



# Specification Searching in the Race between Education and Technology<sup>1</sup>

Joseph Francis<sup>2</sup>

[LINK TO ABSTRACT](#)

In the early 1990s, many economists came to see education as key to growth. N. Gregory Mankiw, David Romer, and David N. Weil (1992) famously augmented Robert M. Solow’s (1956) neoclassical growth model by including the secondary school enrollment rate as a measure of investment in “human capital.” The result was a policy agenda that sought to increase funding for education. Hence, when the Federal Reserve Bank of Kansas City invited numerous leading economists to its annual symposium at Jackson Hole on August 27–29, 1992, this became the major theme of the conference. Mankiw (1992, 90–91), for example, described education as one of the “four secrets to fast growth.” On this, there was some consensus among assembled grandees, who were predominantly employed at Harvard. “If the often-bickering economists were able to forge a consensus on anything,” the *New York Times* reported, “it was that providing more education is a sure way for a nation to increase its output. Time and again, the economists stressed the importance of improving ‘human capital,’ meaning that a better-educated, better-trained work force can lift a nation’s growth rate” (Greenhouse 1992).

Alongside the economic-growth narrative is a parallel narrative that portrays education spending as key to reducing inequality. It is based on a model first proposed by Lawrence F. Katz and Kevin M. Murphy (1992) that has been massively influential. This article reviews how the model has repeatedly failed to predict the

---

<sup>1</sup> Joseph Richardson and three anonymous reviewers kindly gave feedback on earlier drafts. All errors made and opinions expressed are the author’s own.

<sup>2</sup> University of Birmingham, Birmingham B15 2TT, United Kingdom.

evolution of its dependent variable, the college wage premium. Various specifications of the econometrics used to test the model are replicated using data from David H. Autor, Claudia Goldin, and Katz's (2020) most recent update. Their dataset for the college wage premium and the relative supply of college-educated labor covers the period 1914 to 2017, and it has been extended here to 2023 using the same source, the Current Population Survey (CPS).<sup>2</sup> That dataset is first used to replicate Katz and Murphy's (1992) original results and then the original out-of-sample test performed by Autor, Katz, and Melissa S. Kearney (2008). Finally, the elaborate specifications found in Goldin and Katz's (2008) book *The Race between Education and Technology* are replicated. It should be stressed that the replications are not exact, given how the dataset has changed over time. Nonetheless, they are sufficiently close to the originals to demonstrate the problem that the Katz-Murphy model has routinely faced: as Autor, Katz, and Kearney (2008) first noted, the model is unable to predict the evolution of the college wage premium, which has led to ex-post specification searching to make the model fit the data. Standard tests from time series econometrics indicate, moreover, that the model is misspecified and has probably depended on spurious regressions for its validation.

## The Katz-Murphy Model

Katz and Murphy (1992) contributed to the pro-education *zeitgeist*. Published in the *Quarterly Journal of Economics*, their article sought to explain why the college wage premium had risen in the United States since the late 1960s. Their model predicted that skill-biased technological change increases the demand for college-educated labor, which makes the college wage premium rise when the supply of educated labor does not increase at a sufficient rate to meet it. From Katz and Murphy's perspective, more expenditure on education would therefore reduce inequality by increasing the supply of high-skilled workers. Increased education spending would both increase growth and reduce inequality.

The policy implications were clear: the United States and other Western countries had to channel more resources into their education sectors. Katz (1992,

---

<sup>2</sup> As can be found in the supplementary materials of this article, Autor, Goldin, and Katz's (2020) various Stata do files are converted to R scripts. The series are then extended from 2017 to 2023 using the same methodology and new raw data from Flood et al. (2024). The data for earlier years (1914, 1939, 1949, and 1959) are taken from Autor et al. and spliced using a linear offset at 1969, based on the same procedure they use. The R scripts also check the replicated data against Autor et al.'s original Stata files to ensure the series are being reproduced exactly. The only significant methodological improvement made is that Autor et al. arbitrarily splice one series with weights for 1963–2005 with another with weights for 2005–2017, whereas in the new dataset the fixed efficiency-unit weights and composition weights used in constructing the relative supply and wage premium series are computed for each period of the three replications and their out-of-sample tests. This produces series that are theoretically consistent for each period, although the practical difference is minimal.

218) told the conference at Jackson Hole in August 1992 that “widespread investments in education appear not only to be associated with faster growth but also with a more egalitarian distribution of the fruits of economic growth.” More money for education would then cure the ill of rising inequality that had afflicted American capitalism since the 1970s. “A rapid increase in the supply of more educated workers tends to narrow wage differentials by skill,” Katz (1992, 222–223) explained. “Industrialization can be associated with a more equal distribution of economic resources if accompanied by increased access to education.” East Asia was held up as an example. “Countries that invest heavily in widespread education, such as Taiwan and South Korea, appear to grow extremely rapidly and to generate much more equal income distributions than do countries that industrialize in a more unbalanced manner.” It was clear what needed to be done: “increased investments in education have the potential to produce a ‘win-win’ situation of strong economic growth and a more equitable distribution of economic resources,” Katz told the conference.

An aggregate production function was central to the model. Katz and Murphy imagined that the college wage premium was set by the relative supply of college-educated labor and the increasing demand from skill-biased technological change. By equating the ratio of wages to the ratio of marginal products, they transformed the production function into an estimable regression equation:

$$\log\left(\frac{w_{1t}}{w_{2t}}\right) = \beta_0 + \beta_1 \cdot \log\left(\frac{x_{1t}}{x_{2t}}\right) + \beta_2 \cdot \text{time}_t + \varepsilon_t \quad (1)$$

where the log of the college/high school wage ratio  $\left(\frac{w_{1t}}{w_{2t}}\right)$  in year  $t$  is a function of the log of the relative supply of college- to high school-equivalent workers  $\left(\frac{x_{1t}}{x_{2t}}\right)$ . Crucially, the coefficient  $\beta_1$  is not merely a statistical correlation; it represents the inverse elasticity of substitution ( $1/\sigma$ ) between the two labor inputs—a direct structural parameter of the aggregate production function. The coefficient  $\beta_2$  of the linear trend ( $\text{time}_t$ ) is supposed to capture the average annual percentage change in relative demand for college-educated labor due to skill-biased technological change, while  $\beta_0$  is the constant and  $\varepsilon_t$  is the error term. This simple model then provided Katz and Murphy with a parameter—the elasticity of substitution between college and high school-educated labor ( $\sigma$ )—that would be relevant for policymakers.

Katz and Murphy (1992) validated their model using estimates of the college wage premium and the relative supply of college-educated labor for 1963–1987. In the replication in Table 1, a large coefficient for relative supply (–0.691) produces an elasticity of substitution between college and high school-educated workers of  $\sigma = 1.4$ .<sup>3</sup> Given this relatively low elasticity, Katz and Murphy concluded that college-

---

<sup>3</sup> In their original version, Katz and Murphy (1992, 69) reported coefficients of –0.709 for relative supply

and high-school-educated workers are not easily substitutable. As such, an increase in the relative supply of educated workers would exert downward pressure on the college wage premium, making it a potent tool for reducing wage inequality. “Alternative explanations” for rising inequality—“changes in wage-setting institutions such as the decline in unions [...], changes in pay norms [...], and the erosion of the real value of the minimum wage”—were, according to Katz and Murphy (1992, 36), of secondary importance. Increased spending on education should be the primary means to tackle rising inequality.

