

PWBM WORKING PAPER SERIES

PROSPECTS FOR US LABOR PRODUCTIVITY GROWTH
WHAT THE PENN WHARTON BUDGET MODEL'S MICROSIMULATION REVEALS

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ABSTRACT

When making projections of key macroeconomic aggregates such as total output, earnings and payroll tax bases, the Social Security Trustees assume that future labor-productivity growth will continue to remain close to its historical average. The labor productivity projection derived from this assumption is applied to the projected worker population on a per-head basis to project the aforementioned variables. However, assuming labor productivity growth near its historical average implicitly assumes that all contributing factors will also grow close to their historical rates or changes in those factors total will be mutually offsetting. However, the future composition of workers by productive abilities will differ from the past, potentially causing inconsistency between projections of key macroeconomic aggregates and the underlying characteristics of the future population.

One solution is to project as many of the productivity-contributing elements as possible using micro data information and organize them under an aggregate production function framework. This approach forces the budget analyst to define all productive inputs consistently with underlying demographic projections. Under such an approach, labor productivity growth is an auxiliary output consistent with micro-data-based projections of future worker populations, their attributes, macroeconomic aggregates, and projections of finances for programs such as Social Security.

PWBM's microsimulation-based projection of U.S. demographic and economic features yields labor productivity growth estimates that are significantly smaller during the next few decades compared with the close-to-historical average rate of labor productivity growth assumed by the Social Security Trustees. Subtracting PWBM's average projected labor-productivity growth over the next 75 years (2018-92) from the Social Security Trustees' assumed value of 1.68 percent per year yields a difference of 26 basis points. If the effects of changes in the population's demographic attributes on labor productivity growth are excluded from PWBM's projection, the difference from the Trustees labor-productivity growth assumption equals 32 basis points.

A. Introduction

There is growing interest in exploring the economic effects of the demographic transition currently underway in the United States and other developed nations, particularly its effects on future labor productivity. Projecting labor productivity over the long-term is especially important for evaluating the financial condition of federal programs such as Social Security, Medicare and others. Productivity growth projections are used for estimating future growth rates of key variables such as output, earnings, payroll tax bases, revenues and benefit obligations. A key goal of the paper is to derive productivity growth projections for the United States using the PWBM microsimulation approach and comparing it with the assumptions and projections of other budget scoring agencies such as the Social Security Trustees and the Congressional Budget Office.

Labor productivity has declined in the United States since the early part of this century – coincident with the beginning of boomer retirements. Several academic studies have explored the impact of population aging on labor productivity and economic growth, probably because a long term, positive association between labor force growth and productivity growth is broadly, although not universally accepted.² As described in a later section, several academic studies on the effects of population aging on productivity and economic growth appear to confirm this link.

Population aging, however, is not the only type of demographic transition that the United States is undergoing. Other potentially secular shifts include increased representation by women in the work force, increasing worker educational attainments, changing family sizes and structures, and changes in the ethnic composition of the population, among others. Many of these changes in the population's demographic and economic profile could reinforce or offset the impact of population

² For example, see Wall Street Journal article "Utah Shows how Labor Force Growth Fuels Economic Growth", January 18, 019: <https://www.wsj.com/articles/utah-shows-how-labor-force-growth-fuels-economic-growth-11547809200?mod=searchresults&page=4&pos=20>.

aging on economic productivity and growth. Whether the overall effect would be predominantly positive, negative, or negligibly small remains an open question.

The Penn-Wharton Budget Model's microsimulation is eminently suited to undertake a broad analysis of the productivity implications of prospective changes in several demographic and economic characteristics of the U.S. population and workforce. The PWBM microsimulation is a detailed computer model calibrated to the micro- and macro- features of the U.S. economy. This microsimulation is also highly granular in creating a computer-based population that is representative U.S. population. It historically validates and projects for many years into the future, more than 60 person and family attributes calibrated to U.S. Census micro-data. As described in this paper, integration of those micro-variables under a production function framework and aggregation to the economy-wide level yields projections of key macroeconomic variables such as total output, labor supply, total wages, the capital stock, capital income, etc. All of these projections incorporate transitions of individuals and families through their lifecycles and carry forward the demographic and economic processes that the United States economy is currently undergoing.

The PWBM microsimulation enables estimation of the future trends in labor productivity and economic growth conditional on micro-behaviors and transitions calibrated to U.S. Census micro-data surveys. This PWBM working paper describes how the microsimulation's total and worker population projections are aggregated under a production function framework. The aggregation helps to decompose projected output and labor productivity growth into contributing factors, namely growth from technological change, capital deepening, aggregate labor supply, and average worker efficiency. In particular, projected changes in the last component – worker efficiency growth – is decomposed into changes in various worker-attribute distributions such as age, gender, education, ethnicity, labor force participation, work time, family size, family structure, legal status,

and others. The projections are then compared with those made by the Social Security Trustees and the Congressional Budget Office.

B. Summary of Key Result

Subtracting PWBM’s average projected labor-productivity growth over the next 75 years (2018-92) from the Social Security Trustees’ assumed value of 1.68 percent per year yields a difference of 26 basis points. If the effects of demographic changes on labor productivity growth are excluded from PWBM’s projection, the difference from the Trustees labor-productivity growth assumption equals 32 basis points. Figure 1 shows the paths of annual differences between PWBM’s projection and the Trustees’ assumption on future labor-productivity growth under these two alternatives. The blue-dashed line shows *the difference* between Social Security Trustees’ “ultimate long-range assumption” for labor productivity of 1.68 percent per year and PWBM’s labor productivity projection. The red-dotted line shows the same difference when the total effect of projected changes in the demographic composition of the population are excluded from PWBM’s projection.

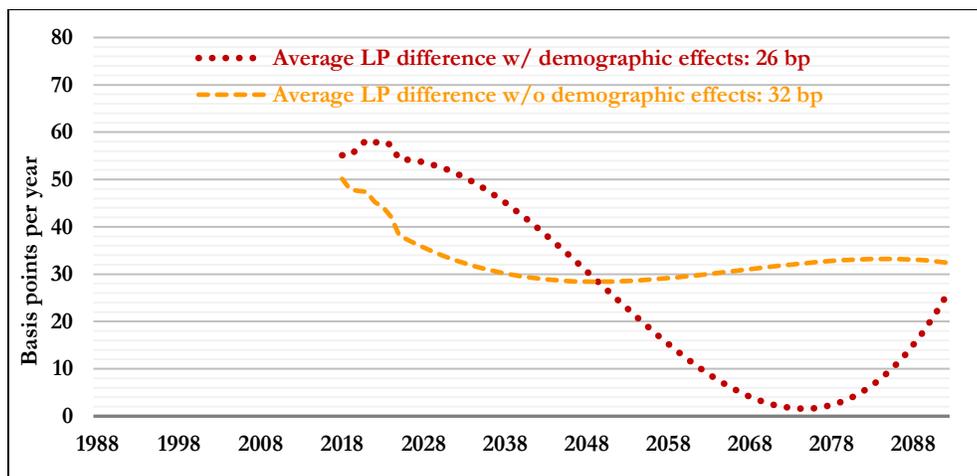


Figure 1: Projected labor productivity growth-rate differences: PWBM versus Social Security Trustees.

By assuming that labor productivity will continue to grow at its long-term historical rate, the Trustees are implicitly assuming that all productivity-contributing factors will also grow at historical

rates or that any changes will be mostly offsetting. As noted above, however, the future composition of the population by productive abilities is likely to be different from the past. Hence, assuming historical productivity for the future would likely misalign estimates of output, earnings, and payroll tax bases compared to the underlying features of the general and worker populations. Sections D through I of this paper describe PWBm projection and aggregation methods, underlying assumptions and their derivation, and projection results for aggregate labor and capital services and their contributions to overall labor productivity. Section J provides examples of particular projected changes in population attributes and their net effect on PWBm's labor productivity projections.

C. Literature Review: The Productivity Effect of Demographic Change

Economists began exploring the possible economic effects of demographic changes as early as during the 1980s and 90s when it became evident that a recovery of fertility rates to pre-1975 levels was very unlikely. [Cutler et al \(1990\)](#) examine the effect of population aging on national saving (a reduction), capital formation, and foreign capital inflows. The study speculates that slower labor force growth would reduce the need for investment (as capital intensity would be increasing) and may spur technical advances. It concludes that anticipated demographic changes are not among the factors leading to low saving and will not worsen U.S. economic performance.

[Bloom et al. \(2003\)](#) summarize sources of the “demographic dividend” accruing as economic development triggers large but unsynchronized declines in mortality and fertility, increases in longevity, decreases in family sizes, and changes in the age distribution of the population, which triggers shifts in savings and human capital acquisition. The process produces a long-amplitude output and productivity growth cycle: a productivity decline, as young dependent populations are initially high; productivity increase as the labor force, education, worker-mobility, and savings grow; and a productivity slowdown again as the population proportion of elderly dependents increases.

More recently, however, [Freyer \(2007\)](#) focuses on the worker, rather than the entire, population and uses a large cross-country panel dataset to show that changes in workforce demographics have a strong and significant correlation with the growth rate of aggregate productivity. [Burtless \(2013\)](#) notes the growing role of older workers in the labor market and steady improvement in their relative education and earnings. The observation that workers that are more productive stay in the workforce longer than less productive ones together with the increase in the pay premium to education means that an aging workforce won't hurt productivity. The Burtless study notes the importance of examining the effect of demographic changes on productivity growth and other macroeconomic variables holistically rather than focusing simply on one dimension such as the population's age structure. [Sheiner's \(2014\)](#) output growth framework is calibrated to the decline in post 1970s U.S. fertility. A net decline in the output-producing-to-output-consuming population ratio directly implies a decline in labor productivity. The implication is a necessary adjustment to consumption per person or an increase in labor force participation and work effort to counterbalance the decline in the support ratio.

[Aksoy et al., 2015](#), estimate a VAR using panel data from 20 OECD countries to examine the impact of changes in population proportions by age, on saving, investment, hours, interest rates, and output growth. They conclude that continued population aging and low fertility impart strong negative forces on output growth and real interest rates. [Maestas et al., \(2019\)](#), explore how differential rates of population aging across U.S. states are associated with economic growth across those states. They report that the elasticity of GDP growth to population aging is about 0.55, two-thirds of which is accounted for by labor productivity declines. [Ozimek et al., 2019](#), use Mincer wage equations on payroll data by firm to estimate the effect of the fraction of workers above age 65. They find negative effects on productivity in firms with larger groups of aged workers – effects that are robust to alternative regression specifications and controls.

Although by no means complete, this literature review suggests several channels whereby population aging and demographic changes could affect overall labor productivity. This suggests the need for a broader framework within which to isolate and measure those channels and estimate their overall effect for constructing financial projections for programs such as Social Security, Medicare, and other welfare programs.

D. Overview of PWBM's Microsimulation Model

1. Microsimulation

PWBM's microsimulation constructs annual populations of individual and families beginning in 1996 calibrated to Census micro-data.³ The aggregate labor supply provided by the population is derived by estimating how labor force participation, annual work time, and annual earnings are associated with individuals' demographic and economic characteristics. Labor force participation is captured by probabilities of shifting into and out of the work force each year conditional on an individual's attributes, including prior workforce attachments. Annual work time is measured in full-time equivalent weeks (FTEW) and a similar transition process is implemented across years that is conditional on the person's other attributes. Finally, participation, FTEW, and other attributes are entered into a regression specification to distinguish relative work efficiencies in proportion to labor earnings reported in Census micro-data surveys.⁴ The product of these three items determines an individual's efficiency adjusted labor supply. Individual labor inputs are aggregated to deliver the economy-wide labor input, L_t , in each period and fed into an aggregate Cobb-Douglas production function (see below). Under this framework, calculating total (nominal) national gross domestic product (Y) each period requires calibration of the other elements of the production function –

³ For details about the construction, operation, and validation of the PWBM microsimulation, see <http://budgetmodel.wharton.upenn.edu/microsimulation>.

⁴ Several concerns raised during presentations at the Social Security Administration and the Congressional Budget Office about PWBM's method of estimating future worker productivities are discussed in Appendix 3.

namely, capital services, multi-factor productivity, the share of capital in total output and the price level in each future period. The following sections describe how all of these items are calibrated to deliver microsimulation-based projections of macroeconomic variables.

