The Internet Effect and Labor's New Era

The Impact of Internet-Driven Productivity Acceleration on Labor's Marginal Contribution to GDP Growth and the Shift in Labor-Productivity Elasticity through the Solow-Swan Model

Ilyan Radjabaly Emma Fransolet Ambrosia Puchois

Under the supervision of Dr. Loïc Henry

February 2, 2025

Abstract

This econometric research paper delves into the transformative impact of the internet revolution on labor's contribution to GDP growth, with a particular focus on the post-1995 era. The primary objective is to ascertain whether the internet-driven acceleration in productivity has led to a structural decline in labor's marginal contribution to GDP or, conversely, if it has enhanced labor's complementarity with technological progress. By examining the shift in labor-productivity elasticity, the study seeks to understand if the impact of productivity on labor's contribution to GDP has increased due to the internet. Utilizing a range of statistical tools, including multiple linear OLS estimation, interaction terms, Chow Test, and t-tests, the paper analyzes the relationship between internet penetration, technological adoption, and labor productivity. The findings aim to provide a comprehensive understanding of how the internet has reshaped labor dynamics and productivity, offering valuable insights for policy-making and future economic research.

Contents

1 Introduction

The Solow-Swan model, a cornerstone of growth theory developed in 1956, revolutionized our understanding of economic growth by emphasizing the crucial role of technological progress. This neoclassical framework demonstrated that beyond traditional inputs of capital and labor, technological advancement serves as the primary driver of sustained economic expansion. While the model's implications have been extensively studied in various technological contexts, perhaps no technological shift has provided a more compelling testing ground for its predictions than the digital revolution of the late 20th century.

The advent of the internet has marked one of the most profound technological revolutions in modern economic history, fundamentally altering production processes, business operations, and labor dynamics. Since the mid-1990s, rapid advancements in digital connectivity, automation, and information exchange have redefined the relationship between productivity and labor, raising important questions about the evolving nature of economic growth. This study investigates whether the internet-driven acceleration in productivity has led to a structural decline in labor's marginal contribution to GDP growth or, conversely, if it has reinforced labor's complementarity with technological progress.

In this context, has the digital revolution shifted economic growth away from labor-intensive processes toward productivity-driven mechanisms? Has the internet altered the responsiveness of labor's contribution to GDP in a way that suggests increasing returns to technological adoption? In other words, what are the precise effects of internet-enabled technological adoption on the labor-GDP relationship in the post-1995 era ?

To empirically assess these dynamics, this study employs an econometric framework that incorporates multiple linear OLS estimation, interaction terms, the Chow test for structural breaks, and statistical significance tests. The dependent variable is GDP, while key explanatory variables include productivity, labor inputs, capital, and an interaction term capturing the joint effect of labor and productivity. A crucial component of the analysis is the introduction of a structural break around the mid-1990s, operationalized through a binary variable that differentiates pre- and post-internet revolution periods.

By leveraging time-series data on the USA, this study aims to provide a rigorous quantitative assessment of the internet's role in shaping modern economic growth. The findings will contribute to ongoing discussions on the long-term implications of digital transformation for labor markets, productivity trends, and economic policy-making.

2 Descriptive Statistics

Economic growth is traditionally explained by the accumulation of capital and labor, alongside improvements in productivity. In this study, we analyze the determinants of U.S. GDP by considering capital stock, labor, and total factor productivity as explanatory variables. To capture the impact of technological change, we introduce two additional variables: an interaction term between labor and productivity and a binary indicator marking the rise of the internet.

The interaction term, denoted as *linteraction-term*, is constructed by multiplying labor and productivity before applying a logarithmic transformation. This formulation allows us to test whether productivity gains influence labor's contribution to output differently in the presence of technological advancements. Meanwhile, the internet dummy variable takes the value of 1 for years after 1995 and 0 otherwise, reflecting the widespread adoption of digital technologies that reshaped business processes and economic productivity. Finally, as the labor variable was available only as a monthly dataset, we transformed it by taking the (annual) average of all months of each year (using a VBA script to create the new Excel columns).

