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ARE IDEAS GETTING HARDER TO FIND?

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There's been ongoing dialogue in the past few years about whether tech innovations have plateaued. While some say that we're still in a golden age of innovation, the *Wall Street Journal* last year declared: *The Economy's Hidden Problem: We're Out of Big Ideas*. It cites slower gains in science, medicine, and technology that hold back economic growth, and posits that American businesses may be too risk-averse. Optimists hope for a fourth industrial revolution that will raise the bar again, while pessimists lament that most potential productivity growth has already occurred. Our research shows some encouraging signs that new concepts are definitely not depleted. On the other hand, unique, original, and untapped ideas are getting more expensive to find—and that's a problem.

THE LINK BETWEEN ECONOMIC GROWTH AND INNOVATION

This paper applies the growth accounting of Solow (1957) to the production function for new ideas. The basic insight can be explained with a simple equation, highlighting a stylized view of economic growth that emerges from idea-based growth models:

Economic growth =	Research productivity x	Number of researchers
e.g. 2% or 5%	(falling)	(rising)

Economic growth arises from people creating ideas. As a matter of accounting, we can decompose the long-run growth rate into the product of two terms: the effective number of researchers and their research productivity. We present a wide range of empirical evidence showing that in many contexts, and at various levels of disaggregation, research effort is rising substantially, while research productivity is declining sharply.

To maintain a given rate of economic growth, resources devoted to research must increase over time—but that's not happening. We cite both aggregate evidence and measures of R&D productivity in specific industries-- in particular, computers, agriculture, and medicine—to illustrate the point.

A good example is Moore's Law. Because research productivity is declining, it is around 18 times harder today to generate the exponential growth behind Moore's Law than it was in 1971. Bang-for-the-buck from research on computer chips has declined at an average annual rate of 6.8 percent.

This is significant, not only because of the high expectations that technology has set for fast-paced, awe-inspiring innovation and growth, but because the two are extrinsically linked: The greater the research investment, the greater the rate of growth.

IN THIS RESEARCH BRIEF

- A wide range of evidence from various industries, products, and firms shows that U.S. research efforts are rising substantially, but at the same time, research productivity is sharply declining.
- A single-minded focus on the quantity of undiscovered ideas is unhelpful. It is not just how many ideas for productivity growth are left, but what it would cost to get them out of the ground – and, crucially, how much we're prepared to spend to do it. Unless research inputs are continuously raised, economic growth will slow in advanced nations.
- We study the idea-production function at the micro level to see directly what is happening to research productivity.
- The fundamental contribution of endogenous growth theory is that ideas are different from all other goods in that they do not get depleted when used by more and more people. Exponential growth in research leads to overall exponential growth.

MIT INITIATIVE ON THE DIGITAL ECONOMY

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We consider detailed microeconomic evidence on idea-production functions, focusing on places where we can get the best measures of both the output of ideas and the inputs used to produce them. In addition to Moore's Law, our case studies include agricultural productivity (corn, soybeans, cotton, and wheat) and medical innovations. Research productivity for seed yields declines at about 5% per year. We find a similar rate of decline when studying the mortality improvements associated with cancer and heart disease.

THE HIGH COST OF IDEAS

Across a broad range of case studies at various levels, we find some truth to the notion that ideas — and in particular, the exponential growth they imply — are getting harder and more expensive to find. This suggests that unless research inputs are continuously raised, economic growth will slow in advanced nations.

At the same time, a single-minded focus on the quantity of undiscovered ideas is unhelpful. It is not just how many ideas for productivity growth are left, but what it would cost to get them out of the ground – and, crucially, how much we're prepared to spend to do it.

For a long time, geologists have been forecasting 'peak oil,' only to be surprised by new deep-sea discoveries and shale oil. We, likewise, see a continuing stream of innovations, but just as newer oil sources are increasingly costly to extract, coming up with new ideas is getting more expensive.

Our study shows that research costs have increased sharply over time (Bloom, Jones, Van Reenen and Webb 2017) while 'research productivity' has declined. In an accounting sense, low productivity growth in the economy is a direct consequence of research effort failing to increase fast enough to offset declining research productivity. If we want to restore economic growth, we need to pay for it. [See Figure 1].

