0.006)	-0.011 (0.010)
<i>Patent Value_t</i> (SM)	0.016*** (0.004)	0.036*** (0.012)	0.049*** (0.018)	0.017*** (0.004)	0.037*** (0.012)	0.051*** (0.018)	0.017*** (0.004)	0.037*** (0.012)	0.051*** (0.018)
R^2	0.185	0.208	0.203	0.182	0.205	0.200	0.182	0.205	0.200
Capital ($N=22,873$)									

Time Horizon =	Foreign-Country Patents		Non-Corporation Patents		Standard Essential Patents	
	$t+1$	$t+3$	$t+5$	$t+1$	$t+3$	$t+5$
<i>Obsolescence_t</i>	-0.005** (0.002)	-0.013** (0.006)	-0.015* (0.008)	Labor ($N=23,511$) -0.004** (0.002)	-0.009* (0.005)	-0.006 (0.007)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005* (0.003)	-0.008 (0.007)	-0.013 (0.011)	-0.005* (0.003)	-0.008 (0.007)	-0.013 (0.011)
<i>Patent Value_t</i> (SM)	0.011*** (0.003)	0.023** (0.009)	0.033** (0.014)	0.011*** (0.003)	0.023** (0.009)	0.034** (0.014)
R^2	0.173	0.185	0.183	0.172	0.184	0.183
<i>Obsolescence_t</i>	-0.006* (0.003)	-0.014*** (0.004)	-0.015*** (0.005)	TFP ($N=16,639$) -0.002 (0.003)	-0.001 (0.004)	-0.001 (0.005)
<i>Citation-Weighted Patents_t</i> (CW)	0.001 (0.003)	0.008 (0.007)	0.006 (0.009)	0.001 (0.003)	0.010 (0.007)	0.007 (0.009)
<i>Patent Value_t</i> (SM)	0.015* (0.008)	0.023** (0.011)	0.033*** (0.010)	0.015* (0.008)	0.024** (0.011)	0.033*** (0.010)
R^2	0.239	0.331	0.350	0.238	0.330	0.349

Notes. This table examines the relation between *Obsolescence* calculated using sub-components of the technology base and firm growth and productivity. Three different components are used in the technology base: international patents, patents owned by non-corporations (government, universities, etc.), and patents that are categorized as standard essential patents (SEP) as proposed in [Lerner and Tirole \(2015\)](#) and classified by [Baron and Pohlmann \(2018\)](#). The empirical design follows that in [Table 4](#), only the $t+1$, $t+3$, and $t+5$ horizon is reported.

Table A.15. Robustness of *Obsolescence* Measure—Patents Owned

Time Horizon =	$t + 1$	$t + 2$	$t + 3$	$t + 4$	$t + 5$
Profits ($N = 21,274$)					
<i>Obsolescence_t</i>	-0.013*** (0.003)	-0.025*** (0.005)	-0.036*** (0.007)	-0.040*** (0.009)	-0.044*** (0.010)
<i>Citation-Weighted Patents_t</i> (CW)	0.001 (0.004)	0.003 (0.008)	0.006 (0.011)	0.004 (0.014)	0.007 (0.016)
<i>Patent Value_t</i> (SM)	0.016** (0.006)	0.024** (0.011)	0.032** (0.013)	0.042*** (0.016)	0.051*** (0.017)
R^2	0.254	0.273	0.274	0.267	0.260
Output ($N = 22,358$)					
<i>Obsolescence_t</i>	-0.008*** (0.003)	-0.016*** (0.006)	-0.022*** (0.007)	-0.022** (0.009)	-0.022** (0.010)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005 (0.004)	-0.006 (0.007)	-0.008 (0.010)	-0.009 (0.012)	-0.008 (0.014)
<i>Patent Value_t</i> (SM)	0.013** (0.006)	0.020** (0.010)	0.028** (0.013)	0.034* (0.019)	0.045** (0.019)
R^2	0.202	0.213	0.213	0.210	0.211
Capital ($N = 22,873$)					
<i>Obsolescence_t</i>	-0.011*** (0.002)	-0.019*** (0.004)	-0.027*** (0.006)	-0.033*** (0.008)	-0.035*** (0.010)
<i>Citation-Weighted Patents_t</i> (CW)	-0.010*** (0.002)	-0.013*** (0.004)	-0.015** (0.006)	-0.014* (0.009)	-0.015 (0.010)
<i>Patent Value_t</i> (SM)	0.016*** (0.004)	0.028*** (0.008)	0.035*** (0.011)	0.040*** (0.015)	0.048*** (0.017)
R^2	0.184	0.202	0.207	0.206	0.202
Labor ($N = 23,511$)					
<i>Obsolescence_t</i>	-0.006*** (0.002)	-0.012*** (0.004)	-0.015*** (0.005)	-0.017** (0.007)	-0.019** (0.008)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005* (0.003)	-0.008 (0.005)	-0.009 (0.008)	-0.011 (0.010)	-0.015 (0.011)
<i>Patent Value_t</i> (SM)	0.011*** (0.003)	0.017** (0.007)	0.022** (0.009)	0.027** (0.012)	0.032** (0.013)
R^2	0.173	0.182	0.185	0.184	0.184
TFP ($N = 16,639$)					
<i>Obsolescence_t</i>	-0.007* (0.004)	-0.012** (0.005)	-0.013** (0.005)	-0.012* (0.006)	-0.012* (0.006)
<i>Citation-Weighted Patents_t</i> (CW)	0 (0.003)	0.005 (0.006)	0.008 (0.007)	0.005 (0.008)	0.005 (0.009)
<i>Patent Value_t</i> (SM)	0.014* (0.008)	0.018 (0.012)	0.023** (0.011)	0.029*** (0.011)	0.032*** (0.010)
R^2	0.239	0.296	0.331	0.346	0.350

