R&D Uncertainty and Cycles [PRELIMINARY; DO NOT CITE]

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I. Introduction

Investment in equipment and structures is one of the most cyclical components of GDP. We show that in contrast, investment in R&D relative to GDP is either stable or rising in most post-WW2 recessions.

Building on work on uncertainty over the business cycle (Bernanke, 1983; Bloom, 2009), we explore why different types of investment respond differently to uncertainty. The literature emphasizes that when uncertainty rises, as it tends to in recessions, firms delay investment: with costly reversibility, there is value in waiting for conditions to improve.

This logic rests on a key assumption: information about the project arrives even if the firm does not invest. This is a good description of investment in equipment and structures: changes in material, labor, or financial costs are central to project value, and evolve independently of the firm's decision to invest. For R&D, on the other hand, the project's value only becomes known through the process of investing itself. A pharmaceutical company doesn't know whether a drug candidate will clear trials until it actually runs trials. Waiting provides no information about efficacy; only spending on R&D and running the process resolves the question.[1]

We use the model of Pindyck (1993) to demonstrate that, when investment reveals project value, uncertainty can cause investment to rise, not fall. Higher uncertainty raises the value of the option to abandon the project, as in models of delay. But when information arrives only through investment, firms have an incentive to invest sooner, rather than later. Investing in more states generates more information, thus increasing the value of the abandonment option. If the trials fail, the drug project can be abandoned; if they succeed, investment continues.[2] This "resolution" effect provides a countervailing force to the "delay" effect of uncertainty on investment — which can help explain why investment of R&D intensive firms is less cyclical.

Barlévy (2007) notes that R&D is only modestly procyclical, attributing this to procyclical opportunity costs. Our mechanism is different: higher uncertainty directly raises the benefit of investing. Bloom (2007) shows that R&D is more persistent than other investment and falls with a lag during recessions. He attributes this to adjustment costs, which generate an inaction region that widens with uncertainty. Our mechanism is independent of adjustment costs. Pastor and Veronesi (2009) emphasize that technological uncertainty is distinct from systematic risk, and that technological revolutions can generate systemic bubbles. This is consistent with the view we propose, which is that R&D uncertainty interacts with investment differently than uncertainty about physical capital.

II. The low cyclical sensitivity of R&D investment in the data

The 2020 recession featured a combination of declining investment in equipment and structures but steady investment in R&D. One might intuitively attribute this to the peculiar business environment associated with the COVID era, during which the pharmaceutical industry under-

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[1] These are both real options effects, reflecting different cases of reversibility and expandability as in Abel et al. (1996) and other work including irreversibility or R & D and uncertainty, Dixit and Pindyck (1994)

[2] Investment in these models is finite, otherwise the firm jumps to the optimal immediately.

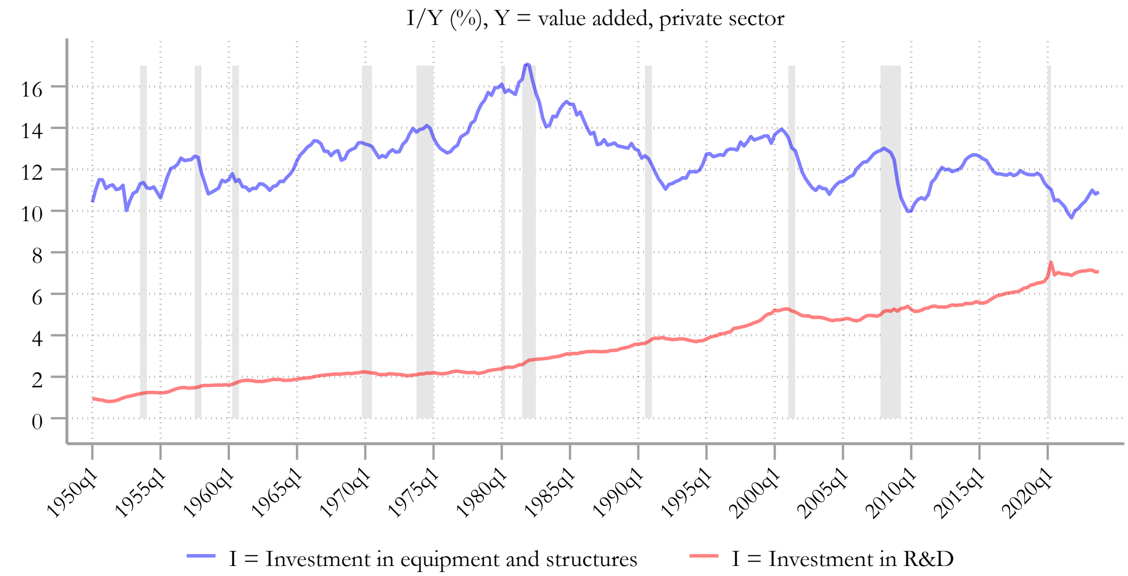

FIGURE 1. INVESTMENT AND R&D TO VALUE ADDED RATIOS.

