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Detailed Terms
Secular Stagnation? The Effect of Aging on Economic Growth in the Age of Automation†

By Daron Acemoglu and Pascual Restrepo*

The rapid aging of the population of both developed economies and much of the rest of the world, depicted in Figure 1, is seen as one of the most dangerous economic ills of the next several decades. An increasingly popular thesis, building on Alvin Hansen’s famous 1938 presidential address to the AEA, views developed economies as being afflicted by “secular stagnation,” partly because an aging population creates an excess of savings relative to investments (Hansen 1939; Summers 2013; and the essays in Teulings and Baldwin 2014). A different but related challenge is emphasized by Gordon (2016), who identifies demographic change as the first “headwind” slowing down economic growth in the developed world, for an older population will reduce labor force participation and productivity (workers’ earnings, and presumably productivity, peak in their 40s, e.g., Murphy and Welch 1990).

Though both perspectives imply that countries undergoing faster aging should be suffering more from these economic problems,1 we show that since the early 1990s or 2000s (the periods commonly viewed as the beginning of the adverse effects of aging in much of the advanced world) there is no negative association between aging and lower GDP per capita.2 Figure 2 provides a glimpse of the relevant pattern by depicting the raw correlation between the change in GDP per capita between 1990 and 2015 and the change in the ratio of the population above 50 to the population between the ages of 20 and 49. In the next section, we show that even when we control for initial GDP per capita, initial demographic composition and differential trends by region, there is no evidence of a negative relationship between aging and GDP per capita; on the contrary, the relationship is significantly positive in many specifications.

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1Three qualifications to this conclusion should be noted. First, there are non-demographic factors, such as increased levels of inequality and slower technological progress, that have also been suggested as potential causes of demand-side secular stagnation. Second, this type of secular stagnation could be partially offset by monetary policy. Third, with international capital flows, aging in one country might affect GDP per capita in others as well.

2Lindh and Malmberg (1999) and Feyrer (2007) investigate the relationship between demographics and aggregate productivity or growth, focusing on pre-1990 data. Both papers find some evidence supporting the notion that the fraction of the population above 50 contributes negatively to GDP per capita. Their findings motivate our baseline choice of demographic variable as the ratio of the population above 50 to those between the ages of 20 and 49.
II. The Cross-Country Evidence

The lack of a strong negative association between changes in age structure and changes in GDP per capita is surprising. So what explains it?

The post-1990 era coincides with the arrival of a range of labor-replacing technologies, most recently robotics and artificial intelligence, which provide a wide variety of options for firms to automate the production process. In Section II, we show that countries undergoing more rapid demographic change are more likely to adopt robots (see also Acemoglu and Restrepo 2017). In Section III, we show that when capital is sufficiently abundant, a shortage of younger and middle-aged workers can trigger so much more adoption of new automation technologies that the negative effects of labor scarcity could be completely neutralized or even reversed.

I. Aging and GDP Per Capita: The Cross-Country Evidence

In this section, we start by showing that the relationship depicted in Figure 2 is robust. We

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3 The recent working paper by Maestas, Mullen, and Powell (2016) shows a negative association between aging and economic growth across US states. To the extent that US states have more similar technologies and more coordinated adoption decisions than countries, the countervailing effects of technology adoption we emphasize would be absent or much muted in this sample.

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4 Figure 2 shows that Equatorial Guinea is an outlier, but leaving it out has essentially no impact on the regressions reported here. For example, in the equivalent specification to column 4 without Equatorial Guinea, the coefficient estimate is 0.615 (standard error = 0.290). Equatorial Guinea is an oil producer, and we also confirmed that oil has no effect on our results by including the share of oil revenues in GDP in 1990 (from the World Bank) as an additional control.
Panel B shows similar patterns with a different measure of aging—change in the average age of the population above 20. Panel C shows that the broad picture is also similar when we focus on the post-2000 sample (2000–2015), where concerns about secular stagnation have become more prominent.

Table 2 extends the sample to 1965 and reports regressions with two differences of 25 years for each country stacked together. Columns 1 and 2 mimic columns 1 and 3 from Table 1 and present very similar results. In addition, columns 3–6 include country dummies, which are equivalent to country-specific linear trends in levels, and report OLS and IV estimates of this more demanding specification. The estimates again point to a positive and statistically significant relationship between population aging and economic growth in the full sample (and a less positive and insignificant one in the OECD).
II. Aging and Robots

Why is there not a strong negative relationship between aging and GDP per capita as predicted by a range of theories, including recent ones on secular stagnation? One possible answer is that technology adjusts so as to undo this potential negative effect. We argue that this answer is plausible in two steps. First, in this section, we draw on Acemoglu and Restrepo (2017) to show that countries experiencing more rapid aging are the ones that have been at the forefront of the adoption of one important type of automation technology: industrial robots.

The relationship between aging and adoption of robotics technology is established in Acemoglu and Restrepo (2017) using data from the International Federation of Robotics (IFR), which provides information on industrial robots across a range of industries for 49 countries. We use the same data in Figure 3 to show the basic cross-country pattern, which reveals a strong correlation between the same measure of demographic change used in our analysis so far—the change in the ratio of the population above 50 to those between 20 and 49, and the change in the number of robots (per million of labor hours) between the early 1990s and 2015.5

Acemoglu and Restrepo (2017) document that this cross-country pattern is robust; it holds if we exclude Korea (a clear outlier) and it holds within the OECD countries. Crucially, as would be expected from a simple model of directed technological change, we also show that it is more pronounced in industries that employ younger workers and those in which there are more opportunities for automation.

