Potential output, capital input and U.S. economic growth

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Abstract

The objective in this paper is to highlight the complex linkages of capital input to potential output in the U.S. nonfarm private business sector. For this purpose the analytical framework used by the Congressional Budget Office (CBO) is adapted and re-estimated using data from the U.S. Bureau of Economic Analysis (BEA) and the U.S. Bureau of Labor Statistics (BLS) over the period 1949-2016. By focusing on the changes in the composition of the capital stock in terms of structures, equipment and intangibles, average service lives, and the relative prices of producer's to consumer's goods, the paper allows for their influence on the capital input and traces the latter's effects on the potential output. It is found that: (a) when the capital input is adjusted to reflect all aforementioned changes, the potential output decelerated in recent decades even faster than suggested by CBO's estimates; (b) in the post-2007 period the shortfall in the estimated potential output widened relative to that computed by CBO, and (c) the faster deceleration of the potential output emanated from the declining share of structures in the capital stock and the spectacular decline in the prices of equipment relative to structures. Drawing on these findings it is concluded that, although the real economy may have overshoot its potential in the last few years, the forces that slow down potential output through changes in the capital input remain intact and, unless some remedial policies are instituted, they will continue to function as significant headwinds to U.S. economic growth, along with all others that are well known.

JEL Classification: E01, E22, O47
Keywords: Potential output, capital input, capital stock, economic growth, economic growth headwinds, secular stagnation.

1. Introduction

The financial crisis that unfolded in U.S. in the years 2007-2008 was accompanied by a recession-recovery cycle much different than those in the preceding decades. In particular, the recession that followed in 2009 was steeper and lasted a longer; despite the fairly quick pace of return to full employment, the expansion of output was sluggish and after eight years continued to remain significantly below the rolling forecasts of the potential output; inflation showed hardly any signs of acceleration; and the central bank policy rate was stuck for several years in the vicinity of the zero bound. Reflecting on these developments, Summers (2013a, 2013b, 2014a) invoked Hansen's (1934) conceptualizations to advance the hypothesis that the U.S. had entered into a period of secular stagnation by which he meant that full employment output with price stability could not be expected to grow in the coming years by more than a modest percentage per annum.

At the time, he and others conjectured that the actual output did not converge to its potential because of insufficient aggregate demand. But as this deficiency could not explain the substantial decline in the economy's productive capacity relative to its pre-2007 trend, Summers (2014b) moved in the direction of Gordon (2012, 2014a) by expanding on the latter's headwinds that hold back potential output. Thus, according to the analyses by these scholars, secular stagnation in the U.S. is propagated by:

- The drag of past economic weaknesses on potential output, i.e. hysteresis;
- The deteriorating demographics due to the ageing of the population;
- The leveling off of the trend towards increased women's participation in the labor force;
- The exhaustion of the gains from an increasingly educated workforce;
- The widening of inequality in the distribution of income;
- The interaction between globalization and information technology and communications;
- The worsening balance in the fronts of energy and the environment, and
- The burgeoning ratio of public and private Debt to Gross National Product.

Observe that absent from this list are factors that may affect the supply of output through the economy's capital stock. Therefore it is worth asking: Aren't there capital related issues that are too significant to ignore? There are because, for example, unlike the ageing of the population, about which very little can be done to slow down its progress, if potential output decelerates due to capital stock growing older, it may be possible by designing and implementing appropriate counterbalancing policies to stem or even reverse its degradation, and hence forestall the erosion of its contribution to economic growth.

The lack of attention to the capital input is puzzling for yet another reason. According to Jorgenson (1991), over the years 1948-1985 aggregate value added in the U.S. grew on the average 3.28 % per annum. To this growth rate the capital input contributed 1.46 percentage points, of which 0.88 emanated from changes in the quality of capital and 0.58 from changes in the capital stock; technological change accounted for another 0.71 percentage points, and the number of hours worked and the quality of labor for 0.73 and 0.39, respectively.[1] More recently, Wasshausen et al. (2016) computed the sources of U.S. growth for the period 1998-2012 and found that the aggregate value added increased 1.94% per annum and that the capital input contributed 1.13 percentage points, technological change 0.38, and the labor input 1.11.[2] From these and other studies, as well as the estimates shown in Table A5 in the Appendix, it follows that: (a) throughout the post war period the capital input has been a prime source of U.S. economic growth; (b) its contribution has been declining, and (c) the rate by which it carries into production new technologies is also slowing down since Total Factor Productivity (TFP) is declining. But in difference to the priorities that this evidence would suggest, research into the headwinds for economic growth that may originate in the capital input has not received the emphasis it deserves.

Moreover, in tackling the aforementioned question, the present paper draws on research that we conducted recently into the behavior of business investment in the U.S. over the post war period. More specifically, in Bitros, Nadiri (2017a) we found that reckoning the size of the undepreciated capital stock in terms of capital years yields a more accurate measure of the capital input, whereas from Bitros, Nadiri (2017b) we learned that changes in the composition of the capital stock render the rate of its replacement, and hence the potential level of its services, variable even over the business cycle. Thus, the approach in this study is to adopt the model and the computational procedures that the Congressional Budget Office (CBO) employs to estimate the trend growth rate of potential output, but do so in conjunction with, first, a new index of capital input that allows for the shift in the composition of the capital stock away from structures and towards equipment and intellectual property products (henceforth referred as intangibles); second, the progressive ageing of the capital

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[1] Several years earlier Fraumeni, Jorgenson (1980) conducted an equally exhaustive study of the sources of U.S. growth for the period 1948-1976. At the time they found that aggregate value added grew 3.50 % per annum; capital contributed 1.61 percentage points, technological change 1.14 and labor 0.75.

[2] Aside from computing the sources of U.S. economic growth by following a bottom-up approach starting at the industry level, this study offers a detailed survey of the main methodological and implementation issues that bear on the differences in the measurement of the capital input.

stock since the 1980s, despite the aforementioned major compositional shift in favor of less durable physical assets; and thirdly, the long term decline in the relative prices of producers' to consumers' goods. Expectedly, introducing the revised index of capital input into the CBO model and solving for the trend growth rate in the potential output will enable gauging of the differences that result and assessing their magnitude and direction. The maintained hypothesis is that the observed slowdown in the U.S of the potential output is not invariant with respect to the aforementioned shifts in the capital input.

Section 2 presents the model by means of which CBO obtains past and future estimates of potential output. Brief references to the data they use, the ways in which they adjust the inputs of labor and capital before introducing them into the model, and the most recent results they have reported are found in the same place. Section 3 explains how CBO computes the index of the capital input, how the latter is adapted to allow for certain related aspects that they leave unaccounted, and how the two indices compare. Then, Section 4 discusses the estimates of potential output when the revised index of the capital input is used in the CBO model. In these computations the series of the labor input is the same as that reported by CBO. Therefore, since the differences in the estimates of the potential output that emerge should be due to the differences in the two indices of the capital input, the section closes with their statistical analysis; Lastly, Section 5 concludes with a summary of the findings and some thoughts about possible policy options.

2. The CBO model of potential output

In the CBO model Gross Domestic Product (GDP) is defined as the sum of five components. That is, GDP produced in the sectors of: private nonfarm business, government, farming, households and nonprofit institutions, and residential housing. Adding to these the gross foreign product, they arrive at the definition of Gross National Product (GNP). Of all sectors by far the largest is the private nonfarm business, since for example in 2016 it accounted for 76.3% of GDP, compared with 11.9% of the government. Thus, to economize on research resources, but also because the objective here is mainly methodological, it is convenient to adopt the following delimitations:

- Restrict attention only to the sector of private nonfarm business.
- Ignore CBO's estimation of rolling ten-year projections of potential output and focus solely on the historical part of the analysis.
- Consider CBO's cyclical adjustment of the labor input as given and concentrate on the in-

put of capital services.

- Limit the disaggregation of the capital input to three components, i.e., structures, equipment and intellectual property products or intangibles.
- Apply the “rental prices” of capital services as computed in Bitros, Nadiri (2017b).

However, it is noted that narrowing the scope of the inquiry along the above lines involves losses neither in the generality of the arguments nor in the findings.

According to the Congressional Budget Office (2001, 8-9), the method by which they estimate past and future growth rates of potential GDP is based on the Cobb-Douglas production function:

$$Q_t = A_t L_t^{1-\alpha} K_{t-1}^{\alpha}, \tag{1}$$

in which the symbols are defined as follows: Q_t = real Gross Domestic Product (GDP) in year *t*; L_t = billion hours worked in year *t*; K_{t-1} = real value of the capital stock in year *t*-1; A_t = Total Factor Productivity (TFP) in year *t;* and the parameter α stands for the income share of capital in the value of output.[3]

Transforming (1) into logarithmic form, differentiating totally the resulting expression, and setting $\alpha = 0.3$ on account of the evidence that the payments to owners of capital have averaged roughly 30 percent of total U.S. income since 1947, yields:

$$\%\Delta Q_t = \%\Delta A_t + 0.7 \cdot \%\Delta L_t + 0.3 \cdot \%\Delta K_{t-1}\,. \tag{2}$$

This equation states that the growth rate of real GDP equals the growth rate of TFP plus the weighted average of the growth rates of labor and capital; Or, to express it in a way indicating that TFP is computed as a residual, the growth rate of A_t is equal to the growth rate of Q_t not accounted for by the weighted average of the growth rates of L_t and K_t.

