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Explaining the Broken Link Between R&D and GDP Growth

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Abstract: *While the link between R&D and economic growth is largely taken for granted, recent evidence suggests the link has been broken. US GDP growth tracked R&D through its rise in the 1950s and decline in the 1970s, but never responded when R&D spending recovered in the 1980s. I examine why. I show first that the GDP growth decline coincides with R&D productivity decline. I then examine why R&D productivity itself declined. Case study evidence as well as econometric tests indicate that interest rate spikes in the early eighties led to divestment of R&D resources. Thereafter adjustment costs for additional capital and scientific labor favored outsourcing. What firms failed to realize however is that outsourced R&D has zero returns (which I also show). Thus a key culprit in the broken link between R&D and GDP growth appears to be outsourced R&D.*

One Sentence Summary: *The broken link between R&D and GDP growth appears to be explained at least in part by the increased prevalence and lower productivity of outsourced R&D.*

In January 2011, President Obama signed into law the "America COMPETES Reauthorization Act of 2010". The goal of the act was to invest in innovation through research and development and to thereby improve the competitiveness of the United States. This act reflects the long-held belief that innovation drives economic growth ([1]). However coarse comparison between R&D spending and economic growth indicates that while this was true through most of the space race (nominal GDP growth lagged R&D intensity by about fifteen years), in the early 1980s the two diverged (Figure 1a). Firms' R&D spending recovered, but GDP growth never followed. I examine why.

[Insert Figure 1 Here]

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The wedge for doing so is the observation that the decline in GDP growth coincides with a decline in firms' R&D productivity, measured as RQ (Figure 1b). RQ (short for research quotient) is the firm-specific output elasticity of R&D in the firm's production function ([2]). Indeed mean RQ for US traded firms explains 54% of the variance in nominal GDP growth.

To understand what triggered the decline in R&D spending, and how its effects may have propogated to produce permanent changes in firm behavior and productivity, I begin by comparing the relevant trends: macro-economics (interest rates), R&D spending (R&D/sales), R&D resources (scientists)[3] and R&D strategy (outsourcing).

[Insert Figure 2 Here]

Figure 2 suggests a sequence of contemporaneously rational, but partially irreversible decisions may have collectively degraded firm R&D productivity: a) high discount rates in the early 1980s reduced R&D spending; b) the reduction in R&D triggered divestment of now-surplus resources (scientists); c) when R&D spending resumed, adjustments costs for new scientists drove firms toward outsourcing, d) outsourcing has lower productivity.

To illuminate how R&D spending cuts might trigger this dominoing, we turn to a case study. The case follows Hughes Research Laboratories (HRL) ([4]). HRL was the central lab for Hughes Aircraft Company, the defense electronics firm founded by Howard Hughes in 1953, which grew to become a $15 Billion company known to "tackle complex and long-term problems shunned by competitors" ([5]).

Because Hughes was a private company that relied on internal funding until its acquisition by General Motors in 1985, it was insulated from the interest rate shock. However it was later subject to an industry specific shock of even greater magnitude—the defense downturn following the end of the Cold War. In 1989, the associated budget cuts forced HRL to reduce its workforce to 400 from a peak of 560 two years earlier. While the workforce ultimately rebounded to 430 in 1993, this was still 23% below the peak--thus consistent with the domino hypothesis that reduced resource levels became semi-permanent features of firms' R&D strategies.

Concurrent with the workforce reductions, HRL implemented a plan to give each division a $1 million budget to "direct" research at HRL. Previously, divisions contributed to HRL through their overhead, but had no say in how those funds were expended. Following the plan's implementation, divisions directed 20% of HRL funding. This shifted HRL's portfolio toward applied research. HRL Director, Dr. Arthur Chester felt one solution to the loss of basic research capability was outsourcing—taking greater advantage of the research capability at universities. In fact, the outsourcing solution was consistent with new CEO, Michael Armstrong's goal of bringing in more outside technology.