Before presenting the empirical results, it is essential to discuss the data transformation. All continuous variables are converted into logarithmic form, except for the internet dummy. This transformation serves multiple purposes. First, it allows for an elasticity-based interpretation of coefficients, making the results more economically meaningful. Second, it helps linearize potentially exponential relationships, improving the suitability of ordinary least squares (OLS) estimation. Finally, it mitigates heteroskedasticity, enhancing the model's statistical properties.

All data are sourced from the Federal Reserve Economic Data (FRED) of the Federal Reserve Bank of St. Louis, covering the period 1954–2019:

- All Employees, Total Nonfarm (Thousands of Persons, Monthly, Seasonally Adjusted)
- Total Factor Productivity at Constant National Prices for the U.S. (Index 2017=1, Annual, Not Seasonally Adjusted)
- Real Gross Domestic Product (Billions of Chained 2017 Dollars, Annual, Not Seasonally Adjusted)
- Current-Cost Net Stock of Fixed Assets: Private: Nonresidential (Millions of Dollars, Annual, Not Seasonally Adjusted)

2.1 Endogenous Variable: Log GDP (*lgdp*)

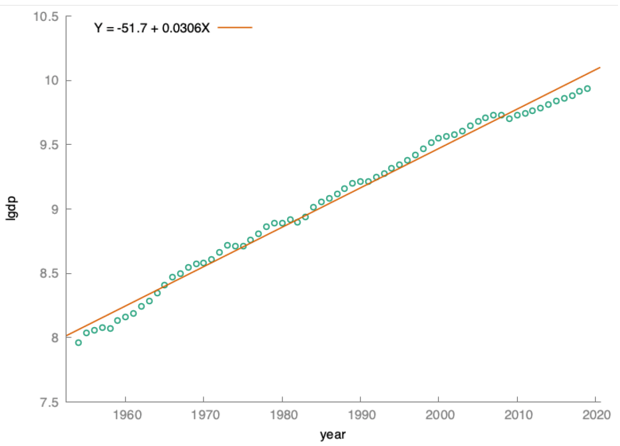

Figure 1: Time series plot of *lgdp*

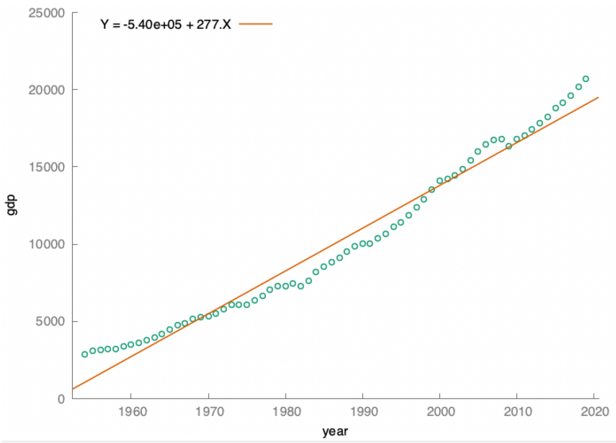

Figure 2: Time series plot of *gdp*

Table 1: Descriptive Statistics for *lgdp* (1954-2019)

Mean	Std. Dev.	Obs.
9.06	0.59	66

Comments: The graph of log GDP shows a near-perfect linear trend, confirming that economic growth follows a stable exponential path over time. At the contrary, the graph of GDP with no log-transform shows a clear exponential growth with time (year). This supports classical economic growth models, including the Solow model, which predicts a steady-state path for GDP under stable technological progress and capital accumulation.