Equation (2) holds generally. That is, it holds for any period, any value of α, and any disaggregation, definition and measurement of the variables involved. Thus, by redefining it as:

$$\%\Delta Q_t^p = \%\Delta A_t^p + 0.7 \cdot \%\Delta L_t^p + 0.3 \cdot \%\Delta K_{t-1}^p, \tag{3}$$

[3] It should be noted that the data we employ in this paper consist of annual observations for the nonfarm private business sector of the U.S over the period 1949-2016. Hence, from now on we shall construe that index *t* stands for years.

where the upper index p denotes the "potential" values of the variables, CBO researchers proceed in two steps. In the first step, using (2) in conjunction with data from the U.S. Bureau of Economic Analysis (BEA), for the variables Q_t and K_t, and from the Bureau of Labor Statistics (BLS), for the variable L_t, they compute the growth rates of A_t going back to 1949. Naturally past values vary due to both regular and irregular factors. Therefore, to obtain the growth rates $\%\Delta L_t^p$ and $\%\Delta A_t^p$, the variables L_t and A_t are purged from their cyclical components. As for the growth rate $\%\Delta K_t^p$, this is obtained by setting $K_{t-1} = K_{t-1}^p$ on account of the rationalization that:

> "…, the capital input does not need to be cyclically adjusted to create a "potential" level—the unadjusted capital input already represents its potential contribution to output. Although use of the capital stock varies greatly during the business cycle, the potential flow of capital services will always be related to the total size of the capital stock, not to the amount currently being used."

Lastly, upon inserting $\%\Delta A_t^p$, $\%\Delta L_t^p$ and $\%\Delta K_{t-1}^p$ into (3), they obtain the trend growth rate $\%\Delta Q_t^p$ as a weighted sum of the trend growth rates of labor and capital services plus the trend growth rate in Total Factor Productivity (TFP).

Table A1 in the Appendix[4] reports the Gross Domestic Product (GDP_t) as a measure of output (Q_t), the labor (L_t) and capital (K_{t-1}) inputs, and labor productivity (Q_t / L_t). These constitute the actual series reported in the sources mentioned at the bottom of the table. Table A2 reports the most recent estimates and projections by CBO of potential output (Q_t^p) and its determinants. In the latter table the rows 1949-2016 refer to the historical estimates, whereas the rows 2017-2027 exhibit those that are projected. Finally, in line with the above remark that $K_{t-1} = K_{t-1}^p$, the series of capital input reported by CBO is the same in both tables.

3. Towards an improved measure of the capital input

According to the Congressional Budget Office (2001, 17-20, 27-29), the capital input is estimated on the basis of an index which measures the proportionate growth rate of an aggregate asset obtained as a weighted average of the proportionate growth rates of seven distinct assets. In particular, this takes the form of the Tornquist index:

[4] Note that all tables having an A in their numbering are located in the Appendix.

$$\log(\frac{K_t}{K_{t-1}}) = \omega_1 \log(\frac{K_{1t}}{K_{1t-1}}) + ... + \omega_7 \log(\frac{K_{7t}}{K_{7t-1}}). \quad (4)$$

The weights ω_{it} are defined as follows:

$$\omega_{it} = (s_{it} + s_{it-1}) / 2$$
$$s_{it} = c_{it} K_{it} / \sum_{i=1}^{7} c_{it} K_{it}, \quad (5)$$

and c_{it} stands for the rental price or "user cost" of asset *i* in year *t*. If the business firms in the non-farm sector pay owners the value of the marginal product that their assets contribute and there are constant returns to scale in production, then s_{it} denotes the share of each asset in total capital costs or in the total income received by the owners of assets.

The computation of the capital assets entering into equation (4) is quite standard. From the Congressional Budget Office (2001, 28) it follows that of the seven assets included, the first five are computed by applying the well-known difference equation:

$$K_{it} = (1 - \delta_i) K_{it-1} + I_{it}, \quad (6)$$

where K_{it} denotes the net stock of asset *i* in year *t*; K_{it-1} stands for the net stock of asset *i* lagged one year; I_{it} represents the investment in asset *i* in year *t*, and δ_i is the depreciation rate of asset *i*. Given a value for asset K_{it} at $t = 0$ and the corresponding series of investment I_{it}, solving equation (6) returns a proportional depreciation rate together with a series of the net capital stock for asset *i,* which is consistent with the series of investment. The assumption that underlies this conceptualization is that the depreciation of asset *i* is geometric or, alternatively, that the decline in its efficiency in period *t* is equal to a constant percentage δ_i of its stock in year *t*-1. As for the remaining two assets, i.e. nonfarm inventories and land, these are computed as fixed percentages of the real economic growth the former, and the investment in nonresidential structures the latter.

This paper departs from the above benchmark model in several ways. One differentiation has to do with the depreciation rate δ_t. Following Bitros, Flytzanis (2007), the rate by which the quantity of services of an asset declines from one period to the other ought to be specified as a function of economic forces like intensity of utilization, maintenance expenditures and technological obsolescence. Such a specification would escape from the strong assumption that the rate of depreciation is a function of the age of the asset in question. However, even though it would be recommended from a microeconomic point of view, venturing into such an undertaking here would take us far afield. So a compromise is in order. CBO's specification in (6) follows Jorgenson's (1963) approach by assuming that over its service life the asset loses efficiency geometrically at the rate δ_i. In Figure 1, the efficiency loses of this asset would follow the path shown by the convex line labeled "geometric". On the contrary, in its multifactor productivity studies the U.S. Bureau of Labor Statistics (BLS) employs an age-efficiency profile like the one shown by aggregating over various assets whose depreciation follows the hyperbolic function in which the

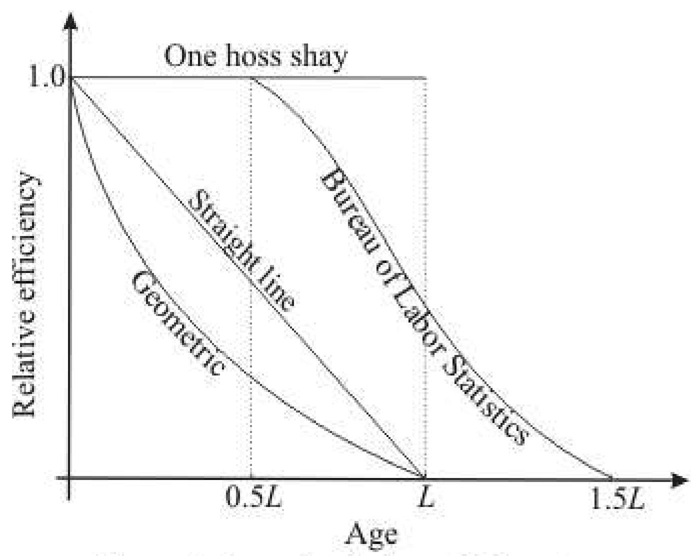

Figure 1:Age related depreciation patterns

single parameter involved takes values from 0, for assets with straight line depreciation, to 1, for those that fall in the one hoss shay pattern.[5] Thus, to simplify matters, but also because the straight line depreciation is nearer to the geometric used by CBO, a good approximation is to set:

$$\delta_{it} = \frac{1}{L_{it}} \ , \tag{7}$$

where L_{it} denotes the service life of asset i in year t. Observe that, whereas under the geometric

[5] For a detailed explanation of the method by which BLS obtains the age-efficiency depreciation pattern shown in Figure 1, see U.S. Bureau of Labor Statistics (1983, 38-45).

pattern depreciation remains a constant proportion of the asset irrespective of its service life, under the straight line scheme the depreciation rate increases as the service lives of assets decline. Hence, if the wear and tear and technological progress accelerate over time and reduce asset lives, as happened mostly in the postwar period, straight line depreciation may be better attuned with experience than the geometric.

A second differentiation is that nonfarm inventories and land are ignored and all other assets are grouped into structures, equipment, and intangibles. The main reasons for adopting this classification are that: (a) it coincides with the disaggregation in the data on "Fixed assets" that the U.S. Bureau of Economic Analysis (BEA) publishes as part of the National Income and Products Accounts (NIPA); (b) this source of data provides rich information on the average service lives of the aforementioned aggregate assets, so that expression (7) may be applied to calculate their depreciation rates,[6] and (c) having used these data in Bitros, Nadiri (2017a, b) to calculate the respective rental prices provides extensive computational synergies.[7] Recall though that CBO splits equipment into computers, communications equipment, and all other equipment. So it is likely that their measure of the capital input may reflect more accurately than ours the impact of rapid technological advances in the activities of information processing and transmission. This is an important aspect to keep in mind later on in the assessment of the comparative effects of the various measures of the capital input introduced in the computations.

After applying equations (4)-(7) to aggregate structures, equipment and intangibles into an overall capital stock, a differentiation is introduced in the measurement by CBO so as to allow for the three trends mentioned in the introduction. To begin with, Figure 2 shows that throughout the decades under consideration the share of structures declined, whereas those of equipment and intangibles increased. This transformation of the capital stock away from long lived producer's goods and towards short lived ones is rather unlikely to have left the contribution of the capital input to productivity, and hence to the growth rate of the economy, unaffected. Drawing on this presumption, an index based in 2009 is derived from the share of structures and used to compute

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[6] More specifically, BEA's NIPA database, Section 6, Table 5.10, reports the average service lives for structures, equipment and intangibles both at current and historical replacement prices. Based on our experience with these data in Bitros, Nadiri (2017a, b), in this paper we have decided to employ the series of service lives at historical replacement prices.

[7] The report by the Congressional Budget Office (2001) does not contain any information about the method by which they compute the rental prices of the aggregated assets via equation (4). It is likely that they apply the procedure described in the U.S, Bureau of Labor Statistics (1983, 49-51). But adopting the latter would involve computations that are too tedious and unnecessary for the test we pursue here.