2. *Dynamic Overlapping Generation's Model*

PWBM's microsimulation model of the U.S. economy maintains constant (probabilistic) patterns of behavior over the lifecycle when making future economic projections. This is similar to the "static" methods employed by the Social Security Trustees in making that program's financial projections. However, unchanging behavior patterns are not consistent with the assumption of a large-open economy that is expected to accrue increases in the debt-to-GDP ratio in the future (under current federal budget policies). Although foreign capital inflows would eventually adjust to prevent a disequilibrium between domestic and world after-tax rates of return, those adjustments are likely to be partial and slow for a large open economy such as the United States. In the meantime, capital crowd-out from rapidly accruing national debt appears likely to increase interest rates and slow wage growth. In turn, a changing economic environment would induce two types of behavioral responses by firms, individuals and households. These include shifting income classification by changing entity forms, accelerating or postponing income accruals, accelerating investments, compensation, deductible input purchases, etc. to minimize tax burdens, and they also include changes in real economic decisions such as total saving, work effort, timing of retirement etc. To account for both types of feedback effects, the microsimulation's conditional economic projections are adjusted by "delta" estimates generated by PWBM's tax calculator and a dynamic overlapping generations (OLG) model. These models use response elasticities from the economics literature to calculate optimal responses and the resulting equilibrium transition path for the economy including equilibrium decisions by individuals and households along available dimensions of marginal adjustments. The resulting outcome is consistent with evolving national debt, interest

rates and wage rates over time under the assumption that current fiscal policies will remain unchanged. The models deliver the appropriate “delta” time series for each variable to layer onto the level projections generated by the microsimulation model.

The economic projections of the Social Security Trustees are mainly implemented on a static basis. They do not include detailed income shifting and dynamic behavioral adjustments and feedback effects when projecting aggregate economic outcomes. To maintain comparability with the projections of the Social Security Trustees “static” projection method the tax and dynamic models’ delta components are not incorporated in PWBM’s projections of aggregate variables that are reported below.

E. Cobb-Douglas Production Function Framework

The PWBM’s microsimulation labor market outcomes – labor force participation, annual full-time-equivalent weeks worked, core labor productivity, and worker compensation – are combined with projections of aggregate capital to generate projections of GDP. The combination of capital and labor service inputs is modeled under a Cobb-Douglas aggregate production function framework. In effect, the aggregate production function specifies the technological rate of converting productive factor services (labor and capital) into the national output (gross domestic product) of useful goods and services. The Cobb-Douglas production function is specified as

$$Y_t = P_t A_t K_t^\alpha L_t^{1-\alpha} \tag{1}$$

Y_t = Total output

P_t = Price level

A_t = Multifactor productivity

K_t = Capital services

L_t = Efficiency adjusted labor services = $h_t \times H_t$

α = Output elasticity of capital

This aggregate production function framework is useful for integrating micro-based labor productivities of individuals into the aggregate labor input. The aggregate labor input combined with capital services yields total output, aggregate labor and capital incomes, and the payroll tax base. Aggregate labor income is then distributed according to individual (micro-level) relative productivities. The resulting annual wages form the basis for computing income and payroll taxes, Social Security benefit eligibilities, and benefit levels for individuals in the microsimulation. In the process described thus far, the determination of total labor and capital incomes each year is contingent on parameter assumptions, multi-factor productivity, A_t , the output share of capital, α , and the price index values, P_t . These assumptions and PWBM's projections of aggregate labor and capital inputs, total output and labor productivity implied by those projections are described in the sections below.

F. Multi-factor Productivity Growth

A key element in projecting labor productivity growth is the rate of multi-factor productivity growth A_t . Historically this factor is estimated as the excess (residual) growth of total economic output after subtracting the growth of (combined capital and labor) service inputs. The Bureau of Labor Statistics (BLS) constructs total economy accounts and reports the growth of multi-factor productivity between 1987 and 2016 to be 0.716 percent per year.⁵ However, Because PWBM's microsimulation calibrates total output, Y_t , in equation (1) to equal the nation's gross domestic product (GDP), BLS' MFP must be adjusted to be consistent with GDP. The adjustment is simple to execute because BLS's definition of combined labor and capital inputs is the same as that for the

⁵ Calculated as the growth of the "output per unit of combined inputs" in the penultimate table on BLS total economy account data available at: https://www.bls.gov/mfp/special_requests/prodaccttables.xlsx.

National Income and Product Accounts of the U.S. Bureau of Economic Analysis that reports U.S. GDP. All that is required is to remove government and non-profit sector imputed capital income net of depreciation from total capital income. This adjustment sets MFP to 0.665 percent per year, about 5 basis point smaller than reported by the BLS.

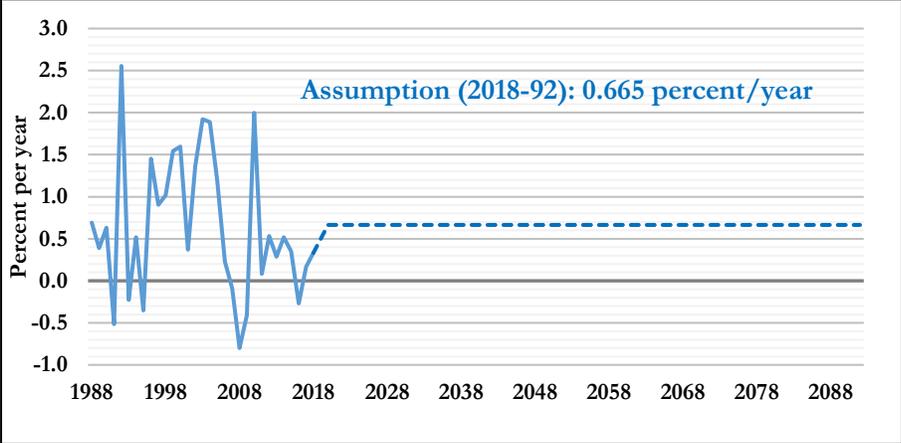


Figure 2: Multi-Factor Productivity Growth.

Figure 2 shows the history and PWBM’s projection MFP.⁶ The projection includes a gradual increase in MFP during the first few years to the assumed long-term value of 0.665 percent per year.

G. Labor Input Growth

The labor input, L_t , equals the sum of productivities contributed by each person simulated to be gainfully employed in the labor market. Each worker’s productivity equals annual work time worked, H_t , times labor efficiency, h_t , per hour worked. Work time and work efficiencies per hour are estimated using regression techniques from micro-data surveys, in particular the U.S. Census. Estimated regression coefficients capture historical correlations between workers’ attributes and

⁶ PWBM’s MFP annual growth rate is pegged to the adjusted annual rates based on BLS data as described in the text. It is smaller than the rate assumed by the Congressional Budget Office of 1.1 percent per year. See Appendix 2 for a detailed accounting of the difference.

labor-market-behavior (participation and full-time-equivalent weeks [FTEW] worked) and relative work efficiency patterns proxied by relative earnings over the lifecycle. These methods are described below.

G1. Full-time-equivalent Weeks (FTEW)

PWBM’s microsimulation models the labor input in three stages: First, the simulation of FTEW in the initial year (1996) is based on a regression of FTEW on person attributes (age, gender, ethnicity, education, health impairment, etc.) using Census micro-data for that year. Those persons simulated to have zero FTEW are not in the labor force. Figure 3 shows that under the population attributes projected by PWBM, the labor-force-participation rate is projected to decline slowly during the next few decades. Of course, a decline in labor force participation does not necessarily imply negative growth of aggregate labor services as a sufficiently high population growth plus improvements in worker efficiencies would be offsetting.

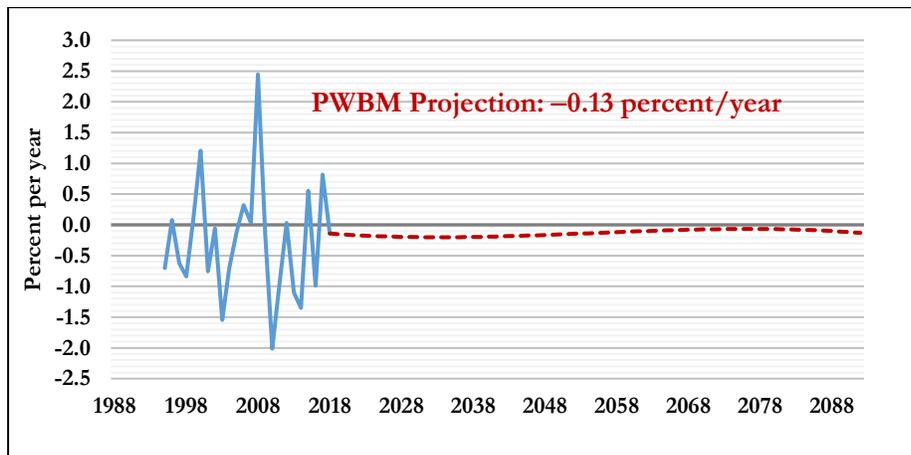


Figure 3: Labor Force Participation Growth

Next, FTEW is categorized into several employment classes and cross-year transition probabilities across employment classes are estimated using short-panel Census micro-data (Current Population Survey).⁷ Finally, conditional on current (simulated) employment class and prior-year

⁷ The FTEW employment classes include 1: FTEW=0; 2: $1 \leq FTEW \leq 39$; 3: $40 \leq FTEW \leq 75$; 4: $\leq FTEW \leq 104$.

FTEW, current-year FTEW is simulated conditional on current person attributes. Figure 4 shows the history and PWBM's projection of growth of FTEW per year.

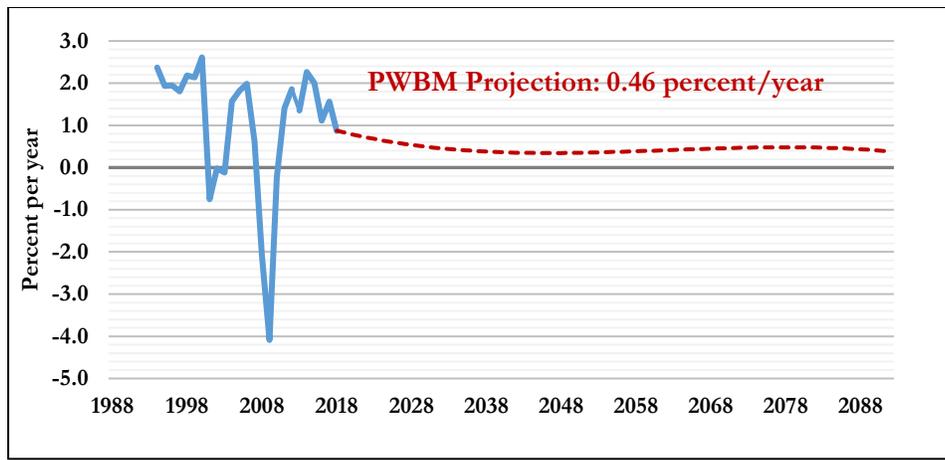


Figure 4: Full Time Equivalent Weeks (H) Growth.

Individuals in the microsimulation may experience positive employment and some duration of unemployment in the same year. Hence, regardless of the simulated outcome for FTEW, unemployment weeks (UW) are also simulated for all persons. The simulation of UW is, again, conditional on each person's current demographic and economic attributes. Figure 5 shows the history and PWBM's projection of growth of UW per year.

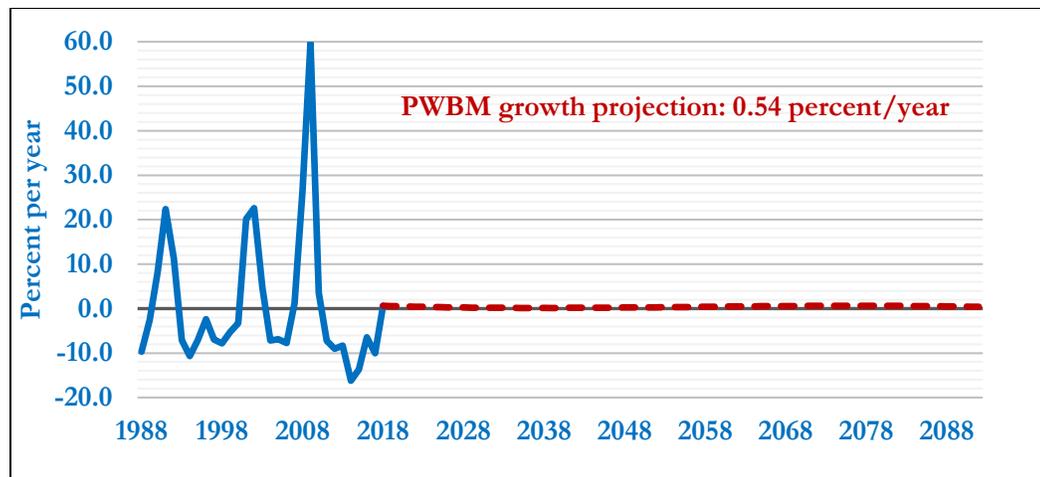
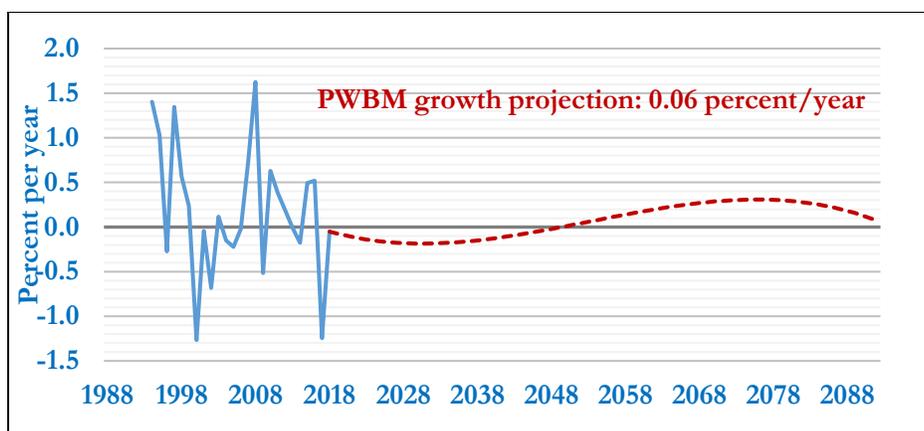


Figure 5: Unemployment Weeks Growth.