**TABLE 1: Replication of Katz and Murphy (1992, 69)**

Log relative supply	−0.691*** (0.133)
Time trend	0.030*** (0.006)
Constant	−0.314* (0.144)
Observations	25
Adjusted $R^2$	0.564
Notes: The dependent variable is the log college wage premium, and the time trend is a proxy for increasing demand due to skill-biased technological change. The regression is for 1963–1987. OLS standard errors are in parentheses; *** $p < 0.001$ , ** $p < 0.01$ , * $p < 0.05$ , · $p < 0.10$ . Calculated from the replication data for Autor, Goldin, and Katz (2020).	

## The Specification Searches

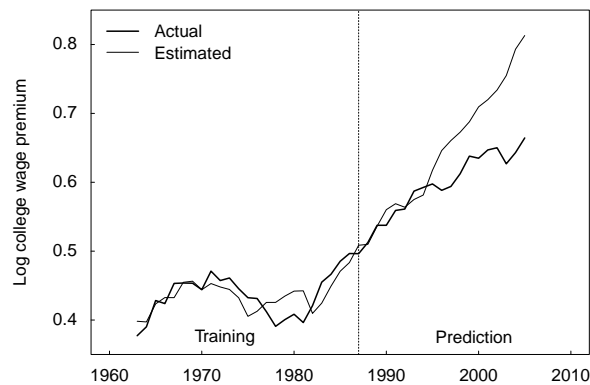
In time, the model’s limitations became apparent. Katz, together with Autor and Kearney, updated the original dataset using more recent versions of the CPS. Their goal was to respond to critics of the Katz-Murphy model who argued that it had too easily dismissed alternative explanations for rising inequality (Card and Lemieux 2001; Lemieux 2006). But in defending the Katz-Murphy model, Autor et al. (2008) revealed something strange. When they trained the model on data from the original sample of 1963–1987, it failed to predict the evolution of the college wage premium during 1987–2005, as replicated in Figure 1. “The Katz-Murphy model does an excellent job of forecasting the growth of the college wage premium through 1992 (with the exception of the late 1970s),” Autor et al. (2008, 307) stated, “but the continued slow growth of relative supply after 1992 leads it to overpredict the growth in the college wage premium over the last decade.” The Katz-Murphy model suggested that the college wage premium should have soared,

---

and 0.033 for the time trend, also implying  $\sigma = 1.4$ .

but it had increased far more slowly. Autor et al. (2008, 308) were then left with the “puzzle posed by slowing trend relative demand for college workers in the 1990s.” In this way, Autor et al. themselves identified the first out-of-sample failure of the Katz-Murphy model, using their own updated dataset—a finding that is confirmed by the replication made here.

**Figure 1:** Out-of-Sample Test of Katz and Murphy (1992), 1963–2005



Notes: The estimated line is calculated using the specification in Table 1, based on the years 1963–1987. Calculated from the replication data underlying Autor, Goldin, and Katz (2020), following Autor, Katz, and Kearney (2008, Figure 4.B).

Ex-post adjustments to the model were the solution. As replicated in Columns 3 to 5 of Table 2, Autor et al. introduced higher-order time trends and time breaks into the model to make it fit the data.<sup>4</sup> The time break in 1992 introduced in Column 3 was seen as particularly important, and Autor et al. (2008, 318–320) hypothesized that it reflected how computerization had affected “abstract” and “routine” tasks differently, making it necessary to modify the Katz-Murphy model. Autor et al. (2008, fn. 15) also pointed toward a working paper in which “Goldin and Katz (2007) find that rather steady relative demand growth for college workers combined with relative supply growth fluctuations does a nice job of explaining the longer-run evolution of the U.S. college wage premium from 1915 to 2005.” *The Race between Education and Technology* was being born.

The warnings about this approach in econometrics textbooks seem to have been overlooked. In the updated edition of *Introduction to Econometrics*, Maddala (2001, 479) described how, in theory, “the statistical model underlying the data is

<sup>4</sup> The results of the replication are again close. In their preferred specification in Column 3, for example, Autor et al. found coefficients of  $-0.619$  for relative supply and  $0.026$  for the time trend, compared to  $-0.642$  and  $0.029$  in the replication here.

**TABLE 2: Replication of Autor, Katz, and Kearney (2008, 307, Table 2)**

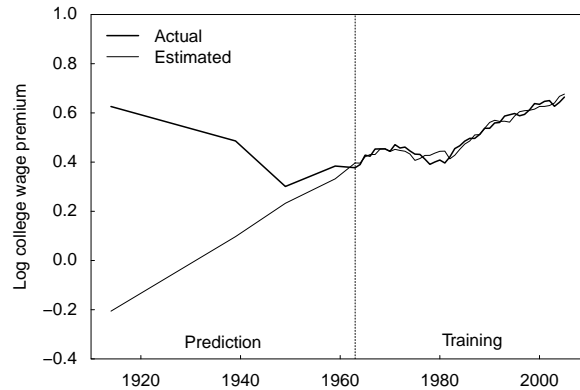
	(1)	(2)	(3)	(4)	(5)
Log relative supply	-0.663*** (0.133)	-0.370*** (0.047)	-0.642*** (0.071)	-0.589*** (0.121)	-0.668*** (0.109)
Time trend	0.029*** (0.006)	0.018*** (0.001)	0.029*** (0.003)	0.030*** (0.007)	0.026*** (0.006)
Time <sup>2</sup> / 100				-0.014 (0.007)	0.030* (0.014)
Time <sup>3</sup> / 1000					-0.008** (0.002)
Time trend × post-1992			-0.010*** (0.002)		
Constant	-0.250 (0.134)	0.041 (0.043)	-0.231** (0.069)	-0.193 (0.127)	-0.250* (0.113)
Observations	25	43	43	43	43
Adjusted $R^2$	0.562	0.923	0.949	0.929	0.944
Notes: The dependent variable is the log college wage premium, and the time trend is a proxy for increasing demand due to skill-biased technological change. Column 1 is for 1963–1987; Columns 2–5 are for 1963–2005. OLS standard errors are in parentheses; *** $p < 0.001$ , ** $p < 0.01$ , * $p < 0.05$ , · $p < 0.10$ . Calculated from the replication data for Autor, Goldin, and Katz (2020).					

assumed to be known at the outset and the problem is merely one of obtaining good estimates of the parameters [...]. In reality, however, the choice of a model is almost always made after some preliminary data analysis.” Edward E. Leamer’s (1978, Ch. 1) description of how economists actually worked was repeated. “[I]n the case of a regression model,” Maddala (2001, 479) wrote, “we start with a specification that seems most reasonable a priori. But after examining the coefficients, their standard errors and the residuals, we change the specification of the model.” Maddala then offered a balanced assessment: “Purists would consider this ‘data mining’ as an illegitimate activity, but it is equally unreasonable to assume that we know the model exactly at the very outset.” Nonetheless, Maddala (2001, 483) also warned against precisely what Goldin and Katz (2008) appeared to subsequently do: “Commence from theories which are drastic abstractions of reality [...]. Formulate highly parsimonious relationships [...]. Estimate the equations... Test a few of the assumptions [...]. Revise the specification in the light of evidence acquired [...]. Reestimate accordingly.” In *Introductory Econometrics: A Modern Approach*, Jeffrey M. Wooldridge (2006, 688) spelled out the consequences in particularly stark terms: “Unfortunately, this practice of data mining violates the assumptions we have made in our econometric analysis,” he explained. “The results on unbiasedness of OLS and other estimators, as well as the  $t$  and  $F$  distributions we derived for hypothesis testing, assume that we observe a sample following the population

model and we estimate that model once.” Specification searching violates that assumption. “In effect, we use the outcome of tests by using the data to respecify our model.”