2.2 Explanatory Variables

Graphical Analysis: Scatter plots relative to *lgdp*

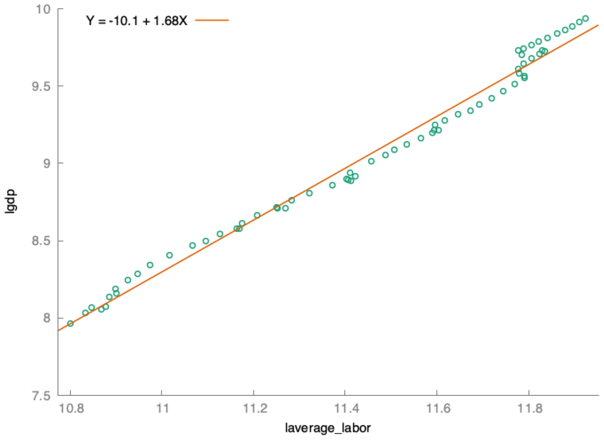

Figure 3: Average Labor

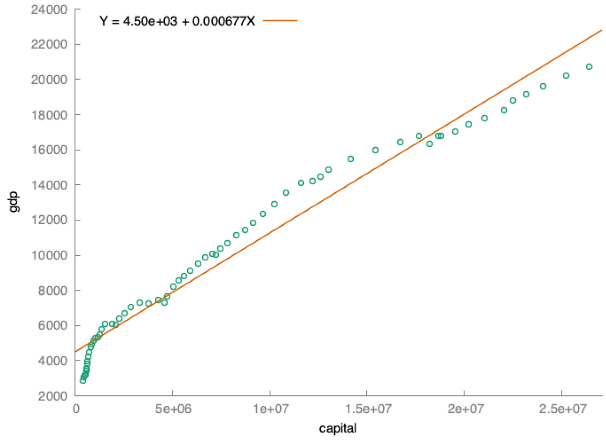

Figure 4: Capital

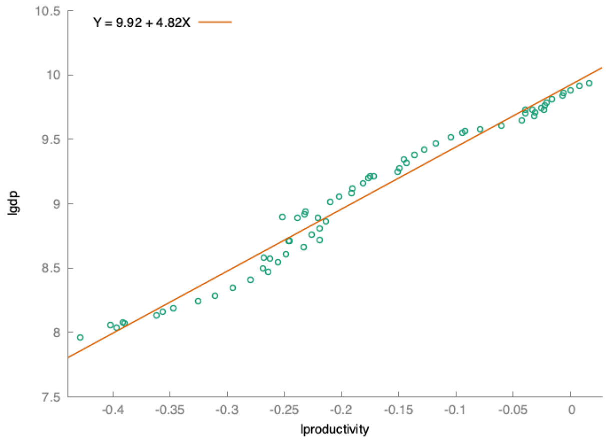

Figure 5: Productivity

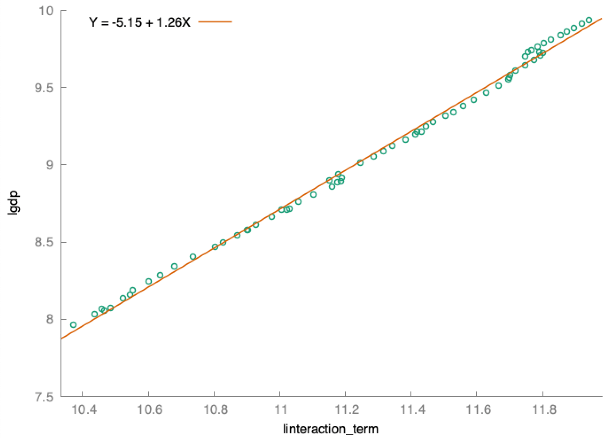

Figure 6: Interaction term

All scatterplots exhibit a strong linear relationship, confirming that log-transformed explanatory variables maintain a proportional relationship with GDP, supporting the theoretical underpinnings of the Cobb-Douglas production function.