G2. Labor Efficiency Growth

The contribution of labor efficiency growth to total labor input growth can be simply derived by dividing the aggregate labor input by FTEW (and subtracting one) in each year and computing growth rates of the result across years. Recall that the aggregate labor input is the sum over all workers' efficiency adjusted labor inputs, which are estimated using coefficients from a regression of wages on worker attributes including employment hours.⁸ The simulated value of workers' labor inputs may be interpreted as their efficiency adjusted FTEWs. The sum over workers' labor inputs, therefore, is the sum over all workers' FTEWs weighted by their individual relative work efficiencies. Hence, the growth of the ratio of aggregate labor input to total FTEWs (minus one) yields an estimate of the contribution of economy-wide (or average) labor-efficiency growth to total labor input growth.

Figure 6 shows the history and PWBM's projection of average labor-efficiency growth for the U.S. economy. It shows that during the first few years of the projection, labor efficiency will decline, detracting from the growth in total labor input. However, after mid-century, labor efficiency will contribute positively to aggregate labor input. The reasons for this result is explored below in section N.



⁸ The wage regression pools Census two-year panel micro-data observations from 1996-2016. Before pooling, however, nominal wages from different years are placed on par with each other by subtracting the effects of inflation, capital deepening and technological growth. See the appendix for a detailed description of the wage regression method.

Figure 6: Average Labor Efficiency (h) Growth.

G3. Total Labor Input Growth

The total labor input is simply the weighted sum of individual workers' FTEW with the weights being their relative work-efficiencies. Total economy labor input can also be viewed as the product of total employment weeks times average worker efficiency per hour. Figure 7 shows PWBM's calculation of historical and projected total labor input in the United States. As expected, labor input growth equals the sum of the growth rates of FTEW (H) and labor efficiency (h). Of these two components, FTEW growth is positive throughout but declines steadily during first few years of the projection window (2018-92). Labor efficiency growth is negative until about 2050 and increases to become positive thereafter. Figure 7 shows that labor input growth remains positive throughout the projection window and its projected time profile is similar to that of labor efficiency growth.

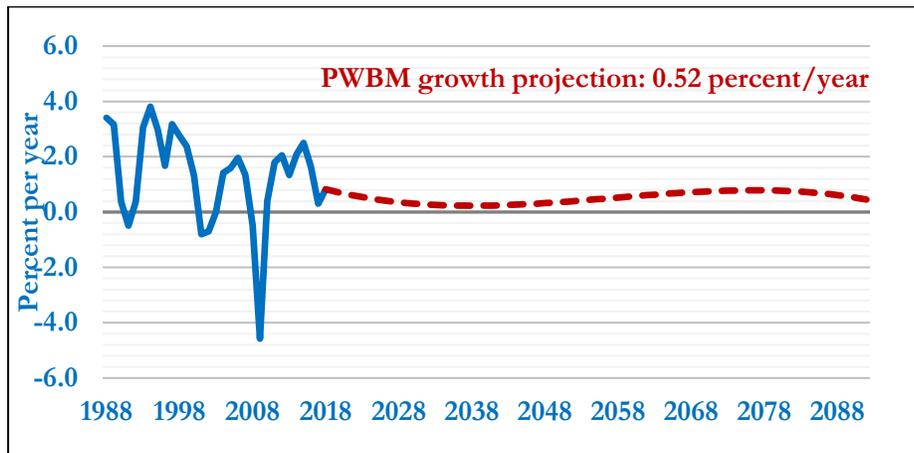


Figure 7: Labor Input ($L=b \times H$) Growth.

H. Capital Services Growth

The future growth of capital services is assumed to equal growth of the labor input and technological progress. The growth rate assumption on capital services growth for the micro-simulation model is anchored to the average growth of the total labor input and multifactor

productivity during the period 2018-2092. These two projected growth rates add up to about 2.54 percent, which is slower than the historical growth rate of capital services during 1987-2017 of 2.8 percent per year. However, the projected rate of capital services growth of 2.52 percent per year is faster than the projected sum of labor input and multifactor productivity growth of 1.18 percent per year.⁹ Figure 8 shows the growth rate of capital services in the PWBM microsimulation. PWBM projects continued increase in capital intensity, albeit at a slower rate than the last three decades (see Figure 10 below).

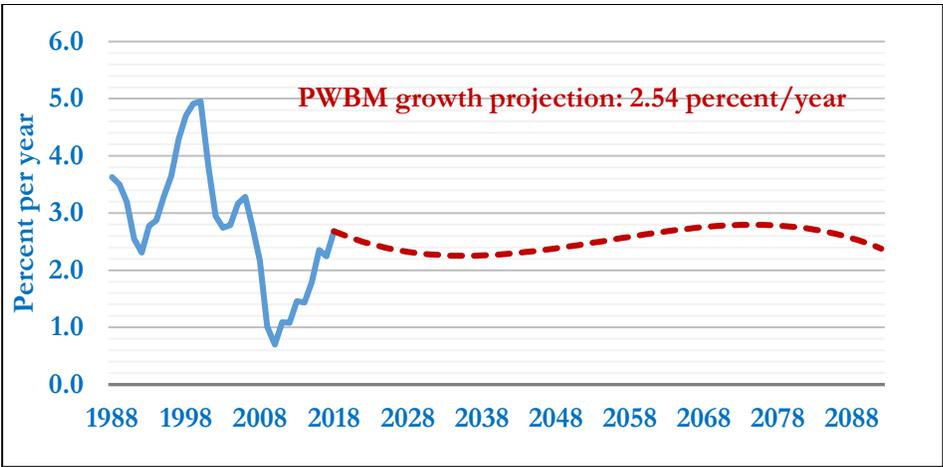


Figure 8: Capital Services (K) Growth

I. The Capital Share

Projected values of capital’s share in output is based on its historical average based on adjusted BLS total economy production accounts.¹⁰ After remaining stable between 1987 and 2000 at 0.32, it increased to as high as 0.40 through 2009. The capital share then declined again through 2016 to 0.345 – very close to its historical average of 0.342 since 1987. PWBM’s long-term projection, shown in Figure 9, assumes that the capital share will remain at 0.345 in the future.

⁹ The historical growth of capital services, however, contains an episode of exceptionally high growth between 1994 and 2006 when capital services grew at an annual average of 3.6 percent.

¹⁰ The historical data on capital incomes is adjusted by subtracting imputed capital incomes for government and non-profit sectors. These adjustments make the capital income definition consistent with GDP.

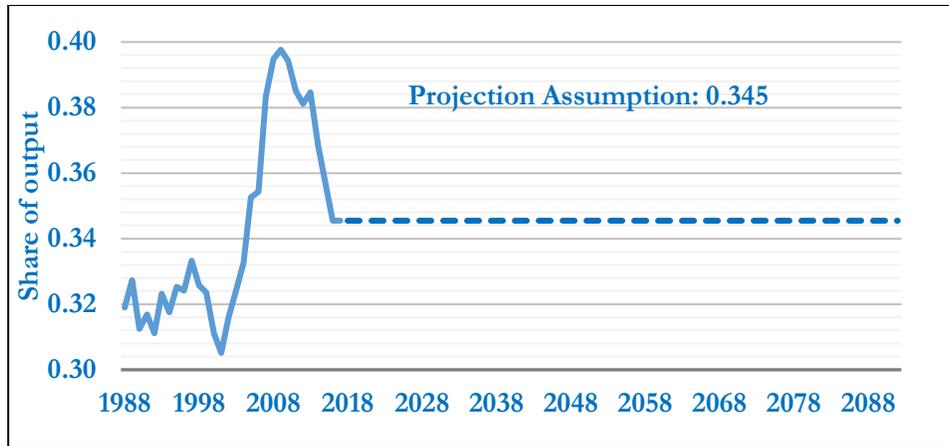


Figure 9: The Share (α) of Capital Services in GDP.

J. Wage and Interest Rate Growth

Growth in total labor input, $L_t = h_t H_t$, capital services, K_t , multifactor productivity, A_t , and capital share, α , calibrations as described above together yield increasing capital intensity calculated as the ratio capital services to the product of multifactor productivity and labor input growth. As described above, projected capital services grow at 2.54 percent per year but the product of projected multifactor productivity growth and labor input growth add up to 1.18 percent per year. This implies capital intensity growth averaging 1.34 percent per year. Figure 10 shows historical and projected growth in the capital intensity (K/AL).

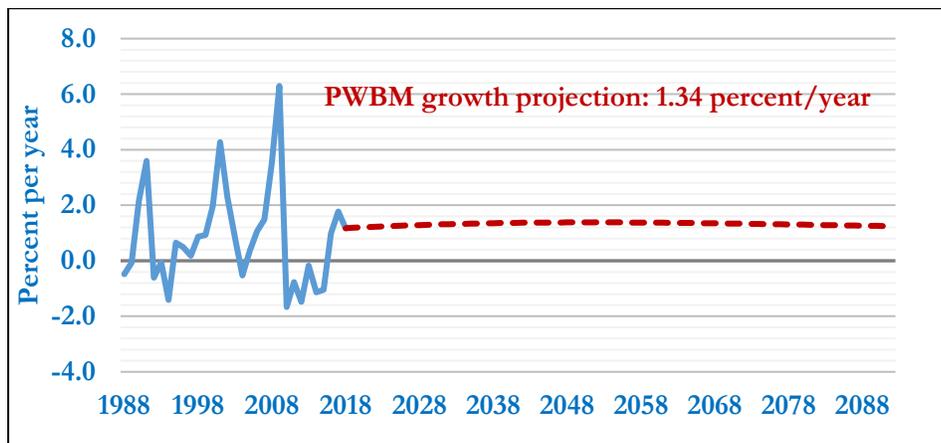


Figure 10: Capital Intensity $[K/(A \times L)]$ Growth

Under the Cobb-Douglas production function specification, wage and interest rate trajectories evolve according to the following relationships (see Appendix 1)

$$g^r = g^A + (1 - \alpha)[g^h + g^H - g^K], \quad (2)$$

$$g^w = g^A + \alpha g^K + (1 - \alpha)g^h - \alpha g^H. \quad (3)$$

Knowing the growth factors and parameters on the right hand sides of equations (2) and (3) easily reveals the left-hand-side terms: $g^r = -0.645$, and $g^w = 1.42$. Figures 11 and 12 show the implied PWBM microsimulation projections of the two factor prices. The interest rate declines from 2.96 percent in year 2018 to 2.45 percent by the year 2092.¹¹ Measured in constant 2018 dollars, the wage rate increases from \$1,658 in year 2018 to \$4,020 per FTEW by year 2092.

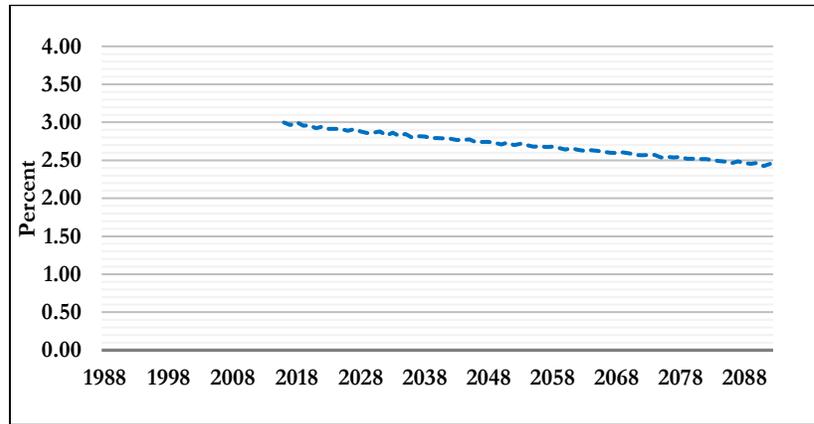


Figure 11: The Interest Rate (r)

¹¹ As shown in Appendix 1, capital services growth would have to equal $\frac{g^A}{(1-\alpha)} + g^L$ for capital intensity to remain constant. Given the values of the three factors in this formula as described in the text, capital services growth required to keep the interest rate constant equals 1.54 percent per year.