Goldin and Katz (2008) nevertheless used a respecified Katz-Murphy model to reiterate the call for more education spending. The CPS data for 1963–2005 were extended back using national censuses for 1959, 1949, and 1939, combined with the Ohio state census of 1914. The results were used to claim that the Katz-Murphy model applied throughout the twentieth century, justifying the familiar policy prescriptions. “If technology continues to race ahead (and history suggests it will) and educational attainment does not begin to increase rapidly,” Goldin and Katz (2008, 325) warned, “we are likely to see continued increases in inequality. For many reasons, then, the United States must find a way to increase the stock of educated Americans.” In this way, the message given by Katz at Jackson Hole more than a decade earlier was reiterated: channeling more money into education was the way to tackle rising inequality. Economic history seemed to prove it.

The empirical basis for these claims still left something to be desired. The Katz-Murphy model continued to fail out-of-sample tests. In Figure 2, Autor et al.’s (2008) preferred specification from Column 3 of Table 2 is tested using the extended dataset first presented by Goldin and Katz (2008). Given Autor et al.’s introduction of a time break in 1992 (rationalized to reflect the arrival of computers), their preferred specification achieves a predictably good fit when trained on the CPS data for 1963–2005. But when it attempts to predict the college wage premium using Goldin and Katz’s historical estimates for 1914, 1939, 1949, and 1959, its failure is significant. The divergence between the actual and the estimated series is immediate and increases as the estimates go back to 1914. From an econometric perspective, this is unsurprising, given that extrapolating far out from the sample period is likely to produce divergence when a positive linear trend is included. Nonetheless, in the case of the Katz-Murphy model, that trend variable has a particular theoretical property that makes the failure of the out-of-sample test a major red flag: the positive linear trend is supposed to represent the steady increase in relative demand for college-educated labor due to skill-biased technological change. And it is precisely the steadiness of that increase that is supposed to make changes in the relative supply of college-educated labor the principal determinant of the college wage premium and, by extension, the level of inequality. The failure of the out-of-sample test in Figure 2 therefore indicates that the Katz-Murphy model cannot explain the evolution of its dependent variable back to the early twentieth century.

**Figure 2:** Out-of-Sample Test of Autor, Katz, and Kearney (2008), 1914–2005

Notes: The estimated line is calculated using the specification in Column 3 of Table 2, based on the years 1963–2005. Calculated from the replication data underlying Autor, Goldin, and Katz (2020).

Further specification searches became necessary. Goldin and Katz (2008, Table 8.2) presented the five specifications replicated in Table 3. A plethora of time breaks and a time dummy variable were introduced, producing close fits with high  $R^2$ s. Goldin and Katz’s iterative additions of time breaks and dummy variables constitute what Leamer (1978, 1) termed “specification searching.” Ex-post adjustments were made to the model in response to the out-of-sample failures. Whether or not the structural breaks they identified reflect genuine macroeconomic shifts, the effect is the same: the model’s explanatory power comes from these undertheorized time components rather than from the supply mechanism that their narrative emphasizes. Goldin and Katz (2008, 298) nevertheless took the close fit achieved by these ex-post adjustments as confirmation of their argument that “changes in the relative supply of college workers had a substantial and economically significant negative impact on the college wage premium across the entire period.” They described how Column 3, in particular, “fits the data extremely well and provides our preferred specification.”<sup>5</sup>

There was no theoretical justification offered for these new specifications. Indeed, their results directly contradicted the long narrative that preceded them in *The Race between Education and Technology*. Throughout the first seven chapters of the book, Goldin and Katz assume a constant growth in relative demand for college-educated labor due to skill-biased technological change across the twentieth century. They establish this early on in their general argument, which persistently emphasizes the stability in the growth of demand. “The skill bias of technology

<sup>5</sup> The replication is close to Goldin and Katz’s (2008, Table 8.2) original: in their preferred specification in Column 3, they find a coefficient of  $-0.610$  for relative supply and  $0.010$  for the time trend, compared to  $-0.626$  and  $0.010$  respectively in the replication.

**TABLE 3: Replication of Goldin and Katz (2008, 299, Table 8.2)**

	(1)	(2)	(3)	(4)	(5)
Log relative supply	-0.474*** (0.090)	-0.634*** (0.098)	-0.626*** (0.075)	-0.614*** (0.102)	-0.654*** (0.090)
Log relative supply × post-1949					0.026 (0.042)
Time trend	0.001 (0.002)	0.010*** (0.002)	0.010*** (0.002)	0.015* (0.006)	0.011*** (0.003)
Time trend × post-1949	0.020*** (0.002)				
Time trend × post-1959		0.018*** (0.001)	0.018*** (0.001)		0.017*** (0.002)
Time trend × post-1992	-0.003 (0.003)	-0.010** (0.003)	-0.009*** (0.002)		-0.009*** (0.002)
1949 dummy			-0.124*** (0.023)		-0.144*** (0.039)
Time <sup>2</sup> / 10				-0.006* (0.002)	
Time <sup>3</sup> / 1000				0.015*** (0.004)	
Time <sup>4</sup> / 100000				-0.009*** (0.002)	
Constant	-0.397* (0.196)	-0.788*** (0.214)	-0.751*** (0.164)	-0.727** (0.223)	-0.819*** (0.200)
Observations	47	47	47	47	47
Adjusted R <sup>2</sup>	0.913	0.916	0.951	0.927	0.950
Notes: The dependent variable is the log college wage premium, and the time trend is a proxy for increasing demand due to skill-biased technological change. OLS standard errors are in parentheses; *** $p < 0.001$ , ** $p < 0.01$ , * $p < 0.05$ , · $p < 0.10$ . Calculated from the replication data for Autor, Goldin, and Katz (2020).					

did not change much across the century, nor did its rate of change,” Goldin and Katz (2008, 8) write. “Rather, the sharp rise in inequality was largely due to an educational slowdown.” And this theme is reiterated: “Since the demand-side changes were similar across the twentieth century,” Goldin and Katz (2008, 93) assert, “the change from the first part of the century to the last part concerns the other half of the inequality equation: supply. Supply fluctuations in educated and skilled labor are key factors in explaining changes in inequality.” It is precisely this emphasis on the importance of supply that leads them to call for more education spending. Their entire policy agenda is predicated on the belief that demand increases at a constant rate, which education has to keep up with. Nonetheless, to make their model fit the data, they had to use dummy variables that introduce time trends,

suggesting that demand actually increased at different rates during different periods in the twentieth century.