Notes. This table examines the relation between *Obsolescence* and firm growth and productivity. We use the technological obsolescence as the rate of change in citations made to the firm's own patent portfolio, instead of the technology base. The design follows that in Table 4.

Table A.16. Robustness of *Obsolescence* Measure—Duplicated Technology Base

Time Horizon =	$t + 1$	$t + 2$	$t + 3$	$t + 4$	$t + 5$
Profits ($N = 21,274$)					
<i>Obsolescence_t</i>	-0.011*** (0.003)	-0.018*** (0.005)	-0.021*** (0.007)	-0.024*** (0.009)	-0.024** (0.010)
<i>Citation-Weighted Patents_t</i> (CW)	0.002 (0.005)	0.005 (0.008)	0.009 (0.011)	0.007 (0.014)	0.011 (0.016)
<i>Patent Value_t</i> (SM)	0.017** (0.007)	0.026** (0.011)	0.035*** (0.014)	0.045*** (0.016)	0.055*** (0.018)
R^2	0.254	0.272	0.272	0.265	0.258
Output ($N = 22,358$)					
<i>Obsolescence_t</i>	-0.008** (0.003)	-0.015*** (0.005)	-0.018** (0.008)	-0.021** (0.010)	-0.025** (0.012)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005 (0.004)	-0.005 (0.007)	-0.007 (0.009)	-0.007 (0.012)	-0.007 (0.014)
<i>Patent Value_t</i> (SM)	0.014** (0.006)	0.021** (0.010)	0.029** (0.014)	0.035* (0.019)	0.046** (0.019)
R^2	0.202	0.213	0.213	0.210	0.212
Capital ($N = 22,873$)					
<i>Obsolescence_t</i>	-0.012*** (0.002)	-0.021*** (0.005)	-0.029*** (0.007)	-0.038*** (0.010)	-0.045*** (0.012)
<i>Citation-Weighted Patents_t</i> (CW)	-0.010*** (0.002)	-0.013*** (0.004)	-0.014** (0.006)	-0.013 (0.008)	-0.014 (0.010)
<i>Patent Value_t</i> (SM)	0.016*** (0.004)	0.028*** (0.008)	0.036*** (0.012)	0.042*** (0.015)	0.049*** (0.018)
R^2	0.185	0.203	0.208	0.207	0.203
Labor ($N = 23,511$)					
<i>Obsolescence_t</i>	-0.006** (0.002)	-0.010** (0.004)	-0.013** (0.006)	-0.014* (0.008)	-0.015 (0.010)
<i>Citation-Weighted Patents_t</i> (CW)	-0.005* (0.003)	-0.007 (0.005)	-0.008 (0.007)	-0.010 (0.009)	-0.013 (0.011)
<i>Patent Value_t</i> (SM)	0.011*** (0.003)	0.018** (0.007)	0.023** (0.009)	0.028** (0.012)	0.033** (0.014)
R^2	0.173	0.182	0.185	0.184	0.183
TFP ($N = 16,639$)					
<i>Obsolescence_t</i>	-0.006* (0.003)	-0.009** (0.004)	-0.012*** (0.005)	-0.014*** (0.005)	-0.012** (0.006)
<i>Citation-Weighted Patents_t</i> (CW)	0 (0.003)	0.006 (0.006)	0.008 (0.007)	0.005 (0.008)	0.006 (0.009)
<i>Patent Value_t</i> (SM)	0.015* (0.008)	0.019 (0.012)	0.024** (0.011)	0.030*** (0.011)	0.033*** (0.010)
R^2	0.239	0.296	0.331	0.346	0.350

Notes. This table examines the relation between *Obsolescence* and firm growth and productivity. We use the duplicated technology base to construct the technological obsolescence; that is, we allow the same patent to appear multiple times in the technology base if it was cited multiple times by different patents of this firm. The design follows that in Table 4.

