## DATA APPENDIX

This appendix describes the data series used in the article. All data are annual and cover the period from 1974 to 2012 inclusive.

### Real Output per Hour in the Non-Farm Business Sector (*Y/H*)

Data from 1974 through 2008 are from the tables the BLS makes available with its multifactor productivity (MFP) release. We used the version of the MFP data released on March 21, 2012.[1] For 2009-2012, we extended the BLS series using the annual growth rate of BLS' series for output per hour in the non-farm business sector from its quarterly Productivity and Cost (P&C) Release.[2] We used data from the P&C release starting in 2009 so as to incorporate revisions to real output in the non-farm business sector in the BEA's 2012 annual revision of the National Income and Product Accounts (NIPAs).

### Real Output (*Y*), Current-dollar Output (*pY*), and Price Index (*p*) for the Non-Farm Business Sector

Data for real output and current-dollar output for 1974-2008 are from the MFP dataset. For 2009-2012 we extended the BLS series using annual growth rates for real output and current-dollar output in the non-farm business sector from the NIPAs.[3] We measured *p* as an implicit price deflator, constructed as the ratio of current-dollar non-farm business output to real non-farm business output from the MFP dataset for the period 1974-2008. For 2009-2012, we extended the series for *p* using annual growth rates constructed from the NIPA data on real output and current-dollar output in the non-farm business sector.

### Labour Hours (*H*)

For 1974 to 2010, labour hours are from the MFP dataset. We extended the data to 2012 using the growth rate in hours of all persons in the non-farm business sector from the P&C release.

### Contribution of Capital Deepening in the Non-Farm Business Sector

#### Overall Capital Deepening

For 1974 to 2010, the contribution of overall capital deepening to growth in labour productivity is calculated as the product of: 1) the log difference of the capital-hours ratio (using real capital input) and 2) capital's income share. Our income shares are time varying and not period averages.[4] The data for the capital-hours ratio and the income shares are from the MFP dataset.

For 2011 and 2012, we extended the series for the overall capital deepening contribution using the following steps. First, we calculated the contributions from 2010 to 2012 for equipment, non-residential structures, inventories, tenant-occupied rental housing, and land (we use these categories because these are the ones for which BLS makes data readily available on their website). For each asset type, the contribution is calculated as the product of the income share and the log difference of the capital-hours ratio. For the numerator of the capital-hours ratio, we constructed productive capital stocks as

1 All other series we use from the MFP data are also from that release. These data are available at http://www.bls.gov/mfp/mprdload.htm. See the spreadsheets titled "Historical Multifactor Productivity Measures (SIC 1948-87 linked to NAICS 1987-2011)" and "Information Capital by Asset Type for Major Sectors."

2 We used data from the release dated February 7, 2013.

3 All of the NIPA data we use are from the release dated January 30, 2013.

4 For each year, the share used is the average of the income share for that year and the income share for the previous year. We use the same procedure for the IT capital shares described below.

described below. For the denominator, we used hours data from BLS as described above. Second, we summed these contributions to obtain a capital deepening contribution for overall capital for 2010 to 2012. Finally, we extrapolated forward from the BLS 2010 contribution with the first-difference in our calculated contributions between 2010 and 2011 and then between 2011 and 2012. We did not use the levels for 2011 and 2012 directly because we are working at a higher level of aggregation than BLS used to calculate the overall capital deepening contribution through 2010, which introduces a wedge between the results in levels for a given year.

### IT Capital Deepening

For 1987 to 2010, capital deepening contributions for each type of IT capital are calculated as the product of: 1) the log difference of the capital-hours ratio using real capital input for each type of IT (computer hardware, software, and communication equipment) and 2) the income share for that type of capital. The data for capital input, hours, and the income shares for each type of IT capital are from the MFP dataset.

For 2011 to 2012, we extended the series for the contributions using a procedure exactly parallel to that for the components of overall capital deepening.