While we don't observe what happens after the case, a number of HRL's scientists were concerned the shift toward outsourcing was irreversible: 1) after a time of not doing basic research, existing researchers would have lost touch, 2) new scientists capable of basic research would no longer be attracted to HRL, and 3) there would no longer be seeds for future projects.

Thus the HRL case is roughly consistent with the domino hypothesis, and provides some insight into its mechanics. First, R&D budget cuts forced a permanent reduction in lab personnel as well as a shift toward more applied research. With insufficient personnel to conduct basic research, HRL began outsourcing to universities.

I examine the extent to which dominoing occurred across the economy using data from the National Science Foundation Survey of Industrial Research and Development (SIRD) from 1973 to 2005. The SIRD is an annual survey of firms conducting R&D in the US. Since historically 69% to 75% of US R&D is performed by firms ([6]), this comprises the majority of US R&D activity. The SIRD is gathered from a sample intended to represent all for-profit R&D-performing companies, either publicly or privately held. ([7]) Summary statistics are reported in Table **S1**.

<u>Step 1: The macroeconomic trigger.</u> While the trigger in the HRL case was the coldwar downturn, a more likely trigger for remaining firms was interest rate spikes. Interest rates affect R&D through their impact on the net present value (NPV)[8] of projects. NPV is an investment decision tool used to capture the value in today's dollars for a stream of investments and returns that are spread out over time. Since the NPV of each project decreases with the firm's cost of capital, when interest rates rise, fewer projects have positive NPV. Accordingly, the total number of projects (and thus the total R&D budget) will decrease.

To test the hypothesis that interest rates decrease R&D investment, I modeled firm R&D for firm i in year t, $lnRD_{it}$, as a function of mean annual interest rate, δ_t. I controlled for firm revenues, $ln(Revenue)_{it}$, to capture the stylized fact that R&D increases with firm size ([9]) and estimated the model using firm fixed effects, α_i. The main result is as expected. The coefficient of -0.007 implies that a percentage point increase in the interest rate decreases R&D 0.007%. Results for size are also as expected—a one percent increase in revenues increases R&D 0.5%.

$$lnRD_{it} = \alpha_i + -0.007\,\delta t + 0.486 * ln(Revenue)_{it} + \varepsilon_{it}$$
$$\quad (0.001) \qquad (0.016)$$

Step 2: Labor (scientists) exhibit muted response to changes in demand. If it were costless to hire and layoff scientists, the number of scientists would fluctuate with interest rates. However, we know that's not the case. It's expensive to hire scientists, not just because of human resource (HR) department costs, but also because new employees have low productivity until they become accustomed to their job. Further it is expensive to layoff scientists because of severance packages and/or subsequent termination lawsuits. We call these costs of changing levels of investment, "adjustment costs". Because firms incur these adjustment costs, they are reluctant to hire or layoff scientists unless the new levels of R&D appear permanent. In essence these adjustment costs create a "zone of inaction" in the response to changes in demand.([10]) Accordingly, we should see the number of scientists grow and decline at a slower rate than demand. Further because hiring costs differ from termination costs, we should see hysteresis--response to growing demand differs from declining demand.

To test this, I examine the set of firms with greater than ten firm-year observations.[11] I model growth in scientific labor as a function of changes in demand (revenue), while controlling for year effects, $year_t$ and firm fixed effects, α_i. I decompose demand changes into growth versus decline, where $(demand\ growth)_{it} = (revenue_{it}/revenue_{it-1}) - 1$ *if* $revenue_{it} > revenue_{it-1}$, *and* $(demand\ decline)_{it} = 1-(revenue_{it}/revenue_{it-1})$ *if* $revenue_{it} < revenue_{it-1}$.

Results (Table 1-models 1 and 2) are as expected. First, labor is highly persistent. The intercept in both the growth and decline specifications is 1.02, meaning that on average firms increase the number of scientists 2.5% per year. Firms tend not to respond to growing demand beyond that. The coefficient on demand growth is essentially zero (0.028 and not significant). Firms do however respond to declining demand. While still muted, the coefficient (-0.247) is ten times that for growth (and significant).

