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Moura, Alban

Banque centrale du Luxembourg

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TREND BREAKS AND THE LONG-RUN IMPLICATIONS OF INVESTMENT-SPECIFIC TECHNOLOGICAL PROGRESS

ALBAN MOURA

Abstract. I update the Greenwood, Hercowitz, and Krusell (1997) decomposition of U.S. growth into contributions from neutral and investment-specific technological progress. I allow the decomposition to vary across sub-samples, reflecting the presence of trend breaks in the data. The estimates suggest that neutral technological progress explained virtually all growth between 1950 and the mid-1970s. However, investment-specific technological progress accounts for about 75 percent of growth since the 1980s. These results support splitting the postwar sample and using two-sector models to study the recent period.

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Keywords: neutral technology, investment-specific technology, sources of long-run growth, structural breaks.

1. Introduction

Greenwood, Hercowitz, and Krusell (1997, GHK hereafter) develop a procedure to decompose aggregate growth into contributions from neutral and investment-specific (IS) technological progress. Their estimates famously attribute 58 percent of postwar U.S. growth to IS technological change. This finding spurred further research about the role of IS technology in growth and business cycles (Whelan, 2003; Fisher, 2006; Justiniano, Primiceri, and Tambalotti, 2010).

In their analysis, GHK treat the postwar period as a homogeneous sample. However, the recent literature acknowledges the presence of trend breaks in both neutral and IS technology during the 1970s and 1980s, with a slowdown in neutral technology growth and an acceleration in IS technology growth (Fernald, 2007; Benati, 2014; Moura, 2021). The existence of these breaks raises two questions: Is GHK's decomposition of aggregate growth sensitive to breaks? What are the respective contributions of neutral and IS technological change in the recent period? The purpose of this note is to address these two questions.

Econometric tests identify a common break date in neutral and IS technology in late 1977. Therefore, I split the postwar sample and repeat GHK's analysis on two sub-periods: 1950-1977 and 1978-2019. The estimates suggest that neutral technological progress explained

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August 2021. Banque centrale du Luxembourg, Département Économie et Recherche, 2 boulevard Royal, L-2983 Luxembourg (e-mail: alban.moura@bcl.lu). I thank Fabrice Collard, Martial Dupaigne, Patrick Fève, Pablo Garcia Sanchez, Paolo Guarda, and Olivier Pierrard for very helpful comments. This paper should not be reported as representing the views of the Banque centrale du Luxembourg or the Eurosystem.

virtually all aggregate growth before 1977, but less than 25 percent of it afterward. However, the contribution from IS technological growth rose from almost zero to 76 percent after. A full-sample analysis considering the 1950-2019 period conceals this heterogeneity, attributing 68% of postwar growth to neutral technological progress and the remaining 32% to IS technological change.

These findings provide a new argument for splitting postwar U.S. samples in empirical work, in addition to the well-known shifts in monetary policy and macroeconomic volatility observed in the early 1980s (Perez-Quiros and McConnell, 2000). The results also emphasize the importance of working with multisector models to study the recent behavior of the U.S. economy.

2. Greenwood, Hercowitz, and Krusell (1997): Setup and Estimates

The analysis is based on a stylized two-sector model à la GHK. The economy is closed and all agents behave competitively. The general equilibrium corresponds to the solution of the planning problem:

$$\max \sum_{t=0}^{\infty} \beta^t \left[\ln C_t + \theta \ln(1 - L_t)\right]$$

subject to

$$\begin{aligned} C_t + I_{e,t} + I_{s,t} &= Z_t K_{e,t-1}^{\alpha_e} K_{s,t-1}^{\alpha_s} L_t^{1-\alpha_e-\alpha_s}, \\ K_{e,t} &= (1-\delta)K_{e,t-1} + Q_t I_{e,t}, \\ K_{s,t} &= (1-\delta)K_{s,t-1} + I_{s,t}, \end{aligned}$$

where C_t, L_t, $I_{e,t}$, and $I_{s,t}$ denote consumption, hours worked, investment in equipment, and investment in structures. $K_{e,t}$ and $K_{s,t}$ are the associated capital stocks. $Z_t = (1 + g_z)^t$ and $Q_t = (1 + g_q)^t$ are deterministic processes for neutral and IS technology, with respective growth rates g_z and g_q. β is the discount factor, θ is a preference weight, α_e and α_s are the capital shares in production, and δ is the depreciation rate.