For 1974 to 1986, the BLS does not make available the needed IT detail on their website. Accordingly, for each type of IT capital, we construct contributions from data for the income share, capital input, and hours, extrapolating back from the 1987 contributions by splicing in values for these variables from the dataset we constructed for Oliner, Sichel, and Stiroh (2007).

### Capital Deepening for Non-IT assets

These contributions are calculated by subtracting the IT capital deepening contributions from the overall capital deepening contribution.

## Productive Stocks

To extend the capital deepening contributions to 2011 and 2012 as described above, we used productive capital stocks to measure capital input for each category of capital, in accord with BLS methodology. For the calculations for total capital, we need productive stocks for each of the capital categories we use to sum up to total capital (equipment, non-residential structures, inventories, tenant-occupied rental housing, and land). For the calculations for IT capital, we need productive stocks for each of the IT capital categories (computer hardware, software, and communication equipment).

### Depreciable Assets

For depreciable assets (equipment and software, non-residential structures, tenant-occupied rental housing, and the three types of IT capital) we started with productive capital stock data from the MFP dataset through 2010 (the same spreadsheets described above). We extended these BLS productive stock series to 2011 and 2012 using the perpetual inventory method with the following equation:

$K_t = f_t K_{t-1} + (I_t + I_{t-1})/2,$

where (following BLS methodology) $K_t$ is measured as the average of the stocks at the end of years $t$ and $t-1$. For the investment series ($I_t$), we started with the series for gross investment through 2010 for each category from the BLS datasets. We extended these investment series to 2011 and 2012 using growth rates of real investment for the corresponding series from NIPAs. The term $f_t$ is a translation factor that converts the productive stock from period $t-1$ into the productive stock for period $t$. We obtain this translation factor ($f_t$) for each period up through 2010 using the published BLS data and solving for $f_t$ for each year in the equation above. We then use the 2010 value of $f_t$ to generate estimates of the productive stock for 2011 and 2012.

### Non-Depreciable Assets (Inventories and Land)

To extend the stock of inventories to 2011, we take the productive stock in 2010 and add the NIPA value for the change in real private inventories for 2011. Then, to extend forward to 2012, we add the 2012 value of the change in inventories to the estimated 2011 stock.

To extend the stock of land to 2011 and 2012, we assume that the real productive stock of land in 2011 and 2012 changed at the average annual rate of change from 2007 to 2010.

## Labour Composition ($q$)

BLS measures the change in labour composition as the difference between the growth rate of labour input and that of labour hours. To calculate labour input, BLS divides the labour force into a number of age-sex-education cells, and then constructs a weighted average of growth in hours worked in each cell, with the weight for each cell equal to its share of total labour compensation. Through 2010, our measure of the change in labour composition is from the MFP dataset. For 2011 and 2012, we assumed that the change in labour composition generated a contribution of 0.25 percentage point to growth in labour productivity.

## Income Shares ($\alpha_j$)

### Total Capital

For 1974 to 2010, the income share for total capital is from the MFP dataset. To extend this series to 2011 and 2012, we construct capital income for the five categories of total capital that BLS provides: equipment and software, non-residential structures, inventories, tenant-occupied rental housing, and land. We sum these estimates to generate an estimate of total capital income. The share is then the ratio of this estimate of capital income to total income in the non-farm business sector. Finally, we take this estimate of the capital income share and difference splice it to the 2010 value of the published BLS series for the capital income share to obtain estimates of the income share for 2011 and 2012. With an estimate of the income share for capital in hand, the income share for labour equals unity minus the income share for capital.

### IT Capital

For 1987 to 2010, the income shares for each type of IT capital are from the MFP dataset. For 1974 to 1986, we difference splice in the income shares that we constructed for Oliner, Sichel, and Stiroh (2007). To extend the income shares for each IT asset to 2011 and 2012, we use a procedure parallel to the one described for the pieces that add up to total capital.