III. Can Labor Scarcity Lead to Higher GDP Per Capita?

In this section, we undertake the second, theoretical step in our argument. Drawing on Acemoglu (2010) and Acemoglu and Restrepo (2016), we demonstrate that the scarcity of younger and middle-age labor can trigger sufficient adoption of robots (and other automation technologies) so as to actually increase aggregate output, despite the reduced labor input.

5 This figure excludes Japan, since the IFR notes that Japanese data are not comparable over time because of a change in classification.
the fact that automating more tasks is costly (differentiable, strictly increasing reflecting the country in question. We assume that
\[ C(\theta) = \begin{cases} 1 & \text{if } \theta \in [0, 1] \\ \infty & \text{otherwise} \end{cases} \]
for the monopolist), strictly convex (with a positive second derivative everywhere), and satisfies the Inada conditions \( C'(0) = 0 \) and \( \lim_{\theta \to 1^-} C'(\theta) = \infty \).

We assume that capital and labor are inelastically supplied, with supplies given, respectively, as \( K \) and \( L \), and
\[ \frac{K}{\theta} > \frac{L}{1 - \theta}. \]
This implies that capital is abundant and cheap relative to labor, which is plausible given the very low interest rates around the world at the moment. This assumption ensures that automating tasks will be profitable and increase aggregate output. In mapping the model to data, we think of \( L \) as the supply of younger and middle-aged workers, so that population aging will correspond to a reduction in \( L \)—a phenomenon to which we also refer as an increase in labor scarcity.

Following the same steps as in Acemoglu and Restrepo (2016), equilibrium aggregate output can be expressed as
\[ Y = \eta^{1-\theta} \left( \frac{K}{\theta} \right)^{\theta} \left( \frac{L}{1 - \theta} \right)^{1-\theta}. \]
Then, taking logs, the profit-maximization problem of the monopolist can be written as
\[
\max_{\theta \in [0, 1]} \theta \ln \frac{K}{\theta} + (1 - \theta) \ln \frac{L}{1 - \theta} + \Gamma(\theta),
\]
where \( \Gamma(\theta) = \ln (\eta \chi - C(\theta)) \) and we assume that \( \eta \chi > C(\theta) \). Because \( C(\theta) \) is increasing and convex, \( \Gamma(\theta) \) is strictly decreasing, has a negative second derivative everywhere, and satisfies \( \Gamma'(0) = 0 \) and \( \lim_{\theta \to 1^-} \Gamma'(\theta) = -\infty \). The presence of the term \( \eta \chi \) reflects the profits of the monopolist from the markup on the intermediates.

The profit maximization of the monopolist, combined with the Inada condition on \( C \), implies
\[ \ln \frac{K}{\theta} - \ln \frac{L}{1 - \theta} + \Gamma'(\theta) = 0. \]
Differentiating this relationship yields
\[ \frac{d\theta}{d \ln L} = \frac{1}{\Gamma''(\theta) \frac{1}{\theta(1 - \theta)}} < 0, \]
since \( \Gamma \) has a negative second derivative. This establishes that labor scarcity—i.e., a lower \( L \) encourages further automation as in Acemoglu (2010) and Acemoglu and Restrepo (2016).

What is the effect of labor scarcity on aggregate output? To answer this question, let us...
totally differentiate the expression for \( \ln Y \), taking into account the indirect effect of \( \ln L \) working through additional automation:

\[
\frac{d \ln Y}{d \ln L} = 1 - \theta + \frac{\partial \ln Y}{\partial \theta} \frac{d \theta}{d \ln L} = 1 - \theta + \frac{\ln K - \ln \frac{L}{1-\theta}}{\Gamma''(\theta) - \frac{1}{\theta(1-\theta)}}
\]

where \( \varepsilon_{\Gamma} = \Gamma''(\theta)/\Gamma'(\theta) > 0 \) is the elasticity of the derivative of the \( \Gamma \) function.

In view of condition (4), the second term is negative. Thus, a lower \( L \) creates a direct effect which is to decrease GDP because of the reduction in the labor input, but also a positive effect through additional automation. If the second term, which is negative, is sufficiently large, then the scarcity of labor caused by an aging population can increase GDP. This will be the case if the gap between \( K \) and \( L \) is sufficiently large, making capital much cheaper than labor, and the elasticity \( \varepsilon_{\Gamma} \) is small (from the third line). Hence, the aging of the labor force, which reduces the available supply of workers to perform productive tasks in the economy, need not reduce GDP per capita, and may in fact increase it, once we take the response of technology into account.

**IV. Conclusion**

This paper establishes that, contrary to a range of theories including recent ones on demographics-based secular stagnation, there is no negative relationship between population aging and slower growth of GDP per capita. This is a major puzzle for several theories that have become very popular over the last several years.

One possible explanation for this pattern is the endogenous response of technology—in particular, the adoption of technologies performing tasks previously undertaken by labor. We document that countries undergoing more rapid population aging have adopted more robots, although we do recognize that this evidence is neither causal nor does it establish that the adoption of robots is the mechanism that neutralizes the potential negative effects of population aging on economic growth. We also demonstrate that models of directed technological change can account for the lack of such a negative relationship, and could generate a positive relationship, between population aging and economic growth.

There is a clear need for future work that systematically investigates the relationship between demographic change and GDP growth as well as the channels via which this relationship works.

**REFERENCES**