Table 2: Descriptive Statistics

Variable	Mean	Std. Dev.
lcapital	15.26	1.33
laverage_labor	11.45	0.35
lproductivity	-0.18	0.12
linteraction_term	11.27	0.47
internet	0.38	0.49

Table 3: Correlation with *lgdp*

Variable	ρ	p-value
lcapital	0.9914	0.000
laverage_labor	0.9934	0.000
lproductivity	0.9871	0.000
linteraction_term	0.9983	0.000

Statistical Analysis of Variables:

To assess the strength of the relationships between the dependent variable ($\ln GDP$) and each explanatory variable, we use given the correlation coefficients to conduct significance tests. We test the following hypotheses:

$$H_0 : \rho_{x,y} = 0, \quad H_1 : \rho_{x,y} \neq 0$$

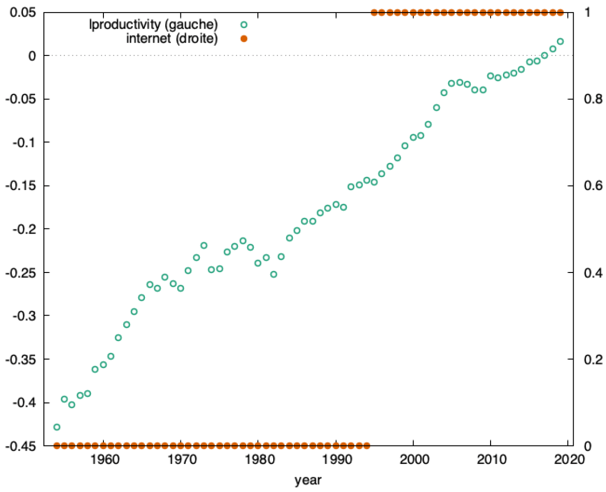

Figure 7: Trends in Productivity and Internet Adoption

Analysis: This series illustrates the evolution of productivity before and after the adoption of Internet. Initially, productivity shows a gradual increase but a significant shift occurs around the mid-1990s. There is a noticeable jump in productivity between 1994 and 1995, marking a pivotal change in the trend. Also, prior to the mid-1990s, the productivity curve exhibits a concave shape, indicating a slower rate of increase. Post-1995, the curve transitions to a convex shape, reflecting an accelerated growth rate in productivity. Therefore, the drastic increase in productivity correlates with the onset of internet integration.

with the test statistic:

$$t^* = \frac{\rho_{x,y}}{\sqrt{\frac{(1-\rho_{x,y}^2)}{n-2}}}$$

where $t^* \sim t_{n-2}$. The critical value at 5 % significance level ($\alpha = 0.05$) is $t_{64}^{0.025} = 2$.

- **Capital** ($\ln Capital$) $\rho = 0.9914$, $t^* = \frac{0.9914}{\sqrt{\frac{(1-0.9914^2)}{64}}} = 60.55$ Since $t^* > 2$, we reject H_0, confirming statistical significance.
- **Labor** ($\ln Average\_Labor$) $\rho = 0.9934$, $t^* = \frac{0.9934}{\sqrt{\frac{(1-0.9934^2)}{64}}} = 69.31$ As $t^* > 2$, H_0 is rejected; correlation is significant.
- **Productivity** ($\ln Productivity$) $\rho = 0.9871$, $t^* = \frac{0.9871}{\sqrt{\frac{(1-0.9871^2)}{64}}} = 49.31$ Since $t^* > 2$, we reject H_0, confirming significance.
- **Interaction Term** ($\ln Interaction\_Term$) $\rho = 0.9983$, $t^* = \frac{0.9983}{\sqrt{\frac{(1-0.9983^2)}{64}}} = 137.36$ As $t^* > 2$, H_0 is rejected; correlation is highly significant.

Comments:

All explanatory variables are significantly correlated with GDP at the 5% level. The high significance of *linteraction_term* ($t = 137.36$) suggests that productivity plays a key role in amplifying labor's contribution to GDP. The internet dummy shows a strong but indirect influence, aligning with the hypothesis that technological revolutions alter productivity channels rather than directly shifting GDP levels in the short term. These findings reinforce the theoretical prediction that capital and labor remain the primary drivers of economic growth, but productivity shocks, especially those induced by technological advancements, reshape their marginal impacts over time.