To the extent that they were given at all, the explanations were weak. Goldin and Katz (2008, 293) indicate that the 1940s are a problem for their model. “The wage compression of the 1940s,” they write, “went far beyond what can be accounted for by market forces alone and was driven in part by institutional factors of the World War II era, such as the greatly expanded role of unions and the residual impact of the wartime wage-setting policies.” A dummy variable for 1949 is then proposed to address the issue, which at least provides a narrative rationale for adjusting a single anomalous observation. There is, by contrast, no explanation at all for the time breaks introduced with the interaction terms for 1949 and 1959. “Interactions with specific years enable demand trend changes,” Goldin and Katz (2008, 298, 301) note, but without reconciling this feature of their econometrics with the narrative that precedes it. Variations in the growth of relative demand for skilled workers are instead treated as given. Goldin and Katz (2008, 301) describe how the specification in Column 1 of Table 3 “allows trend demand to differ between the first and second halves of the twentieth century by including an interaction with a post-1949 dummy variable.” And they note that the coefficients show “slow demand growth for college workers in the first half of the twentieth century” and “a sharp acceleration after 1949.” Adding a different time interaction term in Column 2 then “allows the demand trend shift to occur after 1959, rather than 1949.” The dependence of their respecified Katz-Murphy model on these time interaction terms, which introduce massive shifts in the rate of demand growth and do the heavy lifting in the regressions, is never explained. While the appeal to the wartime-institutions narrative provides a rationale for the 1949 dummy (which adjusts a single census observation), it says nothing about why the rate of demand growth should have accelerated after 1949 or 1959. The specific timing of these demand shifts appears to have been empirically fitted to the data, not derived from any theory.

*The Race between Education and Technology* is thus inconsistent. Over seven chapters, there is a story of constant growth in the demand for college-educated labor due to technological change, with supply described as the key variable determining the college wage premium and inequality. Then, in the econometric chapter, an unexplained demand shift comes to dominate. Furthermore, if the regressions are taken seriously, the demand shift was massive. In Column 1 of Table 3, the coefficients indicate that relative demand grew by just 0.2 percent per year from 1914 to 1949, but by 4.4 percent annually from 1949 to 1992. In Column 2, the annual increase is 1.5 percent from 1914 to 1959 but 4.4 percent from 1959 to 1992. And finally, in Goldin and Katz’s (2008, 301) “preferred specification” in Column 3, relative demand increases by 1.5 percent per year from 1914 to 1959, although

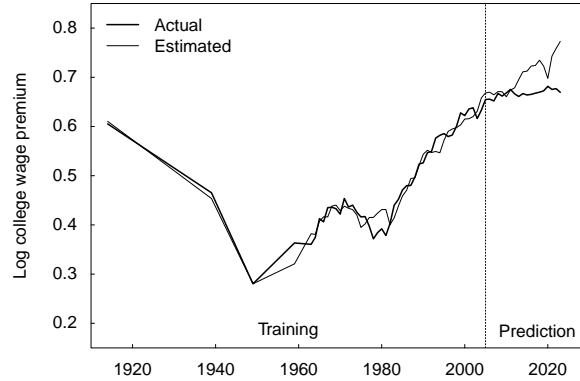
with an incredible 0.12 log-point drop (equivalent to 11.3 percent) imposed by the dummy variable between the 1939 and 1949 censuses; a 4.4 percent annual growth rate follows from 1959 to 1992. After 1992, the implied net trend falls back to 3.0 percent. There is thus a fundamental mismatch between the narrative of a constant rate of growth in the relative demand for college-educated labor and the numbers that are supposed to validate it.

Yet *The Race between Education and Technology* was widely praised upon publication by Harvard University Press. In the *New York Times*, N. Gregory Mankiw asserted that Goldin and Katz had successfully explained why inequality had increased. “The best diagnosis so far comes from two of my Harvard colleagues, Claudia Goldin and Lawrence F. Katz, in their forthcoming book,” Mankiw (2008) wrote. “Their bottom line: ‘the sharp rise in inequality was largely due to an educational slowdown’”—that this bottom line was not supported by the econometrics in the book was not mentioned. In a 38-page review essay in the *Journal of Economic Literature*, MIT professors Daron Acemoglu and David Autor (2012, 426, 427) went further, describing the book as a “monumental achievement [...] supported with compelling historical and econometric evidence.” They did not mention that the historical and econometric evidence directly contradicted each other. Acemoglu and Autor (Ibid., 436) instead reported a “robust inverse relationship” that “demonstrates the key role played by the decelerating supply of college workers in driving the college premium upward in recent decades.”

A final out-of-sample test illustrates why such claims should have been met with more skepticism. While Goldin and Katz’s (2008) time series end in 2005, they have been updated to 2017 by Autor, Goldin, and Katz (2020) and can be extended further to 2023 using the more recent iterations of the CPS. The period 2006–2023 can then be used to test what Goldin and Katz (2008, 298) described as their “preferred specification,” as replicated in Column 3 in Table 3. Figure 3 shows that the ex-post adjustments to the original Katz-Murphy model produce a close fit to the actual college wage premium up to 2005. But the model again fails to predict the evolution of the college wage premium after its training data ends in 2005. Once more, it predicts a surging college wage premium that has in fact remained all but stationary. Out-of-sample  $R^2$  values quantify the severity of these failures:  $-1.83$  for Katz and Murphy’s (1992) prediction in Figure 1,  $-13.46$  for Autor et al.’s (2008) backcast in Figure 2, and  $-43.71$  for Goldin and Katz’s (2008) prediction in Figure 3. These negative values indicate that each model performs worse than simply predicting the historical average of the holdout period.<sup>6</sup>

---

<sup>6</sup> Out-of-sample  $R^2$  is computed as  $1 - \frac{SS_{res}}{SS_{tot}}$ , where  $SS_{tot}$  is the total sum of squares of the holdout-period actuals around their own mean (not the full-sample mean).

**Figure 3:** Out-of-Sample Test of Goldin and Katz (2008), 1914–2023

Notes: The estimated line is calculated using the coefficients for Column 3 in Table 3, based on the years 1914–2005. Calculated from the replication data underlying Autor, Goldin, and Katz (2020), updated with data for 2018–2023 from Flood et al. (2024).