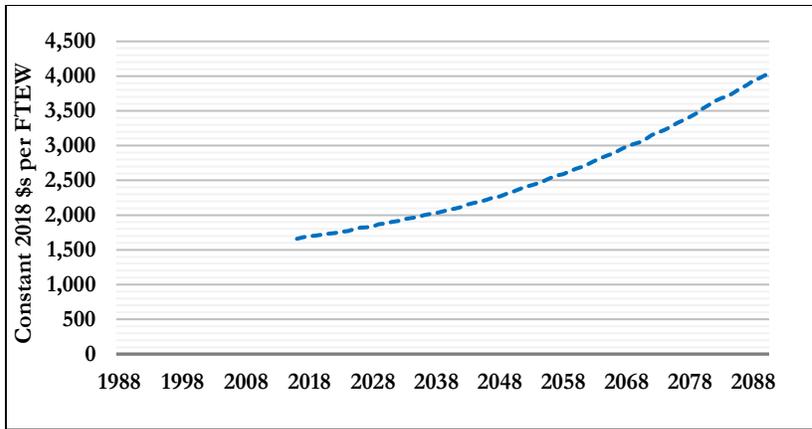


Figure 12: The wage per FTEW (w) in constant 2018 dollars

K. Total Output and Labor Productivity Growth

Total output growth from the PWBM microsimulation is the capital-share-weighted sum of all of the growth factors described earlier. Figure 13 shows historical growth and PWBM’s projected growth of U.S. GDP.

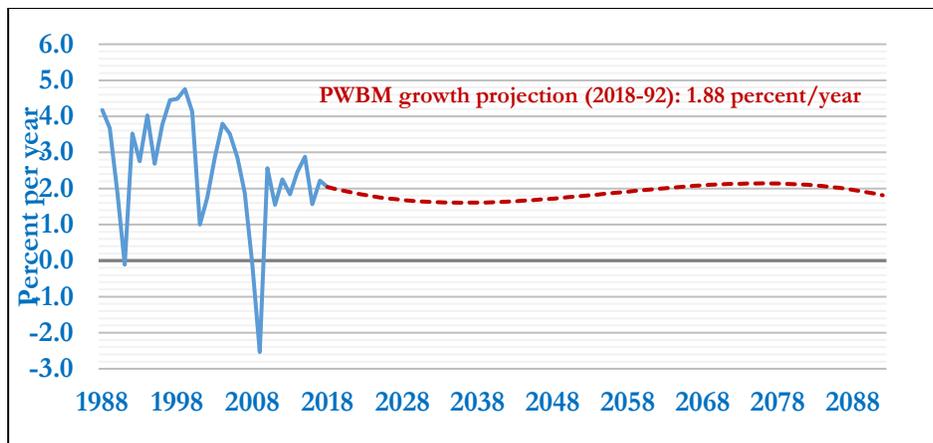


Figure 13: U.S. Gross Domestic Product (Y) Growth

Projected GDP growth follows the time profile of labor efficiency growth – conditioned by the momentum of demographic and economic forces built into the U.S. economy. The detailed person attributes modeled, projected, and associated with relative work efficiencies in PWBM’s microsimulation generate slower labor productivity growth during the short and medium terms

relative to the long term. The Section M below evaluates the key elements – in terms of the evolution of person-attributes – that are projected to deliver slower secular economic growth through mid-century.

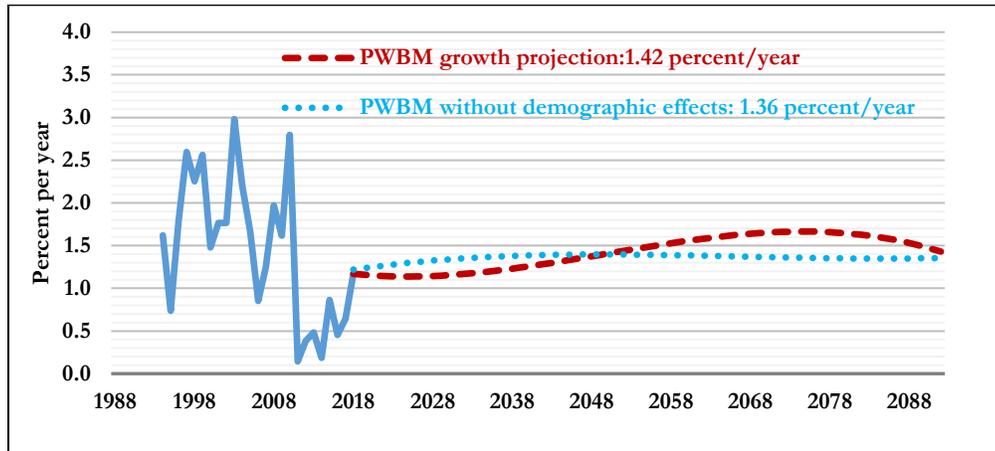


Figure 14: Labor Productivity (GDP/FTEW) Growth.

Labor productivity measured as growth of real GDP divided by FTEW is shown in Figure 14. Because FTEW growth is projected to remain relatively steady after an initial period of decline (see Figure 4), labor productivity, or GDP per FTEW, follows the pattern of GDP growth and labor efficiency growth. It remains relatively low through mid-century before increasing to about 1.5 percent per year during the 2060s. The average growth rate of labor productivity during 2018-92 is 1.42 percent per year.

Figure 14 also shows the outcome from projecting labor productivity without taking account of changes in labor efficiency following upon projected changes in the composition of the U.S. worker population. The projection without demographic effects would be flatter as negative short-term labor-efficiency-growth effects and the positive and relatively rapid long-term labor-efficiency-growth effects (see Figure 5) are removed from the projection.

L. PWBM’s and Social Security Trustees’ Labor Productivity Growth Projections

Each year, the Social Security Trustees project the program's financial condition over the forthcoming 75 years based on assumptions about key economic parameters. One of these parameters is total labor productivity growth, which is applied to the future worker population on a per-head basis (without considering the possibility that their composition would be associated with their work-efficiency) to determine future national output, covered wages, the payroll tax base and benefits. In turn, projected taxes, benefits and earnings are used to measure the program's summary actuarial balance.¹² Under this projection method, a higher assumed growth rate of total labor productivity would boost projected earnings during the 75-year window and improve the program's actuarial balance (make it less negative). The reason is that although higher projected earnings would eventually trigger higher future benefits, a large portion of those benefit increases would accrue beyond the 75-year projection horizon.¹³ Figure 15 repeats Figure 14 by adding Social Security Trustees' total labor productivity projection over the next 75 years.¹⁴ It's evident from Figure 15 that the Social Security Trustees' projection of total labor productivity growth assumes a much higher projected growth rate compared to PWBM. PWBM's projected labor productivity growth averaging 1.42 percent per year over the 75-year projection window is well below the Trustees' assumption of constant annual growth at 1.68 percent per year.

¹² The program's summary actuarial balance (under current Social Security tax and benefit policy) equals the trust fund plus the present discounted value of taxes (payroll taxes plus income taxes on benefits) over the next 75 years less the present discounted value of program costs (benefit payments) over the next 76 years. The result is divided by the present discounted value of taxable payroll over the next 75 years. The Social Security Trustees' 2018 annual report calculates the actuarial balance to be -2.84 percent.

¹³ To their credit, the Trustees also report the program's actuarial balance measures over the infinite horizon and for the closed group of past and current Social Security participants. However, estimating future taxes and benefits based on a higher assumed labor productivity growth would also boost the infinite horizon and closed group actuarial balance measures. That's because, when calculating present discounted values, the resulting higher earnings and payroll taxes in the near term would be discounted much less than the higher benefits that those higher earnings generate over the long term.

¹⁴ Social Security Trustees' 2018 Annual Report, Supplemental Single-Year Tables, Table V.B1, projected values under Intermediate assumptions.

If demographic composition effects are subtracted from PWBM's labor productivity projection, PWBM's average labor-productivity growth equals 1.36 percent during the 75-year projection window (because the six basis point long-term average contribution of labor efficiency to labor input growth has been removed). The average difference between the Trustees and PWBM's labor-productivity growth when demographic effects are ignored under the latter equals 32 basis points. Relative to PWBM's projection exercise, which accounts for the contributions of all underlying productive factors, the excess labor productivity assumed by the Trustees, imparts excess optimism to the Social Security's financial outlook.

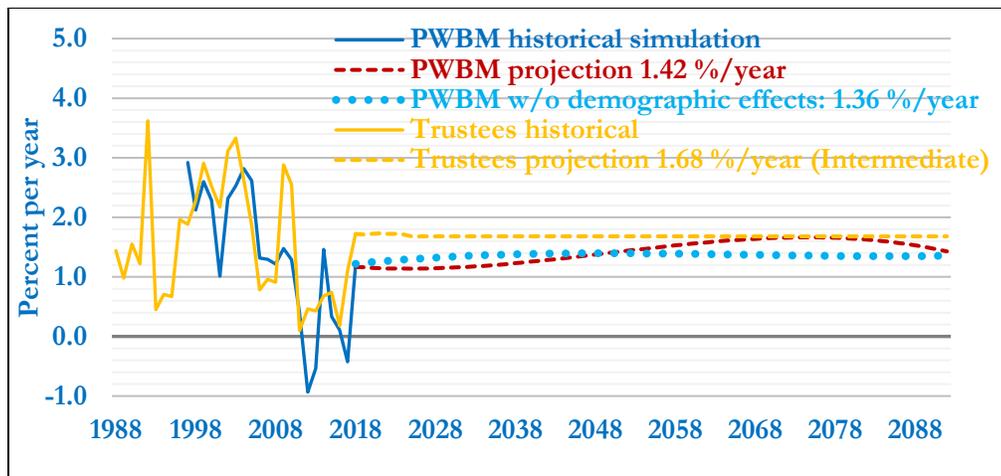


Figure 15: Total Labor Productivity Growth Comparing Social Security Trustees and PWBM's Projections.

PWBM's labor-productivity growth projection has a time-varying profile, because the underlying microsimulation takes into account many types of demographic changes and interactions. The Social Security Trustees apparently do not build the overall labor productivity growth assumption from contributing elements such as capital deepening, multifactor productivity, work time, and labor efficiency as implemented by PWBM by constructing a detailed microsimulation. One aspect of this difference in methodology that is worth noting is that the Trustees' directly assume a value for the

“ultimate long-range labor productivity growth” by setting it close to its historical average.¹⁵ This assumption implicitly projects labor and capital service growth to be the same in the future, on average, as occurred in the past (or any changes in underlying components are assumed to be almost fully offsetting). The labor-productivity growth assumption is a key *input* parameter in the Trustees’ projection of total output, earnings, the payroll tax base, and Social Security’s future benefit obligations. Under PWBM’s method, however, projected labor productivity and its growth are *outputs* derived by integrating contributions from labor and capital services inputs. Those two inputs are projected by carrying forward ongoing and measurable demographic and economic transitions at a considerably more granular level. It is necessary to make assumptions only about production function parameters – the growth rate of multi-factor productivity and the future output share of capital – that will be determined through unknown and difficult-to-estimate processes such as future changes in production technology and in the competitive environment for participants in labor and capital markets.

In particular, PWBM’s total labor input growth projection equals the sum of work-time growth and work-efficiency growth where both elements are conditioned on evolving person and worker characteristics. The next two sections provide examples of the effects of the evolution of particular worker attributes on labor efficiency isolated from PWBM’s microsimulation.

M. Total Labor Productivity Growth by Contributing Factors

Growth rates for the various components reported above can be confirmed by comparing against the growth rate of total output. The implied decomposition of total labor productivity growth is

¹⁵ The Trustees’ historical labor-productivity growth average for 1960-2017 is 1.76 percent per year. During 1997 - 2018, it is 1.64 percent per year.

$$g^Y - g^H = g^A + \alpha g^K + (1 - \alpha)g^h - \alpha g^H. \quad (4)$$

Filling in the growth rates noted in equation (4), a growth decomposition is obtained from PWBM's projections for three alternative periods, 2017-27 and 2017-37, and 2017-2092. These are shown in Table 1.

	Lab or/capital shares	Growth Rates (% per year)			Contribution to GDP Growth (percentage points)		
		2017-27	2017-37	2017-92	2017-27	2017-37	2017-92
GDP (g^Y)	1.000	1.864	1.684	1.876	1.864	1.684	1.876
Labor time (g^H)	1.000	0.719	0.539	0.457	0.719	0.539	0.457
Labor Productivity ($g^Y - g^H$)		1.275	1.311	1.356	1.14	1.14	1.42
MFP (g^A)	1.000	0.615	0.640	0.658	0.615	0.640	0.658
Capital Services (g^K)	0.345	2.458	2.347	2.537	0.843	0.805	0.870
Labor efficiency (g^h)	0.655	-0.111	-0.183	0.062	-0.072	-0.120	0.040
Labor time (g^H)	0.345	0.719	0.539	0.457	-0.248	-0.186	-0.158
Sum of Components					1.14	1.14	1.42

Table 1: Average projected growth rates (percent per year) and contributions of productivity factors to labor productivity growth over selected time horizons.¹⁶

PWBM's short- and medium-term outlook for labor productivity growth is considerably weaker than the long-term outlook. Moreover, even the long-term labor productivity outlook under PWBM's projections is bleaker than the assumptions adopted by other prominent budget and program scoring groups such as the Congressional Budget Office. Appendix 2 compares CBO's growth assumptions and projections with that of PWBM for the 2017-27 period.

