A sensitivity analysis of capital and MFP measurement to asset depreciation patterns and initial capital stock estimates

Pierre-Alain PIONNIER, María Belén ZINNI and Kéa BARET[1]

OECD Statistics and Data Directorate

PRELIMINARY DRAFT – PLEASE DO NOT FURTHER DISSEMINATE

Abstract: This paper discusses the sensitivity of capital and MFP measurement to asset depreciation patterns and initial capital stock estimates. Applying the same depreciation rates in the US as in other G7 countries would significantly reduce the US net investment rates and net capital stocks, by up to one third. Through non-market output, GDP would also be revised upwards, by up to 0.5%. By contrast, the growth rates of capital stocks, capital services and MFP would be largely unaffected. Regarding the estimation of initial capital stocks, usual methods involve stationarity assumptions on investment growth rates or capital-stock-to-output ratios. The first method can be particularly misleading for capital and MFP measurement, mainly because it fails to account for trends and fluctuations in real-estate investment. Relying on cross-country averages of capital-stock-to-output ratios to estimate initial capital stocks works well for the US but given the wide dispersion in such ratios across countries, this result may not be universally true.

Keywords: National accounts, Asset depreciation, Capital stocks, Capital services, Multifactor Productivity (MFP)

JEL classification: E01, E22, E23, O47

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Table of contents

FIGURES

TABLES

1. Introduction

1. Capital measurement plays a fundamental role in national accounts, both to assess the economic wealth and the state of infrastructure in a given country, and to better understand the sources of economic and productivity growth. Nevertheless, measuring capital is a challenging exercise, since capital stocks are typically non-observed and need to be estimated by making assumptions on initial capital stocks and cumulating past investment flows while accounting for the depreciation and the retirement of assets, a statistical process known as the Perpetual Inventory Method (PIM).
2. Statistical agencies in different countries tend to use very different assumptions regarding the depreciation and retirement of assets. While such differences may be justified by country-specific factors (OECD, 2009), they may also simply reflect differences in assumptions as depreciation and retirement patterns tend to be based on thin empirical evidence or old research (Bennett *et al.*, 2020).
3. Unexplained differences in depreciation and retirement patterns across countries may harm the cross-country comparability of capital stocks and macroeconomic indicators that rely on consumption of fixed capital (CFC). This is obviously the case of economic aggregates that are measured net of depreciation, such as net investment (the difference between gross investment and CFC) and net domestic product (the difference between GDP and CFC). Since the CFC also enters the calculation of output and value added of non-market activities, uncertainty around CFC estimates also potentially affect prominent gross indicators such as GDP.
4. Another practical issue that statistical agencies face when estimating capital stocks and CFC is the estimation of initial capital stocks at a given date in the past in order to initialise the PIM. This issue is particularly relevant when only short time series of investment are available.
5. This paper analyses the impact of different depreciation and retirement patterns and assumptions to estimate initial capital stocks on capital and multifactor productivity (MFP) measurement. It can be seen as an extension of a previous sensitivity analysis by Inklaar (2010), who focused on the sensitivity of capital services measures to the type of assets taken into account and to the measurement of capital user costs. While he did not analyse the effect of changing depreciation/retirement patterns or initial capital stocks, Inklaar (2010) acknowledged that they could play a significant role. The present paper extends his work along these two dimensions and discusses the sensitivity not only of capital services, but also of net capital stocks, CFC and MFP. By considering France, Germany, Italy and the UK in addition to Canada and the US, and assessing the reliability of different methods to estimate initial capital stocks, the present paper also extends a recent sensitivity analysis by Giandrea *et al.* (2021) focusing on depreciation rates in Canada and the US.
6. As Inklaar (2010), we use the national accounts produced by the US Bureau of Economic Analysis (BEA) as a laboratory to analyse the sensitivity of capital and MFP measurement to a range of technical assumptions, along with information on how Canada, France, Germany, Italy and the United Kingdom implement the PIM. Indeed, the BEA produces among the longest and most detailed investment time series in OECD countries, hence allowing to apply the assumptions adopted by other countries and test their impact on US capital and MFP measurement.
7. The rest of this paper is organised as follows. Section 2 discusses the replication of the PIM implemented by the BEA in order to produce benchmark estimates for our sensitivity analysis. Section 3 describes a synthetic way to compare combined asset depreciation and retirement patterns across countries, and the sensitivity of capital and MFP measurement

to such patterns. Section 4 discusses two leading methods to estimate initial capital stocks, relying on stationarity assumptions on either investment growth or capital-stock-to-output ratios, and assesses their impact on capital and MFP measurement. Section 5 concludes.

2. Replication of the Perpetual Inventory Method used by the BEA

2.1. US private sector

8. In order to build our benchmark estimates of net capital stocks for the sensitivity analysis, we first replicate the PIM implemented by the BEA.[2] We rely on annual investment (i.e. Gross Fixed Capital Formation, or GFCF) time series compiled by the BEA for the US private sector,[3] broken down into 86 residential and non-residential assets and 63 economic activities over the period 1901-2019.[4] These series are among the longest and most detailed publicly available GFCF series across OECD countries, which allows us to test different scenarios for the estimation of capital and MFP.

9. For each asset and industry, we compute *benchmark* net capital stocks and CFC using the cohort geometric depreciation rates[5] and the PIM applied by the BEA.[6] The BEA estimates the net capital stock of a given asset i at the end of period t as follows:[7]

$$K_{at} = K_{at-1} * (1 - \delta_a) + I_{at} * (1 - \delta_a/2)$$

where:

K_{at} is the net capital stock of asset type a at the end of period t;

δ_a is the geometric cohort depreciation rate of asset type a (see Section 3.1);[8]

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[2] See BEA Fixed Asset Accounts: https://apps.bea.gov/national/FA2004/Details/Index.htm, extracted in October 2020.

[3] The US private sector is defined as industries 11 to 81 in the NAICS 2017 classification, and thus excludes federal, state and local government activities.

[4] We exclude autos, computer and peripheral equipment, and nuclear fuel because the BEA applies a non-geometric combined retirement/depreciation profile for these assets (BEA, 2003). In 2019, these assets accounted for 2.1% of total GFCF and 0.56% of the net capital stock of the US private sector.

[5] See https://apps.bea.gov/national/pdf/BEA_depreciation_rates.pdf.

[6] In the United States, two different statistical agencies produce estimates of capital stocks. The BEA estimates net *wealth* capital stocks, and hence the national balance sheets included in the US national accounts, using geometric cohort depreciation rates. The Bureau of Labor Statistics (BLS) estimates *productive* capital stocks for the business sector assuming a hyperbolic age-efficiency profile. These productive capital stocks are then used in the estimation of capital services and multifactor productivity. The differences between productive and wealth capital are explained in detail in OECD (2009).

[7] Although the industry index is omitted, the formula applies to each asset and each industry. Depreciation rates for a given asset may vary across industries.

[8] For very few assets, the BEA depreciation rates changed at some point (see https://apps.bea.gov/national/pdf/BEA_depreciation_rates.pdf). Nevertheless, we use the most recent value of BEA depreciation rates for the entire period of analysis.

I_{at} is the volume of GFCF in asset type a during period t.[9]

10. All variables above are volumes and expressed in constant prices of a base period. The last term on the right-hand side implies that investment happens at mid-year, or that it is evenly spread out over the year. We then derive a volume measure of consumption of fixed capital (CFC) associated to asset a in period t as:

$$CFC_{at} = K_{at-1} - K_{at} + I_{at} = K_{at-1}\delta_a + I_{at}\delta_a/2$$

We finally construct measures of net capital stock and CFC in current prices by multiplying the volume measures with the asset price index between the base period and the current period.

11. Table 2.1 compares the official net capital stocks estimated by the BEA with the benchmark estimates resulting from our replication of the US PIM. Both estimates are very close to each other. In the subsequent sections, we will use these benchmark estimates as a basis to analyse the impact on capital and MFP measurement of changing cohort depreciation rates and using different approaches to estimate initial capital stocks.

Table 2.1. Replication of the BEA Perpetual Inventory Method: US private sector

Net capital stock to GDP ratios, current prices, 2019

Assets	BEA official estimates	OECD benchmark estimates
Dwellings	1.08	1.11
Other buildings and structures	0.73	0.72
Transport equipment	0.07	0.07
Other machinery and equipment	0.22	0.22
IT equipment and IPP assets excluding R&D	0.09	0.09
R&D	0.10	0.10
TOTAL	**2.29**	**2.31**

Note: Autos, computer and peripheral equipment, and nuclear fuel are excluded from this comparison.
Source: BEA (Fixed Assets Accounts, October 2020), Authors' calculations.

[9] According to Giandrea *et al.* (2021), the BEA also considers in this formula other changes in the volume of the assets. However, in the absence of specific information on other changes in volume, we do not consider them for the estimation of benchmark net capital stocks, which does not impair the accuracy of the replication of official US capital stocks (Table 2.1).