Compared to GHK, I simplify the setup by redefining θ and abstracting from distortionary taxation and heterogeneous depreciation, with no effect on steady-state growth.

The logic of the model is straightforward. Neutral technological progress (growth in Z_t) expands the production frontier for given input levels. This allows more capital accumulation, boosting growth further. IS technological progress (growth in Q_t) shifts the slope of the production frontier toward equipment goods. This allows more equipment capital accumulation and expands future production possibilities.

GHK propose a procedure to disentangle the growth contributions from these two sources. Their procedure is as follows. First, measure aggregate production by output in consumption units, defined as

$$Y_t = Z_t K_{e,t-1}^{\alpha_e} K_{s,t-1}^{\alpha_s} L_t^{1-\alpha_e-\alpha_s}.$$

This is the aggregate supply appearing in the resource constraint. Second, compute the equilibrium balanced growth rate of Y_t, denoted g_y. Standard arguments imply that

$$g_y = \frac{g_z + \alpha_e g_q}{1 - \alpha_e - \alpha_s}. \tag{1}$$

Third, exploit equation (1), which decomposes average growth g_y into the sum of two terms. In particular, $g_z/(1 - \alpha_e - \alpha_s)$ represents the contribution of neutral technological progress, while $\alpha_e g_q/(1 - \alpha_e - \alpha_s)$ represents the contribution of IS technological progress.

In their quantitative application, GHK calibrate g_z, g_q, α_e, and α_s based on annual data ranging from 1954 to 1990. Their estimates imply that the average annual growth rate $g_y = 1.34\%$ can be decomposed into a 0.56 points contribution from neutral technological progress and a 0.77 points contribution from IS technological progress. Hence, GHK conclude that IS technological progress accounts for 0.77/1.34 = 58 percent of postwar U.S. growth. Using the same setup but a different calibration of g_q, Whelan (2003) estimates a smaller contribution of IS technological progress to aggregate growth amounting to 25 percent.[1]

3. The Role of Trend Breaks

Both GHK and Whelan treat the postwar period as a homogeneous sample. In this section, I review empirical evidence suggesting that trend breaks in neutral and IS technology occurred in the 1970s. Then, I update the decomposition of U.S. growth based on a subsample analysis.

3.1. **Evidence for breaks.**

Figure 3 in GHK (p. 351) reports estimates of neutral and IS technology and provides direct evidence of breaks. The figure shows that GHK's estimate of neutral technology until the early 1970s, but then *declined.* This is a major trend break, suggesting that g_z turned from positive to negative in the middle of the GHK sample. IS technology grew over the full sample, but accelerated in the late 1970s. This is a second trend break, representing a rise in g_q. I formalize this evidence using updated estimates of technology and econometric tests.

I work with quarterly data ranging from 1950Q1 to 2019Q4. Following GHK, I measure IS technology by the inverse of the relative price of equipment goods. The model from Section 2 implies that one unit of consumption trades against Q_t units of equipment, so that $1/Q_t$ is the equilibrium relative price.[2] Following Whelan (2003), I rely on National Income and Product Accounts (NIPA) data, measuring the relative price as the ratio between the price of producer equipment and a chained price index for consumer non-durables and services. I measure neutral technology using Fernald's (2014) estimate of total factor productivity