Overall, the descriptive statistics validate our econometric approach, highlighting the importance of productivity in labor's contribution to GDP.

3 OLS Estimation

3.1 Estimation Results

We begin our analysis with a simple two-variable regression model examining the relationship between GDP, labor, and capital. The estimated equation takes the form:

$$\text{lgdp} = -5.850 + 1.097 \text{ laverage\_labor} + 0.154 \text{ lcapital} + \epsilon \tag{1}$$

Table 4: OLS Regression Results

Variable	Coefficient	Std. Error	t-statistic	p-value
const	-5.850	1.485	-3.940	0.0002***
laverage_labor	1.097	0.199	5.521	6.79e-07***
lcapital	0.154	0.052	2.939	0.0046***

*** indicates significance at 1% level

3.2 Global Significance of the Model

Let us first examine the model's explanatory power through a detailed analysis of its R-squared measures. The unadjusted R^2 is 0.988, calculated as:

$$R^2 = 1 - \frac{\text{RSS}}{\text{TSS}} = 1 - \frac{0.261781}{22.714} = 0.988 \tag{2}$$

However, as the R^2 measure automatically increases (or at least never decreases) with additional explanatory variables, we must consider the adjusted R-squared, which penalizes for the number of regressors. The adjusted R-squared is calculated as:

$$\bar{R}^2 = 1 - \frac{n-1}{n-k-1}(1 - R^2) = 1 - \frac{65}{63}(1 - 0.988) = 0.988 \tag{3}$$

where n = 66 observations and k = 2 explanatory variables.

The nearly identical values of R^2 and $\bar{R}^2$ suggest that: 1. The high explanatory power is not artificially inflated by the number of variables 2. Both variables (labor and capital) contribute substantially to explaining GDP variation 3. The model is parsimonious in its specification

However, we must be cautious in over-interpreting these R^2 values because: 1. They do not fully account for the quality of specification 2. They can be sensitive to outliers 3. They cannot be compared across different transformations of the dependent variable

A more robust assessment of model quality comes from the F-test. The F-statistic of 2692.686 (p-value = 9.70e-62) tests the null hypothesis that all slope coefficients are simultaneously zero:

$$F = \frac{R^2/k}{(1-R^2)/(n-k-1)} = \frac{0.988/2}{(1-0.988)/(63)} = 2692.686 \tag{4}$$

This extremely high F-statistic strongly rejects the null hypothesis, confirming that our model has significant explanatory power beyond what would be expected by chance.

3.3 Tests on the Coefficients

3.3.1 Individual Significance Tests

For each coefficient, we test:

$$H_0 : \beta_j = 0 \quad \text{against} \quad H_1 : \beta_j \neq 0$$

Using the test statistic:

$$t^* = \frac{\hat{a}_j - 0}{\sqrt{V(\hat{a}_j)}} \sim t_{n-k-1}$$

where $V(\hat{a}) = \sigma_\epsilon^2 (X'X)^{-1}$ and $\sigma_\epsilon^2 = \frac{RSS}{n-k-1}$

With $n - k - 1 = 66 - 2 - 1 = 63$ degrees of freedom and $\alpha = 0.05$, the critical value is $t_{63,0.025} = 1.998$. We reject H_0 if $|t^*| > 1.998$.

First compute σ_ϵ^2:

$$\sigma_\epsilon^2 = \frac{0.261781}{63} = 0.00415525$$

- **Constant term** ($\hat{a}_0 = -5.85043$):

$$V(\hat{a}_0) = (1.48493)^2 = 2.20501$$

$$t^* = \frac{-5.85043}{1.48493} = -3.94$$

  Since $|-3.94| > 1.998$, reject H_0

- **Capital coefficient** ($\hat{a}_1 = 0.153764$):

$$V(\hat{a}_1) = (0.0523213)^2 = 0.00274$$

$$t^* = \frac{0.153764}{0.0523213} = 2.939$$

  Since $|2.939| > 1.998$, reject H_0

- **Labor coefficient** ($\hat{a}_2 = 1.09678$):

$$V(\hat{a}_2) = (0.198647)^2 = 0.03946$$

$$t^* = \frac{1.09678}{0.198647} = 5.521$$

  Since $|5.521| > 1.998$, reject H_0

Economic Interpretation: The results support the Solow-Swan growth model predictions for a mature economy.