2.2. US government sector

12. In order to assess the impact of changing cohort depreciation rates on non-market CFC and, in turn, non-market output and GDP, we also replicate the PIM used by the BEA for the US government sector. The GFCF series released by the BEA for this sector are much more aggregated than for the private sector. In particular, the available breakdown by asset does not allow matching government GFCF with depreciation rates as accurately as for the private sector. While the BEA kindly provided some unpublished information for this study, a number of depreciation rates used by the BEA had to be averaged across detailed asset types in order to match the available level of detail of GFCF. Nevertheless, the available information allows reproducing the CFC estimates of the BEA quite accurately for broad categories of assets (Table 2.2).

Table 2.2. Replication of the BEA Perpetual Inventory Method: US government sector

Consumption of fixed capital, USD billions, current prices, 2019

Assets	BEA official estimates	OECD benchmark estimates
Dwellings	6.4	8.6
Other buildings and structures	234.7	239.7
Machinery and equipment	133.4	128.6
IT equipment (software)	55.6	55.2
R&D	152.0	154.3
TOTAL	**582.1**	**586.4**

Source: BEA (Fixed Assets Accounts, August 2022), Authors' calculations.

3. Impact of changing asset depreciation and retirement patterns on capital and MFP measurement

3.1. Comparison of combined asset depreciation and retirement patterns across countries

13. Net capital stocks result from successive vintages of investment in productive assets and the combined effect of their depreciation and retirement over time.[10] The depreciation pattern describes how the value of a single asset declines over time as the asset ages. The retirement pattern takes into account that not all assets purchased at the same time (*i.e.* belonging to the same cohort) are removed from the capital stock at the same age. Part of the randomness of the retirement process is captured by the average service life of assets, but non-degenerated probability distributions around average service lives are usually assumed by statistical agencies.

14. Hulten and Wykoff (1981a) showed how the combination of depreciation and retirement gives rise to convex age-price profiles for cohorts of assets, which can usually be approximated by geometric patterns.[11] The main advantage of geometric patterns is that they are characterised by a single and constant parameter (the geometric cohort depreciation rate). This simplicity led several statistical agencies such as the BEA and Statistics Canada to rely on geometric patterns to estimate CFC for their national accounts (Fraumeni 1997, Baldwin *et al.* 2015).

15. However, not all countries rely on geometric patterns combining depreciation and retirement to estimate net capital stocks. For example, France relies on linear depreciation profiles for single assets and combines them with log-normal retirement patterns. Alternatively, the Netherlands and the United Kingdom (UK) derive the combined depreciation and retirement pattern from a hyperbolic age-efficiency profile combined with a Weibull (for the Netherlands) or a normal (for the UK) retirement distribution (Office for National Statistics, 2019; Statistics Netherlands, 2019).[12]

16. In this analysis, we do not rely on Declining Balance Rates (DBRs) to plug the depreciation and retirement patterns of other countries into the PIM used by the BEA. DBRs were first introduced by Hulten and Wykoff (1981b) to provide a simple inverse proportional relationship between geometric cohort depreciation rates (δ) and average asset services lives (T):

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[10] To avoid any ambiguity, we reserve the term depreciation (without any further qualification) to describe how the value (i.e. the market price) of a single productive asset declines over time due to the shortening of its remaining service life as time goes by. Depreciation is reflected in the age-price profile of a single asset. Nevertheless, the depreciation process does not take into account that assets belonging to the same cohort (i.e. purchased at the same time) may be retired from the productive capital stock at a different age. *Cohort* depreciation corresponds to the combined effect of (single-asset) depreciation and retirement and determines how the value of a stock of assets declines over time if depreciation and retirements are not compensated by investment (GFCF) or other positive changes in volume.

[11] Hulten (2008) later summarised this as follows: “The more assets are grouped together, the more the group experience tends to be a geometric-like pattern, regardless of the actual patterns of the individual assets in the group. If the individual patterns are themselves nearly geometric, the group effect is reinforced, but this is not a necessary condition.”

[12] The United Kingdom’s Office for National Statistics applies these assumptions to all assets except research and development, for which they combine a Weibull retirement distribution with a geometric age-efficiency function.

$$\delta \equiv \frac{DBR}{T}$$

Nevertheless, DBRs do not have an obvious economic meaning. Moreover, Annex A shows that they are not universal constants as they depend on the shape of the underlying depreciation and retirement functions used by national statistical agencies. Therefore, DBRs are country specific, and estimating geometric depreciation rates for a country based on its asset service lives and the DBRs of another country would be misleading. This is why, in this paper, we do not mix the average asset service lives of other countries with the US DBRs.

17. In order to introduce the depreciation and retirement patterns of other countries into the PIM used by the BEA, we rather follow Cabannes *et al.* (2013) who suggest estimating geometric approximations of the combined depreciation and retirement patterns and provide such approximations for France. This method consists in combining depreciation and retirement patterns analytically and estimating the geometric function that provides the best fit to the combined pattern in a least square sense. Annex B discusses how these geometric approximations are obtained for France, Germany, Italy and the UK.

18. Table 3-1 provides average ratios of Canadian, French, German, Italian and UK cohort depreciation rates to the corresponding US parameters for aggregate asset categories. In most cases, the cohort depreciation rates used in Canada, France, Germany and the UK are higher or much higher than those used in the US. This is especially true for dwellings and non-residential buildings, as well as other (civil engineering) structures in Canada.[13] The Italian depreciation rates are closer to the US ones.

Table 3-1. Ratios of cohort depreciation rates in Canada, France, Germany, Italy and the UK, relative to the US

Asset label	Canada	France	Germany	Italy	United Kingdom
Dwellings	2.0	5.0	2.4	1.6	2.5
Buildings other than dwellings	3.0	2.8	2.1	1.4	3.1
Other structures	2.7	1.1	1.4	1.6	1.7
Transport equipment	1.5	1.5	1.4	1.1	1.3
Computer hardware	1.3	1.2	0.8	1.4	1.2
Telecom. equipment	2.1	1.4	1.6	2.8	1.2
Other mach. & equipment	1.8	1.1	1.5	1.4	1.1
R&D	1.8	1.0	1.0	1.3	1.8
Software & databases	1.0	0.7	0.9	0.9	0.7
Originals	6.3	2.6	2.7	1.4	1.5

Note: Ratios higher than 1.5 are highlighted in orange, and ratios higher than 2.0 are highlighted in red.
Source: The geometric cohort depreciation rates for Canada and the US are sourced from Statistics Canada and Giandrea *et al.* (2021). Geometric approximations are used for France, Germany, Italy and the UK (see Cabannes et al., 2013, and Annex B). Ratios are first calculated for detailed assets and then aggregated to the upper level of the asset classification using 2019 capital stock shares in the US private sector as weights.

[13] Our results for Canada and the US are in line with Giandrea *et al.* (2021). In the present paper, we extend the comparison to France, Italy and the UK.

3.2. Sensitivity of CFC and net capital stocks to changes in cohort depreciation rates

3.2.1. US private sector

19. This section analyses the sensitivity of capital measurement to changes in cohort depreciation rates. In order to explore the range of possible depreciation patterns, the geometric cohort depreciation rates used by Canada, France, Germany, Italy and the UK are successively introduced into the US PIM along with the original US GFCF time series to recalculate the CFC, net investment rates and net capital stocks for all assets of the US private sector.[14]

20. Consistently with the evidence provided in Table 3-1, Figure 3.1 shows that the US ratio of CFC to gross value added (GVA) would be significantly higher if the BEA relied on the same cohort depreciation rates as Canada, France, Germany and the UK (15.9%, 15.5%, 15.2% and 15.2% against 14.2%, respectively). It would be only slightly higher if the BEA relied on the same cohort depreciation rates as Italy (14.6% against 14.2%). The main differences with the official US accounts relate to the CFC of residential and non-residential buildings.

21. Accordingly, Figure 3.2 and Figure 3.3 show that the US net investment and net capital stocks would be significantly lower, by up to one third, if it relied on the same cohort depreciation rates as Canada, France, Germany and the UK, and only slightly lower if the BEA relied on the Italian cohort depreciation rates. Here again, differences are mainly related to residential and non-residential buildings.

22. Nevertheless, the impact of switching to other countries' cohort depreciation rates is more limited on the growth rate of the US net capital stock (at constant prices) than on its level (at current prices). Figure 3.4 shows that this impact may be more significant for some subperiods, but on average between 1998 and 2019, the annual growth rate of the US net capital stock only changes from 1.9% to 1.7%-1.8% when using Canadian, French or German cohort depreciation rates, and it is unaffected when using Italian or UK cohort depreciation rates. The subperiod most affected corresponds to the Great Recession and the immediately subsequent years.