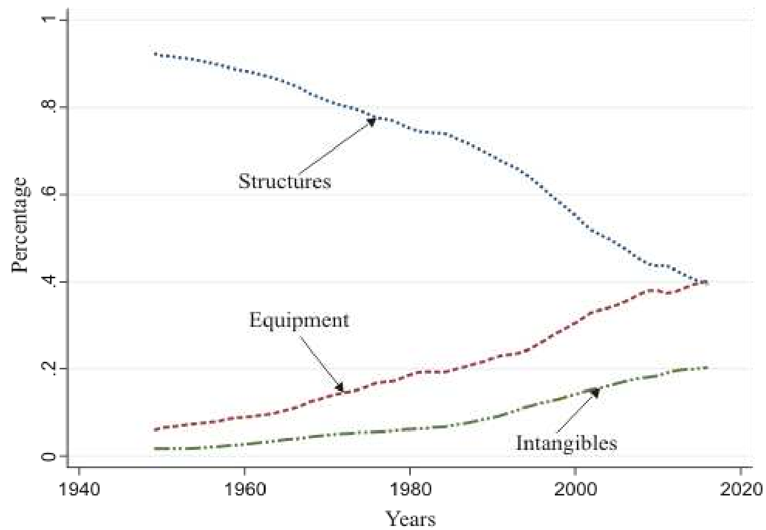

Figure 2: Shares of structures, equipment and intangibles,1947-2016

what the capital stock would have been if its composition remained throughout similar to that in the base year. In other words, the index so constructed is employed to normalize the composition of the capital stock in terms of structures, on the one hand, and equipment and intangibles, on the other, to the one that prevailed in the year 2009.[8] Henceforth this index of the capital stock will be referred to as K_t^1.

Figure 3 displays the evolution over time of the average service lives of structures, equipment, intangibles and overall capital stock since 1947 at historical replacement prices. Observe that for all three assets, as well as for the overall capital stock, service lives declined through the early 1980s, but ever since they have been rising. Apparently, while the capital stock in the U.S. non-farm private business sector was getting younger and thus embodied technological advances at a quicker pace in the first period, in the second period this trend reversed. Is this development unrelated to the decline in the U.S. economic growth in recent decades? Quite likely it is not because irrespective of the systemic forces that may have been responsible for the ageing of the capital stock, from theory it would expected and, as noted earlier, research has confirmed, that its contribution to economic growth has decelerated. But how strong headwinds may emanate for potential output from this source is an issue that can be highlighted only on empirical grounds. To this effect, using the time series of service lives of the overall capital stock an index based on its 2009

[8] The only reason for choosing 2009 as the base year for constructing this and the other indices mentioned below is that it coincides with the most recent base year employed by the Bureau of Economic Analysis (BEA).

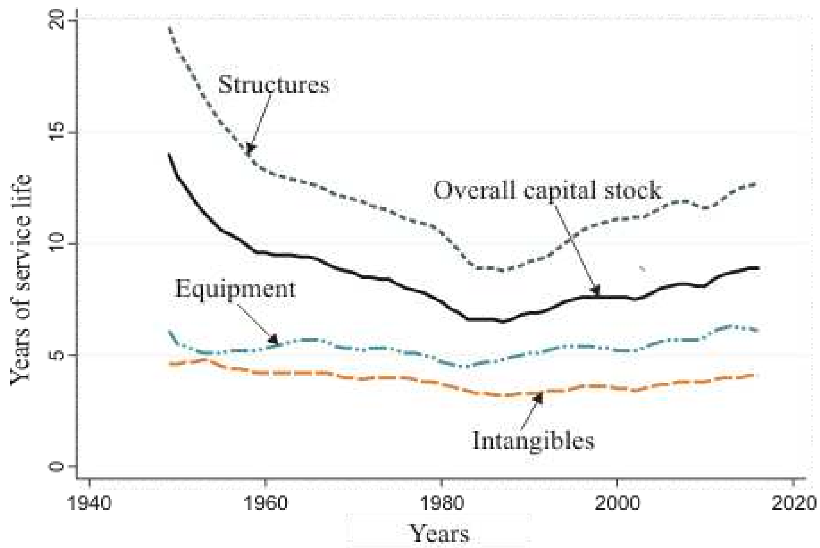

Figure 3: Evolution over time of average service lives

value was derived and employed to adjust the index of the capital stock computed from equations (4)-(6). The result is a new series, referred henceforth as K_t^2, which reflects the changes in the average service lives of the producer's goods in the sector under consideration.

Next, let us turn to the changes in the relative prices of producer's to consumer's goods. Paying attention to this aspect is necessary because of the possibility that relative prices may affect the composition of the capital stock, which in turn may influence the productivity of capital and thereby the rate of economic growth. Relevant to this aspect is Figure 4. Observe that since the 1960s structures became continuously more expensive relative to equipment and intangibles. In Bitros, Nadiri (2017a) we found that the elasticities of investment with respect to the relative prices coincide with the additive inverse of the elasticities of substitution of capital for labor at both the disaggregate and aggregate levels. For example, for structures we found that a 10% increase in their prices relative to consumer's goods would lead to a 6% decline of investment in this asset, whereas an equiproportional decline in the prices of equipment and overall capital stock relative to consumer's goods would reduce investment in these assets by 4.5 and 8.3 percent, respectively. That is, as the quantity of structures declined and those of equipment and intangibles increased (see Figure 2), the composition of the capital stock tilted against the former and in favor of latter, particularly from the early 1980s when with the advent of globalization it became increasingly beneficial for business firms to outsource the construction of machinery and intangibles from third countries. As a result, these developments may have ren-

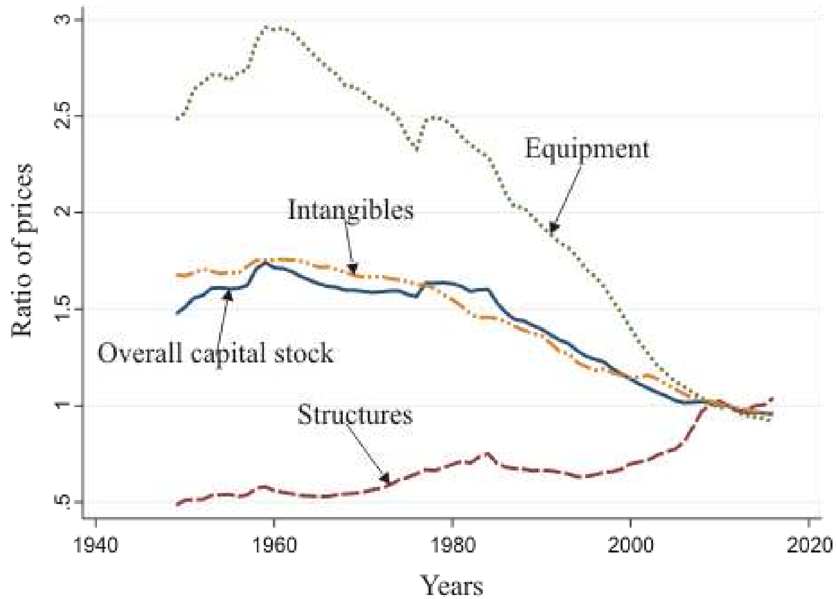

Figure 4: Relative prices of producer's to consumer's goods

dered the composition of capital stock increasingly unbalanced, thereby leading to a deceleration of overall investment and a slowdown in the productivity of capital. To account for the possible effects of this development, an index from the relative prices of the overall capital stock was constructed on the basis of its 2009 value and was employed to adjust the computed index of the capital stock series from equations (4)-(7). For reference and comparison this series will be referred henceforth as K_t^3.

The indices K_t^1, K_t^2 and K_t^3 represent alternative measures of the capital input. Table A4 displays their series along with the indices of $\hat{K}_t$ and K_t, all lagged one period and based in the year 2009. The latter index coincides with the one reported by CBO, whereas the former was obtained by adjusting $\bar{K}_t$, as computed by applying equations (4)-(7) and shown in Table A3, Column 12, for changes in: (a) the composition of the capital stock in terms of structures, equipment and intangibles, (b) the average service lives of these producer's goods, and (c) their prices relative to consumer's goods. Moreover, to get an idea of how these alternative measures of the capital input evolved in the postwar period, Figure 5 brings them all together in a uniform setting. With these data in hand, it is possible now to appraise the contribution of capital input to the potential output.