Note: This graph shows quarterly investment in equipment and structures (blue line) and in R&D (red line) divided by quarterly value added. The sample is 1950q1-2024q4. The data are from the National Product and Income Accounts and covers all non-residential fixed investment by non-government entities. See Appendix for results restricted to the non-financial corporate business sector.

took large research projects to address the health emergency, and other businesses undertook adaptive investments to cope with remote work and distanced interaction.

But the data suggest that the stability of R&D investment through recessions and expansions is a hallmark of most post-WW2 business cycles. Figure 1 shows the ratio of non-residential fixed investment to total value added, at the quarterly frequency, since 1950q1, for the private sector.[3] The figure separates investment in equipment and structures (blue line) from investment in R&D (red line). As is well known, investment in traditional physical assets exhibits a high degree of cyclical sensitivity, generally leading recessions and substantially declining through them, before rising early on during expansions. On the other hand, the investment to value added ratio for R&D has been steadily trending upward since 1950, from approximately 1% of value added to about 7% today. Most strikingly, it does not decline notably during recessions, and in fact increases during some, like the 1982, 1990, 2008 and 2020 recessions.[4]

The fact that the ratio I/Y for R&D is steady or rising during recessions only indicates that R&D dampens overall movements in value added (while investment in equipment and structures amplifies it), not necessarily that R&D investment is a-cyclical or counter-cyclical. Table 1 examines this question by reporting two measures of cyclical sensitivity for different types of investment. In both panels, cyclical sensitivity is measured as the correlation of an investment measure with the Hodrick-Prescott (HP) filtered cyclical component of real value added. In Panel A, the investment measure is the log of investment (deflated and HP filtered). The robust finding is that while R&D is pro-cyclical, its cycli-

[3]This excludes investment by the government, but includes investment by non-profit private entities, such as universities. The figure however looks similar if attention is restricted, within the private sector, to non-financial corporate businesses, which account for about 75% of all non-residential fixed private sector investment; see online appendix for details.

[4]The most notable deviation from trend in R&D to value added occurred in the run-up to the dotcom bubble.

Panel A: Cyclical sensitivity of $\log(I/P)$, P = GDP deflator

	Private sector		NFCB sector		Compustat
	Quarterly	Annual	Quarterly	Annual	Annual
Total investment	0.74	0.78	0.72	0.78	0.66
	(<0.01)	*(<0.01)*	*(<0.01)*	*(<0.01)*	*(<0.01)*
Equipment & structures	0.73	0.77	0.73	0.78	0.68
	(<0.01)	*(<0.01)*	*(<0.01)*	*(<0.01)*	*(<0.01)*
R&D	0.45	0.35	0.26	0.44	0.44
	(<0.01)	*(<0.01)*	*(<0.01)*	*(<0.01)*	*(<0.01)*
p-value for difference in cyclical sensitivity	<0.01	<0.01	<0.01	<0.01	0.01
# obs	289	74	289	74	49

Panel B: Cyclical sensitivity of I/K

	Private sector		NFCB sector		Compustat
	Quarterly	Annual	Quarterly	Annual	Annual
Total investment	0.38	0.46	0.26	0.46	0.46
	(<0.01)	*(<0.01)*	*(<0.01)*	*(<0.01)*	*(<0.01)*
Equipment & structures	0.38	0.42	0.28	0.46	0.37
	(<0.01)	*(<0.01)*	*(<0.01)*	*(<0.01)*	*(0.01)*
R&D	0.09	0.13	0.14	0.28	0.26
	(0.12)	*(0.25)*	*(0.01)*	*(0.02)*	*(0.07)*
p-value for difference in cyclical sensitivity	<0.01	0.08	<0.01	0.02	0.26
# obs	289	74	289	74	49

Table 1—Measures of cyclical sensitivity.