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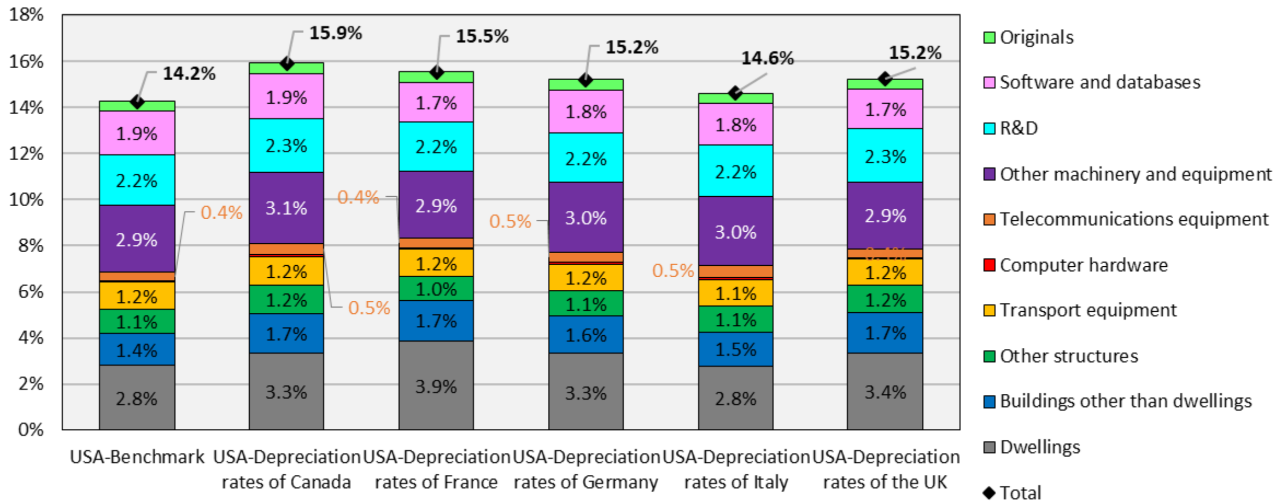
[14] For France, we rely on the geometric approximations provided by Cabannes *et al.* (2013). For Germany, Italy and the UK, we compute the geometric approximations of the combined age-price/retirement profiles used by these countries. The asset classifications used in the five countries are mapped together using information from Cabannes *et al.* (2013), Giandrea *et al.* (2021) and the replies by Statistic Canada, ISTAT and the ONS to the 2019 Eurostat-OECD Questionnaire on the Methodology underlying Capital Stocks (Annex C).

Figure 3.1. Sensitivity of consumption of fixed capital to changes in cohort depreciation rates

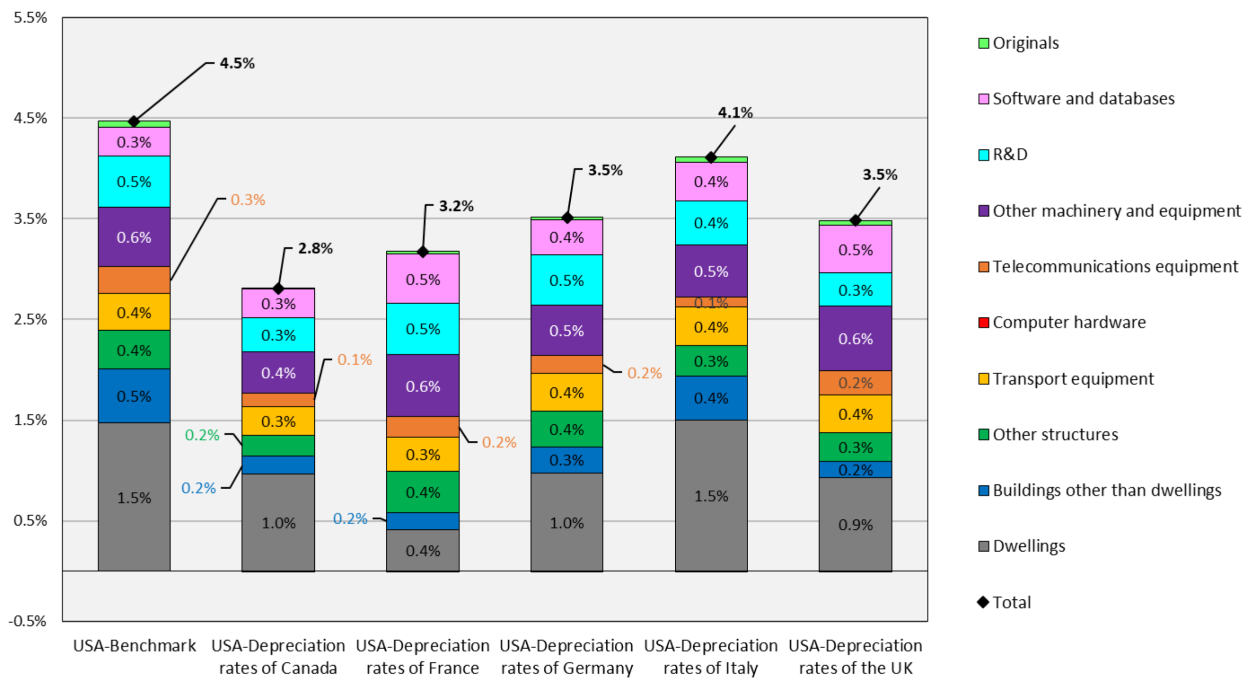
Ratio of consumption of fixed capital to gross value added, US private sector, 2019



Source: Authors' calculations, based on BEA depreciation rates, Cabannes *et al.* (2013), Giandrea *et al.* (2021), information shared by Statistics Canada, DESTATIS (Germany), ISTAT (Italy) and the ONS (United Kingdom).

Figure 3.2. Sensitivity of net investment to changes in cohort depreciation rates

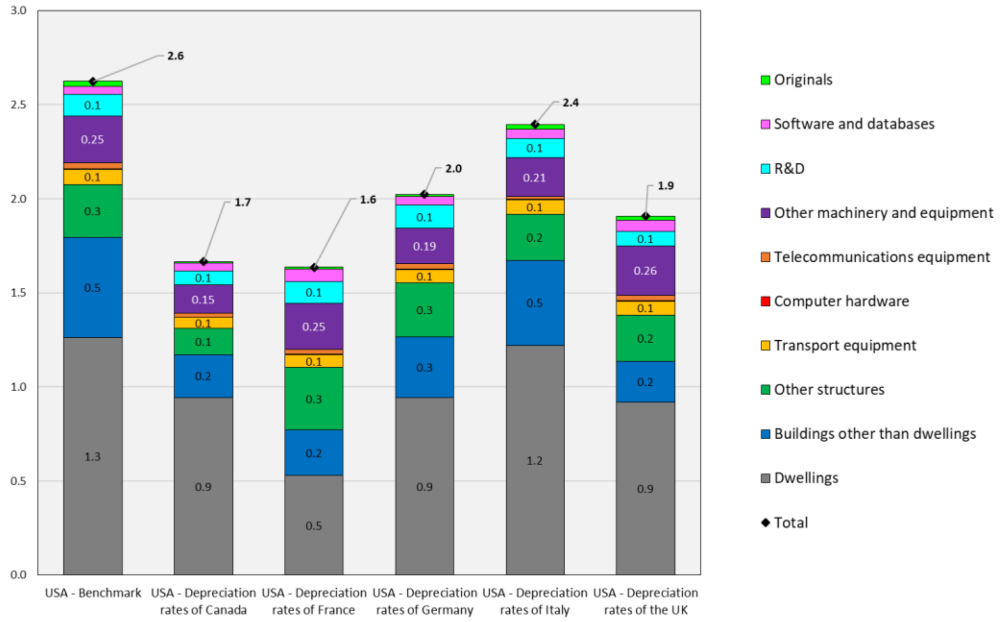
Ratio of net investment to gross value added, US private sector, 2019



Source: Authors' calculations, based on BEA depreciation rates, Cabannes *et al.* (2013), Giandrea *et al.* (2021), information shared by Statistics Canada, DESTATIS (Germany), ISTAT (Italy) and the ONS (United Kingdom).