Table A.17. Technological Obsolescence and Growth, Controlling For Other Innovation Measures

Panel (a): Controlling for $RETech_t$ and $Tech\ Breadth_t$ from BFH					
	(1)	(2)	(3)	(4)	(5)
	Profits $_{t+5}$	Output $_{t+5}$	Capital $_{t+5}$	Labor $_{t+5}$	TFP $_{t+5}$
$Obsolescence_t$	-0.032*** (0.011)	-0.036*** (0.013)	-0.056*** (0.012)	-0.023** (0.010)	-0.014** (0.006)
R^2	0.248	0.205	0.198	0.178	0.348
Industry x Year FE	Yes	Yes	Yes	Yes	Yes
Observations	20,275	21,336	21,820	22,413	15,884
Panel (b): Controlling for % Breakthrough Patents $_t$ from KPST					
	(1)	(2)	(3)	(4)	(5)
	Profits $_{t+5}$	Output $_{t+5}$	Capital $_{t+5}$	Labor $_{t+5}$	TFP $_{t+5}$
$Obsolescence_t$	-0.032*** (0.011)	-0.033** (0.013)	-0.050*** (0.013)	-0.020* (0.010)	-0.016*** (0.006)
R^2	0.255	0.206	0.201	0.183	0.344
Industry x Year FE	Yes	Yes	Yes	Yes	Yes
Observations	19,611	20,592	21,031	20,841	15,327

Notes. This table examines the relation between *Obsolescence* and firm growth and productivity after adding alternative measures of new innovation. Panel (a) controls for the RETech measures from [Bowen III, Frésard, and Hoberg \(2023\)](#) (BFH), and panel (b) controls for the share of breakthrough patents from [Kelly et al. \(2021\)](#) (KPST). The design follows that in [Table 4](#).

Table A.18. Summary Statistics for Asset Pricing Implications

Panel (a): For All Firms on CRSP											
	count	mean	std	10%	25%	50%	75%	90%			
<i>Size</i>	109079	1.589	6.260	9.000	29.000	131.000	659.000	2,775			
$\log(BM)$	109014	0.716	0.713	0.151	0.288	0.521	0.897	1.445			
$Ret(-1, 0)$ (%)	100711	0.197	15.186	-16.398	-7.747	-0.171	6.667	16.667			
$Ret(-12, -2)$ (%)	100412	11.088	58.410	-49.303	-24.591	2.616	33.138	74.661			
Idiosyncratic Volatility	108637	0.041	0.029	0.015	0.022	0.033	0.051	0.077			
<i>SUE</i> (%)	95466	-0.769	14.947	-4.010	-0.583	0.008	0.411	2.570			
Patents/Assets (%)	109687	1.411	4.781	0.000	0.000	0.000	0.342	3.372			
R&D/Market Equity (%)	109079	4.180	9.446	0.000	0.000	0.079	4.382	12.044			
Innovation Originality	109741	5.332	8.241	0.000	0.000	0.000	9.000	15.917			
Citations-Based Innovative Efficiency	109741	0.157	0.642	0.000	0.000	0.000	0.007	0.287			
Patents-Based Innovative Efficiency	109741	0.087	0.331	0.000	0.000	0.000	0.000	0.192			

Panel (b): For Firms with an <i>Obsolescence</i> Measure											
	count	mean	std	10%	25%	50%	75%	90%			
<i>Obsolescence</i>	25577	0.216	0.361	-0.216	-0.005	0.208	0.427	0.661			
<i>Size</i>	25536	5.478	17,829	38.000	132.000	595.000	2,647	10,948			
$\log(BM)$	25533	0.600	0.514	0.160	0.282	0.475	0.766	1.152			
$Ret(-1, 0)$ (%)	25294	0.030	12.603	-13.689	-6.452	-0.395	5.745	13.525			
$Ret(-12, -2)$ (%)	25280	13.501	49.220	-38.798	-15.430	8.133	33.259	65.589			
Idiosyncratic Volatility	25393	0.029	0.019	0.012	0.016	0.024	0.036	0.052			
<i>SUE</i> (%)	24924	-0.284	9.888	-1.776	-0.190	0.018	0.250	1.320			
Patents/Assets (%)	25576	2.950	6.104	0.000	0.079	0.864	2.848	7.448			
R&D/Market Equity (%)	25536	6.346	10.754	0.000	0.946	3.134	7.408	15.468			
Innovation Originality	25577	11.356	9.007	2.000	6.000	9.635	14.222	21.500			
Citations-Based Innovative Efficiency	25577	0.370	1.051	0.000	0.000	0.080	0.287	0.801			
Patents-Based Innovative Efficiency	25577	0.205	0.462	0.000	0.000	0.071	0.203	0.478			