The out-of-sample tests thus suggest that the Katz-Murphy model is probably too parsimonious to explain the evolution of the college wage premium. The model’s initial appeal was how it reduced complexity to a simple story of supply and demand. Yet the time trend was ultimately a poor proxy for the relative demand for college-educated labor. It instead absorbed the effects of all the factors that Katz and Murphy (1992, 36) attempted to sideline, such as “changes in wage-setting institutions such as the decline in unions [...], changes in pay norms [...], and the erosion of the real value of the minimum wage.” The time trend was, in other words, a proxy for economic history—all the things that the Katz-Murphy model ignores due to its excessive parsimony. The emphasis on the relative supply of college-educated labor is, moreover, unwarranted. A Shapley value decomposition can serve as a diagnostic tool to quantify the extent of this reliance on undertheorized time trends. As Table 4 shows for Goldin and Katz’s preferred specification, relative supply explains approximately 15 percent of the variance in the college wage premium. Such a percentage of the variation explained is non-trivial, but still contrasts strongly with the centrality of relative supply in their narrative. In fact, around 80 percent of the variation is explained by the combined effects of the time trends and breaks. The time components are thus doing the vast majority of the work in the regression: the model’s explanatory power comes overwhelmingly not from the relative supply mechanism that Goldin and Katz emphasize, but from variables that absorb all the various alternative factors that have driven rising inequality in the United States.

**TABLE 4: Shapley Values for Goldin and Katz’s Preferred Specification, 1914–2005**

Log relative supply	0.147 (0.119, 0.216)
Time trend	0.125 (0.095, 0.217)
Time break dummies	0.685 (0.529, 0.749)
Notes: The Shapley values are calculated for the regression in Column 3 of Table 3, following the method of Lindeman, Merenda, and Gold (1980, 119–120), as implemented by Grömping (2006). The 95 percent confidence intervals in parentheses are derived from 1,000 bootstrap iterations using resampling with replacement. Bootstrap resampling is conditional: any draw that does not include the 1949 observation is discarded and redrawn. The reported confidence intervals are therefore conditional on 1949 always being represented.	

## The Original Misspecification

The specification searches were necessary because the original Katz-Murphy model was misspecified. Katz and Murphy (1992, 71–72) relied on a constant-elasticity-of-substitution (CES) aggregate production function “with two factors (college and high school equivalents),” whose relative supply determined their relative wages. Following the logic of Charles W. Cobb and Paul H. Douglas (1928), this approach imagines the economy to be a single factory using a single technology to transform two inputs into output. It supposes that relative wages are determined strictly by the intersection of supply curves and the marginal productivity schedules derived from this aggregate function—or, as Cobb and Douglas (1928, 163) concluded, that “the processes of distribution follow in large measure the processes of production.” In Katz and Murphy’s case, they believed that the aggregate production function would allow them to show how the college wage premium was determined by the relative supply of college-educated workers by assuming that competitive markets automatically set relative wages equal to the ratio of the marginal products of the two groups.

By the time that Katz and Murphy used it, this framework had already been subject to significant critiques.<sup>7</sup> Phelps Brown (1957) provided an early critique of the idea that fitting a production function to data could empirically verify the marginal productivity theory of wages. The simple Cobb-Douglas production function could produce impressive statistical fits, but Phelps Brown argued that they were merely a mathematical artifact of an accounting identity, given that the net value of production ( $P$ ) is, by definition, the sum of total wages ( $wL$ ) and total

<sup>7</sup> For surveys of this literature, see Felipe and Fisher (2003), Felipe and Holz (2010), and Felipe and McCombie (2013).

profits ( $rC$ ). This accounting identity mathematically mimics the power relationship of the Cobb-Douglas production function whenever the historical shares of income going to labor and capital remain relatively constant. The regression analysis does not discover a hidden technological parameter ( $k$ ); it merely recovers the labor share of income already present in the data. “The Cobb-Douglas  $k$ , and the share of earnings in income, will be only two sides of the same penny,” Phelps Brown (1957, 557) concluded. The close fits to the time series therefore confirmed that the accounting data is consistent with itself but said nothing about marginal productivity.

And the criticisms mounted. Franklin M. Fisher (1969) demonstrated the severe theoretical constraints of aggregate production functions, warning that they were invalid even as a reliable approximation except under highly unrealistic circumstances: that all firms have identical technologies, employ the same proportions of every type of labor, and produce the same products. Furthermore, Fisher’s (1971) simulations demonstrated that while aggregate Cobb-Douglas production functions yielded close empirical fits, they did so even when the underlying microeconomies firmly violated the strict technical conditions required for aggregation. Economists using these functions to represent underlying technological realities had been taken in by a statistical artifact generated by the tendency of economic time series to move together over time. “It reflects the fact that with everything moving in trends of one sort or another, an excellent fit is obtained regardless of misspecification of different sorts,” Fisher (1971, 312) noted. Fisher thereby anticipated precisely the problem that time series econometricians would subsequently formalize.

Aggregate production functions often seemed convincing due to the problem of what C.W.J. Granger and Paul Newbold (1974) called “spurious regressions.” By the time Katz and Murphy (1992) were writing, the problem was widely known. In his textbook *Econometric Methods*, for example, John Johnston (1987, 372–376), described how the stationarity of the time series needed to be checked before running regressions. He recommended using George E. P. Box and Gwilym M. Jenkins’s (1976) approach of visually inspecting the data and the sample autocorrelation function. G.S. Maddala’s (1988) *Introduction to Econometrics* featured Robert F. Engle and Granger’s (1987) more recent approach of using the Augmented Dickey-Fuller (ADF) test. Had Katz and Murphy (1992) applied it, they probably would have found a “unit root”—a stochastic trend—in both the series for the college wage premium and the relative supply of college-educated workers: in the replication, the test statistics are  $-1.585$  and  $-1.356$ , respectively, above the 5 percent critical value of  $-3.6$ , indicating the presence of a unit root. Following Engle and Granger’s approach, an ADF test applied to the model’s residuals produces a test statistic of  $-2.516$ , above the  $-4.18$  critical value that had recently been provided

by James G. MacKinnon (1990). The test that should have been done implies that the regression used to test the Katz-Murphy model was spurious.

The updated dataset for 1963–2023 supports Joseph Richardson’s (2025) recent critique of the Katz-Murphy model. Richardson uses Autor, Goldin, and Katz’s (2020) own replication data for the period 1963–2017 to test for spurious regressions. His findings are largely confirmed by the replicated and extended dataset used here: as shown in Table 5, a full suite of tests generally confirm the presence of unit roots at the 5 percent critical value, indicating that both the wage premium and relative supply are  $I(1)$  time series.<sup>8</sup> The Zivot-Andrews (ZA) test is the exception: the log wage premium remains non-stationary even after allowing for an automatically-identified structural break in 1982, but the log relative supply series appears stationary when a break is automatically identified in 1981. The cointegration tests in Table 6 are, by contrast, more definitive: the Engle-Granger, Gregory-Hansen, and Johansen tests all cannot reject the null of no cointegration, while the Shin test rejects its own null of there being cointegration. Only the low power of the tests casts doubt on the results.