Figure 3.3. Sensitivity of net capital stock to changes in cohort depreciation rates

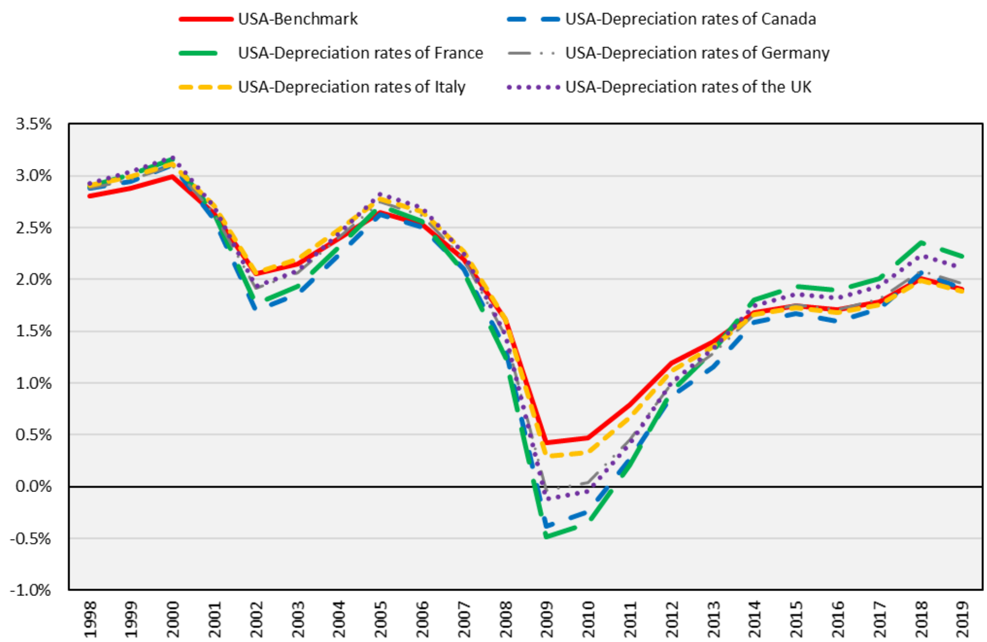
Ratio of net capital stock to gross value added, US private sector, 2019



Source: Authors' calculations, based on BEA depreciation rates, Cabannes *et al.* (2013), Giandrea *et al.* (2021), information shared by Statistics Canada, DESTATIS (Germany), ISTAT (Italy) and the ONS (United Kingdom).

Figure 3.4. Sensitivity of net capital stock growth to changes in cohort depreciation rates

Constant prices, US private sector, 1998-2019



Source: Authors' calculations, based on BEA depreciation rates, Cabannes *et al.* (2013), Giandrea *et al.* (2021), information shared by Statistics Canada, DESTATIS (Germany), ISTAT (Italy) and the ONS (United Kingdom).

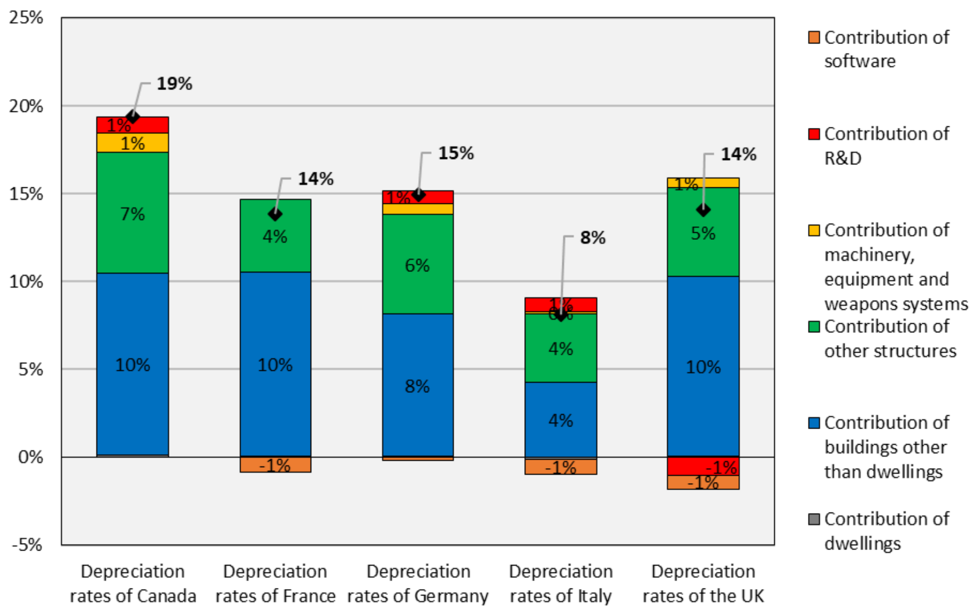
3.2.2. US government sector

23. This section extends the analysis of the previous section to the US government sector. While the lack of detailed GFCF series does not allow assessing how changes in cohort depreciation patterns affect CFC at a detailed asset level,[15] it is possible to assess how they affect overall non-market CFC. Since the gross output of the government sector is calculated as the sum of purchases of intermediate goods and services, compensation of employees and CFC (BEA, 2021), any change to CFC affects the gross output and the value added of the government sector and, in turn, nominal GDP.

24. The CFC of the US government sector in 2019 would increase by up to 19% if the BEA relied on the same cohort depreciation rates as Statistics Canada (Figure 3.5). Accordingly, the US GDP in 2019 would be revised upwards by up to 0.5% (Table 3.2).

Figure 3.5. Sensitivity of consumption of fixed capital to changes in cohort depreciation rates

Percentage increase in CFC and contribution of underlying assets, US government sector, 2019



Note: The CFC of the US government sector would increase by 19% if the BEA relied on the same depreciation rates as Statistics Canada. Buildings other than dwellings would contribute to this increase by 10 percentage points.
Source: Authors' calculations, based on BEA depreciation rates, Cabannes *et al.* (2013), Giandrea *et al.* (2021), information shared by Statistics Canada, DESTATIS (Germany), ISTAT (Italy) and the ONS (United Kingdom).

[15] Detailed GFCF series matching the granularity of depreciation rates used by the BEA would be required for this purpose. Note that, with this information, if would also be possible to assess how changes in depreciation rates affect the stock, average age and remaining service life of infrastructure assets, a large part of which (e.g. roads, schools, hospitals) is being owned by the government sector (Bennett *et al.*, 2020).

Table 3.2. Sensitivity of government sector value added and GDP to changes in cohort depreciation rates

Increase in government sector value added and GDP, 2019

	Depreciation rates of Canada	Depreciation rates of France	Depreciation rates of Germany	Depreciation rates of Italy	Depreciation rates of the UK
Government sector value added	+4.7%	+3.4%	+3.6%	+2.0%	+3.4%
GDP	+0.5%	+0.4%	+0.4%	+0.2%	+0.4%

Source: Authors' calculations, based on BEA depreciation rates, Cabannes *et al.* (2013), Giandrea *et al.* (2021), information shared by Statistics Canada, DESTATIS (Germany), ISTAT (Italy) and the ONS (United Kingdom).

3.3. Selecting a rate of return for the measurement of capital services

25. We now revert back to the US private sector for the analysis of capital services. Indeed, the estimation of capital user costs is inconsistent with the fact that non-market output is defined using a sum of costs approach excluding any return to capital (OECD, 2009).

26. There are two main approaches to calculate the rate of return (rr_{jt}) in the user cost formula for the measurement of capital services:

$$u_{ajt} = p_{ajt-1}\left(d_{aj} - \Delta p_{ajt} + d_{aj}\Delta p_{ajt} + rr_{jt}\right)$$

where:

u_{ajt} is the user cost of capital of asset type a in the detailed industry j in period t;

d_{aj} is the depreciation rate of asset type a in the detailed industry j;

p_{ajt} is the price of asset type a in the detailed industry j in period t; and

Δp_{ajt} is the 5-year centred moving average of changes in the price of asset type a in the detailed industry j in period t.

27. The first approach to calculate the rate of return consists in estimating it endogenously, in such a way that the value of capital services exactly exhausts the gross operating surplus (GOS) and the capital component of gross mixed income (Jorgenson, 1963). The second approach consists in estimating an exogenous rate of return from financial market information.

28. The estimation of an endogenous rate of return has a number of advantages (in particular, it relies on available national accounts data only and leaves no unexplained residual income) but there are also disadvantages. The endogenous approach is only consistent with a fully competitive economy and production processes under constant returns to scale (OECD, 2009). Moreover, this approach assumes that all assets contributing to the production process are taken into account, which may not be very plausible in light of the increasing importance of certain unmeasured intangibles and natural assets that enter the production process.

29. In spite of some of the caveats that come with endogenous rates of return, we test this approach to update Inklaar's (2010) findings regarding the sensitivity of capital services to the choice of the rate of return.

In addition, we estimate two exogenous rates of return:

- a weighted average cost of capital (WACC) taking into account the cost of debt and equity financing. We estimate this rate using the same method and data sources as Inklaar (2010) and extend his time series from 2005 to 2019.[16]
- an exogenous nominal rate of return (ENRR) obtained by combining a constant real long-term interest rate and a smoothed inflation rate. In practice, we estimate the real long-term interest rate r^* as the long-term average of the AAA and BAA corporate bonds yields for the US produced by Moody's, adjusted for CPI inflation. This leads to a value of 4.2% for r^*. Denoting the 5-year centred moving average of the CPI inflation rate as ρ_t, the ENRR is finally estimated as:

$$ENRR_t = (1 + r^*)(1 + \rho_t) - 1$$

A similar method is advocated by Diewert (2001) and Schreyer (2010).