N. Contributions of Specific Population Attributes to Labor Efficiency

¹⁶ Components may not add up to totals because of rounding errors.

Figure 5 displays a sizable decline in the growth of average labor efficiency through mid-century. The rate of decline accelerates through the early 2030s, attaining -25 basis points per year during 2031 and becomes positive only by 2052. This section shows the effects of factors underlying the decline in labor efficiency during the next 30 years – projected worker cohort turnover and projected changes in the distributions of workers by ethnic affiliation, education, FTEW (time), immigrant legal status, and gender.¹⁷

N1. Cohort Turnover

Population aging is a key underlying factor for the projected medium-term decline in labor efficiency and, ultimately, total labor productivity. The contribution of population aging is isolated by a simple experiment age-adjusting individual relative efficiency measures in the PWBM microsimulation. The worker population is divided into two groups – those born in 1968 and earlier (aged 50 and older in 2018) and those born after 1968 (those younger than age 50). Projected average relative efficiencies of these two worker-population groups in each projected year are shown in the left hand panel of Figure 16. The difference in average relative efficiency each year is shown on the right-hand-side panel of Figure 16. Next, overall labor efficiency in each future year is calculated in two ways: (1) the population shares of the young and old groups are varied consistent with their projection after year 2018 and (2) population shares of the young and old groups are held constant at their 2018 levels. The third panel of Figure 16 shows year-specific values of the percentage difference in the two computations of overall efficiency. It shows that, overall, labor efficiency will decline during the next few years as older and more productive workers retire, and are replaced by younger but relatively less productive workers. In the long term, however, the relative

¹⁷ Changes in the projected distributions of workers by marital status and family size were found to have almost negligible effects on overall work efficiency and, therefore, are not shown.

labor efficiency of the younger worker cohort will catch up with that of older workers and overall productivity will recover almost fully.

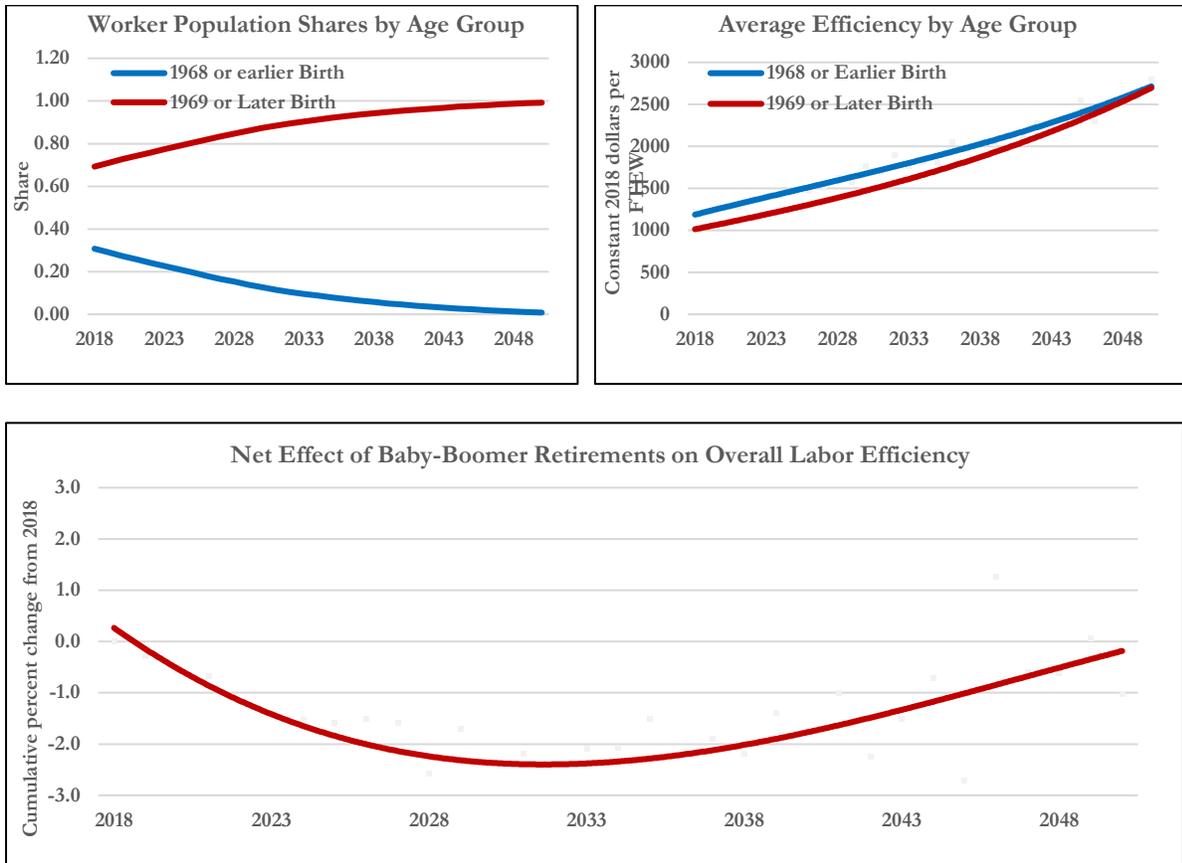


Figure 16: Effects of Changing Shares of Young and Old Workers on Overall Labor Efficiency

N2. Ethnic Affiliation

The PWBM microsimulation’s projection method incorporates relative efficiencies by worker attributes, one of which is ethnic affiliation. The U.S. general and worker population is becoming more ethnically diverse. It implies that any systematic and persistent differences in conditional labor efficiencies by ethnic groups as measured based on micro-data will impart changes to the unconditional overall labor efficiency. Figure 17 shows that these changes may reduce future work efficiency, cumulating to about 1.2 percent by mid-century.

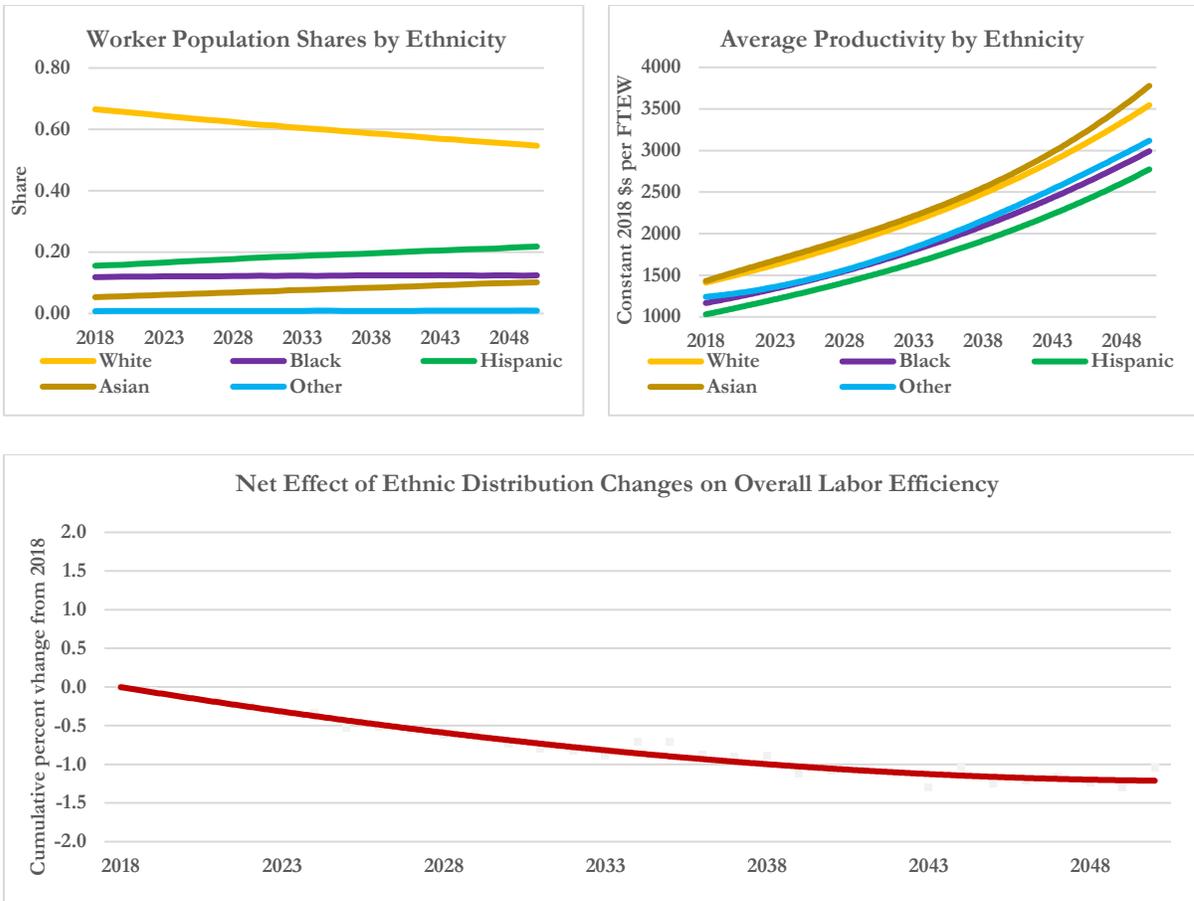


Figure 17: Net Effect of Change in Worker Distribution by Ethnicity on Overall Labor Efficiency

N3. Education

PWBM projects future increases in the share of those with at least a college degree. As the first chart in Figure 18 shows, the fraction of those with at least a college degree is projected to increase over time. The second chart in the Figure shows the gap in relative efficiency between workers in the two education groups is high and projected to increase over time. The final chart of the figure shows that the net overall work efficiency effect of rising education is projected to increase, cumulatively increasing labor earning per FTEW by more than 5 percent through mid-century.

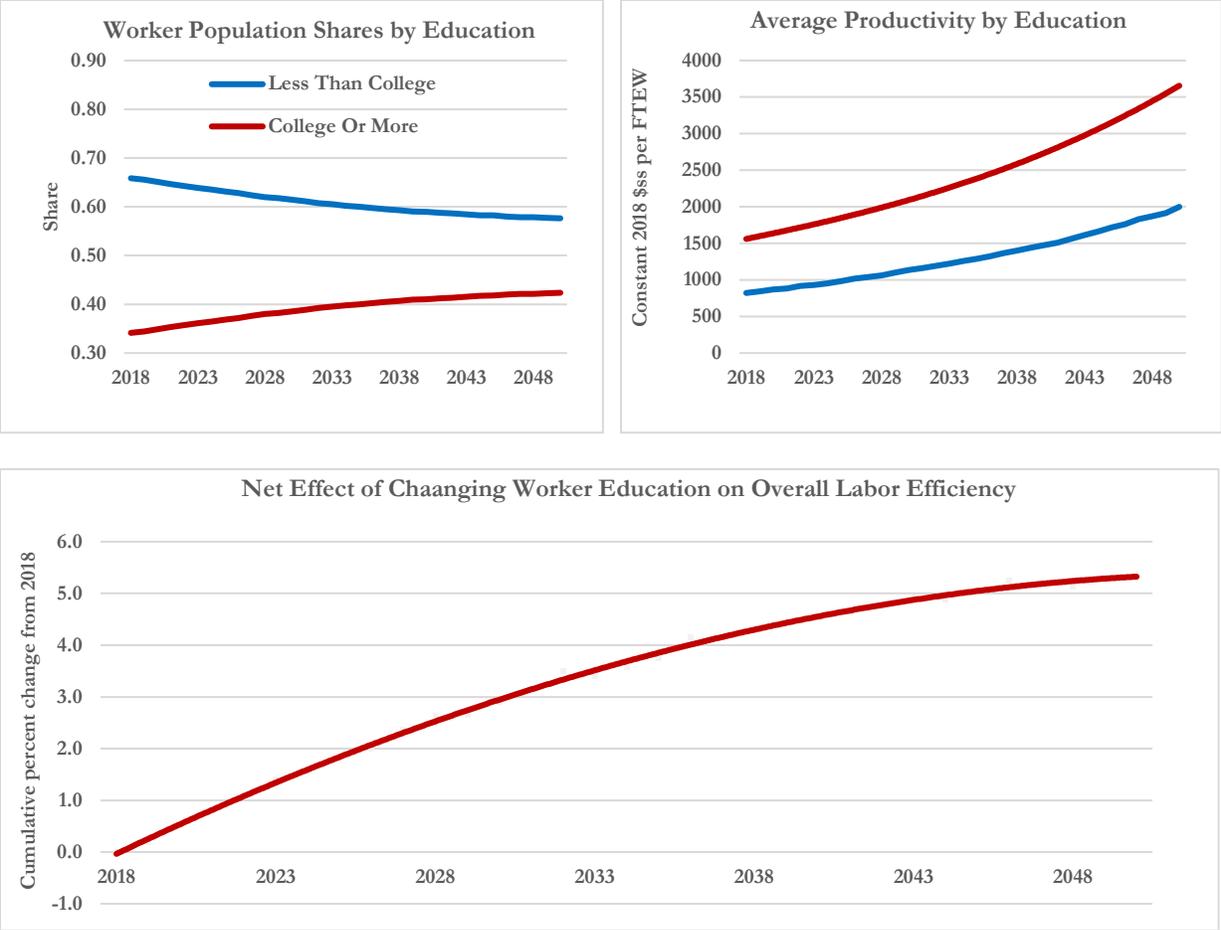


Figure 18: Net Effect of Change in the Worker Distribution by Education on Overall Labor Efficiency

N4. Annual FTEW Worked

The shares of workers by annual FTEW worked is projected to remain quite stable under PWBM’s projections. Hence, despite the highly different relative-efficiencies across workers engaging in different levels of work-effort each year, the effect of this worker attribute is relatively small. As shown in the three charts of Figure 19, the cumulative increase in overall labor efficiency from

projected changes in workers' effort levels is just one tenth of one percent through mid-century.