[Insert Table 2 Here]

Step 3: Outsourcing is a flexible substitute for labor. Firms can either tolerate the labor shortfalls when demand is growing (thereby reducing total R&D investment), or compensate for the shortfalls via outsourcing. What distinguishes outsourcing from labor is lower adjustment costs. Firms sub-contract for short periods and have no further obligation when those periods end. Given these lower adjustment costs outsourcing should be more responsive than labor to changes in demand.

Results (Table 2-models 3 and 4) are consistent with that. Firms increase outsourcing at ten times the rate they increase labor -- the coefficient on outsourcing, while not significant, is 0.268 versus 0.028 for labor. In contrast, outsourcing is not responsive to declining demand. The coefficient is essentially zero (0.055 and not significant). Also noteworthy is that the intercepts indicate outsourcing is growing in the absence of changes to demand. The implied rate is 70% when demand is growing, but it is 14.5% even when demand is declining. The combined effects of the intercepts and the response rates of the two inputs (labor and outsourcing) are depicted graphically in Figure 3.

[Insert Figure 3 Here]

Step 4. Outsourcing has lower productivity. The shift from internal R&D to outsourced R&D is only relevant to the decline in GDP growth if the productivity of internal and outsourced R&D differ. To test the impact of R&D sourcing strategy, I decompose the locus of R&D into its three constituents (internal, outsourced, and foreign), then combine them with other inputs in the firm's production function. Using the production function follows the most common approach to measuring returns to R&D.([12]) I then estimate the contribution of each form of R&D to revenues using random coefficients (RC) estimation ([13]).

$$
\begin{aligned}
Ln(Revenues)_{it} = \underset{(0.047)}{4.721} + \underset{(0.006)}{0.794}\, ln(employees)_{it} + \underset{(0.004)}{0.170}\, ln(R\&D_{internal})_{it} - \underset{(0.002)}{0.007}\, ln(R\&D_{outsource})_{it} \\
+ \underset{(0.002)}{0.014}\, ln(R\&D_{foreign})_{it} + \underset{(0.001)}{0.011}\, ln(spillovers)_{it} + \varepsilon_{it}
\end{aligned}
$$

Results indicate the elasticity of internal R&D is 0.17, whereas the elasticity of outsourced R&D is essentially zero (-0.007) —This means a 10% increase in internal R&D increases revenues 1.7%, whereas a 10% increase in outsourced R&D has no impact on revenues. Thus outsourcing is essentially unproductive for the funding firm.

The result is provocative, so it raises the question of whether the effect is real or merely an artifact of who outsources or what gets outsourced. To investigat whether firm quality is driving the outsourcing result, I employed a two-stage treatment model **[S2]**, where the first stage models the choice to outsource, and the second stage models the impact of that choice on internal R&D productivity.([14]) If who outsources drives the lower productivity of outsourcing, the coefficient for that decision should be significant in the second stage. It's not. This implies that outsourcing firms essentially have the same internal R&D productivity as non-outsourcing firms. As an additional check, I repeated the test and looked instead at the productivity of total R&D (the sum of internal, outsourced and foreign). In that case the coefficient on who outsources was significant. Because the first test rules out differences in internal R&D productivity, the second test suggests the lower R&D productivity of outsourcing firms stems from outsourcing itself.

To investigate whether lower quality projects are driving the outsourcing result, I examine what happens to firms' internal R&D productivity surrounding the time they first outsource. I do this by creating eleven year dummies (one for the fifth year prior to first outsource, and one for each of the next ten years). I then regress firms internal RQs on the set of year dummies. If firms are merely outsourcing their lower quality R&D projects, their internal productivity should increase immediately after they shunt those projects to outsourcing. That doesn't appear to happen (**S3**). In fact, the mean coefficient prior to outsourcing (0.0006) is actually higher than post-outsourcing (0.0000), though not significantly. Thus it appears unlikely that project quality is driving the lower productivity of outsourcing.