30. As mentioned above, the endogenous approach assumes that the value of capital services exhausts the sum of GOS and the capital component of mixed income, which happens in a fully competitive economy under constant returns to scale. We estimate an endogenous rate of return for each aggregate industry by equating the value of capital services to a measure of the industry's capital income, measured residually as all income produced in the industry that is not accruing to labour. In practice, we derive this residual income ($KInc$) as the sum of GOS, the capital component of mixed-income, and taxes less subsidies on production (see Annex D for details). Equating the industry's residual income with the total value of capital services leads to:

$$KInc_{it} = \sum_{a=1}^{A} u_{ait} K_{ait} = \sum_{j=1}^{J_i} \sum_{a=1}^{A} u_{ajt} K_{ajt}$$

where

$KInc_{it}$ is the residual income in industry i at date t;

u_{ait} is the user cost of capital of asset type a in industry i at date t;

K_{ait} is the net capital stock of asset a in industry i at date t;[17]

A is the number of assets;

J_i is the number of sub-industries within industry i.

31. In the user cost formula, we take into account that asset depreciation rates and the revaluation of asset prices can vary across sub-industries (*j*), but we estimate endogenous rates of return for only 13 aggregate industries (*i*) belonging to the US private sector.

[16] Following Inklaar (2010), we calculate the weighted average cost of capital as follows: $WACC_t = s_t^E C_t^E + (1 - s_t^E)(1 - \tau_t) C_t^D$. s_t^E is the share of equity in total funding, constructed as the ratio of the stock of equity and investment fund shares in the total liabilities of US non-financial corporations, sourced from the OECD National Accounts database (Table 720). C_t^E, the cost of equity, is computed as the sum of the earning and dividend yields of the S&P500. C_t^D is the cost of debt, estimated as Moody's BAA corporate bond yield for the US. It is multiplied by one minus τ_t, the marginal corporate tax rate, in order to reflect the tax-deductibility of interest payments. τ_t is proxied by the Statutory Corporate Tax Rate sourced from the Tax Foundation.

[17] The volume of capital services of a given asset in a given industry is assumed to be proportional to the volume of its net capital stock. Time-variation in the factor of proportionality relating the two measures (e.g. due to changes in the capacity utilisation rate of capital) is neglected here.

Indeed, data quality is probably lower at the level of sub-industries, and estimating endogenous rates of return at a higher level limits the number of extreme values likely reflecting measurement errors (Annex D). Introducing the user cost formula in the previous expression leads to:

$$KInc_{it} = \sum_{j=1}^{J_i} \sum_{a=1}^{A} p_{ajt-1}(d_{aj} - \Delta p_{ajt} + d_{aj}\Delta p_{ajt} + irr_{it})K_{ajt}$$

The endogenous, or internal, rate of return (irr_{it}) can then be calculated as follows:

$$irr_{it} = \frac{KInc_{it} - \sum_{j=1}^{J_i} \sum_{a=1}^{A} p_{ajt-1}(d_{aj} - \Delta p_{ajt} + d_{aj}\Delta p_{ajt})K_{ajt}}{\sum_{j=1}^{J_i} \sum_{a=1}^{A} p_{ajt-1}K_{ajt}}$$

32. Figure 3.6 compares the WACC, the ENRR and the average internal rate of return across industries over the period 1998-2019. While the WACC and the ENRR are close to each other, the average internal rate of return is higher and shows larger fluctuations. Increases in the internal rate of return may partly capture increases in overall mark-ups (Calligaris *et al.*, 2018; Basu, 2019; Schreyer and Zinni, 2020).

33. Table 3-3 shows the sensitivity of capital services growth in the US private sector over 1998-2019, based on the three different rates of return.[18] The endogenous (or internal) rate of return results in significantly lower growth rates of capital services over 1998-2019 and all sub-periods. However, using one exogenous rate of return or the other leads to very similar growth rates of capital services. The fact that using an endogenous rate of return leads to significantly lower capital services growth in the US private sector after the mid-1990s was also noticed by Inklaar (2010), but his estimates stopped in 2005. Here, we show that the same applies over the following 15 years.

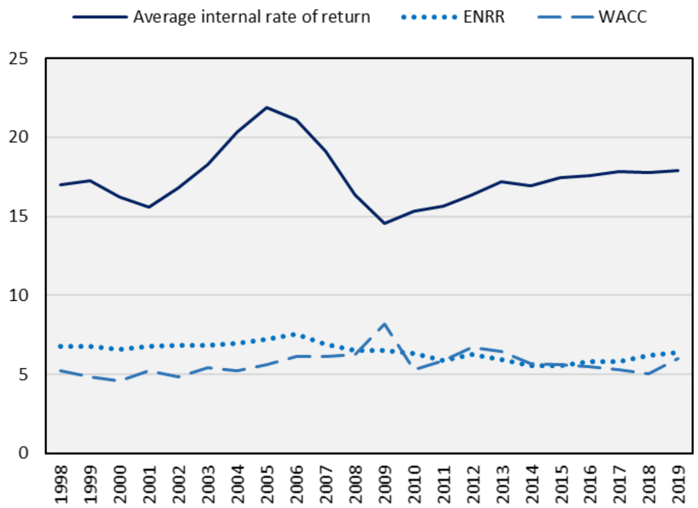
34. Similarly, Table 3-4 shows the sensitivity of MFP growth in the US private sector over 1998-2019, based on the three different rates of return. Here again, using an endogenous rate of return leads to lower MFP growth, and the two exogenous rates of return lead to similar results. Perhaps surprisingly, lower capital services growth with an endogenous rate of return does not translate into higher, but lower, MFP growth. Indeed, a higher endogenous rate of return increases the weight received by capital services in the growth accounts, thus overcompensating their lower growth and reducing growth in MFP.

35. Given all the caveats around endogenous rates of return, we will use the ENRR in the rest of the paper, when assessing the sensitivity of capital services and MFP to changes in cohort depreciation patterns and initial capital stocks.

[18] The calculation of capital services follows the same methodology as in the OECD Productivity Database. See *OECD Productivity Statistics - Methodological Notes* https://www.oecd.org/sdd/productivity-stats/OECD-Productivity-Statistics-Methodological-note.pdf.

Figure 3.6. Endogenous and exogenous rates of return

Percentage points, US private sector, 1998-2019



Note: The average internal rate of return corresponds to the weighted average of the internal rates of return estimated for 13 aggregate industries in the US private sector, where industry shares in gross value added are used as weights.
Source: Authors' calculations.

Table 3-3. Sensitivity of capital services growth to the use of different rates of return

Average annual percentage changes, US private sector, 1998-2019

Period	Rates of return		
	ENRR	WACC	Internal rate of return
1998-2019	**2.8**	**2.9**	**2.4**
1998-2006	3.6	3.9	3.2
2006-2012	1.8	1.9	1.5
2012-2019	2.7	2.8	2.1

Source: Authors' calculations.

Table 3-4. Sensitivity of MFP growth to the use of different rates of return

Average annual percentage changes, US private sector, 1998-2019

Period	Rates of return		
	ENRR	WACC	Internal rate of return
1998-2019	**0.6**	**0.6**	**0.5**
1998-2006	0.7	0.8	0.4
2006-2012	1.5	1.5	1.4
2012-2019	-0.3	-0.3	-0.2

Source: Authors' calculations.

3.4. Sensitivity of capital services and MFP growth to changes in cohort depreciation rates

36. Similarly to what is observed for the evolution of net capital stocks, the average evolution of capital services between 1997 and 2019 is not significantly affected by changes in cohort depreciation rates. As shown in Table 3-5, the average growth rate of capital services is 2.9% per year with the US depreciation rates, and 2.7%, 2.8%, 2.9%, 3.0% and 2.9% with the depreciation rates of Canada, France, Germany, Italy and the UK, respectively.

37. The impact of changing cohort depreciation rates is more significant during the Great Recession and the immediately following years. Over 2006-2012, the average growth rate of capital services is 1.8% per year with US and Italian depreciation rates, 1.6% with German depreciation rates, 1.5% with Canadian and UK depreciation rates, and it is further reduced to 1.2% with French depreciation rates (Figure 3.7). Dwellings and non-residential buildings are the main contributors to these differences, as expected given that cross-country differences in depreciation patterns are larger for these assets.

38. An increase in the depreciation rate of a given asset impacts the growth rate of its capital services via two different channels: it increases the user cost of this asset and modifies the growth rate of its net capital stock. While the sign of the second effect is ambiguous in general, it can be shown that a depreciation rate increase will have a more negative impact on capital accumulation in a period of low investment.[19] This is why the impact of switching to the higher depreciation rates of Canada, France, Germany and the UK is more visible in the low investment years following the Great Recession.