**TABLE 5: Unit Root Tests, 1963–2023**

Test	Lags/bandwidth	Statistic	Critical value (%)		
			1	5	10
(a) Log wage premium					
ADF	1 lag	−1.18	−4.04	−3.45	−3.15
PP	Short	−1.40	−4.12	−3.48	−3.17
KPSS	Short	0.17	0.22	0.15	0.12
ZA	0 lag	−3.27	−5.57	−5.08	−4.82
(b) Log relative supply					
ADF	1 lag	−1.23	−4.04	−3.45	−3.15
PP	Short	−1.23	−4.12	−3.48	−3.17
KPSS	Short	0.36	0.22	0.15	0.12
ZA	1 lag	−6.11	−5.57	−5.08	−4.82
Notes: The table reports the results of four unit root tests: the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), Kwiatkowski-Phillips-Schmidt-Shin (KPSS), and Zivot-Andrews (ZA) tests. The ADF, PP, and ZA tests test the null hypothesis of a unit root (non-stationarity), while the KPSS test evaluates the null hypothesis of trend stationarity. The ZA test also accounts for endogenously identified structural breaks. ADF lag length is selected by AIC; Phillips-Perron and KPSS bandwidth is selected using the Newey-West short-lag formula; the Zivot-Andrews lag is selected automatically based on AIC. There are 61 observations for each test. Calculated from the replication data underlying Autor, Goldin, and Katz (2020), updated with data for 2018–2023 from Flood et al. (2024).					

<sup>8</sup> These tests cannot be applied to the pre-1963 series because the datapoints are discontinuous (1914, 1939, 1949, and 1959), making it impossible to carry out unit root tests.

**TABLE 6: Cointegration Tests, 1963–2023**

Test	Statistic	Critical value (%)		
		1	5	10
Johansen				
$r \leq 0$	11.71	30.45	25.32	22.76
$r \leq 1$	2.58	16.26	12.25	10.49
Engle-Granger (ADF)	-1.11	-4.26	-3.63	-3.34
Shin (KPSS)	0.19	0.184	0.121	0.097
Gregory-Hansen (ADI*)	-4.22	-6.16	-5.59	-5.28
<p>Notes: The table reports the results of four cointegration tests applied to the variables in the Katz-Murphy model: the Johansen test (using <math>K=2</math> lags in the VAR, selected by AIC), the Engle-Granger test (using the ADF statistic on the model's residuals, with MacKinnon critical values for a constant-and-trend cointegrating regression), the Shin test (using the KPSS statistic and residuals from a dynamic OLS cointegrating regression with one lead and one lag of the first difference of relative supply), and the Gregory-Hansen test (allowing for an endogenously determined structural break, found in 1999). The null hypothesis for the Johansen, Engle-Granger, and Gregory-Hansen tests is the absence of cointegration, whereas the null hypothesis for the Shin test is the presence of deterministic cointegration. There are 61 observations for each test. Calculated from the replication data underlying Autor, Goldin, and Katz (2020), updated with data for 2018–2023 from Flood et al. (2024).</p>				

If there is no cointegration, a first differences model becomes the next step. As shown in Table 7, changes in log relative supply have no statistically significant effect on changes in the log college wage premium. Column 1 reports a simple regression of the first difference of the wage premium on the first difference of relative supply, with Newey-West standard errors; the coefficient is small and insignificant, with an adjusted  $R^2$  of approximately zero. Column 2 adds lagged first differences of both variables, with no material change in the result. The Katz-Murphy model's central mechanism finds no support in the first-differenced data: increases in the relative supply of college-educated workers do not seem to depress the college wage premium.

An error correction model (ECM) acts as a further robustness test in case the failure to find cointegration is due to low power. If the wage premium and relative supply series are not cointegrated, the error correction term will be insignificant and the model should collapse to a first-differenced specification. If they are cointegrated, the ECM will capture both the long-run equilibrium and the short-run dynamics with valid standard errors—something that OLS on the levels cannot provide due to the unit roots in the  $I(1)$  time series. The bounds test is also robust to ambiguity about the integration order of the regressors, making it particularly appropriate given that the Zivot-Andrews test found log relative supply to be stationary around a structural break. Table 8 reports the results of an unrestricted ECM with four specifications. Column 1 tests the core supply-demand mechanism in isolation, deliberately excluding the time trend in order to assess whether wages

TABLE 7: First Differences Model, 1963–2023

	(1)	(2)
$\Delta \log$ relative supply	−0.049 (0.084)	−0.081 (0.101)
$\Delta \log$ wage premium (−1)		0.003 (0.124)
$\Delta \log$ relative supply (−1)		0.128 (0.093)
Constant	0.007* (0.003)	0.004 (0.003)
Observations	60	59
Adjusted $R^2$	−0.011	−0.004
Notes: The dependent variable is the first difference in the log college wage premium, and the constant is a proxy for increasing demand due to skill-biased technological change. Newey-West HAC standard errors are in parentheses; *** $p < 0.001$ , ** $p < 0.01$ , * $p < 0.05$ , $\cdot$ $p < 0.10$ . Calculated from the replication data for Autor, Goldin, and Katz (2020), updated with data for 2018–2023 from Flood et al. (2024).		

and relative supply share a genuine long-run cointegrating relationship. Column 2 then adds the time trend from the original Katz-Murphy model, while Column 3 adds the post-1992 break introduced by Autor, Katz, and Kearney (2008). Panel A reports the Pesaran-Shin-Smith bounds test, which returns an  $F$ -statistic of 1.319 in the baseline specification in Column 1, well below the lower critical value bounds at all conventional significance levels, indicating no evidence of a long-run relationship of cointegration; the  $F$ -statistic then falls further to 0.914 and 0.992 as the time components are added in Columns 2 and 3. It then falls further to 0.838 when the more principled 1999 time break suggested by the Gregory-Hansen test is used.

But even setting that lack of cointegration aside, the long-run coefficients clearly contradict the narrative of the race between education and technology. In all specifications in Panel B, the coefficients for relative supply are positive, directly contradicting the Katz-Murphy model's predictions, even if they are statistically insignificant in Columns 2 to 4.

Such complex econometrics may, however, be unnecessary because a simpler diagnostic is available. The Durbin-Watson statistics for the four specifications in Table 8, re-estimated by OLS, are reported in Panel A of Table 9. They range from 0.11 to 0.35, all with  $p < 0.001$ , indicating severe positive autocorrelation in the OLS residuals. This is unsurprising given the unit root test results, but it also means that the OLS standard errors are unreliable and the  $t$ -statistics are inflated. Panel B reports the results of applying the Prais-Winsten transformation, an iterative generalized least squares procedure that estimates and corrects for first-order autocorrelation in the residuals. Unlike unit root and cointegration tests, whose