Panel (c): For Firms with an *Obsolescence* Measure, by Group

	Raw value			Percentile ranks			
	Low	Middle	High	All	Low	Middle	High
Number of firms	256	341	256	853			
<i>Obsolescence</i>	-0.120	0.251	0.607	0.247	15	50	85
<i>Size</i>	4,230	6,740	3,539	5,026	46	54	48
$\log(BM)$	0.583	0.605	0.678	0.620	46	50	54
$Ret(-1,0)$ (%)	0.481	0.139	-0.402	0.078	51	50	49
$Ret(-12,-2)$ (%)	13.188	14.865	13.100	13.829	49	51	49
Idiosyncratic Volatility	0.031	0.027	0.030	0.029	54	46	51
<i>SUE</i> (%)	-0.266	-0.272	-0.384	-0.304	49	50	51
Patents/Assets (%)	3.176	2.766	3.088	2.986	49	51	51
R&D/Market Equity (%)	5.845	6.240	6.626	6.237	49	51	50
Innovation Originality	11.419	10.787	10.236	10.812	51	52	47
Citations-Based Innovative Efficiency	0.461	0.363	0.347	0.387	49	51	50
Patents-Based Innovative Efficiency	0.220	0.221	0.232	0.224	47	51	51

Notes. This table summarizes firm characteristics used in Section 3 at the firm-year level. Panel (a) provides the summary statistics for the entire universe of stocks on CRSP, and panel (b) provides the summary statistics for those firms with an *Obsolescence* measure for the year. Panel (c) reports the time-series mean of cross-sectional average characteristics (both raw value and percentile ranks) of firms in each group. At the end of June of year t from 1986 to 2016, we sort firms with a non-missing *Obsolescence* measure into three portfolios—Low, Middle, and High—based on the 30th and 70th percentile in *Obsolescence* in year $t - 1$. Detailed variable definitions are provided in the Appendix.

Table A.19. Monthly Returns of Obsolescence-Sorted Portfolios—Equal-Weight Portfolio

Panel (a): Equal-Weight Portfolio, with Factor Models

	Extret	3F	4F	4F + RMW + CMA	Q5 (HXZ)	3F ^{INT}	4F ^{INT}	4F ^{INT} + RMW + CMA
Low	0.925*** (0.319)	0.242** (0.098)	0.378*** (0.096)	0.375*** (0.090)	0.332*** (0.110)	0.200** (0.095)	0.344*** (0.095)	0.372*** (0.092)
Middle	0.899*** (0.310)	0.167* (0.099)	0.309*** (0.090)	0.197** (0.083)	0.144 (0.112)	0.082 (0.094)	0.228** (0.089)	0.190** (0.085)
High	0.757** (0.349)	-0.032 (0.110)	0.141 (0.105)	0.087 (0.095)	0.031 (0.113)	-0.109 (0.112)	0.078 (0.111)	0.072 (0.097)
Low-High	0.168* (0.095)	0.274*** (0.081)	0.237*** (0.084)	0.288*** (0.082)	0.301*** (0.087)	0.310*** (0.088)	0.266*** (0.092)	0.301*** (0.085)
All	0.864*** (0.322)	0.130 (0.094)	0.279*** (0.087)	0.217*** (0.080)	0.167 (0.104)	0.060 (0.091)	0.218** (0.088)	0.209** (0.081)

Panel (b): Equal-Weight Portfolio, with Factor Models and Sample-Specific Market Factor

	Extret	3F	4F	4F + RMW + CMA	Q5 (HXZ)	3F ^{INT}	4F ^{INT}	4F ^{INT} + RMW + CMA
Low	0.925*** (0.319)	0.120** (0.049)	0.113** (0.051)	0.160*** (0.050)	0.184*** (0.053)	0.143*** (0.050)	0.131** (0.053)	0.163*** (0.051)
Middle	0.899*** (0.310)	0.040 (0.034)	0.032 (0.031)	-0.016 (0.028)	-0.029 (0.031)	0.024 (0.032)	0.018 (0.030)	-0.015 (0.028)
High	0.757** (0.349)	-0.174*** (0.043)	-0.156*** (0.046)	-0.139*** (0.043)	-0.146*** (0.044)	-0.176*** (0.046)	-0.156*** (0.050)	-0.144*** (0.045)
Low-High	0.168* (0.095)	0.294*** (0.080)	0.268*** (0.088)	0.300*** (0.085)	0.329*** (0.089)	0.319*** (0.086)	0.287*** (0.095)	0.308*** (0.088)

Notes. This table presents equal-weight monthly portfolio returns (in %) for portfolios sorted on *Obsolescence*. At the end of June of year t from 1986 to 2016, we sort firms based on their obsolescence measure into three portfolios. All other analyses follow Table 9 in the main text.