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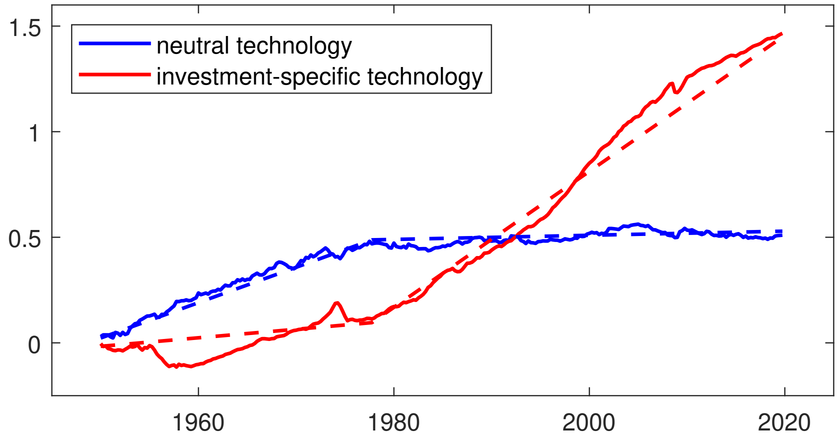
[1] Whelan argues that GHK's data overstate the rate of decline of the relative price of equipment, resulting in an upward-biased estimate of the rate of IS technological growth.

[2] Section 4 discusses potential caveats of this strategy.

Figure 1. Breaks in neutral and IS technology



Notes. The series are in log (see the text for sources). Dashed lines represent estimated deterministic trends with a common break in 1977Q4.

(TFP) for the consumption sector, adjusted for variable utilization. Moura (2021) shows that this is the correct estimate of neutral technology in standard two-sector models.

Let Δz_t and Δq_t denote the log-differences of neutral and IS technology, define $x_t = [\Delta z_t; \Delta q_t]$, and consider the simple model $x_t = \mu + \epsilon_t$, where μ is average growth and ϵ_t is a shock. Qu and Perron (2007) provide a test of the null hypothesis that μ is constant in sample. When applied to neutral and IS technology growth, the test rejects the null at the 1% level, with an exp-Wald statistic of 44.1 and 1977Q4 as the estimated break date. Figure 1 presents the series together with the implied trends: the slowdown in neutral technological growth and the acceleration in IS specific technological growth are apparent to the naked eye. The figure also suggests that a common break date is a reasonable assumption.[3]

The literature recognizes the importance of both breaks. For instance, the 1970s break in neutral technology coincides with the start of the well-known U.S. productivity growth slowdown, as discussed in Fernald (2007) and Gordon (2012). Fisher (2006), Benati (2014), and Moura (2021) provide earlier evidence for the acceleration in the rate of decline of the relative price of investment in the late 1970s-early 1980s.

3.2. **Strategy.** I use a split sample to deal with structural breaks. Based on the Qu-Perron test, I focus on two sub-periods: 1950Q1-1977Q4 and 1978Q1-2019Q4. As explained in Footnote 3, cutting the first subsample in 1973Q1 to allow for a separate break in neutral

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[3] For robustness, I also identified separate breaks. The estimated break dates are 1973Q1 for neutral technology and 1977Q4 for IS technology. I focus on the common break for three reasons: (i) the confidence bands for the separate breaks overlap, making a common break possible; (ii) the common break yields two clear sub-samples, while separate breaks also yield a third "intermediate" sub-period; (iii) the decomposition of aggregate growth in Table 1 barely changes when I use separate instead of common breaks to split the data.

Table 1. Average growth rates and contributions to economic growth.

	Sample		
	1950-2019	1950-1977	1978-2019
A. Average growth rates			
Output in consumption units (g_y)	1.58%	2.40%	1.03%
Neutral technology (g_z)	0.75%	1.61%	0.17%
Investment-specific technology (g_q)	2.09%	0.40%	3.22%
B. Contribution to growth			
Neutral technology ($g_z/[g_z + \alpha_e g_q]$)	68%	96%	24%
Investment-specific technology ($\alpha_e g_q/[g_z + \alpha_e g_q]$)	32%	4%	76%

Notes. Panel A reports the average annual growth rates for output in consumption units, neutral technology, and IS technology. Panel B shows the implied contributions to aggregate growth. See the text for details.

technology leaves the quantitative findings unaffected. Finally, I also consider the full sample for comparison.