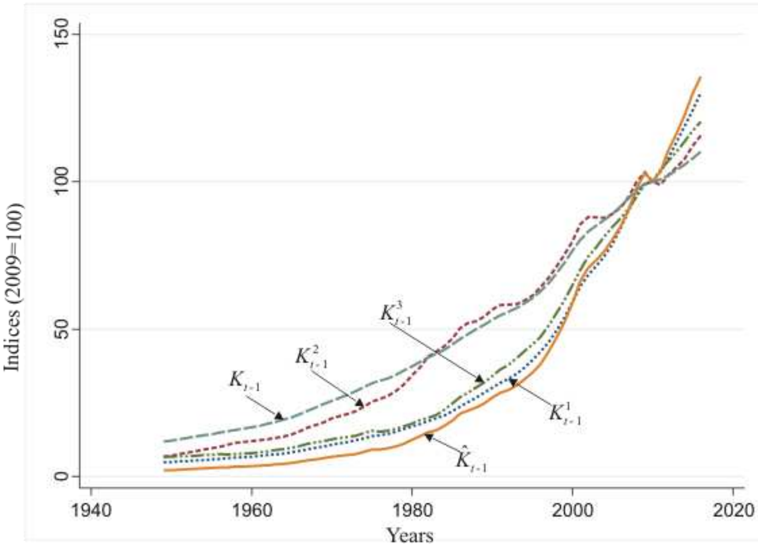

Figure 5: Alternative indices of the capital input

4. Comparative analyses, results and interpretations

The tasks in this section are threefold. The first is to compare the two measures of the capital input, i.e. CBO's K_{t-1} and ours $\hat{K}_{t-1}$, to identify any significant differences among them, and to assess their implications for potential output. The second task is to compute the percentage rate of change of the potential output $\%\Delta\hat{Q}_t^p$ using the capital input $\hat{K}_{t-1}$ and compare it with $\%\Delta Q_t^p$ which is based on K_{t-1}. The expectation being that this comparison will enable us to get a glimpse of the differential influence that K_{t-1} and $\hat{K}_{t-1}$ exert on the potential output. Lastly, in order to highlight the effects of the above changes in the capital stock on the potential output, the second task is repeated using separately each of the K_{t-1}^1, K_{t-1}^2 and K_{t-1}^3 measures of the capital input from Table A4. In all these efforts Q_t and L_t from Table A1 and Q_t^p, L_t^P, and A_t^p from Table A2 will be considered as given

4.1 Capital input related biases of potential output

From equation (3) it follows that CBO researchers reckon the contribution of the capital input to the growth rate of the potential output at .3 times its percentage rate of change. Hence, the first aspect of interest is to compare the differences in the contributions of the capital input by looking at its measurements K_{t-1} and $\hat{K}_{t-1}$. Relevant to this comparison is Figure 6 in which the line labeled $\%\Delta\hat{K}_t^{'}$ depicts our measurement of the capital input, whereas the line labeled $\%\Delta K_t^{'}$ shows the capital input as measured by CBO. Observe certain key similarities and differences. But before turning to their assessment, it is pertinent to note that the series

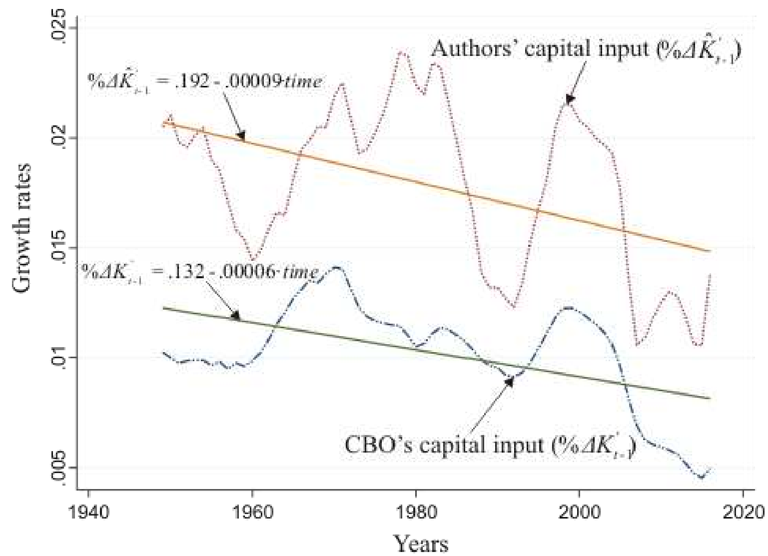

Figure 6: Contribution of capital input to the potential output

$\%\Delta K_{t-1}^{'}$ and $\%\Delta\hat{K}_{t-1}^{'}$ were obtained by passing the variables $.3\cdot\%\Delta K_{t-1}$ and $.3\cdot\%\Delta\hat{K}_{t-1}$ through a ten year centered moving average smoothing filter. The rational for adopting this procedure being to eliminate medium run variations in the capital stock due to reasons other than the above mentioned systematic long run changes in its composition, average service lives and the declining prices of producer's relative to consumer's goods. As for the upper and lower straight lines, these display the trends that were computed for $\%\Delta K_{t-1}^{'}$ and $\%\Delta\hat{K}_{t-1}^{'}$ with the help of the equations shown.[9]

Looking at this figure a key feature worth stressing is how the $\%\Delta K_{t-1}^{'}$ line runs relative to that of $\%\Delta\hat{K}_{t-1}^{'}$. It gives rise to three implications. The first springs from the observation that from 1949 to 2016 the line of $\%\Delta\hat{K}_{t-1}^{'}$ remains above that of $\%\Delta K_{t-1}^{'}$. Surprisingly they never cross. Consequently, CBO's measure of the capital input *underestimates consistently* its contribution to potential output. The second implication is that *the order of the underestimation is very signifi-*

[9] The coefficients in both equations in Figures 6 and 7 are statistically significant with comfortable levels of confidence and the coefficients of determination explain about 25% of the variance in the respective dependent variables.

cant. In particular, if computed at the mean values of $\%\Delta K_{t-1}^{'}$ and $\%\Delta \hat{K}_{t-1}^{'}$, CBO's measure of the capital input underestimates its contribution to potential output by as much as 74.1% (See last row in Table A5 in the Appendix). Lastly, the third implication is that by both measures of the capital input the trend of their contribution to potential output has been declining throughout. This is consistent with the available evidence from the studies mentioned in the introduction, as well as from the literature in this area in general.

In view of the above, one would be justified to suspect that CBO's measurement of the capital input *overestimates* potential TFP. So let us find out by applying the following steps: (a) using equation (2) in conjunction with $\%\Delta Q_t$, $\%\Delta L_t$ and $\%\Delta K_{t-1}$ from Table 1, Columns 1, 2 , 3, we compute $\%\Delta TFP_t$; (b) repeating the last step but using instead $\%\Delta \hat{K}_{t-1}$ from Table A3, Column 13, gives us $\%\Delta T\hat{F}P_t$; and (c) subjecting $\%\Delta TFP_t$ and $\%\Delta T\hat{F}P_t$ to a ten year centered moving average smoothing filter, yields $\%\Delta TFP_t^{'}$ and $\%\Delta T\hat{F}P_t^{'}$. Figure 7 juxtaposes these series to gauge the direction and magnitude of possible bias. Observe that CBO's measure of the capital

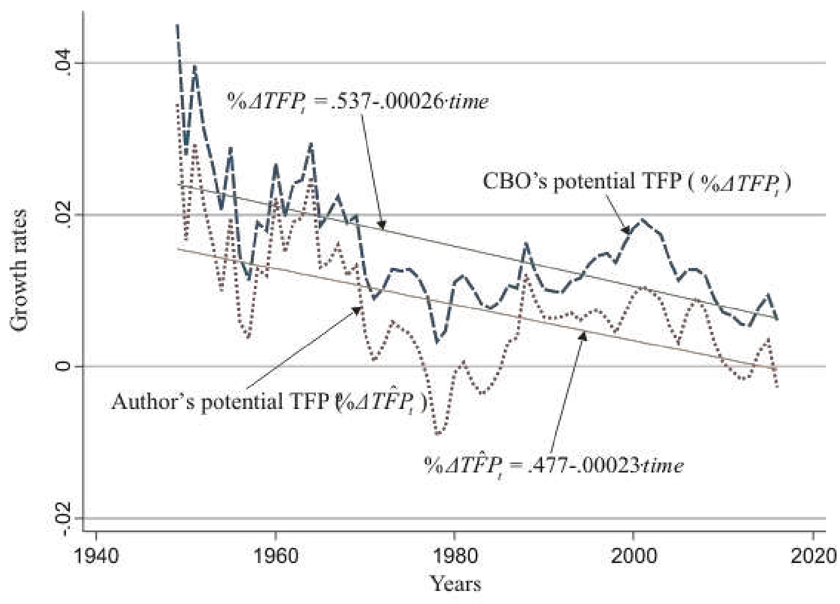

Figure 7: Bias in CBO's measurement of potential TFP

input does indeed overestimate its contribution to potential TFP. In particular, if calculated at the mean values of $\%\Delta TFP_t^{'}$ and $\%\Delta T\hat{F}P_t^{'}$, this overestimation amounts to 100.7% (See last row in Table A5 in the Appendix).

The implications of these findings are straightforward. According to equation (3), the percentage rate of change in the capital input is weighted by .3 while the percentage rate of change of potential TFP is weighted by 1. Hence, as the low weight assigned to an already underestimated capital input combines with the high weight assigned to an already overestimated total factor productivity, CBO's measure of the capital input raises the percentage rate of change of potential output more than it would be warranted if the capital input was measured by allowing for the changes in the composition, service lives and relative prices of the assets in the capital stock. This happens at the same time that the trends in the contributions to potential output of both the capital input and TFP are declining (see Figures 6 and 7). From this analysis it follows that the deceleration of potential output may be far more serious than that estimated by CBO because of the deceleration not so much in the contribution of the capital input but in TFP.

4.2 New estimate of potential output versus that of CBO's

To highlight further this finding, $\%\Delta Q_t^p$ will be computed by applying equation (3) twice, once by using the measure of input $\%\Delta\hat{K}_{t-1}$ and another by relying on $\%\Delta K_{t-1}$. Moreover, these computations will be carried out without any smoothing of the two measures so as to keep in line with the practice by CBO.