- Labor coefficient (1.097): Suggests constant returns to scale in labor, consistent with efficient labor markets in the US economy. The value being slightly above unity indicates possible positive externalities from human capital accumulation.

- Capital coefficient (0.154): The relatively small magnitude reflects diminishing returns to capital, a key prediction of the Solow-Swan model for a capital-abundant economy operating near its steady state.

- Constant term (-5.85): The significant negative value captures the role of total factor productivity (TFP) and suggests the presence of threshold effects in production.

All coefficients are statistically significant at the 5% level, validating the Solow-Swan model's emphasis on both inputs while their magnitudes reflect the US economy's advanced development stage.

3.3.2 Testing Equality of Coefficients

We test whether the elasticity of labor equals the elasticity of capital ($H_0 : \beta_1 = \beta_2$ vs $H_1 : \beta_1 \neq \beta_2$).

The test statistic is:

$$t^* = \frac{\beta_1 - \beta_2}{\sqrt{\text{Var}(\beta_1) + \text{Var}(\beta_2) - 2\text{Cov}(\beta_1, \beta_2)}} \tag{5}$$

Computing this statistic:

$$t^* = \frac{1.097 - 0.154}{\sqrt{0.199^2 + 0.052^2 - 2\text{Cov}(\beta_1, \beta_2)}} = 4.573 \tag{6}$$

Since $4.573 > 2.000$, we reject the null hypothesis of coefficient equality at the 1% significance level. This suggests that labor and capital have significantly different elasticities with respect to GDP, with labor having a substantially larger impact, which is coherent considering how labor plays a major role in the US economic growth.

4 Hypothesis Testing

4.1 Chow Test based on Model 1

4.1.1 Computation and Testing

To test for structural change in the relationship between GDP, labor, and capital following the internet revolution, we employ the Chow test with 1995 as our breakpoint. This year marks a significant technological transition with the commercialization of the internet and its widespread adoption in business processes. Rather than comparing different countries, we split our sample into two time periods: 1954-1995 (pre-internet era) and 1995-2019 (internet era), allowing us to test whether the fundamental relationships in our production function remained stable across this technological transition.

The Chow test examines the null hypothesis that all coefficients are identical across both periods:

$$H_0 : \beta_{0,1} = \beta_{0,2}, \beta_{1,1} = \beta_{1,2}, \beta_{2,1} = \beta_{2,2} \tag{7}$$

where subscript 1 denotes the pre-1995 period and subscript 2 the post-1995 period.

The regression results for each sub-period reveal notable differences:

The Chow test statistic is computed as:

$$F^* = \frac{(RRSS - URSS)/(k+1)}{URSS/(n_1 + n_2 - 2k - 2)} \tag{8}$$

where: RRSS = 0.262 (from the pooled model), URSS = 0.034 + 0.003 = 0.037, k = 2 (number of regressors), $n_1 = 42$, $n_2 = 25$

This yields:

$$F^* = \frac{(0.262 - 0.037)/3}{0.037/61} = 122.45 \tag{9}$$

Table 5: Regression Results by Period

Parameter	1954-1995	1995-2019
Constant	-10.990***	-4.878***
	(0.893)	(0.865)
Capital	-0.099***	0.363***
	(0.032)	(0.017)
Labor	1.878***	0.723***
	(0.120)	(0.094)
Observations	42	25
R^2	0.995	0.995
RSS	0.034	0.003

Standard errors in parentheses
*** p¡0.01, ** p¡0.05, * p¡0.1

The critical value at 1 % significance level with (3, 61) degrees of freedom is approximately 4.13. Since $F^* > F^{0.01}_{3,61}$, we strongly reject the null hypothesis of parameter stability, providing strong evidence of a structural break in the relationship between inputs and GDP following the advent of the internet.