As noted above, I measure the rate of IS technological progress g_q by the average rate of decline of the relative price of equipment. I compute the growth rate of neutral technology g_z from equation (1), given values for average growth of output in consumption units and of IS technology, g_y and g_q, and the two exponents α_e and α_s. I measure Y_t as the ratio of per-capita nominal GDP to the consumption price index used to compute the relative price of equipment. Nominal GDP comes from the NIPA and the population series is civilian non-institutional population over 16. I use the same values $\alpha_e = 0.17$ and $\alpha_s = 0.13$ as GHK.

3.3. **Findings.** Table 1 contains the results. Panel A reports the annual growth rates for output in consumption units, neutral technology, and IS technology over both the full 1950-2019 sample and the two sub-periods. Panel B shows the implied decomposition of aggregate growth into contributions from neutral and IS technological change.

Over the full postwar sample, per-capita output in consumption units grew at an annual rate of 1.6%. The decomposition indicates that 68 percent of this average growth rate originates from neutral technological progress. The remaining 32 percent comes from IS technological growth. These estimates are close to those reported in Whelan (2003), confirming that using NIPA data to compute the relative price of equipment leads to a smaller contribution of IS technological change compared to GHK.

The main point of this note is that the full-sample analysis masks substantial heterogeneity across sub-periods. The second column in Table 1 shows the results for the 1950-1977 sample. At 2.4% per year, average per-capita output growth was about 1 percentage point higher than in the full sample. Furthermore, neutral technological progress grew at an annual rate above 1.5%, explaining 96 percent of aggregate growth. On the other hand, the contribution of

IS technological change was negligible. Clearly, a one-sector growth model seems reasonable for this period.

The third column in Table 1 reports the results for the more recent 1978-2019 sample. Compared to the earlier period, average per-capita output growth is divided by 2, reaching only 1 percent per year. This slowdown is due to the fall in average neutral technological growth, which barely reaches 0.2% percent a year since the 1980s. Contrasting this figure with the 1.6% value in the earlier sample highlights the size of the downward break in neutral technology. At the same time, IS technological progress accelerated, reaching more than 3% per year. As a result, the decomposition of aggregate growth for the recent period looks very different: neutral technological progress only accounts for 24 percent of growth, while IS technological change contributes as much as 76 percent.

4. Discussion

These findings have two important implications for macroeconomic analysis. First, they provide a strong argument for splitting the postwar sample. Indeed, the measured shifts in average growth and its sources are sufficiently large and persistent to justify taking them into account, for example in the calibration of general-equilibrium models. Second, the fact that the second sub-sample exhibits slow neutral change and fast IS technological progress makes a strong case for using two-sector models, instead of one-sector models, to study the recent period.

The dramatic slowdown in neutral technological progress has strong implications for the U.S. economy's productive capacity and, ultimately, welfare. Understanding the causes, timing, and persistence of this break seems especially important. Available theories emphasize learning costs related to the adoption of new capital goods (Greenwood and Yorukoglu, 1997) or falling returns to past inventions (Gordon, 2012), but more research is needed to reach consensus.

Finally, I mention two caveats implying that inferring IS technology from relative equipment prices may be misleading. First, various wedges may complicate the pass-through of relative technology to relative prices, for instance time-varying markups or sticky prices (Basu, Fernald, Fisher, and Kimball, 2011; Moura, 2018). As long as these wedges remain stationary, they should not bias inference based on long-run averages.

Second, equipment prices are heterogeneous: recent research by Gourio and Rognlie (2021) argues that the rapid decline in equipment prices originates from computers, with other equipment goods featuring more stable prices. As a result, inferring IS technology from aggregate equipment prices may entail an upward bias, overestimating the growth contribution of IS technological progress. Furthermore, overestimating physical capital growth may lead to underestimating neutral technological progress in growth-accounting exercises. Whether this channel might account for the measured productivity slowdown is an important open question.

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