Since neither low quality firms nor low quality projects explains the lower productivity of outsourced R&D, it appears outsourced R&D inherently has lower productivity than internal R&D. What might drive that? One possible explanation for fundamental differences between the productivity of internal R&D and outsourced R&D is that R&D produces internal learning that can be redeployed throughout the firm. When R&D is outsourced that learning is captured by the performing firm. As an example, a recent study of banks adoption of internet banking find that firms who outsource the initial IT integration are less able to develop new applications and accordingly have lower revenues from their internet operations. ([15])

An alternative explanation is that outsourced R&D is more costly to exploit and/or less likely to be exploited because key technical resources lie outside the firm. This explanation would be consistent with prior work in manufacturing showing that co-locating design engineers and manufacturing engineers dramatically reduced the duration and cost of automobile development ([16]). Similar effects have been found for technology outsourcing ([17 18]).

Both explanations may be at play. However one clue as to which is more compelling is the productivity of foreign R&D. If the primary problem is costly handoff between developers and exploiters, we would expect those problems to be more pronounced for foreign R&D. That's not what we see. As shown earlier, the productivity of foreign R&D is higher than R&D outsourced to US firms (0.014 versus -0.007). Thus of the two explanations, loss of internal spillovers seems more plausible.

While the question of why outsourced R&D has lower productivity than internal R&D is interesting and important, a related and equally important question is why firms persist with outsourcing. Again the data provide no insights here. However there is substantial evidence that firms don't know the underlying productivity of their R&D ([19]). Indeed the Industrial Research Institute (IRI) reports the need for better R&D metrics is a top concern of members. ([20]) Despite the lack of measures, a survey of CIOs and CEOs indicates that 70% of them believe outsourced innovation improves financial performance ([21]).

Given this uncertainty, firms are vulnerable to information cascades. An information cascade occurs when it is optimal for an individual, having observed the actions of others ahead of him, to follow the behavior of the preceding individual without regard to his own information" ([22]). The relevant cascade in this instance pertains to open innovation, which was first mentioned in 1983, but was later popularized by articles in MIT Sloan's Review([23]) and Business Week ([24]). Its espoused benefits include reduced cost of R&D as well higher R&D productivity. Indeed the CEO in the Hughes case expressed a goal of increasing outsourcing to "bring in more outside technology".

It is worth noting that outsourcing is just one form of open innovation. Another form—"eternal knowledge sourcing" for new innovation ideas appears to increase innovation—measured as the percentage of sales from products introduced in the last few years ([25 26]). The key distinction between the two forms of open innovation is that external knowledge sourcing pertains to the locus of an existing idea (and includes customers, suppliers, etc), whereas internal R&D pertains to the locus for researching and developing an idea.

While the questions of why outsourced R&D has lower productivity and why, despite the lower productivity firms persist with it, are ripe areas for future research, we have developed a plausible explanation for the broken link between R&D and GDP growth. It is that the recovery of R&D spending in the mid-eighties required investment in new resources. Uncertainty about future demand combined with substantial adjustment costs, led to slow expansion of R&D labor. This forced greater reliance on outsourcing. Unfortunately, it now appears outsourced R&D is unproductive for the funding firm.