Figure 8 displays the path of the actual GDP from the U.S. nonfarm private business sector in the postwar period, along with the paths of potential output as calculated using the above distinct

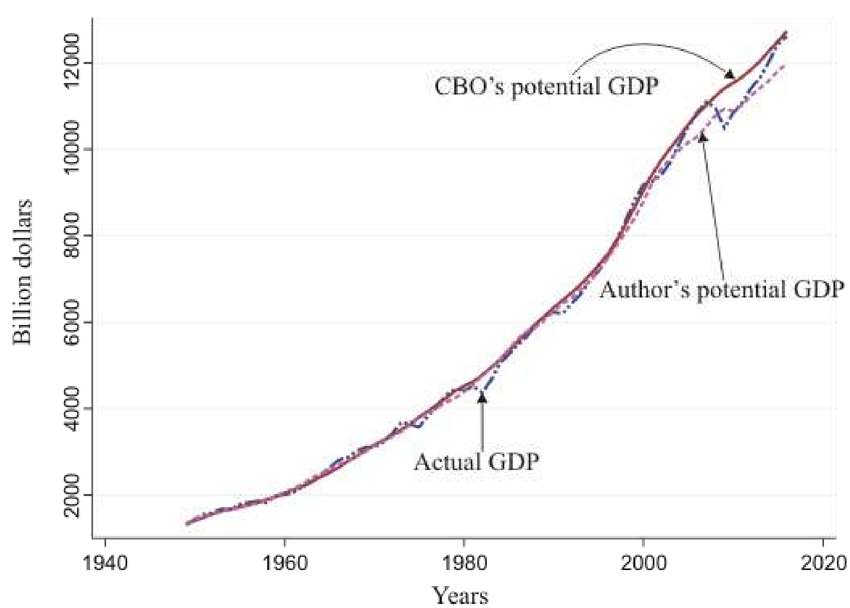

Figure 8: Actual and alternative measurements of potential GDP

measures of the capital input. Observe that: (a) according to both estimates, the potential output started to decelerate from the middle 1990s; (b) the path of potential output estimated by CBO runs consistently above the one estimated by us; (c) the divergence between the two paths is widening after 2009, and (d) whereas by CBO's estimate of potential output the real economy adjusted sluggishly after the 2007 financial crisis, by our estimate the economy adjusted fairly quickly to its lower potential output and in the last few years it has even exceeded it. Recall at this point that the contribution to potential output from the potential labor input is the same in both estimations. Hence, the reason why our estimate of potential output runs lower than CBO's and the gap between the two estimates widens after 2009 should be due to the different rates by which the contributions of the capital input and TFP to potential output decline. Figures 6 and 7 show that, while the trend growth rates of both the capital input and the TFP are declining, with CBO's measure of the capital input the trend growth rate of potential output decelerates slower (see K_t and $\hat{K}_t$ lines in Figure 5 and $\%\Delta K'_{t-1}$ line in Figure 6) and TFP decelerates faster (see $\%\Delta TFP_t$ line in Figure 7), thus pushing CBO's path of potential output further above that of ours (see Figure 8). Or, expressing this finding in a forward looking manner, if the capital input is measured properly, the outlook for economic growth in the coming years is even bleaker than glimpsed from CBO's estimates of the potential output because, in addition to the headwinds mentioned in the introduction, both the capital input and TFP decelerate, and indeed the latter faster than the former.

To summarize, irrespective of the issues of measurement, the long term trend in the contribution of the capital input to potential output, and hence to U.S. economic growth, is declining. This is a matter of grave importance because it points to headwinds that inhibit the acceleration of investment, the renewal of the capital stock, and the speedy introduction of new technologies that may invigorate TFP. How pervasive these headwinds may be was highlighted recently from the article by Bloomberg (2017). Even though U.S corporations are awash with trillions of dollars in cash, the interest rates are at record lows, and the effective tax rates are extremely competitive relative to other countries, from this article we learned that corporate executive would not be incentivised to boost investing by the reduction in the statutory tax rate which is discussed currently in the Congress. Headwinds to investing may spring from the demand side, the uncertainty that emanates from the huge public and private debts, or even abrupt and unforeseen changes in institutions and policies. However, whatever the reasons may be, one thing is certain. The changes in the structure of the capital stock and the reasons for the profound slowdown of the capital input are too important and they should be given the urgent attention they deserve.

4.3 Capital input adjustments and potential output

Regarding their effects on potential output, Figure 5 helps us classify capital input adjustments into two categories. One that includes the adjustments giving rise to profiles adjacent to $\hat{K}_t$, and another that includes profiles closed to K_t. Observe that the profiles of K_t^1 and K_t^3, which allow respectively for changes in the composition of the capital stock and the relative prices of the underlying assets, fall in the first category, whereas the profile of K_t^2, accounting for the changes in the average service lives of these assets, falls in the second. Focusing on the effects of the capital input adjustments in the first category, the conclusions would differ from those reached earlier only in degree. In particular, the adjustments for compositional and relative price changes would influence the contributions of the capital input to the potential output in a way that would push the latter's estimated profile further below that estimated by CBO. Therefore, the only case of interest remaining is to focus on the effects of K_t^2.

Relevant to this case is Figure 9. Observe that throughout the period under consideration the path of estimated potential output us runs narrowly around that of CBO. Thus, by comparing the graphs in Figures 9 and 8 arise two implications. The first is that the said adjustment in the capital input gives an improved estimation of the potential output. For, while on the one hand it does

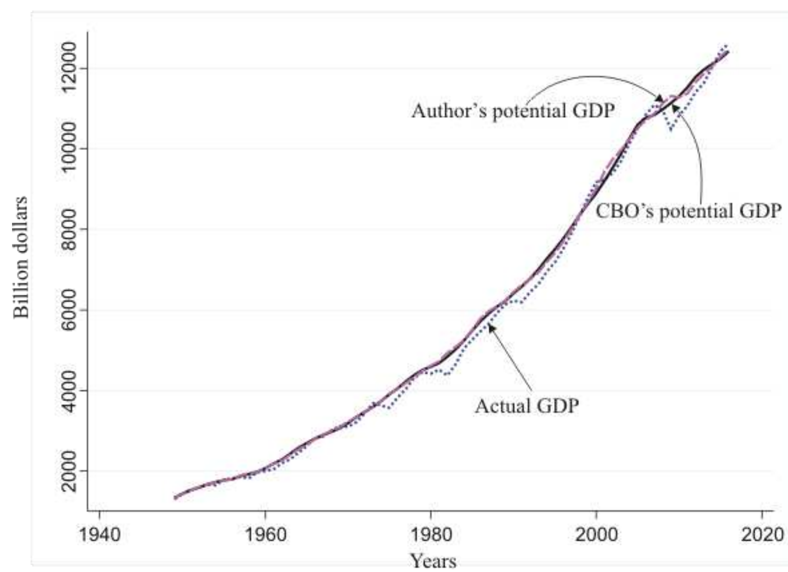

Figure 9: Actual and alternative profiles of potential GDP

not result in systematic overestimation or underestimation relative to the estimate by CBO, on the other it captures the losses and gains in efficiency that are associated with the long cycles over which producer's goods are getting older or younger, respectively. As for the second implication, this suggests that service life adjustments in the capital input influence the path of the estimated potential output in the opposite direction to that under the adjustments for changes in the composition and the relative prices of productive assets. To ascertain that this is case, notice from Figure 8 that, when all three adjustments are imposed, the path for potential output runs consistently below that by CBO and from the late 1990s it decelerates at an increasing rate. From these implications it follows that the changes in the capital input which are reflected in the indices K_t^1, K_t^2 and K_t^3 influence differently the estimates of potential output and that ignoring them may lead to significant errors of measurement, interpretations and recommended remedial policies.

5. Summary of findings and conclusions

Considered in the context of CBO's pessimistic projections of the potential output, the long lag in the recovery of the U. S. economy from the 2007 financial crisis, stirred in 2013 a lot of heated debates regarding the future of U.S. economic growth. At the time some economists even interpreted this experience as a sign of alarm strong enough to hypothesize that the economy had entered into a protracted period of secular stagnation. However, since then the economy has recovered wonderfully, and this turnaround has encouraged some observers like Coy (2017) to feel justified in expressing the view that devoting resources to promote the Secular Stagnation Project and to organize high level conferences devoted to this agenda are unwarranted, if not wasteful.[10]

The objective in this study was to contribute to the debate by looking into the possible linkages between potential output and capital input, which has not received the attention it deserves. For this purpose the analytical framework of the U.S. Congressional Budget office was adapted and used in conjunction with data from the U.S. Bureau of Economic Analysis pertaining to nonfarm private business sector over the period 1947-2016. By focusing on the changes in the composition of the capital stock in terms of structures, equipment and intangibles; average service lives; and the relative prices of producer's to consumer's goods, it became possible to allow for their influence on the capital input and trace the latter's effects on potential output. In particular, it was

[10] For an explanation of the objectives of the Secular Stagnation Project and the related conference that was convened in December 15, 2017, in New York, see Summers (2017).

found that: a) when the capital input is adjusted to reflect all aforementioned changes, potential output in recent decades decelerates even faster than CBO's estimates; b) in the post-2007 period the gap between our estimate of potential output and that by CBO is widening, and (c) the accelerated slowing down of potential output is due to the declining share of structures in the capital stock and the spectacular decline in prices of equipment relative to the prices of structures in terms of consumer's goods. Drawing on these findings led to the conclusion that, although the real economy may have overshoot its potential in recent years, the forces that slow down potential output through the capital input remain intact and that, unless some remedial policies are instituted, they will continue to function as significant headwinds to U.S. economic growth, along with all others impediments mentioned in the introduction.

6. References

Bitros, G. C., Flytzanis, E. G., (2009). "Operating policies in a model with terminal scrapping," *European Journal of Operational Research*, 194, 551-573.

Bitros, G. C., Nadiri, M. I., (2017a), "Elasticities of business investment in the U.S. and their policy implications: A disaggregate approach to modeling and estimation," in **https://www.dept.aueb.gr/sites/default/files/econ/dokimia/wp07-2017-Bitros-Nadiri-150617.pdf .**

--------------------------, (2017b), "Behavior of business investment in the USA under variable and proportional rates of replacement," in **http://www.econ.aueb.gr/en/uploadfiles/wp08-2017-Bitros-Nadiri-180617.**

Bloomberg, M. R., (2017), "This Tax Bill Is a Trillion-Dollar Blunder," in https://www.bloomberg.com/view/articles/2017-12-15/this-tax-bill-is-a-trillion-dollar-`blunder.