Table A.20. Return Predictive Power of Technological Obsolescence—5 Sorted Portfolios

Panel (a): Value-Weight Portfolio									
	Exret	3F	4F	4F + RMW + CMA	Q5 (HXZ)	3F ^{INT}	4F ^{INT}	4F ^{INT}	4F ^{INT} + RMW + CMA
1	0.949*** (0.269)	0.460*** (0.099)	0.471*** (0.100)	0.530*** (0.104)	0.462*** (0.112)	0.492*** (0.109)	0.495*** (0.109)	0.495*** (0.109)	0.561*** (0.109)
2	0.842*** (0.250)	0.318*** (0.084)	0.329*** (0.088)	0.289*** (0.095)	0.217* (0.112)	0.333*** (0.091)	0.337*** (0.097)	0.337*** (0.097)	0.319*** (0.101)
3	0.649*** (0.249)	0.072 (0.085)	0.107 (0.089)	0.004 (0.088)	-0.125 (0.092)	0.032 (0.089)	0.059 (0.094)	0.059 (0.094)	0.020 (0.090)
4	0.543** (0.240)	-0.074 (0.083)	-0.023 (0.093)	-0.181* (0.096)	-0.248** (0.096)	-0.110 (0.086)	-0.055 (0.101)	-0.055 (0.101)	-0.166* (0.095)
5	0.534** (0.242)	-0.090 (0.124)	-0.012 (0.116)	-0.181 (0.120)	-0.204 (0.150)	-0.142 (0.123)	-0.062 (0.117)	-0.062 (0.117)	-0.166 (0.122)
1-5	0.415** (0.182)	0.550*** (0.161)	0.484*** (0.152)	0.711*** (0.162)	0.666*** (0.190)	0.634*** (0.164)	0.557*** (0.157)	0.557*** (0.157)	0.727*** (0.160)

Panel (b): Equal-Weight Portfolio									
	Exret	3F	4F	4F + RMW + CMA	Q5 (HXZ)	3F ^{INT}	4F ^{INT}	4F ^{INT}	4F ^{INT} + RMW + CMA
1	0.902*** (0.323)	0.228** (0.105)	0.361*** (0.105)	0.398*** (0.101)	0.393*** (0.117)	0.200* (0.104)	0.344*** (0.107)	0.344*** (0.107)	0.395*** (0.101)
2	0.946*** (0.309)	0.238** (0.096)	0.369*** (0.092)	0.266*** (0.086)	0.198* (0.113)	0.157* (0.090)	0.290*** (0.091)	0.290*** (0.091)	0.262*** (0.088)
3	0.916*** (0.307)	0.190* (0.108)	0.339*** (0.098)	0.228** (0.094)	0.163 (0.127)	0.103 (0.104)	0.256*** (0.097)	0.256*** (0.097)	0.221** (0.096)
4	0.804** (0.329)	0.042 (0.104)	0.180* (0.097)	0.101 (0.093)	0.027 (0.096)	-0.026 (0.106)	0.123 (0.105)	0.123 (0.105)	0.094 (0.094)
5	0.754** (0.362)	-0.048 (0.124)	0.147 (0.113)	0.093 (0.103)	0.052 (0.134)	-0.134 (0.123)	0.076 (0.117)	0.076 (0.117)	0.075 (0.104)
1-5	0.148 (0.115)	0.276*** (0.097)	0.214** (0.096)	0.305*** (0.097)	0.340*** (0.107)	0.335*** (0.103)	0.268** (0.104)	0.268** (0.104)	0.320*** (0.099)

Notes. This table presents monthly portfolio returns (in %) for portfolios sorted on *Obsolescence*. At the end of June of year t from 1986 to 2016, we sort firms based on their obsolescence measure into five portfolios—1–5 from low to high. All other analyses follow Table 9 in the main text.

Table A.21. Return Predictive Power of Technological Obsolescence

Panel (a): Value-Weight Portfolio			
	Ind-adjret	Size/BM-adjret	Size/BM/Mom-adjret
Low	-0.181 (0.174)	0.178* (0.096)	0.118* (0.070)
Middle	-0.314** (0.153)	-0.065* (0.038)	-0.046 (0.033)
High	-0.222* (0.124)	-0.129 (0.091)	-0.114** (0.058)
Low-High	0.041 (0.123)	0.307* (0.174)	0.231** (0.118)
Panel (b): Equal-Weight Portfolio			
	Ind-adjret	Size/BM-adjret	Size/BM/Mom-adjret
Low	0.060 (0.040)	0.051 (0.053)	0.072* (0.040)
Middle	0.008 (0.035)	0.044 (0.030)	0.031 (0.024)
High	-0.071* (0.041)	-0.110** (0.046)	-0.113*** (0.038)
Low-High	0.131** (0.066)	0.161* (0.091)	0.185*** (0.072)

Notes. The portfolio industry-adjusted returns (Ind-adjret) are based on the difference between individual firms' returns and the returns of firms in the same industry (based on Fama-French 48 industry classifications). The portfolio characteristic-adjusted returns are computed by adjusting returns using 25 Size/BM portfolios (Size/BM-adjret, (Fama and French, 1993)) and 125 size/BM/Mom-adjusted returns (Size/BM/Momentum-adjret, (Daniel et al., 1997)).