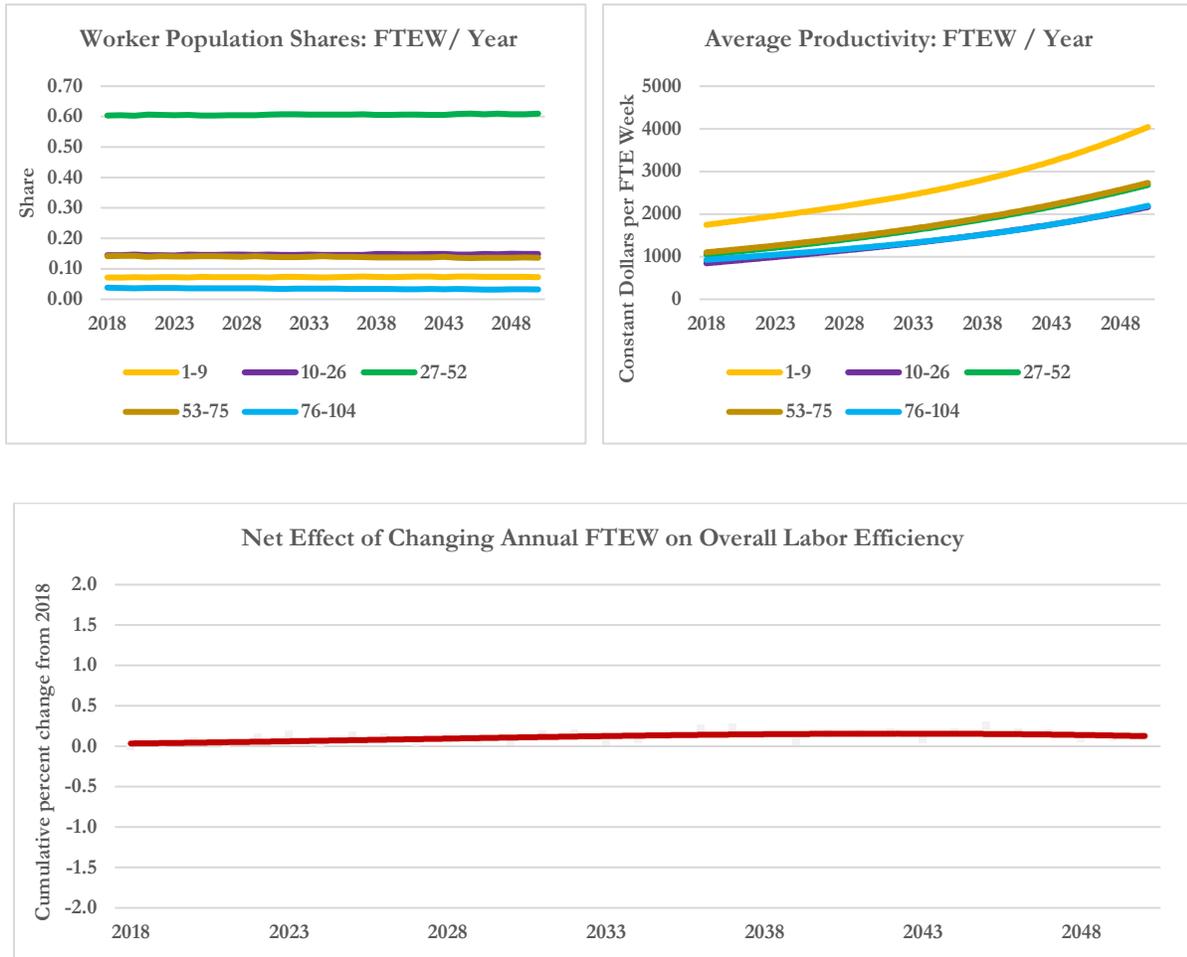


Figure 18: Net Effect of Change in the Worker Distribution by Annual FTEW on Overall Labor Efficiency

N5. Immigrant Legal Status

Figure 20 shows PWBm projections of the U.S. workers by legal status, their relative efficiencies on average, and the cumulative effect of those changes on overall work efficiency through mid-century. The figure shows a decline in the projected share of native-born citizens and an increase in the share of legal immigrants. The shares of undocumented immigrants and naturalized citizens are projected to remain stable. The average work-efficiency of native-born citizens exceeds that of legal

immigrants. Hence, projected trends in those two categories of workers leads to a decline in overall work efficiency approaching 1 percentage point by mid-century.

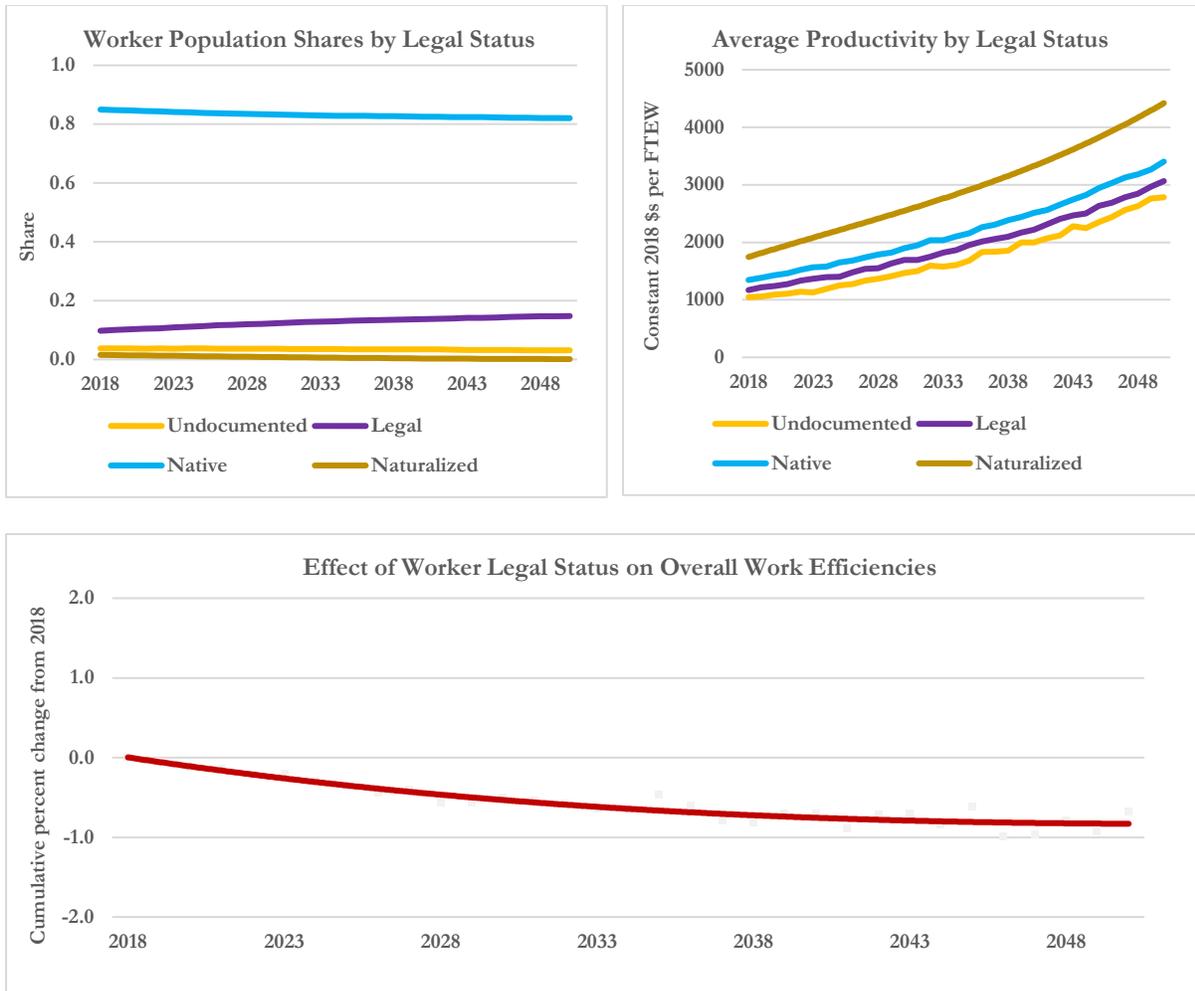


Figure 20: Net Effect of Change in the Worker Distribution by Legal Status on Overall Labor Efficiency

N6. Gender

Figure 20 shows the effect of increasing representation of women in the workforce under the assumption that gender occupational choices remain unchanged. The charts in figure 21 show the changes in worker distributions by gender, the differences in their relative efficiencies under the

constant occupation choice assumption, and the net effect on overall worker efficiency. The latter cumulates to XX percentage points by mid-century.

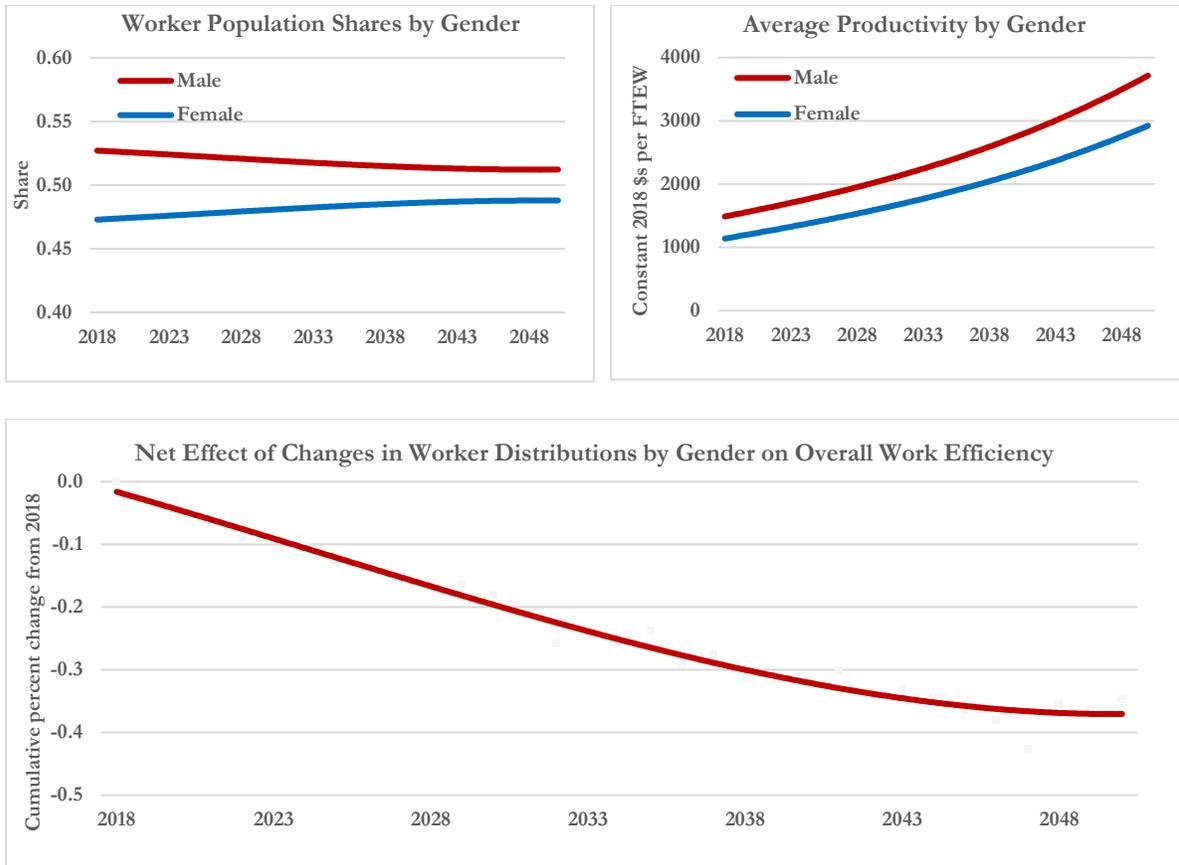


Figure 21: Net Effect of Changes in the Worker Distributions by Gender on Overall Work Efficiency

O. Conclusion

The PWBM microsimulation’s very detailed demographic and economic projections are used to estimate the future course of labor supply – work time adjusted by relative worker efficiencies. The integration of micro-level labor supply projections with other productive factors such as technological growth and capital intensity is achieved through an aggregate production relationship between inputs and GDP. The non-labor factors of productivity are calibrated to historical U.S. trends. GDP growth is then decomposed onto the growth rates of inputs under an assumed rate of

technological growth that is consistent with historical estimates. The decomposition of labor input in particular suggests that the United States will experience a considerable period of slow growth beginning in 2018 and lasting through mid-century. The chief source of slow projected GDP and labor productivity growth is slower projected growth of work efficiency and work time through the mid-2030s. As Table 1 (in section M) shows, That decline is mostly explained by changes in the underlying distributions of workers by attributes, namely age, education, legal status, ethnic affiliation, work time, gender and others.

