1. Is the semi-endogenous growth framework justified? Provide and describe the evidence in favor of this framework available in the paper.

Jones tries to address three possible criticisms that the framework can potentially face and will provide an elaboration on related research. Afterward, he provides some findings that give good insights on the parameters of the model trying to justify how well the parameters can be interpreted.

Firstly, he mentions the possible underfitting of the model with country-level data. He carefully addresses the fact that there is a diffusion of ideas among countries. He uses small countries such as Luxembourg or Singapore as an example of receivers of the flow of ideas from other countries. Moreover, even bigger countries' growth rates cannot be explained only by their population's growth (thus, with a fixed rate of researchers, researchers' growth) and disregarding the diffusion of ideas.

Secondly, the semi-endogenous model considers the number of researchers as a proxy for innovation (creation of ideas as they refer to), whereas, the improvements in quality of researchers can substitute the number of researchers. To dilute the effect of this new perspective on the legitimacy of the model, he refers to Lucas's model (1998) [1] with endogenous human capital growth as a successful theoretical implementation of this idea supporting the findings in the paper for the U.S. where human capital accounts for 25% of recent decade's growth rates. However, Mincer's (1974) [2] approach shows the level effect of human capital improvements not managing to create lasting growth increase. Moreover, Bils and Klenow (2000) [3] assert that countries with different investment rates in human capital or educational attainment do not have different permanent growth rates using the data from the 20th century, and focusing on the comparison of the U.S. as an example of high investments and attainment with other countries.

The **Third** criticism he tries to justify is the linear population equation in the model. He mentions two facts about this specification. First, by growth, he always means growth per capita, which adjusts for the

population that has grown exponentially. Second, he uses Mitosis as an illustration of how biological beings, including humans, grow proportional to their level.

At last, the evidence from Bloom, Jones, Van Reenen, and Webb (2020) give good elaborations on β (proportional improvements in productivity) in different goods from semiconductors to agricultural goods for U.S. Jones uses this study to show how the heterogeneity of goods and services can play a role in the model, and continues with how dependent the long-run growth rate is to this key parameter β by simulating different time intervals that it takes a hyped growth rate caused by permeant shock (increase in researchers portion of the population) converge to long-run steady state.

2. What are the components of U.S. economic growth from the 1950s? Describe the contribution of each factor (population growth, human capital, etc.) to economic growth, by relying on the growth accounting exercise based on a semi-endogenous growth framework.

U.S. average growth rate from 1950 is 2%. The semi-endogenous model fitted to U.S. data (1953-1993) shows that approximately 20% of the historical growth rate is due to population growth (regarding two different channels: increase in the number of researchers and consumers). The remaining 80% are explained by improvements in human capital factors such as educational attainment, number of researchers, decreasing trend in misallocation. These factors are estimated through the following model:

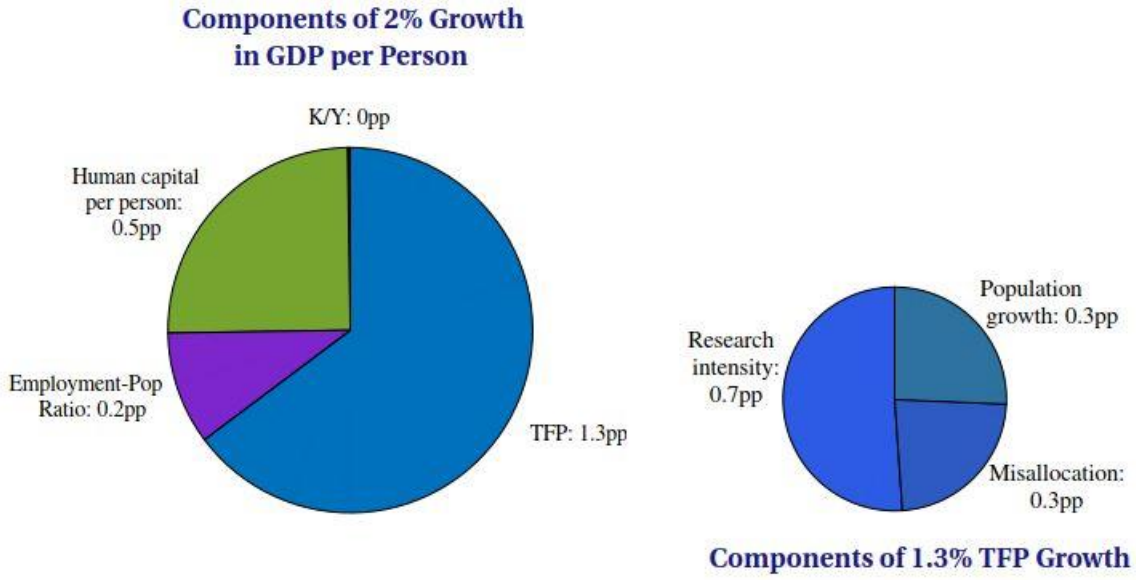
$$\underbrace{d\log\, y_t}_{\text{GDP per person}} = \underbrace{\frac{\alpha}{1-\alpha} d\log \frac{K_t}{Y_t}}_{\text{Capital-Output ratio}} + \underbrace{d\log\, h_t}_{\text{Educational att.}} + \underbrace{d\log\, \ell_t}_{\text{Emp-Pop ratio}} + \underbrace{d\log\,(1-s_t)}_{\text{Goods intensity}} + \underbrace{d\log\, M_t + d\log\, A_t}_{\text{TFP growth}}$$