Fraumeni, B. M., Jorgenson, D. W., (1980), "The role of capital in U.S. economic Growth, 1948-1976). In George M. von Furstenberg (Ed.) *Capital, Efficiency and Growth*, Cambridge Mass.: Ballinger Publishing Company, 9-200.

Gordon, R. J., (2012), "Is U.S. Economic Growth Over? Faltering Innovation Confronts the Six Headwinds," National Bureau of Economic Research, Working paper 18325.

-------------------, (2014a), "US Economic Growth is Over: The Short Run meets the Long Run," in THINK TANK 20: Growth, Convergence and Income Distribution: The Road from the Brisbane G-20 Summit, https://www.brookings.edu/.../2016/07/tt20-united-states-economic-growth-gordon.pdf .

-------------------, (2014b), "A New Method of Estimating Potential Real GDP Growth: Implications for the Labor Market and the Debt/GDP ratio," National Bureau of Economic Research, Working paper 20423.

------------------, (2015a), "Secular Stagnation on the Supply Side: U.S. Productivity in the Long Run," *Digiworld Economic Journal*, 100, 19-45.

------------------, (2015b), *Beyond the Rainbow: The Rise and Fall of Growth in the American Standard of Living*, Princeton, NJ: Princeton University Press.

Coy, P., (2017), “Growth Is Gangbusters, but Some Economists Are Still Warning about ‘Secular Stagnation”,”https://www.bloomberg.com/news/articles/2017-12-19/growth-is-gangbusters-but-some-economists-are-still-warning-about-secular-stagnation.

Jorgenson, D. W., (1963), "Capital Theory and Investment Behavior," *American Economic Review*, 53, 247-259.

-----------------------, (1991), “Productivity and Economic growth,” in Ernst R. Berndt and Jack E. Triplett (Eds.), *Fifty Years of Economic Measurement: The Jubilee of the Conference on research in Income and Wealth*, National Bureau of Economic Research, Chicago Ill: University of Chicago Press, 19-118.

Jorgenson, D. W., Stephenson, J. A., (1967), “Investment Behavior in U.S. Manufacturing, 1947-1960,” *Econometrica*, 35, 169-220.

Summers, L. H., (2013a), “IMF Fourteen Annual Research in Honor of Stanley Fisher,” in Http://larrysummers.com/imf-fourteen-annual-research-in-honor-of-stanley-fisher/.

---------------------, (2013b), ‘Why stagnation might prove to be the new normal,” in Http://larrysummers.com/commentary/financial-times-columns/why-stagnation-might-prove-to-be-the-new-normal/.

----------------------, (2014a), “U.S. Economic Prospects: Secular Stagnation, Hysteresis, and the Zero Lower Bound,” *Business Economics*, 49, 65–73.

----------------------, (2014b), “Bold Reform Is the Only Answer to Secular Stagnation.” *Financial Times*, September 8.

----------------------, (2017), “Secular Stagnation Project,” www.ineteconomics.org .

U.S. Bureau of Labor Statistics, (1983), *Trends in multifactor productivity 1948-81*, Bulletin 2178, Bulletin 2, 178.

U.S. Congressional Budget Office, (2001), *CBO’S method for estimating potential output: An update,* The Congress of the United States, Congressional Budget Office.

Wasshausen, D. B., Samuels, J. D., Stewart, J., Strassner, E. H., (2016), “Estimating capital services in the U.S.: An empirical assessment of implementation difference,” Paper prepared for the 34th IARIW General Conference, Dresden, Germany, August 21-27, 2016.

APPENDIX

Table A1: **Actual** data underlying CBO's computations of potential GDP in the U.S nonfarm private business sector

Year	$GDP = Q_t$ (1)	L_t (2)	K_{t-1} (3)	Labor productivity (4)=(1):(2)		Year	$GDP = Q_t$ (1)	L_t (2)	K_{t-1} (3)	Labor productivity (4)=(1):(2)
1949	1,309	83.4	11.8	15.7		1986	5,463	143.4	46.6	35.1
1950	1,441	80.1	12.1	16.2		1987	5,658	148.0	48.3	35.8
1951	1,548	82.7	12.6	16.8		1988	5,916	152.4	49.9	36.5
1952	1,595	86.6	13.0	17.4		1989	6,134	157.2	51.5	37.3
1953	1,675	87.5	13.5	17.9		1990	6,228	157.3	53.2	38.0
1954	1,650	89.7	13.9	18.2		1991	6,191	154.3	54.6	38.6
1955	1,790	86.7	14.3	18.5		1992	6,442	154.7	55.8	39.1
1956	1,823	90.1	14.8	18.8		1993	6,642	158.8	57.1	39.6
1957	1,860	92.4	15.3	19.3		1994	6,950	165.3	58.7	40.2
1958	1,823	91.8	15.8	19.8		1995	7,191	169.6	60.6	40.7
1959	1,975	88.0	16.2	20.3		1996	7,516	173.4	62.9	41.5
1960	2,010	92.0	16.7	20.8		1997	7,909	179.2	65.6	42.6
1961	2,053	92.6	17.2	21.4		1998	8,325	184.1	68.8	44.0
1962	2,194	91.6	17.9	22.0		1999	8,789	188.1	72.5	45.5
1963	2,295	93.6	18.5	22.6		2000	9,173	191.3	76.5	47.2
1964	2,448	94.6	19.2	23.2		2001	9,240	188.4	80.3	48.8
1965	2,624	98.7	20.0	23.9		2002	9,404	184.8	83.2	50.3
1966	2,812	103.0	21.1	24.8		2003	9,697	183.2	85.2	51.5
1967	2,865	103.7	22.3	25.7		2004	10,131	185.6	87.1	52.9
1968	3,018	106.0	23.4	26.5		2005	10,513	188.9	89.2	54.1
1969	3,110	109.3	24.5	27.3		2006	10,848	193.1	91.7	55.2
1970	3,105	107.9	25.6	28.0		2007	11,097	195.1	94.5	56.2
1971	3,222	107.3	26.7	28.5		2008	10,954	192.7	97.3	57.1
1972	3,438	111.3	27.7	28.9		2009	10,488	180.2	99.3	57.9
1973	3,687	115.9	29.0	29.4		2010	10,823	180.4	100.0	58.4
1974	3,631	116.2	30.4	29.9		2011	11,061	184.8	100.8	58.9
1975	3,571	111.4	31.6	30.4		2012	11,406	188.8	102.2	59.5
1976	3,826	115.6	32.4	30.8		2013	11,633	192.5	104.0	60.2
1977	4,044	120.0	33.3	31.2		2014	12,015	196.9	105.9	60.8
1978	4,312	126.0	34.5	31.7		2015	12,426	201.3	108.0	61.6
1979	4,455	130.3	35.9	32.2		2016	12,611	204.6	110.3	62.4
1980	4,415	129.5	37.4	32.3						
1981	4,517	130.9	38.9	32.3						
1982	4,373	128.1	40.3	32.7						
1983	4,657	130.3	41.6	33.2						
1984	5,047	138.1	42.9	33.7						
1985	5,262	142.0	44.8	34.4						

Notes
1. Actual GDP in billions of chained 2009 dollars.
2. Actual hours worked, billions of hours. Data from 1964 to 2016 from U. S. Bureau of Labor Statistics (BLS), Division of Major Sector Productivity, August 18, 2017. Data for 1949 to 1963, computed backwards using the percentages of annual change from BLS series PRS85006032.
3. Capital Services, index: 2009 = 100, lagged one year.

Source: CBO's June 2017 report: An Update to the Budget and Economic Outlook: 2017 to 2027, www.cbo.gov/publication/52801

Table A2: Historical and projected potential values of GDP and its determinants in the U.S nonfarm private business sector