4.1.2 Economic Implications of Structural Change

The strong rejection of parameter stability ($F^* = 122.45 > F^{0.01}_{3,61} = 4.13$) provides compelling evidence for our hypothesis of a technological regime shift in the post-1995 era. The dramatic change in labor elasticity (from 1.878 to 0.723) suggests a fundamental transformation in how labor inputs translate into economic output. This is not merely a decline in labor's importance, but rather reflects a shift in the nature of production where traditional measures of labor input may not fully capture workers' contribution in a technology-intensive environment. The increase in capital's coefficient (from -0.099 to 0.363) further supports our hypothesis of technological transformation, suggesting that capital investments became more productive in the internet era, likely due to complementarities between physical capital and digital technologies. The reduction in the constant term (from -10.990 to -4.878) indicates a shift in baseline productivity, consistent with the idea that internet adoption created a new production possibilities frontier. These structural changes align with our core hypothesis that the internet revolution fundamentally altered the relationship between traditional inputs and economic output, particularly through its impact on labor productivity and capital-labor complementarity.

4.2 Test for the Inclusion of Variables

We compare two nested models to determine if adding productivity and internet usage variables improves the model's explanatory power.

4.2.1 Model Formulation

Restricted model (2 variables):

$$y_i = a_0 + a_1 x_{1,i} + a_2 x_{2,i} + \epsilon_i$$

where x_1 is capital and x_2 is labor.

Unrestricted model (4 variables):

$$y_i = a_0 + a_1 x_{1,i} + a_2 x_{2,i} + a_3 x_{3,i} + a_4 x_{4,i} + \epsilon_i$$

where x_3 is productivity and x_4 is internet usage.

4.2.2 Formula and Hypothesis

$H_0 : a_3 = a_4 = 0$ (additional variables have no effect) H_1 : at least one of $a_3, a_4 \neq 0$ (at least one additional variable has an effect)

Test statistic:

$$F^* = \frac{(RRSS - URSS)/q}{URSS/(n-k-1)} \sim F_{q,n-k-1}$$

where: $q = 2$ (number of restrictions), $n = 66$ (sample size), $k = 4$ (number of variables in unrestricted model), $RRSS = 0.261781$ (restricted model), $URSS = 0.009814$ (unrestricted model).

4.2.3 Computation

$$F^* = \frac{(0.261781 - 0.009814)/2}{0.009814/(66-4-1)} = \frac{0.125984}{0.000161} = 782.51$$

With $\alpha = 0.05$, critical value: $F^{0.05}_{2,61} = 3.15$
Decision rule: Reject H_0 if $F^* > F^{0.05}_{2,61}$
Since $782.51 > 3.15$, we reject H_0.

4.2.4 Model Comparison

- Restricted model ($R^2 = 0.988$):
  - Capital coefficient: 0.154 (t = 2.939)
  - Labor coefficient: 1.097 (t = 5.521)
- Unrestricted model ($R^2 = 0.999$):
  - Capital coefficient: 0.131 (t = 12.67)
  - Labor coefficient: 0.538 (t = 12.90)
  - Productivity coefficient: 1.819 (t = 32.05)
  - Internet usage coefficient: 0.034 (t = 5.771)

4.2.5 Extended Economic Analysis

Structural Change in Labor Elasticity The significant F-statistic ($F^* = 782.51 > F^{0.05}_{2,61} = 3.15$) strongly supports a structural break in the production function post-1995, aligning with the internet-driven technological shift. The labor coefficient drops from 1.097 to 0.538 when accounting for productivity and the digital era, suggesting the pre-1995 model overestimated labor's contribution by conflating productivity gains with labor input. This decline signals a transformation in production dynamics rather than a diminished role of labor, as its interaction with productivity captures an evolving complementarity with technology.