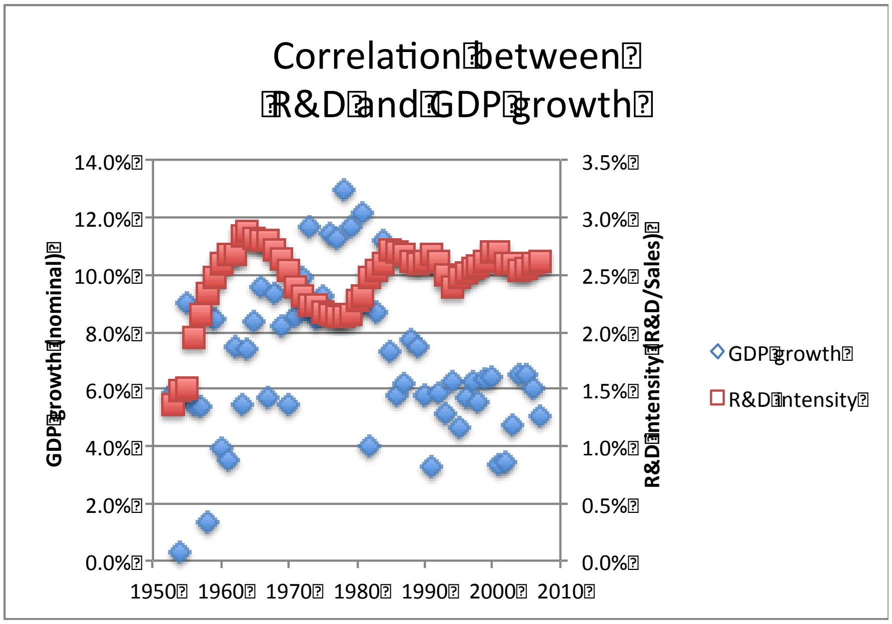
Table 1. Test of the R&D Input Decision. (firms with more than 10 observations)

Fixed Effects	(1)	(2)	(3)	(4)
Dependent Variable:	Scientist growth	Scientist growth	Outsource growth	Outsource growth
revenue growth +	0.029		0.269	
	0.023		0.404	
revenue growth -		**-0.246**		0.055
		0.030		0.172
constant	**1.025**	**1.025**	**1.707**	**1.146**
	0.015	0.016	0.230	0.121
Year effects	included	included	included	included
R-square				
within	0.087	0.039	0.016	0.089
between	0.385	0.042	0.001	0.110
overall	0.105	0.036	0.009	0.101
observations	14500	6500	3000	1000
firms	2000	2000	1000	500

Obs and firms rounded to nearest 500

Standard errors (clustered at firm) below coefficient

Coefficients in bold significant at $p<0.05$



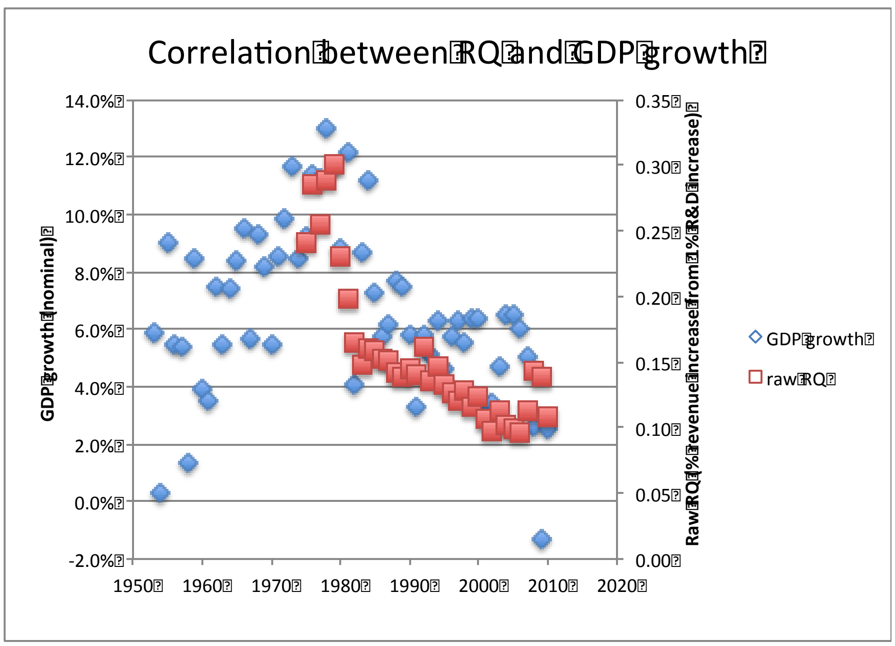
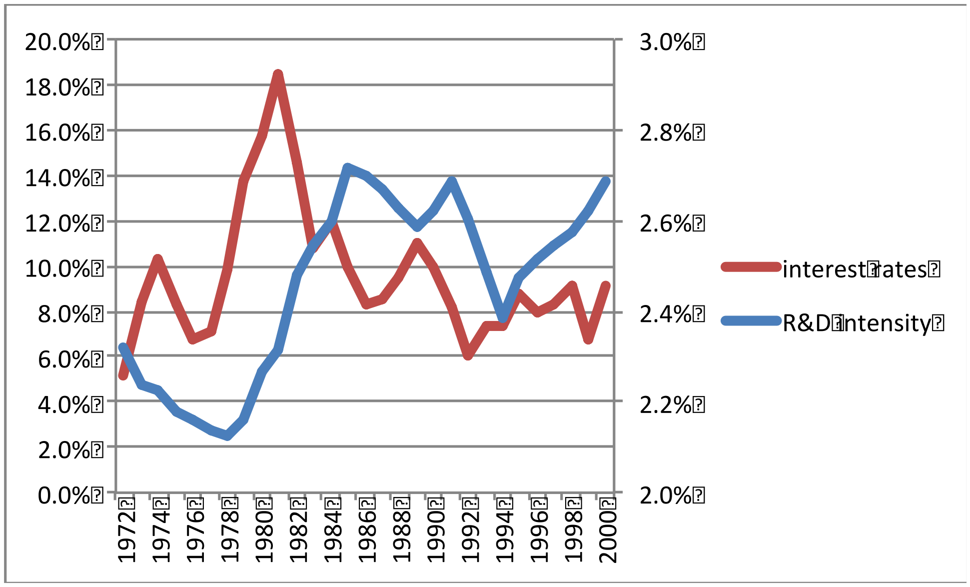