Table A.22. Return Predictive Power of Technological Obsolescence: Industry-Related Sorting

Panel (a): By-Industry Sorting: Value-Weight Portfolio									
	Exret	3F	4F	4F + RMW + CMA	Q5 (HXZ)	3F ^{INT}	4F ^{INT}	4F ^{INT} + RMW + CMA	
Low	0.834*** (0.246)	0.307*** (0.062)	0.329*** (0.060)	0.282*** (0.061)	0.178** (0.073)	0.310*** (0.070)	0.326*** (0.068)	0.309*** (0.068)	
Middle	0.678*** (0.237)	0.108* (0.062)	0.138*** (0.064)	0.064 (0.061)	-0.054 (0.071)	0.091 (0.066)	0.117* (0.069)	0.083 (0.063)	
High	0.621*** (0.237)	0.043 (0.075)	0.068 (0.081)	-0.087 (0.073)	-0.084 (0.079)	0.008 (0.077)	0.028 (0.085)	-0.062 (0.077)	
Low-High	0.214** (0.102)	0.264*** (0.091)	0.262*** (0.096)	0.368*** (0.095)	0.262*** (0.101)	0.302*** (0.096)	0.298*** (0.102)	0.370*** (0.095)	

Panel (b): By-Industry Sorting: Equal-Weight Portfolio									
	Exret	3F	4F	4F + RMW + CMA	Q5 (HXZ)	3F ^{INT}	4F ^{INT}	4F ^{INT} + RMW + CMA	
Low	0.918*** (0.319)	0.204** (0.093)	0.347*** (0.092)	0.316*** (0.088)	0.285** (0.111)	0.147 (0.091)	0.300*** (0.093)	0.308*** (0.088)	
Middle	0.848*** (0.312)	0.110 (0.097)	0.256*** (0.086)	0.155* (0.079)	0.070 (0.102)	0.025 (0.092)	0.176** (0.086)	0.146* (0.081)	
High	0.829** (0.343)	0.079 (0.111)	0.238** (0.105)	0.195** (0.097)	0.167 (0.120)	0.015 (0.110)	0.185* (0.109)	0.188* (0.099)	
Low-High	0.089 (0.068)	0.124* (0.065)	0.109 (0.067)	0.121* (0.066)	0.118* (0.065)	0.133** (0.067)	0.115* (0.069)	0.120* (0.065)	

Panel (c): Industry-Demean Sorting: Value-Weight Portfolio

	Exret	3F	4F	4F + RMW + CMA	Q5 (HXZ)	3F ^{INT}	4F ^{INT}	4F ^{INT} + RMW + CMA
Low	0.852*** (0.253)	0.341*** (0.067)	0.341*** (0.065)	0.329*** (0.069)	0.245*** (0.079)	0.365*** (0.076)	0.358*** (0.073)	0.360*** (0.075)
Middle	0.678*** (0.234)	0.103* (0.058)	0.134** (0.059)	0.040 (0.057)	-0.078 (0.071)	0.079 (0.062)	0.106* (0.064)	0.058 (0.060)
High	0.639*** (0.241)	0.058 (0.079)	0.103 (0.084)	-0.038 (0.080)	-0.044 (0.086)	0.024 (0.081)	0.065 (0.090)	-0.014 (0.082)
Low-High	0.213* (0.120)	0.283*** (0.098)	0.238** (0.100)	0.368*** (0.109)	0.289** (0.121)	0.341*** (0.105)	0.293*** (0.110)	0.374*** (0.109)

Panel (d): Industry-Demean Sorting: Equal-Weight Portfolio

	Exret	3F	4F	4F + RMW + CMA	Q5 (HXZ)	3F ^{INT}	4F ^{INT}	4F ^{INT} + RMW + CMA
Low	0.917*** (0.322)	0.203** (0.095)	0.344*** (0.093)	0.317*** (0.087)	0.288*** (0.107)	0.150 (0.092)	0.300*** (0.094)	0.310*** (0.087)
Middle	0.849*** (0.307)	0.111 (0.096)	0.254*** (0.087)	0.145* (0.081)	0.062 (0.105)	0.022 (0.091)	0.171** (0.086)	0.135 (0.082)
High	0.831** (0.347)	0.083 (0.113)	0.248** (0.106)	0.213** (0.097)	0.184 (0.121)	0.020 (0.112)	0.197* (0.109)	0.207** (0.098)
Low-High	0.087 (0.074)	0.120* (0.070)	0.096 (0.069)	0.104 (0.071)	0.104 (0.070)	0.130* (0.073)	0.103 (0.072)	0.104 (0.070)