PWBM's projection methodology is fundamentally different than that employed by the Social Security Trustees. The latter appears to assume that future labor-productivity growth will remain close to its historical average. The implied productivity time series is applied to workers per head to project the economy's total output. Such a methodology, where labor productivity is an input into projections of future output does not consider the influence on future productivity by changes in the population's composition from ongoing demographic changes. In contrast, PWBM projects the key components of labor productivity growth – namely, capital services, work-time, and work-efficiency – from projected changes to the population's detailed demographic features at the individual and family levels. Aggregate labor productivity is therefore an output of PWBM's more granular projection method.

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Appendix 1

Setting Growth Rates of Capital Services and Multi-factor Productivity in the PWBM Microsimulation

The Cobb-Douglas production function framework specifies the relationship between productive factors and nominal national output (gross domestic product, Y_t) as:

$$Y_t = P_t A_t K_t^\alpha L_t^{1-\alpha}$$

Y_t = Nominal national output

P_t = Price level

A_t = Multifactor productivity

K_t = Capital services input

L_t = Efficiency adjusted labor services input

α = Output elasticity of capital

Labor services can be further decomposed: $L_t = h_t \times H_t$, where H_t refers to annual FTEW and h_t refers to average worker efficiency per hour.

A1. Capital services growth

As noted above, capital services are calibrated to keep pace with the growth of other productive factors such that capital's after-tax return is maintained equal to the world rate of return.

Standard derivation shows the capital services growth required to maintain a fixed after tax rate of return: Differentiating the production function with respect to capital services, K_t , and applying the tax function, yields the after tax rate of return.

$$r_t = \frac{dY_t}{dK_t} = \alpha A_t K_t^{\alpha-1} L_t^{1-\alpha} = \alpha \frac{Y_t}{K_t}.^{18} \quad (a1)$$

Differentiate equation (a1) to get

$$dr_t = d\left(\frac{dY_t}{dK_t}\right) = \alpha\{K_t^{\alpha-1} L_t^{1-\alpha} dA_t + (\alpha - 1)A_t K_t^{\alpha-2} L_t^{1-\alpha} dK_t + (1 - \alpha)A_t K_t^{\alpha-1} L_t^{-\alpha} dL_t\}. \quad (a2)$$

Substituting from (a1) and expressing in growth rates yields

$$g^r = g^A + (1 - \alpha)[g^h + g^H - g^K]. \quad (a3)$$

In equation (a3), $g^X = \frac{1}{X_t} \frac{dX_t}{dt}$. The interest rate grows with MFP and labor input growth and declines with capital services growth. To keep the interest rate constant, capital services growth must satisfy

$$g^K = \frac{g^A}{(1-\alpha)} + g^h + g^H. \quad (a4)$$

A2. Wage growth

Maintaining the domestic rate of return constant (or equal to that of the rest of the world in after-tax terms) does not necessarily require a constant capital to labor input ratio. That means the domestic wage rate could change with changes in either of the components of the labor input.

Differentiating the production function with respect to annual FTEW (H) yields

$$w_t = (1 - \alpha) \frac{Y_t}{H_t} = (1 - \alpha) A_t K_t^\alpha h_t^{1-\alpha} H_t^{-\alpha}. \quad (a5)$$

Differentiate equation (a6) to obtain

$$dw_t = d\left(\frac{dY_t}{dH_t}\right) = (1 - \alpha)\{K_t^\alpha h_t^{1-\alpha} H_t^{-\alpha} dA_t + \alpha A_t K_t^{\alpha-1} h_t^{1-\alpha} H_t^{-\alpha} dK_t + (1 - \alpha)A_t K_t^\alpha h_t^{-\alpha} H_t^{-\alpha} dh_t - \alpha A_t K_t^\alpha h_t^{1-\alpha} H_t^{-\alpha-1} dH_t\}. \quad (a6)$$

Substituting from (a5), manipulating, and expressing in growth terms yields

¹⁸ The capital income tax rate, τ , is assumed constant and invariant with respect to changes in all other variables. It is ignored in the the derivation.

$$g^w = g^A + \alpha g^K + (1 - \alpha)g^h - \alpha g^H. \quad (\text{a7})$$

Finally, substitute for capital services growth from (a4) to get

$$g^w = \frac{g^A}{(1-\alpha)} + g^h. \quad (\text{a8})$$

Equation (a8) says that if the growth of capital services were consistent with keeping the after tax interest rate constant (say, at the world rate), domestic wages would grow at the rate equal to $1/(1 - \alpha)$ times the growth of MFP plus the rate of growth of labor efficiency.

Appendix 2

Growth Accounting: A Comparison of PWBM with CBO's Economic Outlook

This Appendix compares PWBM's labor-productivity growth decomposition for the 10-years (2017-2027) with corresponding 10-year economic projections of the Congressional Budget Office's policy model.¹⁹ The comparison is not straightforward because the CBO's uses internal estimation methods, metrics, and information sources that are different from those used by PWBM.

Row		PWBM (2017-27)			CBO (2017-27) ¹			CBO – PWBM
		Growth	Share Parameter	Contribution	Growth	Share Parameter	Contribution	
1	GDP (g^Y)	1.86	1.00	1.86	1.84	1.00	1.84	-0.03
2	Labor time ³ (g^H)	0.72	1.00	0.72	0.48	1.00	0.48	-0.24
3	Implied Labor Productivity ($g^Y - g^H$)			1.14			1.35	0.21
4	MFP (g^A)	0.61	1.00	0.61	0.90	1.00	0.90	0.29
5	Capital Services (g^K)	2.46	0.34	0.85	2.16	0.32	0.68	-0.17
6	Labor efficiency (g^h)	-0.11	0.66	-0.07	-0.11	0.68	-0.08	0.00
7	Labor Time ² (g^H)	0.72	-0.34	-0.25	0.48	-0.32	-0.15	0.10
8	Sum of Components ²			1.14			1.35	0.21

Appendix Table A2: Difference between CBO and PWBM's GDP Growth Decompositions¹

¹Data for CBO calculated for 2017-27 from <https://www.cbo.gov/system/files/2019-04/51137-2017-06-potentialgdp-2.xlsx>

²Refer to equation (4) in the text.

³Labor time is individual full-time equivalent weeks worked based on the Annual Social and Economic Supplement (ASEC) for PWBM and Current Population Survey (CPS) monthly household employment and other labor force information in for the CBO.

⁴The CBO reports the MFP assumption for the non-farm business sector, which contributes about 75 percent of the economy's output. See Shackleton (2018), page 5.

⁴The capital share for CBO is implicit: It is set to the value that makes the sum of contributions equal to CBO's projected labor productivity growth.

Appendix Table A2 shows the differences in PWBM's and CBO's decompositions of labor productivity during 2017-27. The remainder of the discussion provides a row-by-row description of the differences between CBO's and PWBM's labor-productivity growth components shown in Appendix Table A2.

Production-function factor inputs in CBO's policy model are based on information from many sources including the Bureau of Economic Analysis (BEA), the Bureau of Labor Statistics (BLS), and the Census Bureau. Making 10-year and longer-term labor productivity projections invariably

¹⁹ CBO's policy model description is provided in Shackleton (2018). CBO values in the Table are based on "Productivity and Growth in CBO's Forecasts," page 10, available at <https://www.cbo.gov/publication/52912>.

require judgments on sub-components such as MFP growth. In the case of CBO, some decisions on parameters may be influenced by the outcomes of CBO's 10-year business-cycle forecasts determined using an alternative, but not necessarily a fully independent estimation process.²⁰

Row 1: PWBM's 10-year GDP annual growth of 1.86 percent is close to CBO's rate of 1.84 percent.

Row 2: PWBM's labor time growth is based on demographic transitions at the micro-level under a different definition (annual full time equivalent weeks worked), compared to CBO's (annual hours) based on monthly data from the Current Population Survey. A simple conversion of full-time weeks to annual hours would be inappropriate because the two variables are based on different micro-survey questions administered at different time intervals.

PWBM's growth rate of labor time is larger than that of CBO. One reason for this is that PWBM's detailed microsimulation projects a faster rate of labor force entry and work-effort by younger "echo-boomer" birth cohorts and young immigrants through 2027. This provides a larger offset to slowing labor time growth from baby-boomer retirements under PWBM's projections.

Row 3: PWBM's GDP and labor-time growth projections imply labor productivity growth of 1.14 percent per year during 2017-27. This growth is smaller than CBO's 1.35 percent per year by 21 basis points.

The remaining rows of Appendix Table A2 show decompositions of PWBM's and CBO's labor productivity growth into four source components: multifactor productivity, capital services, labor efficiency, and labor time. To understand how the components are summed, refer to the right-hand-side of equation (4) in the main text.

Row 4: CBO's published MFP of 1.1 percent per year is for the non-farm private business sector only. CBO's estimation method documentation (Shackleton [2018]) notes that the NFB sector accounts for 75 percent of the total economy.²¹ Multiplying CBO's MFP estimate of 1.1 percent per year by 0.75 yields 0.83.²² CBO's model documentation also notes that CBO does not decompose labor input growth into growth in labor time and labor efficiency. Instead, labor efficiency growth is included within MFP growth.²³ In contrast, PWBM's microsimulation generates a very fine-grained decomposition of labor efficiency growth along many dimensions of worker attributes. Examples are provided in Section N of the main text. The total contribution of labor efficiency from projected changes in worker attributes is estimated separately from the contribution of labor time under PWBM's projection method.

Absent any information on CBO's estimate of the contribution of labor efficiency growth to labor productivity growth, PWBM's estimate of labor efficiency growth is netted out of CBO's

²⁰ According to Shackleton (2018, pp. 33) "The policy model is calibrated to match historical data and the Congressional Budget Office's forecast over the 10-year window." According to the description of the policy model's methodology, the policy model is "... used to forecast long-term economic trends beyond the 10-year window for the agency's 30-year projections of budgetary and economic conditions, under the assumption that current laws generally remain in place over that period."

²¹ See Shackleton (2018) pp 5-7.

²² This assumes that the output of all sectors other than the non-farm business sector are fully accounted for by input growth and their contribution to MFP is zero.

²³ See Shackleton (2018), footnote #13.

labor-efficiency-inclusive MFP growth of 0.83.²⁴ The removal of PWBM’s estimate of labor efficiency growth during the next decade would *subtract* –8 basis points to CBO’s labor-efficiency-inclusive MFP growth, pushing it up to 0.90 percent per year. Comparing this estimate to PWBM’s MFP growth projection for 2017-27 of 0.61 yields a difference of 29 basis points that remains unreconciled.

Regarding MFP estimation, CBO’s method documentation states²⁵ “projecting trends in TFP is particularly challenging because it is, by definition, a measure of unexplained growth. In addition, it has been marked, historically, by lengthy periods of relatively steady growth followed by rather abrupt transitions to substantially different growth rates. The agency (CBO) therefore *applies a substantial degree of judgment to its projections of potential TFP rather than simply projecting the most recent estimated trend* (emphasis added).” It further writes that the “...the agency currently projects trend growth in TFP to *gradually increase from its recent low rate to a more rapid rate that is more consistent with such long-term trends* (emphasis added). Specifically, growth in potential TFP is projected to converge to its weighted average trend over the preceding 25 years, with twice as much weight placed on recent trend rates as on trend rates 25 years in the past. Nevertheless, the agency will revise that judgment as necessary as new data dictate.”²⁶

It’s worth noting that basing the MFP on historical data when elements of labor efficiency are included appears to be less than ideal. The labor-efficiency element of MFP can be estimated separately, conditioned on demographic features and separated from MFP, both historically and for future projections. This is the method employed by PWBM.