TABLE 8: Error Correction Model, 1963–2023

	(1)	(2)	(3)	(4)
A. Bounds test ( $F$ -statistic)				
$F$ -statistic	1.319	0.914	0.992	0.838
Critical values for I(0)/I(1): 10% = 3.84, 4.58, 5% = 4.94, 5.73, 1% = 7.84, 8.82				
B. Long-run coefficients				
Log relative supply	0.175* (0.074)	0.416 (0.885)	0.182 (0.315)	0.186 (0.846)
Time trend		−0.007 (0.026)	−0.003 (0.010)	0.003 (0.024)
Time breaks			0.115 (0.084)	−0.193 (0.414)
Constant	0.622*** (0.067)	0.856 (0.888)	0.607* (0.299)	0.650 (0.832)
C. Error correction estimates				
Log wage premium (−1)	−0.059 (0.039)	−0.044 (0.057)	−0.094 (0.073)	−0.037 (0.058)
Time trend		−0.000 (0.001)	−0.000 (0.001)	0.000 (0.001)
Time breaks			0.011 (0.010)	−0.007 (0.009)
Constant	0.037· (0.021)	0.037· (0.021)	0.057* (0.028)	0.024 (0.027)
Observations	60	60	60	60
ARDL order (p, q)	(1,0)	(1,0,0)	(1,0,0,0)	(1,0,0,0)
Notes: Panel A reports the Pesaran-Shin-Smith bounds test for a long-run relationship; Panel B reports implied long-run coefficients; Panel C reports the unrestricted ECM (UECM) estimates. Lag orders are selected automatically using the Akaike Information Criterion (AIC), subject to a maximum of two lags for the dependent variable and relative supply. In Column 3, the time break is post-1992; in Column 4, it is post-1999; they enter as a level shift. The time break dummies and time trend are constrained to enter contemporaneously only (zero lags). Standard errors are in parentheses; *** $p < 0.001$ , ** $p < 0.01$ , * $p < 0.05$ , · $p < 0.10$ . Calculated from the replication data underlying Autor, Goldin, and Katz (2020), updated with data for 2018–2023 from Flood et al. (2024).				

power is notoriously low in small samples, the Prais-Winsten correction does not require taking a position on whether the series are stationary or integrated; it simply asks whether the OLS results survive a standard correction for autocorrelated errors. The estimated autocorrelation parameters ( $\hat{\rho}$ ) are high, ranging from 0.92 to 0.97. After correction, the coefficient on relative supply is either insignificant or, in the specification without a time trend, significantly *positive* (0.139 in Column 1), directly contradicting the Katz-Murphy model's prediction. In Columns 2 to 4, the point estimates are small and insignificant, ranging from −0.04 to −0.05. The Katz-Murphy model's results, across all specifications, do not survive a standard

correction for autocorrelated errors.

**TABLE 9: Durbin-Watson and Prais-Winsten Estimates, 1963–2023**

	(1)	(2)	(3)	(4)
A. Durbin-Watson statistics				
DW statistic	0.112	0.174	0.354	0.181
$p$ -value	0.000	0.000	0.000	0.000
B. Prais-Winsten estimates				
Log relative supply	0.139** (0.041)	−0.042 (0.078)	−0.039 (0.076)	−0.048 (0.079)
Time trend		0.007** (0.002)	0.006** (0.002)	0.007** (0.002)
Post-1992 dummy			0.024 (0.015)	
Post-1999 dummy				−0.011 (0.015)
Constant	0.536*** (0.040)	0.337*** (0.073)	0.341*** (0.069)	0.330*** (0.075)
$\hat{\rho}$	0.966	0.933	0.917	0.937
Observations	61	61	61	61
DW (after correction)	1.891	1.901	1.885	1.850
Notes: Panel A reports Durbin-Watson test statistics and $p$ -values for the OLS regressions. Panel B reports Prais-Winsten iterative GLS estimates that correct for first-order autocorrelation. Columns 1 to 4 correspond to the four specifications in Table 8, estimated by OLS rather than as an error correction model. Standard errors are in parentheses; *** $p < 0.001$ , ** $p < 0.01$ , * $p < 0.05$ , · $p < 0.10$ . Calculated from the replication data underlying Autor, Goldin, and Katz (2020), updated with data for 2018–2023 from Flood et al. (2024).				

Three different approaches to handling the time series properties of the data thus converge on the same conclusion. The convergence is itself revealing. The error correction model finds no significant adjustment toward a long-run equilibrium between relative supply and the wage premium: the error correction terms are insignificant in every specification, and the bounds test finds no evidence of cointegration. The Prais-Winsten correction estimates autocorrelation parameters so close to unity (0.92 to 0.97) that the transformation effectively differences the data. Both approaches therefore reduce to something close to a first-differenced specification, which itself finds no significant relationship. This is not a coincidence; it reflects the nature of the data. The Katz-Murphy model posits a structural equilibrium linking relative supply to the college wage premium. Every method applied here either rejects that equilibrium directly or, when allowed to find one, fails to do so and instead collapses to a specification that examines only changes. In changes, relative supply has no significant effect on the college wage premium. Whether the series are stationary, integrated, or some mixture of the two, the Katz-Murphy

model cannot produce a meaningful estimate of the elasticity of substitution between college and high school-educated labor. It cannot produce the  $\sigma$  needed to support the policy agenda that has been built upon it.

## The Agenda

These econometrics matter because the pro-education *zeitgeist* seen at Jackson Hole in August 1992 has been highly influential. On the growth side, it was codified in economics textbooks, such as Romer's (1996) *Advanced Macroeconomics* and Mankiw's (1997) *Principles of Economics*. That education spending was key to promoting growth became the accepted wisdom, even as the research that originally inspired it came under greater scrutiny. When the *New York Times* reported from Jackson Hole, for example, it had cited Robert J. Barro as the main authority for the claim that "a better-educated, better-trained work force can lift a nation's growth rate" (Greenhouse 1992). But Barro and his co-author Jong-Wha Lee (2015, 149) eventually concluded that there was only a "weak or insignificant effect of overall educational attainment on output growth." A generation of students had read Romer's (1996) and Mankiw's (1997) claims about education's contribution to growth, despite the empirical evidence supporting those claims being weak.

The Katz-Murphy model was similarly influential. The various iterations of the model, especially those found in Goldin and Katz (2008), featured heavily in the Council of Economic Advisers' annual *The Economic Report of the President*. Two years after *The Race between Education and Technology* was published, the Council of Economic Advisers (2010, 223) described how "Harvard economists Claudia Goldin and Lawrence Katz contend that America's strong educational system helped make the United States the richest nation in the world," but the "slowdown in the growth of educational attainment has contributed to rising income inequality." The econometrics presented in the book seemed to demonstrate it. Hence, the Council of Economic Advisers (2014, 191) described how "Goldin and Katz (2008) show that a constant increase in the demand for relative skill, combined with the post-1980 slowdown in the supply of relative skill, explains the time path of the logarithm of the college wage premium, which is one measured aspect of wage inequality." There was apparently no awareness of how the respecified Katz-Murphy model had come to depend on demand shifts that directly contradicted Goldin and Katz's narrative.

Such intellectual mistakes can have real-world consequences due to their effects on policymakers. By pushing for more spending on education, the Katz-Murphy model may have helped to crowd out other policy agendas, such as encouraging investment in physical rather than human capital. The question for future research then becomes whether the pro-education *zeitgeist* of the early 1990s did

more harm than good. Did a misspecified model contribute to a misallocation of resources? Were more important policy agendas crowded out? Such questions cannot be answered here, but asking them would be worthwhile due to the influence of the Katz-Murphy model over the past three decades.