Notes. This table presents monthly portfolio returns (in %) for value-weight and equal-weight portfolios sorted on *Obsolence* within industry in panel (a) and panel (b), respectively; monthly portfolio returns (in %) for value-weight and equal-weight portfolios sorted on *Obsolence* after being demeaned by industry in panel (c) and panel (d), respectively. The definitions of the excess returns of one-month Treasury bill rate and a vast set of risk factors are the same as those in Table 9. Standard errors are reported in parentheses.

Table A.23. Return Predictive Power of Technological Obsolescence: Fama-MacBeth Regressions

	VWLS				OLS			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
<i>Obsolescence</i>	-0.187** (0.079)	-0.216*** (0.058)	-0.196*** (0.053)	-0.121*** (0.035)	-0.070* (0.037)	-0.080** (0.031)	-0.082*** (0.031)	-0.067*** (0.026)
<i>Size</i>		-0.182 (0.121)	-0.159 (0.118)	-0.180* (0.106)		-0.235*** (0.079)	-0.204** (0.081)	-0.204** (0.082)
$\log(BM)$		0.132* (0.076)	0.157** (0.074)	0.132** (0.063)		0.094* (0.050)	0.065 (0.047)	0.078* (0.042)
$Ret(-1, 0)$		-0.376*** (0.094)	-0.405*** (0.090)	-0.444*** (0.079)		-0.532*** (0.060)	-0.552*** (0.062)	-0.611*** (0.064)
$Ret(-12, -2)$		0.100 (0.125)	0.078 (0.120)	0.071 (0.107)		0.026 (0.112)	-0.000 (0.110)	-0.047 (0.104)
Idiosyncratic volatility		-0.510 (0.311)	-0.608** (0.289)	-0.537** (0.266)		-0.446** (0.192)	-0.554*** (0.179)	-0.565*** (0.177)
<i>SUE</i>		-0.021 (0.092)	0.015 (0.090)	0.009 (0.082)		0.054 (0.038)	0.051 (0.037)	0.044 (0.036)
Patents/Assets			0.253* (0.149)	0.106 (0.117)		0.064 (0.064)	0.064 (0.064)	0.029 (0.056)
R&D/Market equity			0.120 (0.100)	0.135 (0.087)			0.227*** (0.062)	0.207*** (0.059)
Innovation originality			-0.023 (0.042)	0.054 (0.039)			0.022 (0.027)	0.023 (0.027)
Citations-based innovative efficiency			0.147 (0.116)	0.105 (0.095)			0.099** (0.039)	0.110*** (0.037)
Patents-based innovative efficiency			-0.113 (0.099)	-0.067 (0.094)			-0.100** (0.041)	-0.098** (0.038)
Industry fixed effect	No	No	No	Yes	No	No	No	Yes
Observations	298,759	289,919	289,919	289,919	298,759	289,919	289,919	289,919
# firms	829	805	805	805	829	805	805	805
R2	0.138	0.251	0.283	0.456	0.003	0.069	0.084	0.148

Notes. This table reports the average slopes (in %) and their [Newey and West \(1987\)](#) autocorrelation-adjusted heteroscedasticity-robust standard errors in parentheses from monthly [Fama and MacBeth \(1973\)](#) cross-sectional regressions. For each month from July of year t to June of year $t + 1$, we regress monthly returns of individual stocks on *Obsolescence* of year $t - 1$, different sets of control variables, and industry fixed effects. We omit the intercept, the slopes on the 48 industry dummies, and the slopes on the missing dummy and its interactions with all other control variables for brevity. All variables are defined in the Appendix. *Obsolescence* measures are defined in equation (1). *Size* is the natural logarithm of market capitalization at the end of year $t - 1$. $\log(BM)$ is the natural logarithm of book value of the common equity scaled by market value of common equity at the end of year $t - 1$. $\log(-1, 0)$ is the monthly returns in the prior month. $Ret(-12, -2)$ is the previous eleven-month returns (with a one-month gap between the holding period and the current month). SUE is the unexpected quarterly earnings scaled by fiscal-quarter-end market capitalization, where unexpected earnings is $I/B/E/S$ actual earnings minus median forecasted earnings if available; otherwise it is the seasonally differenced quarterly earnings before extraordinary items from the Compustat quarterly file. *Patents/Assets* is the number of patents granted to that firm in year $t - 1$ scaled by the firm's book assets at the end of year $t - 1$. *R&D/Market Equity* is the R&D expenses in fiscal year ending in year $t - 1$ scaled by market capitalization at the end of year $t - 1$. *Innovation Originality* is the innovation originality measure defined in [Hirshleifer, Hsu, and Li \(2018\)](#) in year $t - 1$. *Citations-based* and *Patents-based Innovative Efficiency* are the natural logarithms of one plus the citations-based and patents-based innovative efficiency measures in year $t - 1$, defined in [Hirshleifer, Hsu, and Li \(2013\)](#). All independent variables are normalized to zero mean and one standard deviation after winsorization at the 1% and 99% levels. The return data are from July of 1986 to June of 2016. *R-squared* (number of firms) is the time-series average of the *R-squared* (number of firms) from the monthly cross-sectional regressions.