### Capital Income

To estimate capital income for each type of capital for the extension to 2011 and 2012, we use the following equation:

$$capital\ income_j = [(R + \delta_j - \Pi_j)\ p_j K_j]\ T_j.$$

We discuss each component of this equation below. Although we have suppressed the time subscript for expositional convenience, these estimates of capital income vary from year to year. The extension from 2010 to 2011 and 2012 only requires data on the components for those years, but we compile data for each component back to 1974 because the steady-state calculations require the full history.

### Depreciation Rate ($\delta_j$)

For equipment and software, non-residential structures, and tenant-occupied rental housing, we use depreciation rates reported in the MFP dataset through 2010. For 2011 and 2012, we use the value reported for 2010. For land and inventories, the depreciation rate is zero. For IT assets, we use a parallel procedure.

### Expected Nominal Capital Gain/Loss ($\Pi_j$)

For each type of capital, we calculated $\Pi j$ as a three-year moving average of the per cent change in the price of asset $j$ ($p_j$). The moving average serves as a proxy for the unobserved expectation of price change. Through 2010, the $p_j$ series for these assets are the investment price indexes from the MFP dataset. Except for land, each $p_j$ series was extended to 2011 and 2012 using the growth rate of the corresponding series for NIPA investment prices.[5] For land, we extended prices to 2011 and 2012 using the average growth rate of land prices in the MFP dataset from 2007 to 2010.

### Current-Dollar Productive Capital Stock ($p_j K_j$)

For each asset, this series is simply the product of the real productive stock ($K_j$) and the asset price index ($p_j$), both of which are discussed above.

### Tax Adjustment ($T_j$)

For each asset j, this adjustment is $T_j = (1 - c - \tau v)/(1 - \tau)$, where $c$ is the rate of investment tax credit, $\tau$ is the corporate tax rate, and $v$ is the present value of \$1 of tax depreciation allowances. We include a tax term ($T_j$) for each asset in the capital income and income share variables we construct. Through 2010, we construct the tax terms ($T_j$) we need from the MFP dataset.[6] For 2011 and 2012, we use the 2010 value of each tax term.

### Nominal Net Return ($R$)

We calculated $R$ as the ex post net return earned on the productive stock of equipment and non-residential structures. Thus, we obtain $R$ as the solution to the following equation:

$$\sum_{j=1}^{N} [(R + \delta_j - \Pi_j)\, p_j K_j]\, T_j / pY = \sum_{i=1}^{N} \alpha_j$$

where the summations are over computer hardware, software, communication equipment, and other business fixed investment. This procedure yielded an annual series for $R$ from 1990 to 2010. (The BLS data begin in 1987 and we need three lags for the capital gain term so these estimates of $R$ begin in 1990.) For 2011 and 2012, we estimate $R$ as the predicted value from a regression with the following explanatory variables: a constant, two lags of $R$, the rate of price change for non-farm business output, the acceleration in real non-farm business output, the unemployment rate, and the share of corporate profits in GNP. For the period from 1974 to 1989, we

5 For equipment and software and non-residential structures, we used the price series from NIPA Table 5.3.4. For inventories, we used the implicit price deflator for non-farm inventories from NIPA Table 5.7.9B. For tenant-occupied rental housing, we used the price series for investment in multifamily residential structures from NIPA Table 5.3.4. For each type of IT capital, we used prices from NIPA Table 5.5.4.