Where,

$$\text{TFP growth} \equiv \underbrace{d\log\, M_t}_{\text{Misallocation}} + \underbrace{d\log\, A_t}_{\text{Ideas}} = \underbrace{d\log\, M_t}_{\text{Misallocation}} + \underbrace{\gamma d\log\, s_t}_{\text{Research intensity}} + \underbrace{\gamma d\log\, L_t}_{\text{LF growth}}$$

These findings are better illustrated by the represented figure as follows:

Figure 2: Historical Growth Accounting



Note: The figure shows a growth accounting exercise for the United States since the 1950s using equations (15) and (16). See the main text for details.

Where population growth explains 0.3 percentage points (pp) of the 2 percent, Along with 0.3 pp caused by misallocation reduction and 0.7 pp research intensity, they form the total factor production causing 1.3 pp of the 2% long-run growth rate. Moreover, human capital causes 0.5 pp and $\frac{Employment}{Population}$ explains 0.2 pp of the 2% growth rate in GDP per capita. The interesting finding is that the Capital to GDP ratio almost does not explain any portion of the growth rate. Moreover, Goldin and Katz (2008) [4] have a good illustration of these findings using 20th-century data (a longer period of evidence).

3. Economic growth will be slower or faster in the future? Provide arguments based on the semi-endogenous growth framework.

Regarding the prospects of economic growth (more of a worldwide perspective), Jones mentions possible positive and negative events. On the negatives, slower expected population growth and end of the historical transition dynamics are the trends that could lower the growth rates. On the other hand, "Finding new Enisteins" effect through better educational and economic opportunities for the people into recently booming economics (such as China and India) and more opportunities to female innovators

in the modern societies, along with the rising trend in automation and AI shines a silver lining to the prospects of economic growth.

Slowing population growth: Jones (2020) [5] considers a scenario where the population growth is negative. From the initial form of the model, the technological growth $(\frac{\dot{A}_t}{A_t} = R_t^{\lambda} A_t^{-\beta}, where\ R_t\ is\ the\ number\ of\ researchers)$, is dependent on the number of researchers, since the number of researchers process is assumed as $R_t = R_0 e^{-\eta t}$ the number of researchers can be decreasing if $\eta > 0$. Thus, the technological growth can be re-written as $\frac{\dot{A}_t}{A_t} = R_0^{\lambda} A_t^{-\beta} e^{-\lambda \eta t}$. Taking integral and calculating the limit to infinity (representing the long-run), the stock of ideas converges to:

$$A^* = \begin{cases} A_0 \left(1 + \frac{\beta g_{A0}}{\lambda \eta}\right)^{1/\beta} & \text{if } \beta > 0 \\ A_0 \exp\left(\frac{g_{A0}}{\lambda \eta}\right) & \text{if } \beta = 0 \end{cases}$$

Since β is estimated to be a positive value under a semi-endogenous model, the stock of ideas converges to a finite value, contradictory to the exponential trend we experienced historically. In other representation, since innovation is the engine of growth, the GDP per capita will converge to a finite value and growth will cease to exist.

Declining Research Efforts: The statistics on research employment in various countries, groups and worldwide, show a declining growth in research employment. In a semi-endogenous growth model, the researcher rate of the population $(\bar{s})$ were considered fixed. If this portion starts to decrease, and other factors constant, the growth will slow down.

The silver linings: Jones simplifies the developed population to about 1 billion people. The other 6 billion are located in developing and less-developed countries. Assuming the geniuses like Tomas Edison could have been flourished in these areas if the necessary environment were suitable for their growth (which are usually is in developed countries), the growth rate can boost when these developing countries reach the developed state. Jones uses a hypothetical situation where if 3 or 7 billion people live in developed

countries, the increase in proportional improvements in productivity (λ), in comparison to benchmark (1/3) can increase the growth rate by 0.2 to 0.4 pp. Moreover, he refers to Bell, Chetty, Jaravel, Petkova, and Van Reenen (2019) [6], to elaborate on **expanding opportunities for women**, which could have the same effect as the above mechanism. Jones uses the expression "**Finding new Einsteins**" to refer to these two trends.