Fig 1. Relationship between R&D and nominal GDP growth



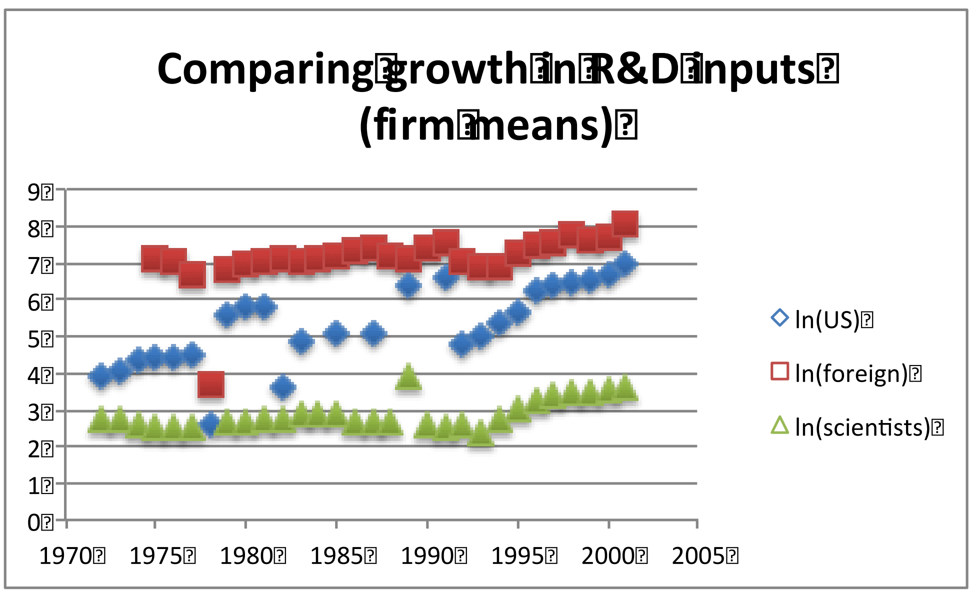


Fig 2. Trends relevant to the decline in R&D productivity

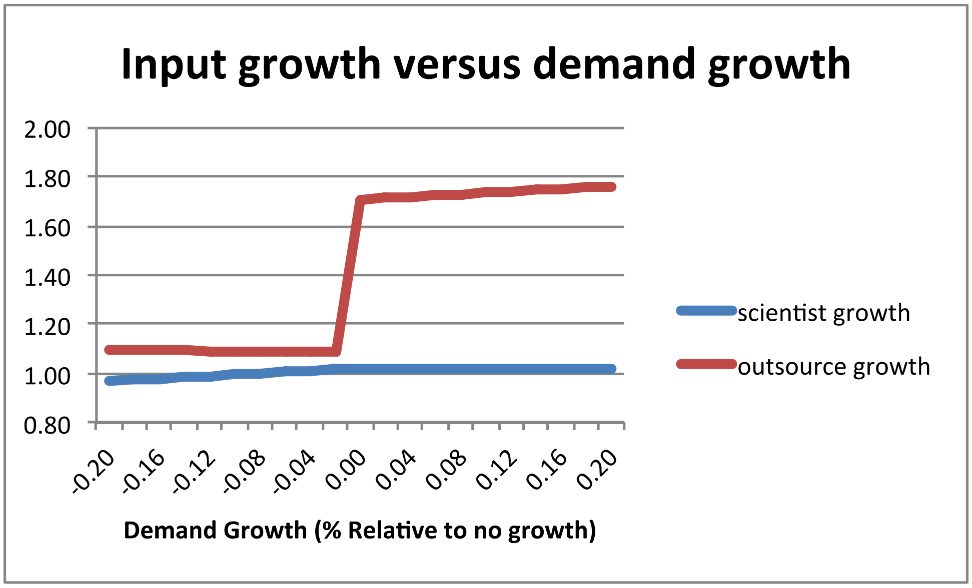


Fig 3. Relative response of labor and outsourcing to changes in demand

Supplementary Materials:

SUPPLEMENT 1

Data Summary

	Mean	Std.Dev.	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
1.ln(revenue)	10.89	2.28	1.00										
2.ln(RDtrue)	7.66	2.54	0.45	1.00									
3.ln(scientists)	2.82	1.93	0.53	0.78	1.00								
4.ln(depreciation)	7.22	2.08	0.36	0.70	0.64	1.00							
5.mean(prime rate)	8.18	3.04	0.05	-0.14	0.00	-0.20	1.00						
6.sd(prime rate)	0.62	0.60	0.04	-0.02	0.02	0.01	0.63	1.00					
7.public	0.03	0.16	-0.07	-0.01	-0.01	-0.09	0.10	-0.06	1.00				
8.ln(employees)	6.20	2.00	0.92	0.70	0.76	0.58	0.07	0.00	-0.05	1.00			
9.ln(InternalRD)	7.73	2.46	0.63	0.99	0.91	0.80	0.09	0.06	-0.01	0.71	1.00		
10. ln(outUS)	5.45	2.47	0.29	0.69	0.54	0.53	0.04	0.04	0.00	0.33	0.63	1.00	
11.ln(foreign)	7.27	2.29	0.44	0.70	0.62	0.55	-0.01	0.00	-0.01	0.49	0.64	0.51	1.00