6 As part of the MFP dataset, under the heading "Additional Available Measures," BLS provides spreadsheets for 1987-2010 Rental Price Detail Measures by Asset Type for both manufacturing and non-manufacturing industries. To construct income shares for total capital and for IT capital, we need tax terms for computer hardware, software, communication equipment, other business fixed investment, inventories, tenant-occupied rental housing, and land. The tax terms do not vary across industries and do not vary much within asset classes. For computer hardware, we use the common tax term that applies to every type of hardware. For software, we use a weighted average of the tax term for pre-packaged software and custom software and the separate term for own-account software, with a weight of 0.60 on pre-packaged and custom. For communication equipment, inventories, and land, we use the single tax term for each asset type provided by the BLS. To construct the tax term for other business fixed investment (BFI excluding IT), we calculated a weighted average of the tax terms for equipment excluding IT assets and non-residential structures. All types of non-residential structures have a common tax term; for non-IT equipment, we used the tax term that applies to most types of equipment other than motor vehicles, nuclear fuel or IT assets. The weights are year-by-year nominal productive capital shares for equipment excluding IT assets and non-residential structures.

difference splice in estimates of *R* from Oliner, Sichel, and Stiroh (2007).

### Current-Dollar Output Shares ($\mu_C$, $\mu_{SW}$, $\mu_M$, $\mu_O$, $\mu_S$)

The denominator of each output share is current-dollar non-farm business output ($pY$), the data source for which was described above. Here, we focus on the measurement of current-dollar sectoral output ($p_iY_i$ for $i$ = *C*, *SW*, *M*, *O*, and *S*), which is the numerator in each share.

#### Computer Sector

For 1987 to 2011, we used Census Bureau data from the Annual Survey of Manufacturers (ASM) on product shipments of computer and peripheral equipment (NAICS category 3341). This series includes computer and peripheral equipment shipped by domestic establishments regardless of their industry classification. Before 1987, the ASM data are available only on an industry basis. Industry shipments differ from product shipments by including secondary non-computer products shipped by establishments in the computer and peripheral equipment industry and by excluding computer and peripheral equipment shipped by establishments in other industries. Because of the resulting level difference between the two series, we extrapolate the 1987 level of ASM product shipments back in time using the annual per cent changes in ASM industry shipments. For 2012, we extrapolated the 2011 level of the ASM product shipments forward using a proxy for current-dollar shipments of computer and peripheral equipment. The proxy variable is the product of the annual average level of the Federal Reserve's industrial production index for computer and peripheral equipment and the NIPA price index for all final sales of this equipment (NIPA Table 1.2.4, line 17). We moved the 2011 level of ASM product shipments forward to 2012 by the per cent change in the proxy series.

#### Software Sector

For 1995 to 2011, we used NIPA data on current-dollar final sales of software, adjusted to exclude own-account software produced by the government. The data are in supplemental NIPA tables posted at http://www.bea.gov/national/info_comm_tech.htm under the headings "GDP and Final Sales of Software" and "Software Investment and Prices, by Type".

We extrapolated the 1995 level back to earlier years and the 2011 level forward to 2012 using the annual per cent changes in the NIPA series for private fixed investment in software (NIPA Table 1.5.5, line 33).

#### Communication Equipment Sector

We follow the same procedure described above for the computer sector. That is, we use ASM product shipments for communication equipment (NAICS category 3342) for 1987-2011; we then extrapolate back in time with the annual per cent changes in ASM industry shipments and forward to 2012 with the per cent change in a proxy series for current-dollar output of communication equipment. The proxy variable is the product of the annual average level of the Federal Reserve's industrial production index for communication equipment and a price index for domestic output of this equipment constructed using the method described in Byrne and Corrado (2007). Because the Byrne-Corrado index is not yet available for 2012, we assume the 2012 per cent change equaled that for 2011.

#### Semiconductor Sector

Here too we rely on Census shipments data. For 1987-2011, we use ASM product shipments for integrated circuits (NAICS category 3344131). We then extrapolate back in time with the annual per cent changes in ASM industry shipments for semiconductors and related devices (NAICS code 334413), the closest available industry to integrated circuits. For 2012, we extrapolate the 2011 level of the ASM product shipments forward using the annual per cent change in current-dollar shipments of integrated circuits calculated by Federal Reserve Board staff.