Year	$GDP_t^P = Q_t^P$ (1)	L_t^P (2)	K_{t-1}^p (3)	A_t^P (4)		Year	GDP_t^P (1)	L_t^P (2)	K_{t-1}^p (3)	A_t^P (4)
1949	1,341	85.5	11.8	46.4		1989	6,142	164.7	51.5	85.9
1950	1,412	87.2	12.1	47.8		1990	6,332	166.5	53.2	86.9
1951	1,481	88.1	12.6	49.1		1991	6,508	168.4	54.6	87.8
1952	1,558	89.3	13.0	50.5		1992	6,680	170.7	55.8	88.7
1953	1,629	91.1	13.5	51.5		1993	6,869	173.4	57.1	89.5
1954	1,680	92.3	13.9	52.1		1994	7,080	176.3	58.7	90.4
1955	1,722	93.1	14.3	52.6		1995	7,313	179.6	60.6	91.3
1956	1,768	93.9	14.8	53.1		1996	7,564	182.4	62.9	92.3
1957	1,823	94.7	15.3	53.8		1997	7,871	184.9	65.6	93.9
1958	1,891	95.6	15.8	54.9		1998	8,242	187.4	68.8	95.8
1959	1,962	96.8	16.2	56.1		1999	8,639	189.7	72.5	97.9
1960	2,041	98.1	16.7	57.4		2000	9,035	191.3	76.5	100.0
1961	2,123	99.3	17.2	58.6		2001	9,415	192.8	80.3	102.0
1962	2,210	100.5	17.9	59.9		2002	9,737	193.8	83.2	103.9
1963	2,309	102.2	18.5	61.2		2003	10,015	194.3	85.2	105.9
1964	2,412	103.9	19.2	62.5		2004	10,290	194.7	87.1	107.9
1965	2,520	105.3	20.0	63.8		2005	10,569	195.2	89.2	109.8
1966	2,637	106.5	21.1	65.2		2006	10,809	195.7	91.7	111.1
1967	2,769	107.8	22.3	66.6		2007	11,016	196.0	94.5	111.9
1968	2,906	109.5	23.4	68.1		2008	11,226	196.5	97.3	112.7
1969	3,041	111.2	24.5	69.4		2009	11,405	197.1	99.3	113.5
1970	3,160	112.9	25.6	70.3		2010	11,525	197.4	100.0	114.3
1971	3,271	114.9	26.7	70.9		2011	11,657	197.9	100.8	115.1
1972	3,387	117.3	27.7	71.6		2012	11,829	198.8	102.2	115.9
1973	3,508	119.4	29.0	72.3		2013	12,033	200.0	104.0	116.7
1974	3,653	122.0	30.4	73.2		2014	12,257	201.4	105.9	117.5
1975	3,806	125.0	31.6	74.2		2015	12,492	202.9	108.0	118.3
1976	3,945	128.0	32.4	75.2		2016	12,719	203.9	110.3	119.2
1977	4,086	130.9	33.3	76.3		2017	12,943	204.6	112.6	120.1
1978	4,241	133.7	34.5	77.3		2018	13,191	205.4	115.0	121.1
1979	4,399	136.6	35.9	78.2		2019	13,459	206.2	117.7	122.3
1980	4,516	139.8	37.4	78.1		2020	13,740	207.0	120.4	123.5
1981	4,620	143.0	38.9	77.8		2021	14,033	207.8	123.0	124.9
1982	4,773	146.1	40.3	78.4		2022	14,339	208.6	125.6	126.3
1983	4,944	149.1	41.6	79.4		2023	14,655	209.5	128.3	127.8
1984	5,129	152.2	42.9	80.5		2024	14,977	210.4	130.9	129.3
1985	5,336	155.2	44.8	81.5		2025	15,306	211.3	133.7	130.9
1986	5,548	158.0	46.6	82.6		2026	15,642	212.2	136.5	132.4
1987	5,753	160.7	48.3	83.7		2027	15,986	213.0	139.4	134.0
1988	5,949	162.9	49.9	84.8						

Notes
1. Potential GDP in billions of chained 2009 dollars.
2. Potential hours worked in billions of hours.
3. Cyclically unadjusted capital Services, index: 2009 = 100, lagged one year. Hence, $K_{t-1} = K_{t-1}^P$.
4. Potential Total Factor Productivity, index: 2000 = 100

Source: CBO's June 2017 report: An Update to the Budget and Economic Outlook: 2017 to 2027, www.cbo.gov/publication/52801

Table A3: Actual data underlying CBO's computations of capital input in the U.S nonfarm private business sector

Year	K_{St} (1)	K_{Et} (2)	K_{It} (3)	K_t (4)	c_{St} (5)	c_{Et} (6)	c_{It} (7)	c_t (8)	ω_{St} (9)	ω_{Et} (10)	ω_{It} (11)	$\bar{K}_t$ (12)	$\hat{K}_t$ (13)
1948	1.484	0.486	0.033	2.027	0.051	0.623	0.535	0.197	0.488	0.488	0.085	2.78	10.2
1949	1.490	0.454	0.034	2.061	0.057	0.686	0.527	0.213	0.461	0.461	0.080	2.83	10.4
1950	1.492	0.422	0.034	2.076	0.057	0.736	0.522	0.224	0.444	0.444	0.079	2.90	10.6
1951	1.503	0.399	0.035	2.097	0.065	0.839	0.585	0.258	0.450	0.450	0.072	2.97	10.9
1952	1.523	0.381	0.036	2.120	0.084	1.011	0.670	0.323	0.447	0.447	0.074	3.03	11.1
1953	1.541	0.365	0.038	2.133	0.083	0.961	0.645	0.318	0.445	0.445	0.080	3.13	11.5
1954	1.570	0.356	0.043	2.159	0.087	0.960	0.682	0.333	0.432	0.432	0.087	3.20	11.7
1955	1.603	0.345	0.047	2.181	0.079	0.882	0.643	0.309	0.430	0.430	0.090	3.30	12.1
1956	1.645	0.343	0.051	2.217	0.081	0.876	0.647	0.313	0.434	0.434	0.091	3.43	12.6
1957	1.702	0.343	0.057	2.265	0.089	0.905	0.662	0.336	0.438	0.438	0.092	3.55	13.0
1958	1.754	0.344	0.062	2.304	0.099	0.953	0.694	0.368	0.433	0.433	0.099	3.61	13.2
1959	1.790	0.337	0.067	2.320	0.097	0.934	0.698	0.364	0.430	0.430	0.103	3.69	13.5
1960	1.827	0.336	0.072	2.343	0.100	0.943	0.715	0.379	0.427	0.427	0.108	3.79	13.9
1961	1.878	0.338	0.077	2.383	0.100	0.928	0.717	0.379	0.424	0.424	0.116	3.88	14.3
1962	1.926	0.339	0.084	2.423	0.099	0.894	0.712	0.371	0.419	0.419	0.121	4.00	14.7
1963	1.980	0.346	0.090	2.474	0.095	0.843	0.688	0.358	0.412	0.412	0.126	4.13	15.2
1964	2.031	0.356	0.097	2.529	0.094	0.826	0.680	0.352	0.403	0.403	0.130	4.29	15.8
1965	2.101	0.373	0.104	2.607	0.092	0.796	0.665	0.342	0.392	0.392	0.130	4.51	16.6
1966	2.204	0.402	0.113	2.728	0.091	0.785	0.638	0.336	0.390	0.390	0.131	4.77	17.5
1967	2.317	0.439	0.124	2.867	0.099	0.809	0.664	0.354	0.381	0.381	0.135	4.98	18.3
1968	2.413	0.470	0.136	2.981	0.103	0.833	0.681	0.366	0.383	0.383	0.136	5.20	19.1
1969	2.506	0.501	0.148	3.092	0.115	0.876	0.720	0.397	0.383	0.383	0.138	5.44	20.0
1970	2.607	0.537	0.160	3.210	0.125	0.912	0.761	0.425	0.396	0.396	0.135	5.62	20.7
1971	2.699	0.564	0.168	3.312	0.136	0.916	0.760	0.444	0.399	0.399	0.136	5.79	21.3
1972	2.779	0.588	0.175	3.394	0.133	0.861	0.722	0.424	0.402	0.402	0.137	6.01	22.1
1973	2.862	0.623	0.183	3.494	0.131	0.804	0.686	0.402	0.403	0.403	0.135	6.29	23.1
1974	2.964	0.676	0.192	3.625	0.132	0.771	0.666	0.395	0.413	0.413	0.130	6.56	24.1
1975	3.049	0.724	0.201	3.726	0.146	0.785	0.673	0.417	0.412	0.412	0.126	6.71	24.6
1976	3.092	0.747	0.207	3.758	0.159	0.846	0.697	0.455	0.398	0.398	0.131	6.90	25.3
1977	3.138	0.775	0.218	3.801	0.152	0.828	0.684	0.441	0.391	0.391	0.129	7.15	26.3
1978	3.193	0.822	0.231	3.866	0.150	0.804	0.651	0.431	0.389	0.389	0.125	7.49	27.5
1979	3.290	0.888	0.245	3.987	0.157	0.815	0.651	0.439	0.395	0.395	0.121	7.89	29.0
1980	3.426	0.960	0.264	4.141	0.172	0.835	0.658	0.460	0.410	0.410	0.119	8.27	30.4
1981	3.574	1.010	0.282	4.275	0.200	0.895	0.713	0.521	0.437	0.437	0.116	8.69	31.9
1982	3.745	1.059	0.305	4.413	0.233	0.920	0.746	0.575	0.453	0.453	0.120	9.07	33.3
1983	3.894	1.087	0.328	4.515	0.235	0.859	0.739	0.558	0.443	0.443	0.133	9.43	34.6
1984	3.980	1.119	0.353	4.567	0.204	0.749	0.703	0.499	0.442	0.442	0.141	9.99	36.7
1985	4.116	1.187	0.387	4.726	0.209	0.737	0.734	0.503	0.447	0.447	0.148	10.60	38.9
1986	4.274	1.258	0.422	4.908	0.198	0.660	0.700	0.474	0.456	0.456	0.159	11.13	40.9
1987	4.363	1.320	0.459	5.030	0.194	0.588	0.692	0.456	0.455	0.455	0.160	11.62	42.7
1988	4.432	1.373	0.491	5.150	0.190	0.566	0.658	0.436	0.446	0.446	0.163	12.13	44.5
1989	4.497	1.435	0.526	5.294	0.182	0.547	0.633	0.413	0.447	0.447	0.172	12.68	46.6
1990	4.566	1.502	0.571	5.460	0.173	0.491	0.598	0.387	0.447	0.447	0.172	13.20	48.5
1991	4.635	1.552	0.620	5.628	0.174	0.483	0.568	0.381	0.431	0.431	0.183	13.60	49.9
1992	4.648	1.579	0.668	5.742	0.159	0.458	0.541	0.351	0.419	0.419	0.194	14.01	51.4
1993	4.635	1.619	0.717	5.866	0.149	0.428	0.515	0.325	0.414	0.414	0.199	14.52	53.3