SUPPLEMENT 2

Impact of interest rate on R&D

Dependent variable: ln(R&D)	(1) OLS	(2) FE
ln(revenue)	**0.685**	**0.486**
	0.002	0.016
Prime rate	**-0.095**	**-0.007**
	0.002	0.001
Public	**1.958**	-0.001
	0.033	0.038
Constant	**0.256**	**1.760**
	0.029	0.178
R-squared-overall	0.405	0.379
within		0.176
between		0.287
Adjusted R-sq	0.405	
Observations	135500	135500
Firms		37500

Obs and firms rounded to nearest 500

Std errors below coefficients

Coefficients in bold significant at 0.05

SUPPLEMENT 3

Impact of R&D practices on R&D productivity

Random coefficients estimation Dependent variable: ln(Revenues) *Yit*	(1)	(2)
ln(employees) *(Lit)*	**0.794**	**0.788**
	0.006	0.006
ln(internalR&D) *(Rit-1)*	**0.170**	**0.172**
	0.004	0.004
ln(outsource R&D) *(Ot-1)*	**-0.007**	**-0.007**
	0.002	0.002
ln(foreignR&D) *(Fit-1)*	**0.014**	**0.015**
	0.002	0.002
ln(spillovers) *(Sit-1)*	**0.011**	
	0.001	
Constant	**4.721**	**4.861**
	0.047	0.045
Wald chi2	25162	25236
prob>chi2	0	0
Observations	33000	33000
Firms	3500	3500