### Other Non-Farm Business

We estimate current-dollar output in this sector as a residual after accounting for all other components of non-farm business output:

$$p_O Y_O = pY - p_C Y_C - p_{SW} Y_{SW} - p_M Y_M - p_S (S_x - S_m),$$

where the final term is current-dollar net exports of semiconductors. (This is the only part of semiconductor production that shows up in domestic final output.) The data sources for $pY$, $p_C Y_C$ , $p_{SW} Y_{SW}$ , and $p_M Y_M$ were described above. We obtain data on current-dollar net exports of semiconductors as follows. For 1989 to 2011, we use series constructed by Federal Reserve Board staff for current-dollar exports and imports of integrated circuits (NAICS code 3344131), which are based on data from the International Trade Commission. We extrapolate the 1989 levels for both series back to 1978 using similarly constructed series for semiconductors and related devices (NAICS code 334413). Before 1978, the detailed trade data are not available, and we extend the export and import series back in time using the annual per cent change in domestic shipments of semiconductors (the series $p_S Y_S$ described above). For 2012, we extrapolate forward the 2011 levels of both exports and imports using the annual per cent change in current-dollar shipments of integrated circuits calculated by Federal Reserve Board staff (the same series used for the 2012 value of semiconductor sector output).

## Ratio of Semiconductor Output to Domestic Semiconductor Use ($1+\theta$)

Domestic semiconductor use can be expressed as domestic semiconductor output minus net exports of semiconductors. Thus,

$$1+\theta = Y_S / [Y_S - (S_x - S_m)] = p_S Y_S / [p_S Y_S - (p_S S_x - p_S S_m)],$$

where the second equality converts each series to current dollars. The data sources for $p_S Y_S$ and $p_S S_x - p_S S_m$ were described above.

## Rates of Relative Price Change ($\pi_C$ , $\pi_{SW}$ , $\pi_M$ , $\pi_S$)

Each $\pi_i$ series ($i = C$, $SW$, $M$, and $S$) represents the rate of change in the price ratio $p_i / p_O$, where $p_O$ is the price index for other non-farm business.[7] Here, we describe the data source for each price series that enters these ratios.

### Computer Sector

For 1978-2012, we measure $p_C$ with the NIPA price index for final sales of computers and peripheral equipment (NIPA Table 1.2.4, line 17). For earlier years, we extrapolate back the 1978 level with the per cent change in the NIPA price index for private fixed investment in computers and peripheral equipment (NIPA Table 1.5.4, line 32), trend-adjusted to decline one percentage point faster per year. This trend adjustment accounts for the difference in the average annual decline over 1978-95 between the price indexes for private fixed investment in computers and final sales of computers.

### Software Sector

For 1995-2011, $p_{SW}$ is an implicit price deflator for final sales of software excluding own-account software produced by the government. Using NIPA data, we calculate this deflator as the ratio of current-dollar final sales excluding

7 We compute the rate of change in each relative price as the per cent change from the prior year's price ratio, not as a log difference. Although growth accounting studies typically use the log difference approximation to calculate rates of change, this approximation is inaccurate for per cent changes as large as those observed for the relative prices of computers and semiconductors.

government own-account software (the series $p_{SW}Y_{SW}$ described above) to a chain aggregate of real software outlays with the same coverage. The data for this calculation come from the supplemental NIPA tables posted at http://www.bea.gov/national/info_comm_tech.htm under the headings "GDP and Final Sales of Software" and "Software Investment and Prices, by Type". We extrapolate the 1995 level of the price deflator back in time and the 2011 level forward to 2012 with the annual per cent change in the NIPA price index for private fixed investment in software (NIPA table 1.5.4, line 33). We did not use a trend adjustment because the price series for software investment fell at a similar rate on average over 1995-2011 as the price deflator for final sales of software.

### Communication Equipment Sector

For 1974-2011, we measure $p_M$ with a price index for domestic output of communication equipment constructed using the method described in Byrne and Corrado (2007). Because this index is not yet available for 2012, we assume the per cent change in 2012 was the same as in 2011.