On the other hand, Automation and AI can have a positive impact on the growth rate. Jones refers to Zeira's (1998) [7] model using the Acemoglu and Autor (2011) [8] interpretation of the intermediate goods as tasks to show the theoretical effect of automation. If the general form of production is:

$$Y = AX_1^{\alpha_1}X_2^{\alpha_2} \cdot \ldots \cdot X_n^{\alpha_n} \text{ where } \sum_{i=1}^{n} \alpha_i = 1$$

The intermediate goods can be:

$$X_i = \begin{cases} L_i & \text{if not automated} \\ K_i & \text{if automated} \end{cases}$$

The production function can be written in form of Cobb-Douglas in a static analysis where α is constant, with the growth rate in GDP per capita growth rate as:

$$g_y = \frac{g}{1-\alpha}$$

Thus, an increase in α through automation and the use of highly effective AI tools can boost the growth rate in the long run. Moreover, if the creation of ideas becomes automated, a similar analysis by Aghion, Jones, and Jones (2019b) [9] and Agrawal, McHale, and Oettl (2019) [10] shows the same effect on growth. At last, this scenario is considered as probable to happen in the next 100 years according to Davidson (2021) [11] reporting on many expert opinions.

Research Proposal

Relying on the unresolved research questions suggested in Section 7 of Jones (2021), draft a research proposal (maximum two pages) describing your research question, the methodology (e.g., empirical exercise, theoretical model and calibration, etc.), and the data that you would like to use to address that question.

How can we best measure ideas? [Could be a research proposal for thesis and possible future publications]

Introduction

Without a doubt, measuring ideas is a key factor in understanding the state of aggregated innovation and thus, the prospects of economic growth. There are many policies invented to impact the level of innovation, missing a good empirical evaluation due to the absence of a better measure of aggregated ideas, in an economy other than simple measures such as the number of patents or simple citations.

Statement of the Problem

The previous measures, such as the number of patents are aimed at the number of ideas published. Other measures such as patent citations aim to measure the quality of patents. However, none are successful at measuring what they focus on. Several patents disregard the fact that a lot of ideas are not just published in the form of patents but also research papers. Consider the paper published by Chetty, Hendren, Kline, and Saez (2014) [12] focused on a topic in public economics. The implication of this paper (idea) is usually in the governance area helping with the struggle to improve government efficiency leading to economic prosperity in the long run. Moreover, some research papers are the basis of a lot of new innovative ideas that revolutionize the economy. For example, Fuzzy sets by Lotfi Zadeh (1996) [13] revolutionized the electronics/ AI field, meanwhile, many patents based on this research where exploitation of the original idea, the policymaker aiming to maximize this exploitation will fail to recognize the roots of this hype. On the other hand, variables representing the quality of patent/research can be misleading. A lot of patents/research papers are used and not cited, while a lot of patents/research papers are cited just to fill in the blanks in papers or try to justify a technologies genuineness. A lot of businesses based on blockchain technology who turned out to be scams were citing the related patents in the field to seem genuine. We propose a new measurement trying to shed light on ideas represented by research papers which can be extended to patents as well.

Literature review

Traditional measures of ideas such as patents, patent citations, and stock market reaction to patents were used in papers such as Griliches (1984) [14], Hall et al (2005) [15], Budish (2015) [16] ,and Kogan et al. (2017) [17]. Moreover, Argente, Hanley, Baslandze, and Moreira (2020) [18] showed that at least half of the firms producing goods never patent, lowering the legitimacy of patents as a proxy for innovative ideas.

Research Questions

1. What are the insights of the new measurement?

Proposed Research Methodology

Struggling to measure a typical research paper's contribution to innovation, each paper has a finite amount of citation and a fixed number of references (except for working papers). The measurement is based on the idea that the number of references in the paper is inputs of the paper, while citations are the output. Thus, a paper with a high number of citations in year t, and a low number of references in the paper, is highly innovative. Therefore, for a typical paper i at time t, we have:

$$\boldsymbol{Innovative\ Value_{i,t}} = \frac{\boldsymbol{Num.of\ citations_{i,t}}}{\boldsymbol{Num.of\ references_{i,t}}}$$

Therefore, a review paper with a high number of citations gets penalized by the high number of references. A very good paper with high novelty is also clearly distinct by the measure. However, what if a paper has few citations and few references? What if a review paper not adding many new ideas get a very high value of citations? Therefore, some extended versions of the previous measure can be introduced.

$$\boldsymbol{text-innovative\ Value_{i,t}} = \frac{\dfrac{\boldsymbol{number\ of\ words\ in\ the\ paper_{i,t}}}{\boldsymbol{cosine\ distance\ with\ references_{i,t}}}}{\boldsymbol{references_{i,t}}}$$

Where the cosine distance measures the similarity of paper's text to reference's texts. Thereafter, a lot of other measures with similar ideas can be created and discussed. Then, the distribution of the variable (momentums) and the aggregation can be used to make an index for innovation.

Data and Variables

The paper's materials and metadata including references, citations, and text, etc. can be scraped using a web crawler implemented in python and useful packages such as selenium and beautiful soup.

Implications

With a good, accurate, and formulated measure of ideas, policy effects targeting innovation and entrepreneurship can be evaluated better. Policymakers could spot the field with potential for research exploitation and nudge the educational policy towards the expansion and exploitation of the field.

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