Note: In Panel A, cyclical sensitivity is defined as the correlation between the HP-filtered component of the log of investment deflated by the GDP deflator, and the HP-filtered component of a measure of value added deflated by the GDP deflator for the corresponding sector. In Panel B, cyclical sensitivity is defined as the correlation between the I/K ratio and the HP-filtered component of a measure of value added for the corresponding sector. For Compustat, the measure of value added is NFCB sector value added. For quarterly time series the smoothing parameter is 1600; for annual time series the smoothing parameter is 6.25. Numbers in parentheses are p-values for statistical significance of the correlation. The test at the bottom of each panel reports the p-value for the null that physical investment has a lower cyclical sensitivity than R&D, $\text{corr}(I_{\text{Physical}}, \text{GDP}) \leq \text{corr}(I_{\text{RD}}, \text{GDP})$.

cal sensitivity is substantially lower than that of traditional investment, with its correlation ranging from one-third to one-half of the correlation of traditional investment with detrended GDP. This holds both in the private sector as a whole, within non-financial corporate businesses, and within the narrower set of publicly traded firms.[5] Panel B repeats this analysis using the ratio of investment to the stock of existing assets; this ratio is somewhat less cyclically sensitive overall, but the gap between R&D and traditional investment is even starker.[6] At most levels of aggregation and data frequencies reported in Table 1, we can reject the null that investment in R&D is more correlated with detrended GDP than investment in physical assets.

Thus, *aggregate* R&D seems to be substantially less cyclical than normal capital expenditures involving equipment and structures. Does this reflect a lower cyclical sensitivity of R&D *within firm*, or a systematic reallocation of R&D across firms during

[5] We use Compustat as our source for measuring aggregate investment of the latter group, and exclude non-financials and utilities. The resulting group of public firms accounts for about 45% of investment of the private sector and 60% of investment of all non-financial corporate businesses.

[6] In some cases, we cannot reject the null that the correlation of I/K with contemporaneous detrended GDP is zero for R&D investment.

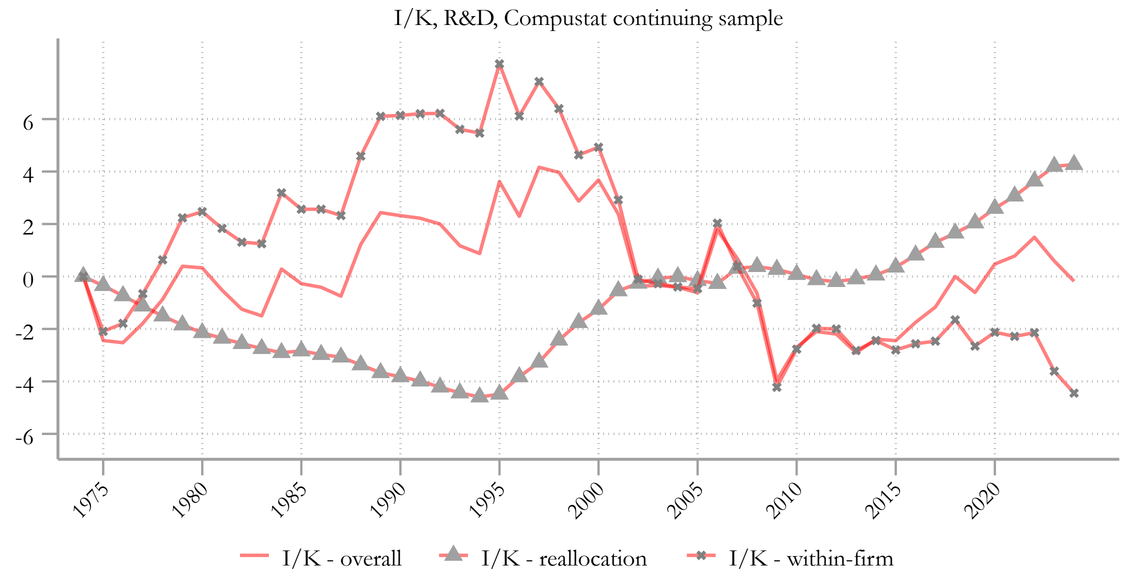

FIGURE 2. WITHIN-FIRM AND REALLOCATION COMPONENTS OF R&D INVESTMENT.