### Other Final-Output Sector

$p_O$ is measured as an implicit deflator that equals the ratio of current-dollar output for this sector (the series $p_OY_O$ defined above) to a chain aggregate of the sector's real output ($Y_O$). We construct $Y_O$ by starting with our series for real non-farm business output ($Y$) and then "chain stripping-out" all other components of $Y$ (that is, real output of computers, software, and communication equipment, along with real exports and imports of semiconductors). To construct the series for real exports and imports of semiconductors needed for the chain strip-out, we assumed that the price of both exports and imports of semiconductors equals the semiconductor price series described in the next paragraph.

### Semiconductor Sector

For 1977-2012, the data source for $p_S$ is the internal Federal Reserve price index for integrated circuits (NAICS product class 3344131 back to 1992, linked to the analogous index for SIC code 36741 for 1977-92). For the years before 1977, we extrapolate back using the price index for memory chips in Grimm (1998). Because Grimm's index covers a narrower set of chips than the Federal Reserve index, we level-adjust the annual per cent changes in Grimm's index by the ratio of the per cent change in the Federal Reserve index to that in Grimm's index between 1977 and 1978, the earliest overlap period.

## Semiconductors as a Share of Current-Dollar Input Costs ($\beta_C^S$, $\beta_{SW}^S$, $\beta_M^S$, $\beta_O^S$)

### Computer sector

For 1997-2011, we estimate $\beta_C^S$ with proprietary data from iSuppli Corp. on the annual semiconductor cost share of seven different types of computing equipment. We aggregate the product-specific cost shares with domestic shipments weights that vary from year to year. For 2012, we use the share estimated for 2011. For 1990-96, we extrapolate back the 1997 share using the annual per cent changes in the estimated worldwide semiconductor share in computing equipment; we estimate these shares from a variety of proprietary data sources. Finally, for years before 1990, we set the cost share to be a shipment-weighted average of the cost shares for personal computers and all other computing equipment; in this calculation, we use the semiconductor cost shares from 1997, the earliest year for which we have the iSuppli data.

### Software Sector

We set $\beta^S_{SW}$ to zero because semiconductors are not a direct input to software production. (The software industry uses computers and communication equipment that contain semiconductors, but it does not directly use semiconductors.)

### Communication Equipment Sector

For 1997-2011, we estimate $\beta^S_M$ with proprietary data from iSuppli Corp. on the annual semiconductor cost share of 14 different types of communication equipment. We aggregate the product-specific cost shares with domestic shipments weights that vary from year to year. For 2012, we use the share estimated for 2011. For 1990-96, we extrapolate back the 1997 share using the annual per cent changes in the estimated worldwide semiconductor share in communication equipment; we estimate these shares from a variety of proprietary data sources. Finally, for years before 1990, we extrapolate back the 1990 share using the annual per cent changes in the share constructed in Oliner and Sichel (2002) using data from the Semiconductor Industry Association. See the data appendix in Oliner and Sichel (2002) for details.

### Other Final-Output Sector

To estimate $\beta^S_O$, note that equation A22 in Oliner and Sichel (2002) shows that:

$$\mu_S = \sum_{i=1}^{4} \mu_i \beta^S_i (1+\theta)'$$

which can be written with explicit sectoral notation as

$$\mu_S = [\mu_C\beta^S_C + \mu_{SW}\beta^S_{SW} + \mu_M\beta^S_M + \mu_O\beta^S_O](1+\theta).$$

Solving this equation for $\beta^S_O$ yields

$$\beta^S_O = \frac{\mu_S - (1+\theta)[\mu_C\beta^S_C + \mu_{SW}\beta^S_{SW} + \mu_M\beta^S_M]}{\mu_O(1+\theta)}.$$

The data sources for all series on the right-hand side of this expression have been discussed above.