Table A.24. Return Predictive Power of Technological Obsolescence: Value Weight Portfolios' Factor Loadings

Panel (a): Four-Factor + RMW + CMA Loadings

	MKT	SMB	HML	UMD	RMW	CMA
Low	0.958*** (0.021)	-0.048 (0.040)	-0.289*** (0.042)	0.011 (0.024)	-0.002 (0.054)	-0.119* (0.062)
Middle	1.009*** (0.022)	-0.099*** (0.029)	-0.195*** (0.032)	-0.073*** (0.025)	0.121*** (0.033)	0.231*** (0.066)
High	1.018*** (0.024)	-0.001 (0.047)	-0.121*** (0.041)	-0.107*** (0.030)	0.151*** (0.051)	0.540*** (0.065)
Low-High	-0.059* (0.034)	-0.047 (0.063)	-0.167** (0.067)	0.118*** (0.045)	-0.153** (0.061)	-0.659*** (0.099)

Panel (b): q -Factor Loadings

	MKT	SMB	Investment factor	ROE factor	Expected growth factor
Low	0.979*** (0.025)	-0.054 (0.040)	-0.468*** (0.067)	-0.069 (0.056)	0.254*** (0.065)
Middle	1.026*** (0.022)	-0.113*** (0.027)	0.005 (0.063)	-0.032 (0.037)	0.244*** (0.045)
High	1.013*** (0.024)	-0.036 (0.051)	0.405*** (0.074)	-0.031 (0.050)	0.104 (0.076)
Low-High	-0.034 (0.031)	-0.018 (0.080)	-0.873*** (0.122)	-0.039 (0.074)	0.150 (0.110)

Panel (c): Intangible Asset-Adjusted Four-Factor Loadings

	MKT	SMB	HML ^{INT}	UMD
Low	0.997*** (0.025)	0.006 (0.032)	-0.287*** (0.031)	0.015 (0.031)
Middle	0.979*** (0.030)	-0.116*** (0.022)	0.005 (0.032)	-0.045* (0.027)
High	0.935*** (0.030)	-0.053 (0.039)	0.197*** (0.059)	-0.068* (0.040)
Low-High	0.062 (0.039)	0.059 (0.058)	-0.484*** (0.073)	0.083 (0.063)

Panel (d): Intangible Asset-Adjusted Four-Factor + RMW + CMA Loadings

	MKT	SMB	HML ^{INT}	UMD	RMW	CMA
Low	0.968*** (0.026)	0.006 (0.043)	-0.189*** (0.041)	0.023 (0.027)	0.019 (0.057)	-0.234*** (0.064)
Middle	1.010*** (0.023)	-0.068** (0.032)	-0.092* (0.054)	-0.060** (0.029)	0.118*** (0.037)	0.125 (0.084)
High	1.021*** (0.025)	0.021 (0.046)	-0.076 (0.051)	-0.101*** (0.033)	0.158*** (0.058)	0.489*** (0.076)
Low-High	-0.053 (0.035)	-0.015 (0.062)	-0.113* (0.068)	0.125*** (0.048)	-0.139** (0.071)	-0.723*** (0.109)

Notes. This table provides factor loadings of the value-weighted *Obsolence*-sorted portfolio returns on the Fama-French Four Factors + RMW + CMA (robust-minus-weak, conservative-minus-aggressive) (Fama and French, 1992; Carhart, 1997) in panel (a); the factor loadings of the portfolio on the q -factors in Hou, Xue, and Zhang (2015) in panel (b); the factor loadings of the portfolio on the Fama-French Four Factors after replacing the value factor with the intangible-adjusted value factor (Eisfeldt, Kim, and Papanikolaou, 2020) in panel (c); and the factor loadings of the portfolio on the Fama-French Four Factors + RMW + CMA after replacing the value factor with the intangible-adjusted value factor (Eisfeldt, Kim, and Papanikolaou, 2020) in panel (d).