1994	4.622	1.691	0.763	6.030	0.142	0.395	0.483	0.303	0.404	0.404	0.194	15.11	55.5
1995	4.617	1.792	0.806	6.241	0.145	0.406	0.469	0.304	0.391	0.391	0.200	15.81	58.0
1996	4.637	1.923	0.856	6.512	0.141	0.392	0.460	0.289	0.381	0.381	0.205	16.62	61.0
1997	4.679	2.073	0.921	6.839	0.139	0.377	0.449	0.277	0.371	0.371	0.213	17.51	64.3
1998	4.750	2.250	1.007	7.244	0.134	0.355	0.433	0.260	0.365	0.365	0.225	18.51	68.0
1999	4.838	2.466	1.105	7.722	0.132	0.328	0.428	0.240	0.357	0.357	0.231	19.65	72.2
2000	4.920	2.720	1.222	8.254	0.137	0.327	0.432	0.240	0.352	0.352	0.240	20.83	76.5
2001	5.033	2.996	1.345	8.840	0.146	0.330	0.456	0.248	0.355	0.355	0.236	21.71	79.7
2002	5.128	3.196	1.439	9.326	0.147	0.320	0.430	0.240	0.356	0.356	0.234	22.24	81.7
2003	5.123	3.324	1.508	9.647	0.150	0.316	0.413	0.235	0.358	0.358	0.240	22.76	83.6
2004	5.101	3.452	1.576	9.978	0.143	0.286	0.385	0.216	0.360	0.360	0.242	23.42	86.0
2005	5.079	3.611	1.650	10.356	0.146	0.275	0.374	0.210	0.371	0.371	0.236	24.25	89.1
2006	5.067	3.815	1.735	10.811	0.153	0.262	0.351	0.200	0.386	0.386	0.230	25.22	92.6
2007	5.085	4.053	1.822	11.332	0.168	0.258	0.349	0.202	0.389	0.389	0.230	26.25	96.4
2008	5.160	4.280	1.913	11.883	0.173	0.251	0.344	0.201	0.402	0.402	0.228	27.09	99.5
2009	5.259	4.407	1.997	12.351	0.192	0.259	0.357	0.215	0.397	0.397	0.237	27.23	100.0
2010	5.248	4.321	2.052	12.514	0.179	0.246	0.341	0.204	0.384	0.384	0.248	27.60	101.3
2011	5.166	4.352	2.104	12.733	0.161	0.224	0.318	0.184	0.376	0.376	0.254	28.18	103.5
2012	5.100	4.478	2.164	13.073	0.156	0.216	0.312	0.178	0.363	0.363	0.258	28.92	106.2
2013	5.087	4.676	2.231	13.554	0.147	0.208	0.299	0.166	0.360	0.360	0.255	29.68	109.0
2014	5.081	4.883	2.302	14.066	0.148	0.207	0.290	0.164	0.355	0.355	0.255	30.59	112.3
2015	5.120	5.110	2.379	14.643	0.147	0.205	0.285	0.161	0.348	0.348	0.256	31.49	115.7
2016	5.135	5.335	2.469	15.202	0.149	0.208	0.286	0.163	0.342	0.342	0.261	32.30	118.6

Notes

1. Capital stock in structures chained 2009 dollars.
2. Actual hours worked, billions of hours. Data from 1964 to 2016 from U. S. Bureau of Labor Statistics (BLS), Division of Major Sector Productivity, August 18, 2017. Data for 1949 to 1963, computed backwards using the percentages of annual change from BLS series PRS85006032.
3. Capital Services, index: 2009 = 100, lagged one year.

Source

CBO's June 2017 report: An Update to the Budget and Economic Outlook: 2017 to 2027, www.cbo.gov/publication/52801

Table A4: Alternative indices of the capital input in the U.S nonfarm private business sector[1,2]

Year	K^1_{t-1} (1)	K^2_{t-1} (2)	K^3_{t-1} (3)	$\hat{K}_{t-1}$ (4)	K_{t-1} (5)		Year	K^1_{t-1} (1)	K^2_{t-1} (2)	K^3_{t-1} (3)	$\hat{K}_{t-1}$ (4)	K_{t-1} (5)
1949	4.9	6.6	6.7	2.1	11.8		1986	23.7	50.3	26.9	21.2	46.6
1950	4.9	7.0	6.7	2.1	12.1		1987	25.2	52.0	28.4	22.3	48.3
1951	5.1	7.5	6.8	2.3	12.6		1988	26.7	52.7	30.2	23.3	49.9
1952	5.2	8.0	6.8	2.4	13.0		1989	28.3	54.2	31.9	24.7	51.5
1953	5.4	8.5	6.9	2.5	13.5		1990	30.1	56.7	34.0	26.7	53.2
1954	5.5	9.1	7.2	2.7	13.9		1991	31.7	58.2	36.2	28.4	54.6
1955	5.7	9.5	7.3	2.9	14.3		1992	33.1	58.3	37.8	29.2	55.8
1956	5.9	10.0	7.5	3.0	14.8		1993	34.8	58.4	40.1	30.8	57.1
1957	6.2	10.7	7.4	3.1	15.3		1994	36.9	59.7	42.5	32.9	58.7
1958	6.4	11.4	7.5	3.2	15.8		1995	39.4	61.3	44.8	35.2	60.6
1959	6.5	11.6	7.7	3.3	16.2		1996	42.3	64.2	47.4	38.2	62.9
1960	6.7	12.0	7.9	3.5	16.7		1997	45.6	67.4	51.2	42.3	65.6
1961	6.9	12.3	8.2	3.6	17.2		1998	49.4	71.1	55.2	46.9	68.8
1962	7.2	12.6	8.5	3.8	17.9		1999	53.7	75.1	59.7	52.2	72.5
1963	7.4	13.1	8.9	4.0	18.5		2000	59.1	79.7	64.9	58.7	76.5
1964	7.7	13.5	9.3	4.2	19.2		2001	64.5	85.7	70.2	66.3	80.3
1965	8.1	14.2	9.7	4.5	20.0		2002	68.5	88.1	74.7	71.0	83.2
1966	8.6	15.3	10.3	4.9	21.1		2003	71.5	87.9	77.9	73.5	85.2
1967	9.2	16.5	11.0	5.4	22.3		2004	74.9	87.8	81.5	76.6	87.1
1968	9.7	17.5	11.5	5.8	23.4		2005	79.0	89.2	84.7	80.7	89.2
1969	10.2	18.4	12.0	6.2	24.5		2006	84.3	91.2	87.6	85.0	91.7
1970	10.8	19.7	12.6	6.7	25.6		2007	90.3	94.9	90.9	90.7	94.5
1971	11.2	20.4	13.0	7.0	26.7		2008	95.8	100.0	95.0	97.9	97.3
1972	11.6	21.3	13.3	7.3	27.7		2009	99.5	103.2	99.2	102.9	99.3
1973	12.2	22.1	13.8	7.6	29.0		2010	100.0	100.0	100.0	100.0	100.0
1974	12.9	23.7	14.7	8.4	30.4		2011	103.4	99.0	104.0	103.6	100.8
1975	13.6	25.3	15.4	9.1	31.6		2012	108.2	102.3	107.2	110.8	102.2
1976	13.9	26.2	15.1	9.0	32.4		2013	113.6	105.0	110.3	116.6	104.0
1977	14.4	27.3	15.5	9.5	33.3		2014	118.9	107.8	113.8	122.7	105.9
1978	15.1	29.0	16.0	10.2	34.5		2015	124.4	112.3	117.4	130.0	108.0
1979	16.0	31.2	16.9	11.1	35.9		2016	130.3	115.7	120.5	135.8	110.3
1980	17.0	34.3	17.9	12.4	37.4							
1981	17.8	37.0	19.1	13.6	38.9							
1982	18.8	40.6	19.9	15.0	40.3							
1983	19.7	42.4	20.8	15.6	41.6							
1984	20.6	44.1	22.6	17.1	42.9							
1985	22.1	46.7	24.7	19.0	44.8							

Notes

1. Capital Services, index: 2009 = 100, lagged one year.
2. Series K^r_{t-1} comes from Table A2, Column 3.

Source: All underlying data for the figures in Columns 1-4 come from the National Income and Product Accounts published by the U.S Bureau of Economic Analysis. The figures in Column 5 come from Table 3, Column 2, in the Appendix.

Table A5: CBO's and author's estimates of the sources of economic growth in the potential output of U.S. nonfarm private business sector over the period 1950-2016

	CBO's estimates					Author's estimates			
Years & Periods	$\%\Delta L_t^p$	$\%\Delta K_{t-1}$	$\%\Delta TFP_t^p$	$\%\Delta GDP_t^p$		$\%\Delta L_t^p$	$\%\Delta \hat{K}_{t-1}$	$\%\Delta T\hat{F}P_t^p$	$\%\Delta G\hat{D}P_t^p$
1950-1059	.0088	.0097	.0218	.0402		.0088	.0190	.0196	.0474
1960-1969	.0098	.0127	.0231	.0455		.0098	.0182	.0131	.0410
1970-1979	.0146	.0117	.0118	.0380		.0146	..0202	.0043	.0391
1980-1989	.0008	.0110	.0091	.0209		.0008	.0199	-.0004	.0203
1990-1999	.0100	.0105	.0132	.0336		.0100	.0169	.0071	.0339
2000-2009	.0027	.0096	.0137	.0260		.0027	.0045	.0032	.0108
2010-2016	.0034	.0045	.0074	.0153		.0034	.0105	.0034	.0173
1950-1979	.0110	.0113	.0189	.0413		.0110	.0191	.0123	.0425
1980-2016	.0076	.0093	.0111	.0280		.0076	.0167	.0033	.0277
1950-2016	.0092	.0102	.0146	.0339		.0092	.0178	.0074	0.0343