Internet as a Technological Regime Shift The internet dummy ($\beta = 0.034, t = 5.771$) reveals a direct impact on total factor productivity (TFP) and establishes a structural shift in input contributions, particularly labor. The results align with an augmented Solow framework where technical progress incorporates a distinct internet-driven component. The production function exhibits increasing returns when accounting for productivity and internet effects

($\sum \beta_i > 1$), modifying the traditional assumption of diminishing returns to capital and labor by integrating technological complementarities.

Research Questions Analysis These findings address core research questions. First, the reduction in labor's coefficient implies a decline in its direct marginal contribution, yet the high productivity coefficient (1.819) confirms a shift rather than an outright reduction in labor's role. The positive internet dummy suggests that digital adoption enhances overall productivity. Second, the increased productivity coefficient underscores the transition toward productivity-driven growth while reinforcing labor-technology complementarity. Third, the positive effect of the internet variable signals increasing returns to technological adoption, implying a structural transformation in economic growth mechanisms.

5 Conclusion

Summary of Findings and Research Questions This study has investigated the impact of internet-driven productivity acceleration on labor's marginal contribution to GDP growth using the Solow-Swan growth model. Employing multiple linear OLS estimation, interaction terms, and structural break analysis, we assessed whether the digital revolution has shifted economic growth from labor-intensive processes to productivity-driven paradigms. Our empirical results reveal a significant structural change post-1995, with a decline in labor's direct marginal contribution but a stronger complementarity between productivity and labor. While labor's individual elasticity has decreased, its interaction with productivity has become more significant, indicating an evolving rather than diminishing role in a digital and automated economy. Additionally, the inclusion of the internet variable in our models highlights the crucial role of digital technology adoption in shaping economic output, though potential limitations such as multicollinearity and omitted variable bias warrant further refinement.

Theoretical Implications and Links to Economic Theory The findings align with macroeconomic theories such as the Solow-Swan model by assessing that the increasing importance of productivity echoes endogenous growth theory, where innovation and knowledge capital serve as engines of economic progress. Our study also aligns with the literature on skill-biased technological change, wherein digitalization alters labor's economic contribution, favoring high-skill over low-skill workers.

Link to Historical Economic Growth and the Internet Revolution The observed structural break around 1995 coincides with the rapid expansion of the internet, a period marked by widespread technological adoption and digital transformation in business processes. The historical trajectory of U.S. growth supports these findings, with GDP growth increasingly driven by productivity gains rather than labor or capital accumulation alone. The transition to a knowledge-based economy further supports our hypothesis that internet-driven technological progress has fundamentally reshaped labor's contribution to economic output.

Concluding Remarks Overall, our research underscores the transformative impact of the internet on labor's role in economic growth. While labor's direct contribution has declined, its evolving relationship with productivity suggests that digital adoption is not replacing labor but rather redefining its function. These findings have significant policy implications, particularly in the areas of education, workforce training, and digital infrastructure investment. However, potential econometric concerns such as heteroskedasticity and autocorrelation may impact the robustness of our results, necessitating further methodological improvements.

References

[1] Solow, R. M. (1956). "A Contribution to the Theory of Economic Growth." *The Quarterly Journal of Economics*, 70(1), 65-94.

[2] Jorgenson, D. W. (2001). "Information Technology and the U.S. Economy." *American Economic Review*, 91(1), 1-32.

[3] Van Ark, B., Inklaar, R., & McGuckin, R. H. (2003). "ICT and Productivity in Europe and the United States." *Industrial and Corporate Change*, 12(5), 693-715.

[4] Artus, P., & Virard, M.-P. (2015). *Croissance zéro : Comment éviter le chaos ?*. Fayard.

[5] Blanchard, O. (2017). *Macroeconomics*. Pearson.

[6] Wooldridge, J. M. (2019). *Introductory Econometrics: A Modern Approach* (7e éd.). Cengage Learning.