Obs and firms rounded to nearest 500
Std errors below coefficients
Coefficients in bold significant at 0.05

SUPPLEMENT 4

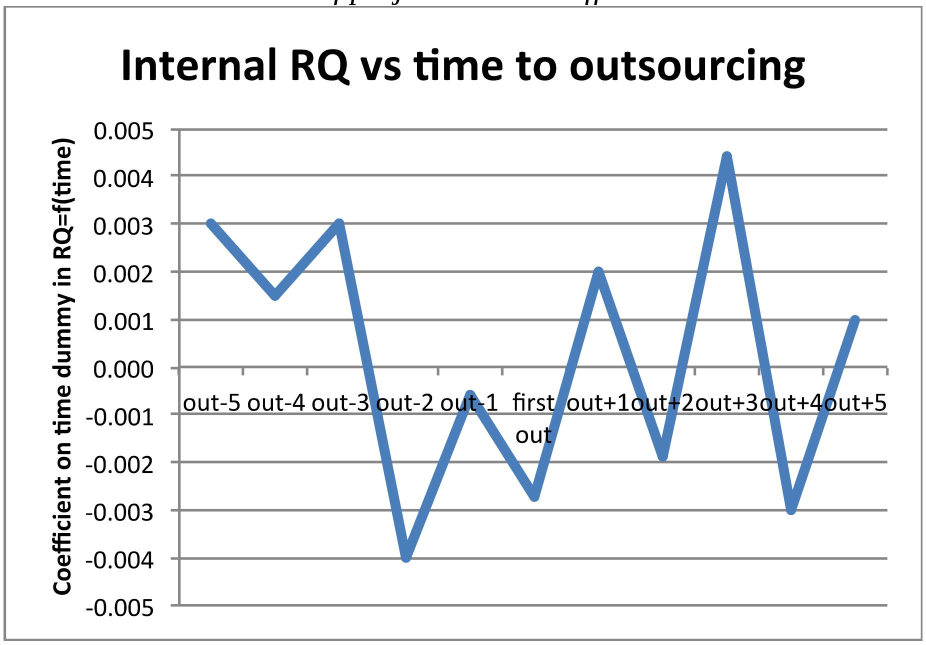
Impact of firm selection

Treatment regression	(1)	(2)
Dependent variable:	Internal RQ	Aggregate RQ
ln(employees)	0.000	**-0.004**
	0.000	0.000
Scientist ratio (dns/dne)	**0.006**	**0.012**
	0.001	0.002
Scientist cost (totcost/dns)	**0.000**	**0.000**
	0.000	0.000
Neverout	0.000	0.015
	0.001	0.008
Constant	**0.093**	**0.087**
	0.001	0.007
wald chi2	40.46	484.5
prob>chi2	0	0
stage 1 neverout		
Basic percent (brtot/rdtotown)	**0.511**	**0.508**
	0.122	0.117
Applied percent (ardtot/rdtotown)	-0.186	**-0.291**
	0.124	0.118
Foreign percent (outforeign/RDtrue)	**-1.330**	**-1.451**
	0.215	0.194
Federal percent (fedtot/Rdtrue)	0.194	0.098
	0.164	0.180
Constant	**0.857**	**0.870**
	0.078	0.073
/ath rho	0.030	-0.242
/lnsigma	-4.548	-3.676
rho	0.030	-0.237
sigma	0.010	0.025
lambda	0.000	-0.006
prob>chi2	0.690	0.026
observations	6000	6500
firms	500	500

Obs and firms rounded to nearest 500
Std errors below coefficients
Coefficients in bold significant at 0.05

SUPPLEMENT 5

Test of project selection effects



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