Note: This graph decomposes changes in the aggregate ratio of R&D investment to the stock of R&D capital in the sample of continuing Compustat firms into a within-firm component, which reflects changes in investment rates keeping the distribution of R&D capital across firms constant, and a reallocation component. The underlying sample are all US publicly traded non-financial firms. Details of the decomposition are reported in Appendix.

recessions, with some interrupting spending while others pick it up? Figure 2 reports a decomposition of the aggregate I/K ratio among continuing public firms into a within and a between-firm component.[7] The figure indicates that the cyclical variation in R&D is largely due to within-firm variation, while cross firm reallocation has tended to move slowly with little cyclical sensitivity. Theories attempting to account for the low cyclical sensitivity of R&D investment should therefore focus on within-firm mechanisms, as opposed to mechanisms involving reallocation of R&D activity across firms.

[7]For this decomposition we first compute the change in the aggregate investment rate, $\Delta \frac{I_t}{K_t}$ among firms present in the sample at both $t-1$ and t, and then express this change as the sum of a within-firm component and a reallocation component. We then compute their cumulative sum, normalizing them to 0 in 1974, the year our sample starts, and remove a linear time trend from each component before plotting. The details of the decomposition and statistics of the decomposed data are reported in the online appendix, where we also apply it to physical investment and find similar results.

III. A theoretical explanation

1. Description

We use the model of Pindyck (1993) as the underlying structure. Consider a firm with an irreversible project with known future payoff V. The project requires the firm to invest in order to reduce remaining completion costs, which we denote by C_t. The project's payoff is realized once the remaining completion costs reach zero, that is, at date:

$$T = \inf_{s \geq t} \{ \, s \text{ s.t. } C_s \leq 0 \, | \, C_t \, \} . \tag{1}$$

The firm can invest in the project with intensity $I_t \in \left[0, \bar{I}\right]$ per unit of time. Investment is irreversible but the project can be paused by setting $I_t = 0$ at any time. The firm is risk-neutral and discounts the project's cashflows at rate $r > 0$.

With no uncertainty, given remaining completion costs C_t, the completion time at the maximum investment intensity is $T = t + C_t/\bar{I}$. The firm invests if the present discounted value of the project exceeds the present value of the cost of investing $\bar{I}$ per period for $T-t$ periods. The project is undertaken if this value is positive, or equivalently if C_t is low enough.[8]

We focus on the case where expected completion costs are stochastic and follow:
(2)
$$dC_t = -I_t dt + \sigma\left(\beta\sqrt{I_t C_t}dz_t + (1-\beta)C_t dw_t\right)$$

Here, $\sigma > 0$, $\beta \in [0,1]$, and z_t and w_t are independent Wiener processes. Investment I_t reduces the expected cost of the project, subject to two random shocks. The shocks dz_t capture cost uncertainty that is revealed through investment, in the sense that if the firm is not investing at all ($I_t = 0$), these shocks will not affect (positively or negatively) the remaining costs to completion. We associate this investment with R&D spending, with the idea that for R&D projects, investing reveals how costly the project will ultimately be. Research, development, and experimentation can reveal or generate more efficient projects, but the outcome is still stochastic — R&D outcomes are not known in advance. On the other hand, the shocks dw_t capture cost uncertainty that is unaffected by the investment process. We refer to it as "external" risk and associate it with traditional investment in equipment and structures, for which costs to completion are well understood and primarily fluctuate because of changes in input or labor costs.[9] Finally, the parameter β captures how exposed the firm is to each type of risk: when $\beta = 1$, the project only features investment outcome (or R&D-like) risk, while when $\beta = 0$ the project only features "external" (or capex-like) risk. In what follows we will refer to β as the R&D intensity of the project.

[8]See the online appendix for the analytical solution in the case of no uncertainty.

[9]Pindyck (1993) suggests these two shocks are idiosyncratic and systematic, respectively, which is similar in spirit to the approach in Pastor and Veronesi (2009). In our interpretation, the z process represents shocks to investment outcomes. For example, even though wages could be exogenous to the firm, the firm can choose labor allocations and conduct research to automate and reduce the wage cost impact. On the other hand, the process w_t captures shocks for which the firm has no response, such as exogenous input cost shocks.