Table 3-5. Sensitivity of capital services growth to changes in cohort depreciation rates

Average annual percentage changes, US private sector, 1997-2019

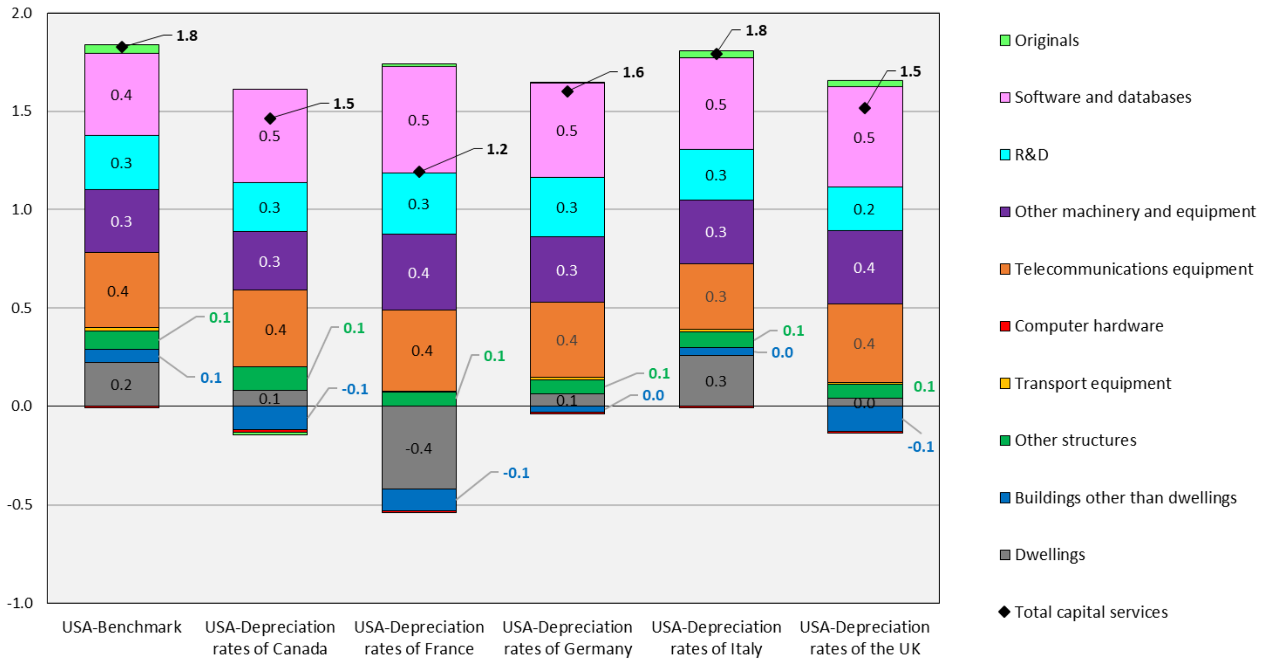
	USA - Benchmark	USA – Depreciation rates of Canada	USA – Depreciation rates of France	USA – Depreciation rates of Germany	USA – Depreciation rates of Italy	USA – Depreciation rates of the UK
1997-2019	**2.9**	**2.7**	**2.8**	**2.9**	**3.0**	**2.9**
1997-2006	3.7	3.6	4.0	3.9	3.8	3.8
2006-2012	1.8	1.5	1.2	1.6	1.8	1.5
2012-2019	2.7	2.8	2.7	2.8	2.8	2.8

Source: Authors' calculations.

[19] Rewriting the generic capital accumulation equation $K_t = I_t + (1-\delta)K_{t-1}$ in terms of capital growth rate $\frac{\Delta K_t}{K_{t-1}} = \frac{I_t}{K_{t-1}} - \delta$ clearly shows that an increase in δ has an ambiguous effect on $\frac{\Delta K_t}{K_{t-1}}$ because it increases $\frac{I_t}{K_{t-1}}$ (through a decline in K_{t-1}). This latter effect becomes negligible in a period of low investment. In this case, an increase in δ unambiguously reduces $\frac{\Delta K_t}{K_{t-1}}$.

Figure 3.7. Sensitivity of capital services growth to changes in cohort depreciation rates

Average annual percentage changes, US private sector, 2006-2012



Source: Authors' calculations.

39. As shown by Table 3-6, and consistently with the results obtained for capital services, US MFP growth rates are only marginally affected by changes in depreciation patterns. Over 2006-2012, they are slightly higher with the depreciation rates of Canada, France and the UK.

Table 3-6. Sensitivity of MFP growth to changes in cohort depreciation rates

Average annual percentage changes, US private sector, 1998-2019

	USA - Benchmark	USA – Depreciation rates of Canada	USA – Depreciation rates of France	USA – Depreciation rates of Germany	USA – Depreciation rates of Italy	USA – Depreciation rates of the UK
1998-2019	**0.6**	**0.7**	**0.7**	**0.6**	**0.6**	**0.6**
1998-2006	0.7	0.8	0.6	0.7	0.7	0.7
2006-2012	1.5	1.7	1.8	1.6	1.6	1.7
2012-2019	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3

Source: Authors' calculations.

4. Impact of initial capital stock estimates on capital and MFP measurement

4.1. Options for estimating initial capital stocks in the absence of long investment time series

40. In addition to specific assumptions on the depreciation and the retirement of assets, the estimation of capital stocks using the PIM requires investment time series and initial capital stocks to initiate the estimation process. Initial capital stocks matter all the more if the available investment time series are shorter and the corresponding assets have longer service lives.

41. Unlike the US, a number of European countries, mostly in Central and Eastern Europe, only dispose of investment series going back to the mid-1990s. In such cases, there are two main avenues for the estimation of initial capital stocks. The first possibility is to estimate initial capital stocks from national sources such as population censuses (giving information on the number of dwellings owned by households) and company accounts (giving information on the fixed assets owned by firms). Note that company accounts usually value assets at their book value (i.e. at their historical purchase price) and need to be supplemented with specific assumptions on the depreciation and information on the date of purchase of all assets in order to be able to value them at the price of a given year using national accounts' deflators. The second possibility is to rely on stationarity assumptions to backcast investment time series, or estimate initial capital stocks directly. In the absence of long investment time series, both avenues to estimate initial capital stocks require making strong assumptions. Since the use of national sources to estimate initial capital stocks is country-specific and the lessons one may draw for the US would be difficult to generalise to other countries, we will focus on the second possibility.

42. When the available investment time series are shorter than the desired length of the capital stock series plus the maximum service life of the asset, researchers and statistical agencies usually rely on stationarity assumptions to estimate initial capital stocks. These assumptions may concern investment, in which case they are used to backcast investment time series, or capital stock-to-output ratios, in which case initial capital stocks can be derived from the value of output (GDP) at the initial date.

4.1.1. Stationarity assumption on investment growth rates

43. A standard procedure to estimate initial capital stocks is to assume that investment in each asset grows at a constant rate, usually taken equal to the average growth rate observed over the period where data are available (OECD, 2009). In this case, if the average growth rate of investment in asset *i* is equal to θ_i and its geometric depreciation rate is equal to δ_i, the initial capital stock of asset *i* at the end of period *t* can be calculated as follows:

$$K_{i,t} = \sum_{j=0}^{N} (1 - \delta_i)^j I_{i,t-j} = \sum_{j=0}^{N} \left(\frac{1 - \delta_i}{1 + \theta_i}\right)^j I_{i,t}$$

Provided that $\left|\frac{1-\delta_i}{1+\theta_i}\right| < 1$ and letting *N* tend to infinity, the previous formula simplifies to:

$$K_{i,t} = \frac{1 + \theta_i}{\theta_i + \delta_i} I_{i,t}$$

4.1.2. Stationarity assumption on capital stock-to-output ratios

44. Alternatively, it can be assumed that the capital stock-to-output ratio is constant over time. This assumption is based on the Solow (1957) growth model where, on a balanced growth path, capital and output grow at the same rate. Initial capital stocks in the Penn World Tables are estimated in this way (Inklaar and Timmer 2013, Feenstra *et al.* 2015).

4.2. Accuracy of initial capital stock estimates and impact on net capital stocks at later dates

45. In order to assess the accuracy of initial capital stock estimates and their impact on net capital stocks at later dates, we assume that the US investment time series start in 1950, 1980 or 1995, instead of 1901 as in the BEA national accounts.[20] We then apply the above-described stationarity assumptions on investment growth rates and capital stock-to-output ratios for specific assets.

46. In the first case, we estimate average investment growth rates for each aggregate asset and industry[21] over the first 20 years for which investment series are available.[22] We then use these average growth rates to backcast investment series for each underlying asset and industry.