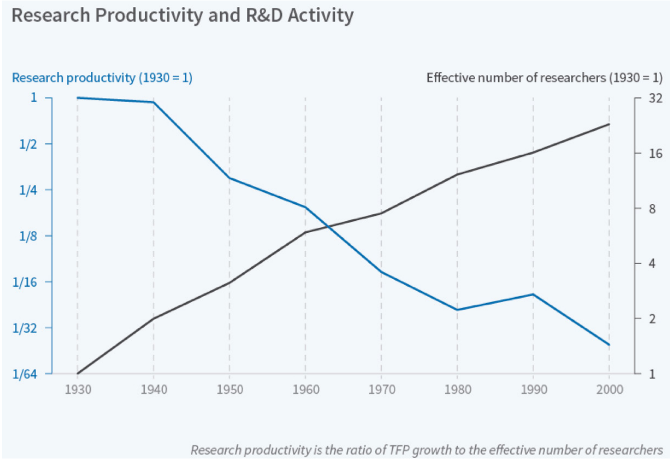

Figure 1; Source: Bloom et al (2017).

Our research also indicates why we think looking at the macro data is insufficient and why it's crucial to study the idea-production function at the micro level. The overwhelming majority of papers on economic growth published in the past decade are based on models in which research productivity is constant. An important justification for assuming constant research productivity is an observation first made in the late 1990s by a series of papers written in response to the aggregate evidence[1]. These papers highlighted that composition effects could render the aggregate evidence misleading: perhaps research productivity at the micro level is actually stable. More in-depth study, however, shows that the aggregate evidence may tell us nothing about research productivity at the micro level. Hence, the contribution of this paper: we study the idea-production function at the micro level to see directly what is happening to research productivity.

Not only is this approach interesting in its own right, but it is also informative about the kind of models that we use to study economic growth. Despite large declines in research productivity at the micro level, relatively stable exponential growth is common in the cases we study and in the aggregate U.S. economy. How is this possible? Declines in research productivity must be offset by increased research

1 The initial papers included Dinopoulos and Thompson (1998), Peretto (1998), Young (1998), and Howitt (1999)

effort. Moreover, we suggest that the rapid declines in research productivity that we see in semiconductors, for example, might be precisely due to the fact that research effort is rising so sharply. Because it gets harder to find new ideas as research progresses, a sustained and massive expansion of research like we see in semiconductors (for example, because of the "general-purpose technology" nature of information technology) may lead to a substantial downward trend in research productivity.

A key assumption of many endogenous growth models is that a constant number of researchers can generate constant exponential growth. We show that this assumption corresponds to the hypothesis that the total factor productivity of the idea-production function is constant, and we proceed to measure research productivity in many different contexts.

CONCLUSIONS

Our robust finding is that research productivity is falling sharply everywhere we look. Taking the U.S. aggregate number as representative, research productivity falls in half every 13 years — clearly, ideas are getting harder and harder to find. Put differently, just to sustain constant growth in GDP per person, the U.S. must double the amount of research effort searching for new ideas every 13 years to offset the increased difficulty of finding new ideas.

Our paper, therefore, clarifies that the fundamental contribution of endogenous growth theory is not that research productivity is constant or that subsidies to research can necessarily raise growth. Rather, it is that ideas are different from all other goods in that they do not get depleted when used by more and more people. Exponential growth in research leads to exponential growth in A_t[2]. And because of non-rivalry, this leads to exponential growth in per-capita income.

In part, declining research production may be explained by firms shifting to 'defensive' R&D to protect their market positions. Further, overall research productivity may have suffered because of a decline in basic research spending stemming from cuts in publicly funded research as a share of GDP.

Nevertheless, whether we look at crop yields for corn and soybeans, or medical innovations that reduce mortality from heart disease and breast cancer, we find similar trends: There have been technological improvements, but they require the devotion of ever-growing amounts of research resources to maintain steady rates of improvement. We find a similar pattern using data at the firm level, as well, based on firm-level data from Compustat to provide another perspective.

While the data quality from this sample is not as good as for our case studies-- the latter may not be as representative-- we find substantial heterogeneity across firms, but research productivity is declining in more than 85% of our sample. Averaging across firms, research productivity declines at a rate of around 10% per year.

To our mind, this is all convincing evidence that ideas are becoming more expensive to find. Unless we keep raising research inputs—at the university, government, and individual business level-- economic growth will continue to slow in advanced nations such as the United States.

2 A_t is total factor productivity growth in the economy.

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The full research paper can be accessed here http://www.nber.org/papers/w23782

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