Given current expected cost to completion C_t, the firm chooses its investment policy according to:

$$F(C_t) = \max_{\{I_s\}_{s\geq t}} \mathbf{E}_t\left[e^{-r(T-t)}V - \int_t^T e^{-r(s-t)} I_s ds\right]$$

subject to (1), (2) and $I_s \in \left[0, \bar{I}\right]$ for all $s \geq t$. The online appendix describes the recursive formulation of the problem and characterizes the optimal policy. This policy is simple: there exists a threshold for cost to completion, C^* such that

$$(3)\quad I_t^* = \begin{cases} 0 & \text{if} \quad C_t \geq C^* \quad \text{(pause)} \\ \bar{I} & \text{if} \quad C_t < C^* \quad \text{(invest)} \end{cases},$$

where the threshold C^* satisfies the smooth-pasting condition:

$$(4)\qquad 1 = -F_C(C^*) + \frac{1}{2}\sigma^2\beta^2 F_{CC}(C^*).$$

The left-hand side represents the flow cost of investment, and the right-hand side represents the flow benefits. Independent of the source of uncertainty (i.e. the value of β), investment reduces cost to completion — the term $-F_C(C^*)$. Crucially, though, whenever the project involves *some* R&D-like uncertainty ($\beta > 0$), there is an additional benefit: by investing in the project, the firm reveals information about its true value. This is increasing in volatility σ because the firm can pause investment if costs turn out to be too large, while it can continue investing if costs turn out to be low.

2. Special cases: $\beta = 0$ and $\beta = 1$

When $\beta = 0$, the project only features "external" uncertainty; we interpret this as low R&D intensity. While there is no analytical solution, numerical analysis indicates that $\partial C^*/\partial\sigma < 0$: as uncertainty increases, only projects closer to completion (with low costs) remain active. This version has only a traditional "delay" mechanism. Uncertainty is resolved independently of whether the firm invests, so it is worth waiting for costs to potentially fall

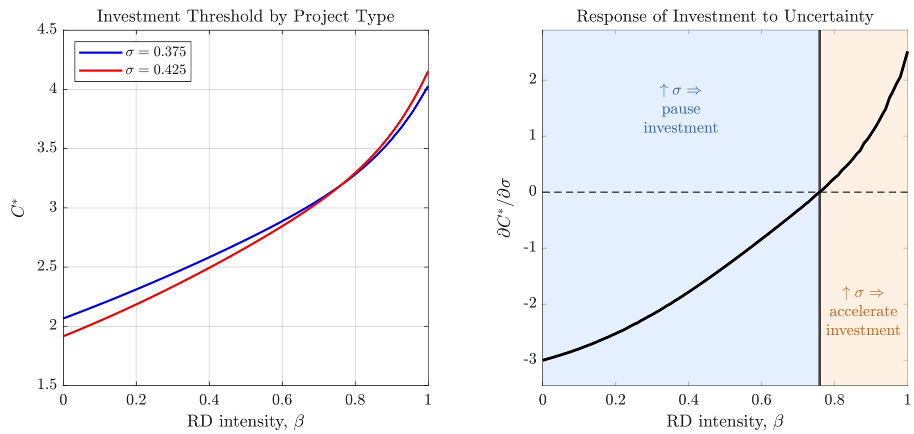

FIGURE 3. THE EFFECTS OF GREATER UNCERTAINTY ON INVESTMENT.

Note: The left panel plots the investment threshold C^* against R&D intensity β for two volatility levels ($\sigma = 0.375$ and $\sigma = 0.425$). Firms invest when cost-to-completion C falls below C^*; a higher C^* means more projects are initiated. The right panel shows $\partial C^*/\partial\sigma$, the sensitivity of the threshold to uncertainty, computed numerically using centered differences around a baseline value of $\sigma = 0.40$. In the blue region ($\beta < \beta^*$), higher uncertainty lowers C^*, causing firms to pause investment. In the orange region ($\beta > \beta^*$), higher uncertainty raises C^*, causing firms to accelerate investment. In the right panel, the vertical line marks where the degree of R&D intensity at which the two effects exactly offset. Parameter values are $V = 10$, $\bar{I} = 0.1$, and $r = 0.05$.

exogenously.[10]

When $\beta = 1$, the project only features uncertainty resolved or revealed by investment. When there is no discounting, $r = 0$, it can be shown that the optimal threshold is:

$$C^* = \left(1 + \frac{1}{2}\sigma^2\right)V. \tag{5}$$

This threshold *increases* with uncertainty. To see why note that when $\beta = 1$, costs evolve as:

$$dC_t = -I_t dt + \sigma\sqrt{I_t C_t} dz_t. \tag{6}$$

In particular, if the firm pauses investment, $I_t = 0$, costs remain frozen. There is no incentive to pause and wait for the costs to improve, as in the $\beta = 0$ case. Remaining costs only change when the firm invests. Moreover, if costs turn out to be too high, the project can be stopped, which is an absorbing state.[11]

[10]In the case where $r = 0$ and $\beta = 0$, the firm never invests, instead waiting for costs to fall to zero alone.