Row 5 of Appendix Table A2 shows that CBO’s average capital-service growth of 2.16 percent per year, which is not markedly different from PWBM’s projection of 2.44 percent per year.²⁷ However, there is a considerable difference in the two capital measures. CBO’s capital stock measure pertains to the NFB sector alone. Other sectors’ contributions to output are estimated by CBO using a one-factor (labor) production framework.²⁸ In contrast, PWBM’s capital services growth includes capital in the government and non-profit sectors.

Row 5 also shows the implied capital share parameter for PWBM and the CBO. PWBM’s value of 0.345 is almost identical to the historical average as described in Section I of the main text. For CBO, the capital share parameter is set so that the sum of all contributing factors equals CBO’s overall labor productivity growth shown in Row 3. The implied capital share parameter equals 0.32, which is also not very different from PWBM’s capital share assumption of 0.345.

²⁴ The calculation subtracts PWBM’s labor efficiency growth, g^{PWBMLE} , times one minus the capital share, α , from CBO’s reported MFP growth, g^{CBOMFP} , to yield MFP growth attributable only to non-labor technological or other sources: $g^{CBOMFP} - (1 - \alpha)g^{PWBMLE} = g^{TECHMFP}$.

²⁵ See Shackleton 2018, pp. 35. The CBO uses the term “total factor productivity” or TFP instead of the term multifactor productivity or MFP that is used in this paper.

²⁶ *Ibid.* This description of the weighting process for recent MFP growth versus MFP growth during earlier years is insufficient to replicate and apply it to the historical MFP growth series.

²⁷ The CBO’s capital services growth rate refers to the non-farm business sector. The same growth rate is assumed for the total economy.

²⁸ The output of the government sector is defined as the sum of labor services and capital depreciation. See Shackleton (2018) Table 1 and associated text.

Because PWBM's capital growth is driven by both labor input growth and MFP growth, the considerably faster projected growth of PWBM's labor input causes the PWBM capital services growth to exceed that of CBO. Faster capital growth and the slightly larger value of PWBM's capital's share in output causes PWBM's capital contribution to labor productivity growth to be larger by 17 basis points during 2017-27.

Row 6 of Appendix Table A2 shows the contribution of PWBM's labor efficiency growth to its labor productivity growth. This value is almost identical to the CBO columns because the identical growth in labor efficiency is multiplied by CBO's almost identical labor share to obtain the contribution to labor productivity. Recall that the labor efficiency component is separated from CBO's labor-efficiency-inclusive MFP growth after adjustment to reflect the total economy (see the description for Row 4 above).²⁹

Row 7: PWBM's projected growth of labor time takes away 25 basis points from overall labor productivity growth (right-hand-side of equation (4) in the main text) whereas CBO's relatively slower labor time growth takes away 15 basis points (see description of Row 2 above). The labor-time component therefore accounts for a ten basis point difference in the two labor-productivity decompositions.

Row 8: Overall, PWBM's projected growth rate for labor productivity over the next decade is 21 basis points slower than CBO's projection. As noted above, however, the comparison of CBO's and PWBM's labor productivity components is subject to several caveats. Relative to PWBM's estimates, CBO's MFP growth assumption is larger, the labor-time growth estimate is smaller, and the productivity effects of labor efficiency changes are not explicitly estimated. The main sources of CBO's higher projected labor-productivity growth rate relative to PWBM are

1. CBO's primarily models only the NFB sector by using the standard growth-accounting framework including capital. The farm, non-profit, household, and government sectors are estimated using a one-factor production framework. This makes comparison of capital services growth difficult.
2. CBO's judgmental approach to determining MFP growth appears to set it much higher than is consistent with its historical average since 1987 based on BLS total economy estimates.
3. CBO does not explicitly project the labor-productivity effects of changes in labor efficiency, in effect folding them within MFP. It's unclear how and to what extent the CBO makes a judgment call on these sources of future labor productivity when basing its MFP growth assumption on historical data.
4. CBO's considerably slow projected growth in labor time of just 0.48 percent per year versus PWBM's 0.72 percent per year also accounts for a sizable part of the difference in labor productivity between CBO and PWBM. The labor-time comparison, however, is subject to all of the qualifications noted in the description of Row 2 above.

²⁹ See Shackelton (2018), footnote 13.

Appendix 3

Methodological Issues in using Aggregated Microsimulation Outcomes to Derive Labor Productivity Projections

This section discusses three methodological issues that emerged during discussions with external reviewers of PWBM's labor productivity projections.

Issue 1: The microsimulation based projection approach takes account of compositional changes in future population attributes but not potential future adjustments of productivity coefficients associated with those attributes.

Discussion of Issue 1: It is true that under PWBM's method, worker attribute productivity coefficients are held fixed while projected attribute distributions are allowed to change over time according to their demographic and economic transition probabilities as estimated from historical micro-data.

First, the wage regression estimates attribute productivity coefficients by pooling data across several periods (after appropriately removing the effects of capital intensity, MFP, and prices) including boom times and recessions. The resulting coefficients span periods of high and low demand for many types of worker characteristics associated with the supply of labor services.

Second, while changes in attribute distributions determine the "supply of labor services," the attribute productivity coefficient values, themselves, may increase, decrease, or remain unchanged depending on whether changes in the demand for labor services that those attributes promote is larger or smaller *relative* to changes in their supply. Changes in the demand for those attributes relative to supply may happen for many reasons and generate outcomes that are different than those projected by any estimation system (not just that developed by PWBM). The changes could arise because of never-before experienced changes in consumer preferences, production technologies, and government budget policies.³⁰ Since these changes could trigger increases, decreases, or no change in demand relative to supply of attributes, attribute productivity coefficients may correspondingly increase, decrease, or not change in the future. This implies that estimates based on historical micro-data that are used in forming projections are not necessarily biased in either direction.

³⁰ It is important to recognize the distinction between making projections about the future and forecasting it. Projections are conditional statements about the central tendency of future outcomes while forecasts must always be "acceptably close" to future outcomes unconditionally. PWBM, similar to other agencies such as the CBO, Social Security Trustees, the Office of Management and Budget, etc., makes projections and not forecasts about the future. All of these projections are based on historical information. Therefore, by construction, projections cannot estimate the effects of major (and persistent) shocks to consumer preferences, production technologies, and government economic and budget policies that push the economy far from the projected outcome. Actual economic outcomes usually diverge from projections made previously because consumer preferences, production technologies, and government policies usually change considerably relative to those on which projections are conditioned. The failure of projections to always be "acceptably close" to actual outcomes over time do not make them "incorrect" or "valueless." For example, a projection may indicate an undesirable outcome or, at the extreme, that the economy would collapse if current economic policies are continued. If policymakers then respond by making large policy changes and succeed in avoiding those outcomes, the prior projections conditioned on the old economic policies would not be realized.

Third, the objective of microsimulation is to create an explicit decomposition within and between demographic and economic variables to create discipline and reduce “story telling” that might not have a material impact on the projected variable of interest. In particular, microsimulation does not replace an equilibrium-based economics model.³¹ For example, based on historical relationships, PWBM’s microsimulation currently assumes that the gender wage gap will persist into the future, *conditional* on age, education, and other modeled attributes. In contrast, an equilibrium model, for example, might predict that this gap---even after conditioning on these same variables---begins to close over time. The impact of such a prediction on overall productivity could initially be tested by incorporating ad-hoc time-varying shift parameters into the microsimulation. If the impact on overall productivity is large, then additional work could be done to structurally estimate this change over time and include reduced-form estimates and trends into the microsimulation.³²

Issue 2: The definition of PWBM’s labor time is different from that of BLS, SSA, and CBO and may account for most of the differences in labor productivity compared to values estimated or assumed by those agencies for making financial projections.

Discussion of Issue 2: Historically, PWBM’s labor productivity estimates are based on the Census Bureau’s Annual Social and Economic (ASEC) Supplement survey. However, the ASEC definition of labor time is different from those of the BLS, which requires an adjustment before the results can be compared to those of the BLS, SSA, and CBO. Therefore, PWBM’s labor time calibrations are adjusted in two ways to achieve comparability, as described next.

First, labor time (FTEW) growth was benchmarked to ASEC historically and that adjustment was carried forward into the projections. An adjustment to labor-time in this manner compels a commensurate adjustment to PWBM’s projection of capital services, which follow labor-time and MFP growth rates. This benchmarking step added 19 basis points to labor time growth and a commensurate adjustment to capital services to maintain historical capital intensity growth. Because both labor and capital growth is higher, so is output growth. This benchmarking-to-ASEC step leaves labor productivity unchanged by construction.

Second, PWBM also includes an additional adjustment to eliminate the growth difference due to the different definition of labor time between BLS (annual hours) and PWBM (FTEW). A different definition of labor time may be associated with a different measured growth rate because the elements included or excluded under the alternative definitions may grow at different rates. However, this difference does not trigger an increase in capital services because it only re-defines the measure of capital-intensity in the same way both historically and in the projections. This adjustment to labor time (FTEW) was negative 21 basis points.

Following these two adjustments to PWBM’s labor time measure, any remaining difference between PWBM’s (estimated) and SSA’s (assumed) labor productivity remains unexplained. The adjustments show the SSA’s excess labor productivity relative to PWBM to be 26 basis points (based on the Social Security Trustees’ 2018 annual report). If demographic effects are excluded from

³¹ Conversely, an equilibrium-based model does not attempt to replace the attribute richness of a microsimulation model. Instead, PWBM uses both types of models and integrates them at points where equilibrium conditions (e.g., savings and labor supply) are especially important.

³² For example, PWBM’s microsimulation marriage and divorce transition processes are based on a structural estimation of a dynamic programming model of marriage and divorce.

PWBM's efficiency-adjusted labor service projection, SSA's excess productivity differential increases to 32 basis points.

Issue 3: PWBM calibrates MFP growth based on data from the BLS, which is available only since 1987. Were pre-1987 data available and were it taken into account, the historical MFP growth average would be higher because of the boom periods of the 1950s and 60s.

Discussion of Issue 3: The period after 1987 includes three phases: Two low MFP periods: 1987-94 and 2005-17 and one period of high MFP growth: 1995-2004. It implies that PWBM's MFP estimate is not based exclusively on periods of low MFP growth.

Two considerations suggest that excluding periods before the mid-1980s for calculating the MFP growth average for future labor-productivity projections: First, the U.S. economy was considerably less developed during the 1950s and 60s. It benefitted hugely from global reconstruction and the opening of new markets under a postwar pro-trade international economic order that the United States established and helped to maintain. That special economic environment seems unlikely to be repeated in the future.

Second, during the twenty years between the mid-sixties and mid-eighties, prime-the-pump fiscal policies together with the Fed's accommodative monetary policy to exploit an apparently stable trade-off between inflation and unemployment (the Phillips curve) led to accelerating inflation. High and rising inflation (1) dilutes market price signals and hampers efficient capital allocation, (2) biases output measurement downward leading to understatement of productivity growth, (3) interacts with income and business tax systems to erode capital returns (by reducing depreciation and increasing the rental price of capital services) and retards innovation and capital formation. See the last column of Appendix Table 3.1 below and Clark (1982). These factors may have contributed, along with energy shocks [Nordhaus, (2004)] to the observed productivity slowdown after the mid-1960s. With the Federal Reserve committed to be vigilant in preventing inflation after the experience of the 1970s and new energy supply technologies, neither higher inflation nor severe energy supply shocks appear likely during the next few decades in the United States.³³

Third, PWBM's MFP estimate conservatively equally weights all years since 1987. In contrast, many forecasters would advocate some type of geometric weighting that places more weight on recent experience. As such, years prior to 1987 would have less weight, and more weight in our MFP would shift toward years after 2004 with lower MFP.

Appendix Table 3.1: S&P 500 returns

	Price Change	Dividend Dist. Rate	Total Return	Inflation	Real Price Change	Real Total Return
1950's	13.2 %	5.4 %	19.3 %	2.2 %	10.7 %	16.7 %

³³ Low capital returns during the 2000s (Appendix Table 3.1, penultimate row) are not sourced to inflation but to a recession in housing and dislocations in financial markets, events that could be repeated in the future.

1960's	4.4 %	3.3 %	7.8 %	2.5 %	1.8 %	5.2 %
1970's	1.6 %	4.3 %	5.8 %	7.4 %	-5.4 %	-1.4 %
1980's	12.6 %	4.6 %	17.3 %	5.1 %	7.1 %	11.6 %
1990's	15.3 %	2.7 %	18.1 %	2.9 %	12.0 %	14.7 %
2000's	-2.7 %	1.8 %	-1.0 %	2.5 %	-5.1 %	-3.4 %
1950-2009	7.2 %	3.6 %	11.0 %	3.8 %	3.3 %	7.0 %

Source: <http://www.simplestockinvesting.com/SP500-historical-real-total-returns.htm>)

Source footnotes: Figures for dividend distribution rates in the previous table present high uncertainty, of about ± 5 percent. Geometric averages were calculated for price changes, total returns and inflation. Raw data for this work was obtained from the following sources: Standard & Poor's S&P 500; U.S. Department of Labor; Yahoo Finance; Data collected by Robert Shiller, Yale University.