## Data and Code

Data and code used in this research are available [here](#)

## References

- Acemoglu, Daron, and David Autor.** 2012. What Does Human Capital Do? A Review of Goldin and Katz's *The Race between Education and Technology*. *Journal of Economic Literature* 50(2): 426–463. [Link](#)
- Autor, David, Claudia Goldin, and Lawrence F. Katz.** 2020. Extending the Race between Education and Technology. *AEA Papers and Proceedings* 110: 347–351. [Link](#)
- Autor, David H., Lawrence F. Katz, and Melissa S. Kearney.** 2008. Trends in U.S. Wage Inequality: Revising the Revisionists. *Review of Economics and Statistics* 90(2): 300–323. [Link](#)
- Barro, Robert J., and Jong-Wha Lee.** 2015. *Education Matters: Global Schooling Gains from the 19th to the 21st Century*. Oxford, UK: Oxford University Press. [Link](#)
- Box, George E. P., and Gwilym M. Jenkins.** 1976. *Time Series Analysis: Forecasting and Control*, rev. ed. San Francisco, CA: Holden-Day.
- Card, D., and T. Lemieux.** 2001. Can Falling Supply Explain the Rising Return to College for Younger Men? A Cohort-Based Analysis. *Quarterly Journal of Economics* 116(2): 705–746. [Link](#)
- Cobb, Charles W., and Paul H. Douglas.** 1928. A Theory of Production. *American Economic Review* 18(1): 139–165. [Link](#)
- Council of Economic Advisers.** 2010. *Economic Report of the President: Transmitted to the Congress, February 2010, together with the Annual Report of the Council of Economic Advisers*. Washington, D.C.: U.S. Government Printing Office. [Link](#)
- Council of Economic Advisers.** 2014. *Economic Report of the President: Transmitted to the Congress March 2014, together with the Annual Report of the Council of Economic Advisers*. Washington, D.C.: United States Government Printing Office. [Link](#)
- Engle, Robert F., and C. W. J. Granger.** 1987. Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica* 55(2): 251–

276. [Link](#)

- Felipe, Jesus, and Franklin M. Fisher.** 2003. Aggregation in Production Functions: What Applied Economists Should Know. *Metroeconomica* 54: 208–262. [Link](#)
- Felipe, Jesus, and Carsten A. Holz.** 2010. Why do Aggregate Production Functions Work? Fisher’s Simulations, Shaikh’s Identity and Some New Results. *International Review of Applied Economics* 15(3): 261–285. [Link](#)
- Felipe, Jesus, and John S. L. McCombie.** 2013. *The Aggregate Production Function and the Measurement of Technical Change: “Not Even Wrong.”* Cheltenham, UK: Edward Elgar.
- Fisher, Franklin M.** 1969. The Existence of Aggregate Production Functions. *Econometrica* 37(4): 553–577. [Link](#)
- Fisher, Franklin M.** 1971. Aggregate Production Functions and the Explanation of Wages: A Simulation Experiment. *Review of Economics and Statistics* 53(4): 305–325. [Link](#)
- Flood, Sarah, Miriam King, Renae Rodgers, Steven Ruggles, J. Robert Warren, et al.** 2024. IPUMS CPS: Version 12.0. Minneapolis, MN: IPUMS.
- Goldin, Claudia, and Lawrence F. Katz.** 2008. *The Race between Education and Technology.* Cambridge, MA: Harvard University Press.
- Granger, C. W. J., and P. Newbold.** 1974. Spurious Regressions in Econometrics. *Journal of Econometrics* 2(2): 111–120. [Link](#)
- Greenhouse, Steven.** 1992. Economists Put Forth Plans to Stimulate Growth. *New York Times*, August 31. [Link](#)
- Grömping, Ulrike.** 2006. Relative Importance for Linear Regression in R: The Package relaimpo. *Journal of Statistical Software* 17(1): 1–27. [Link](#)
- Johnston, John.** 1987. *Econometric Methods*, 3rd ed. New York, NY: McGraw-Hill.
- Katz, Lawrence F.** 1992. Commentary: Human Capital and Economic Growth. *Proceedings—Economic Policy Symposium—Jackson Hole*: 217–224. Federal Reserve Bank of Kansas City. [Link](#)
- Katz, Lawrence F., and K. M. Murphy.** 1992. Changes in Relative Wages, 1963–1987: Supply and Demand Factors. *Quarterly Journal of Economics* 107(1): 35–78. [Link](#)
- Leamer, Edward E.** 1978. *Specification Searches: Ad Hoc Inference with Nonexperimental Data.* New York, NY: John Wiley & Sons, Inc.
- Lemieux, Thomas.** 2006. Increasing Residual Wage Inequality: Composition Effects, Noisy Data, or Rising Demand for Skill? *American Economic Review* 96(3): 461–498. [Link](#)
- Lindeman, Richard Harold, Peter Francis Merenda, and Ruth Z. Gold.** 1980. *Introduction to Bivariate and Multivariate Analysis.* Glenview, IL: Scott Foresman.

- MacKinnon, James G.** 1990. Critical Values for Cointegration Tests. *University of California San Diego Discussion Paper* 90–94.
- Maddala, G. S.** 1988. *Introduction to Econometrics*. New York, NY: Macmillan.
- Maddala, G. S.** 2001. *Introduction to Econometrics*, 3rd ed. Chichester, England: John Wiley & Sons, Ltd.
- Mankiw, N. Gregory.** 1992. Commentary: The Search for Growth. *Proceedings—Economic Policy Symposium—Jackson Hole*: 87–92. Federal Reserve Bank of Kansas City. [Link](#)
- Mankiw, N. Gregory.** 1997. *Principles of Economics*. Fort Worth, TX: Dryden Press.
- Mankiw, N. Gregory.** 2008. The Wealth Trajectory: Rewards for the Few. *New York Times*, April 20. [Link](#)
- Mankiw, N. Gregory, David Romer, and David N. Weil.** 1992. A Contribution to the Empirics of Economic Growth. *Quarterly Journal of Economics* 107(2): 407–437. [Link](#)
- Phelps Brown, E. H.** 1957. The Meaning of the Fitted Cobb-Douglas Function. *Quarterly Journal of Economics* 71(4): 546–560. [Link](#)
- Richardson, Joseph.** 2025. Unpacking Skill Supply and Wages. Working paper. [Link](#)
- Romer, David.** 1996. *Advanced Macroeconomics*. New York, NY: McGraw-Hill Companies.
- Solow, Robert M.** 1956. A Contribution to the Theory of Economic Growth. *Quarterly Journal of Economics* 70(1): 65–94. [Link](#)
- Wooldridge, Jeffrey M.** 2006. *Introductory Econometrics: A Modern Approach*, 3rd ed. Mason, OH: Thomson South-Western.

## About the Author



**Joseph Francis** is an economic historian from Wales. He has a Ph.D. in economic history from the London School of Economics and is an Honorary Research Fellow in the Department of Economics of the University of Birmingham in the United Kingdom. Dr. Francis is currently writing books on Argentina and the United States. His email address is [joe Francis505@gmail.com](mailto:joe Francis505@gmail.com).

[Go to archive of Comments section](#)  
[Go to March 2026 issue](#)