[11]In both the $\beta = 0$ and $\beta = 1$ case, greater uncertainty increases the value of the abandonment option that the firms has. In the $\beta = 0$ case, information arrives even when the firm pauses investment; so greater uncertainty increases the incentive to pause. In the $\beta = 1$ case, information arrives *only* when the firm invests; so greater uncertainty increases the incentive to invest. The difference between the two cases is whether the firm must pay (invest) to generate the information that makes the option valuable.

3. GENERAL CASE: $\beta \in [0, 1]$

When both types of uncertainty are present, the firm may invest and in doing so reveal information about the cost of the project, or it can pause investment and let exogenous shocks drive expected costs.

Figure 3 illustrates how the response of investment to uncertainty depends on the nature of the project. The parameter β indexes R&D intensity: projects with β close to zero resemble traditional physical capital investment, where cost uncertainty is largely external to the firm's actions, while projects with β close to one resemble R&D, where uncertainty is resolved primarily through the investing itself. Two competing effects govern how investment responds to an increase in uncertainty σ. The *delay effect*, dominant for low-β projects, implies that higher uncertainty raises the value of waiting, since costs may fall on their own, leading firms to delay investment. The *resolution effect*, dominant for high-β projects, works through a different channel: when uncertainty is technical, investing (research, development) generates valuable information about the ultimate project cost. Although investing does expose the firm to volatility, this volatility is informative. Combined with the option to abandon, the firm captures favorable cost realizations while exiting when costs rise. Higher uncertainty amplifies this value, making early investment more attractive.

The left panel of Figure 3 plots the investment threshold C^* as a function of R&D intensity for two levels of volatility. A higher threshold means more projects are initiated, since firms are willing to begin projects with higher remaining costs. For low values of β, the threshold is lower when volatility is high (red below blue), indicating that uncertainty discourages investment. For high values of β, this relationship reverses: the threshold is higher when volatility is high (red above blue), indicating that uncertainty encourages investment. The right panel quantifies this pattern by plotting $\partial C^*/\partial\sigma$, the sensitivity of the threshold to uncertainty. The blue-shaded region corresponds to project types for which an increase in uncertainty causes firms to pause investment, while the orange-shaded region corresponds to project types for which an increase in uncertainty causes firms to accelerate investment.

The two effects exactly offset at a critical R&D intensity β^*, where $\partial C^*/\partial\sigma = 0$. For firms or industries with R&D intensity below this threshold, investment behaves conventionally: uncertainty depresses investment through the familiar delay channel. For firms or industries above this threshold, investment behaves differently: uncertainty stimulates investment through the resolution channel. This result offers one explanation for the relatively low cyclicality of R&D investment. Since uncertainty tends to rise during recessions, the delay effect predicts that investment should fall. Traditional capital expenditure, concentrated in the blue region, follows this pattern. R&D investment, concentrated in the orange region, faces a countervailing force: the resolution effect pushes toward more investment precisely when uncertainty is high. Even if R&D does not increase during downturns, the resolution effect provides a stabilizing force that tends to offset the delay effect, resulting in a more muted response to the business cycle than would otherwise obtain.

REFERENCES

Abel, Andrew, Avinash Dixit, Janice Eberly, and Robert Pindyck. 1996. "Options, the Value of Capital, and Investment." *Quarterly Journal of Economics*, 111(3): 753–777.

Barlévy, Gadi. 2007. "On the Cyclicality of Research and Development." *American Economic Review*, 97(4): 1131–1164.

Bernanke, Ben S. 1983. "Irreversibility, Uncertainty, and Cyclical Investment." *The Quarterly Journal of Economics*, 98(1): 85–106.

Bloom, Nicholas. 2009. "The Impact of Uncertainty Shocks." *Econometrica*, 77(3): 623–685.

Bloom, Nick. 2007. "Uncertainty and the Dynamics of R&D." *American Economic Review*, 97(2): 250–255.

Dixit, Avinash, and Robert Pindyck. 1994. *Investment under Uncertainty.* Princeton University Press.

Pastor, Lubos, and Pietro Veronesi. 2009. "Technological Revolutions and Stock Prices." *American Economic Review*, 99(4): 1451–83.

Pindyck, Robert S. 1993. "Investments of uncertain cost." *Journal of Financial Economics*, 34(1): 53–76.