47. In the second case, we use the asset-specific capital stock-to-output ratios calculated by Inklaar and Timmer (2013) as our starting point. They are reported in Table 4-1. These are average capital stock-to-output ratios that they estimated on a sample of 142 countries with

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[20] These cut-off dates are representative of the typical length of publicly available investment time series across OECD countries. While according to the 2019 Eurostat-OECD Questionnaire on the Methodology underlying Capital Stocks, many OECD countries rely on unpublished historical investment series to implement their PIM, this is apparently not the case for Central and Eastern European countries, for which investment time series do not seem to available before 1995.

[21] More precisely, we estimate average investment growth rates for Dwellings, Buildings other than dwellings, Other structures, Transport equipment, Computer hardware, Telecommunication equipment, Other machinery and equipment, R&D, Software and Originals, in each aggregate industry shown in Table D.1 of Annex D.

[22] For example, for the scenario where investment series are assumed to start in 1950, we estimate average investment growth rates over the period 1950-1969 for each aggregate asset/industry.

investment series going back at least to 1970.[23] Output corresponds to GDP and both capital and GDP are measured at current national prices.

Table 4-1. Stationarity assumptions on capital stock-to-output ratios to estimate initial capital stocks

Asset category	Capital stock-to-output ratio (total economy)
Structures (residential and non-residential)	2.2
Transport equipment	0.1
Other machinery and equipment	0.3
All other assets (i.e. IT equipment, Software, and Originals)	0

Note: Inklaar and Timmer (2013) did not cover R&D which, at the time, was considered intermediate consumption (not investment) in the System of National Accounts (SNA).
Source: Inklaar and Timmer (2013, Table 4).

48. For the purpose of this sensitivity analysis focusing on the US private sector, we simply multiply the three capital stock-to-output ratios given by Inklaar and Timmer (2013) by a factor 0.8, corresponding to the ratio between the capital stocks in the US private sector and the US economy as a whole.[24] We then further break down initial capital stocks into assets and industries based on their respective investment shares over the first 20 years where investment series are available. Finally, we use these initial capital stocks as starting points to apply the PIM and estimate net capital stocks at the same level of detail as the BEA (see Section 2).

49. Table 4-2 shows the accuracy of both methods to estimate initial capital stocks by comparing their results with the official capital stocks published by the BEA.[25] As expected, initial capital stocks have a long-lasting influence on future capital stocks for Structures and, to a lesser extent, for Transport equipment and Other machinery and equipment. For example, of the initial capital stocks of structures estimated in 1950, 1980 and 1995, 25%, 52% and 76%, respectively, remain in use in 2005.[26] It is especially for long-lived assets that the accuracy of the methods to estimate initial capital stocks should be assessed.

[23] The reader should note that we do not implement one further adjustment advocated by Inklaar *et al.* (2019) to account for slight increase in cross-country average capital stock-to-output ratios over time. Since the US capital stock-to-output ratios in the BEA accounts do not show any time trend (see Figure 4.3 to Figure 4.5), this adjustment would not improve the accuracy of the initial capital stocks estimates we compute for the US.

[24] We take this ratio from the actual BEA accounts. Nevertheless, this operation does not bias our results in favour of this method because the actual capital-stock-to-output ratio for the US economy as a whole (2.75) is close to the cross-country average (2.6) calculated by Inklaar and Timmer (2013), which is the key reason why this method works well for the US. The multiplication by 0.8 simply allows focusing on the US private sector rather than the US economy as a whole.

[25] The BEA capital stock series start in 1947, or even 1925 for some assets, but these estimates are based on unpublished historical investment time series. Based on publicly available investment series starting in 1901, we cannot recalculate capital stocks for the longest-lived assets (residential buildings) before 1981. Therefore, we rely on the BEA official capital stock series in Table 4-2.

[26] These numbers are implied by the BEA geometric cohort depreciation rates. See the note underlying Table 4-2.

Table 4-2. Accuracy of stationarity assumptions to estimate initial capital stocks

			Stationarity assumptions on investment growth rates		**Stationarity assumptions on capital stock-to-output ratios**	
Starting date of investment series (D)	Asset	Share of initial capital stock remaining in 2005 (%)	Ratio between estimated and official (BEA) capital stocks at initial date (D)	Ratio between estimated and official (BEA) capital stocks in 2005	Ratio between estimated and official (BEA) capital stocks at initial date (D)	Ratio between estimated and official (BEA) capital stocks in 2005
1950	All structures	24.9	2.0	1.0	1.0	1.0
	Of which: Dwellings	20.5	1.5	1.0	1.0	1.0
	Of which: Other buildings and structures	25.0	2.7	1.0	1.0	1.0
	Transport equipment	0.6	1.0	1.0	1.6	1.0
	Other machinery and equipment	0.8	1.1	1.0	1.1	1.0
	IT equipment, Software and Originals	0.1	0.9	1.0	0.0	1.0
	R&D	0.0	0.9	1.0	not estimated	not estimated
	Total		**1.8**	**1.0**	**1.0**	**1.0**
1980	All structures	51.9	1.3	1.1	1.0	0.9
	Of which: Dwellings	41.3	0.7	0.9	0.9	0.9
	Of which: Other buildings and structures	52.0	2.3	1.3	1.0	1.0
	Transport equipment	5.2	1.8	1.1	1.1	1.0
	Other machinery and equipment	6.5	1.0	1.0	0.8	1.0
	IT equipment, Software and Originals	2.3	1.2	1.0	0.0	1.0
	R&D	1.0	1.0	1.0	not estimated	not estimated
	Total		**1.3**	**1.0**	**0.9**	**0.9**
1995	All structures	76.4	26.1	15.8	1.2	1.0
	Of which: Dwellings	64.7	3.8	2.7	1.1	1.0
	Of which: Other buildings and structures	76.4	59.0	37.1	1.2	1.1
	Transport equipment	24.6	1.2	1.0	1.5	1.0
	Other machinery and equipment	28.2	1.1	1.0	1.0	1.0
	IT equipment, Software and Originals	15.2	1.2	1.1	0.0	0.9
	R&D	11.3	1.1	1.0	not estimated	not estimated
	Total		**20.5**	**13.0**	**1.1**	**1.0**

Note: The asset-specific shares of initial capital stock remaining in 2005 are calculated as $(1-\delta_i)^{2005-D}$, where δ_i is the geometric cohort depreciation of asset *i* and *D* the initial starting date of investment series. These shares only depend on geometric cohort depreciation parameters, not on initial capital stocks themselves. In case assets have industry-specific depreciation parameters, or these parameters are set at a low level of the asset classification, an unweighted average of the corresponding shares is reported in Table 4-2. This unweighted average is only reported for quite homogeneous asset categories (e.g. Structures or Transport equipment), but not for the whole economy.
When relying on stationarity assumptions on capital-stock-to-output ratios, the net capital stocks of R&D is not estimated but taken from BEA accounts because R&D is not covered by Inklaar and Timmer (2013).

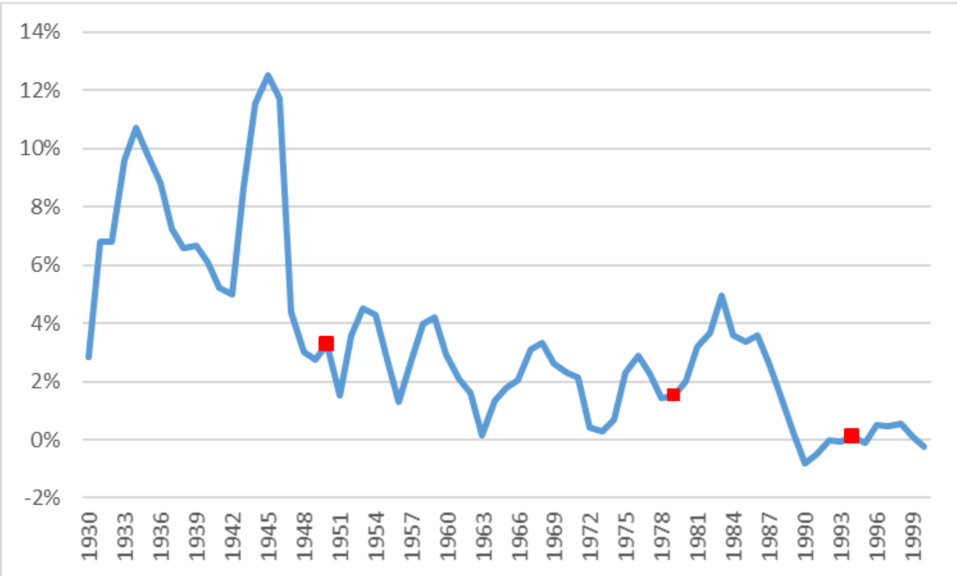
Source: Authors' calculations.

50. The first conclusion that can be drawn from Table 4-2 is that the stationarity assumption on investment growth rates to estimate initial capital stocks can be very misleading, especially in the case of Structures for which estimated capital stocks with investment series starting in 1995 are 16 times higher than in the official BEA accounts in 2005. This reflects the fact that the growth rate used to backcast investment series before 1995 is far below the actual average growth rate over the past, which leads to way too large estimates of past investment, especially for Buildings other than dwellings.

51. As shown by Figure 4.1 and Figure 4.2, the US private sector exhibits large fluctuations and/or long-term trends in the growth rates of investment in Dwellings and Buildings other than dwellings, even when these growth rates are averaged over 20 years.[27] Therefore, using investment growth rates that are observed on a specific sample to backcast investment series over long periods in the past may lead to very inaccurate results. This issue is of course magnified if available time series are short, like in the 1995 scenario. Nevertheless, given that more than half of the initial capital stock in structures remains in use after 25 years, a similar issue could have easily happened in the 1980 scenario. Therefore, we do not recommend relying on the stationarity assumption of investment growth rates to estimate initial capital stocks of long-lived assets such as structures, except if the PIM is run over several decades before the resulting capital stocks start to be used for economic analysis.

Figure 4.1. Investment growth rate in dwellings

20-year forward moving average, US private sector, 1930-2000

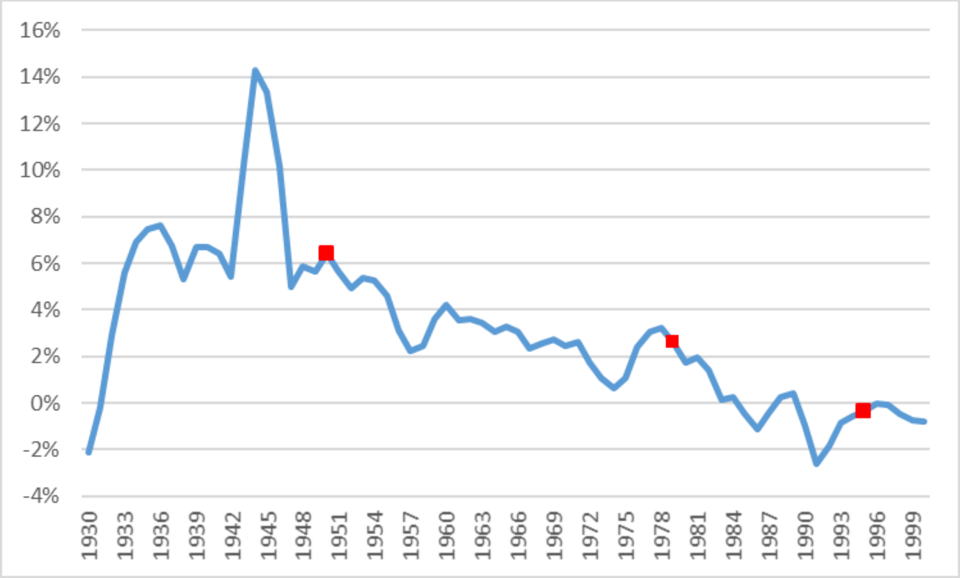


Note: The red dots indicate the moving average investment growth rates that are used to backcast investment time series from 1950, 1980 and 1995 backwards, respectively.
Source: Authors' calculations, BEA Fixed Assets Accounts.

[27] Buildings other than dwellings account for the largest part of Other buildings and structures, the remaining part corresponding to Other (civil engineering) structures.

Figure 4.2. Investment growth rate in buildings other than dwellings

20-year forward moving average, US private sector, 1930-2000



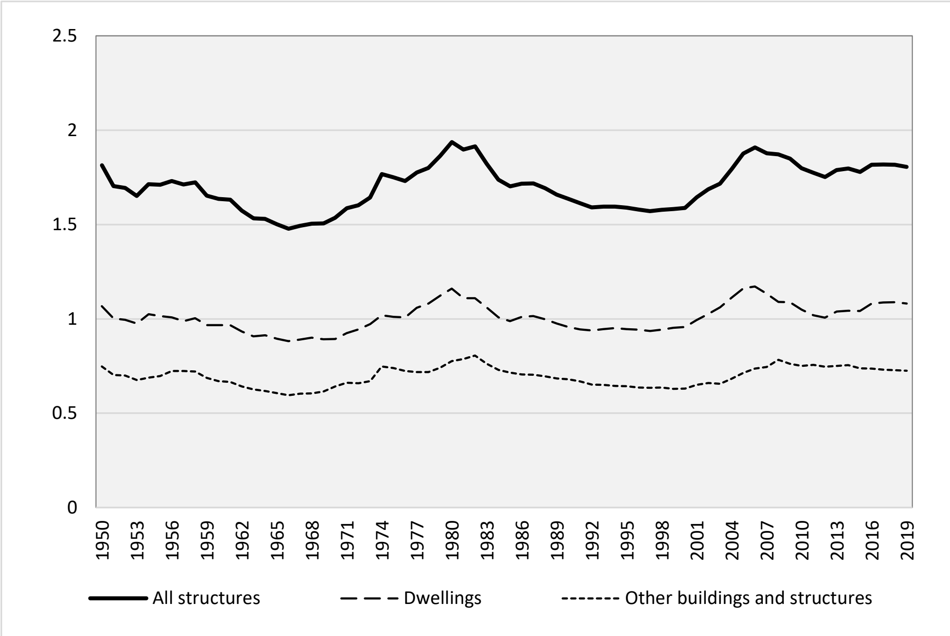
Note: The red dots indicate the moving average investment growth rates that are used to backcast investment time series from 1950, 1980 and 1995 backwards, respectively.
Source: Authors' calculations, based on BEA Fixed Assets Accounts.

52. By comparison, Figure 4.3, Figure 4.4 and Figure 4.5 show that capital-to-output ratios for the US private sector are much more stable over time than investment growth rates. They are also relatively close to the cross-country averages estimated by Inklaar and Timmer (2013), especially once they have been multiplied by a factor 0.8 to take into account that we are focusing on the US private sector. Assuming zero initial net capital stocks for IT equipment, Software, and Originals as Inklaar and Timmer (2013) looks reasonable given the actual values for these ratios and the relatively short service lives of these assets.

53. Overall, estimates of net capital stocks in 2005 are in the +10/-10% range around official values reported by the BEA for all main asset categories and under all scenarios (investment series starting in 1950, 1980 or 1995) when capital-stock-to-output ratios are used to estimate initial capital stocks. Nevertheless, given the dispersion around the mean of capital-stock-to-output ratios across countries reported by Inklaar and Timmer (2013, Figure 1), we cannot exclude that the same assumptions about the capital stock-to-output ratios would give less reliable results for other countries than the US. We leave it for further research to explore this issue.

Figure 4.3. Capital-stock-to-output ratios for structures

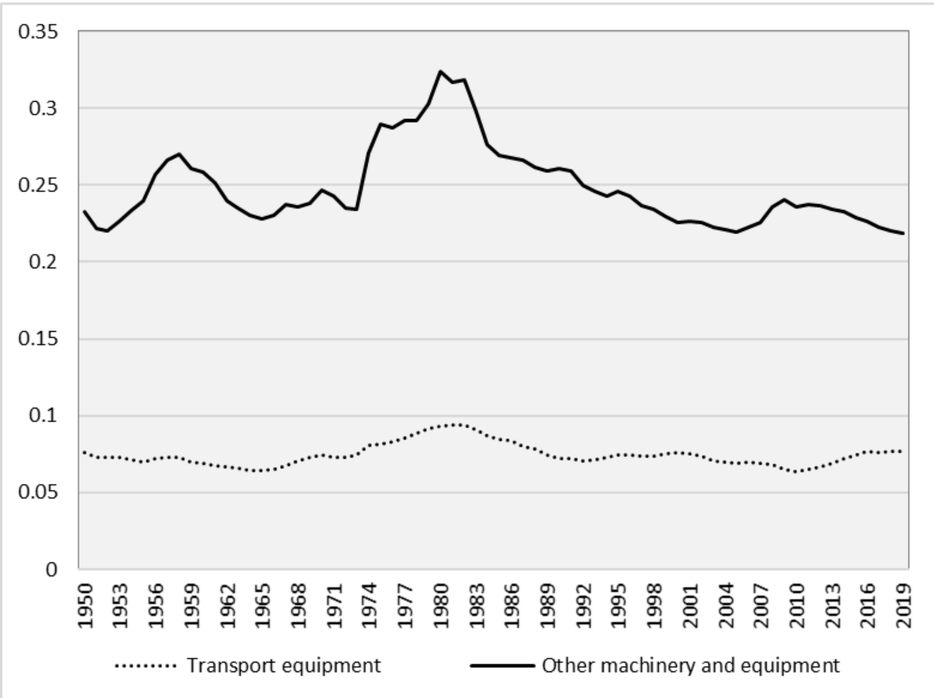
Current prices, US private sector, 1950-2019



Source: Authors' calculations based on official BEA accounts.

Figure 4.4. Capital-stock-to-output ratios for transport equipment, and other machinery and equipment

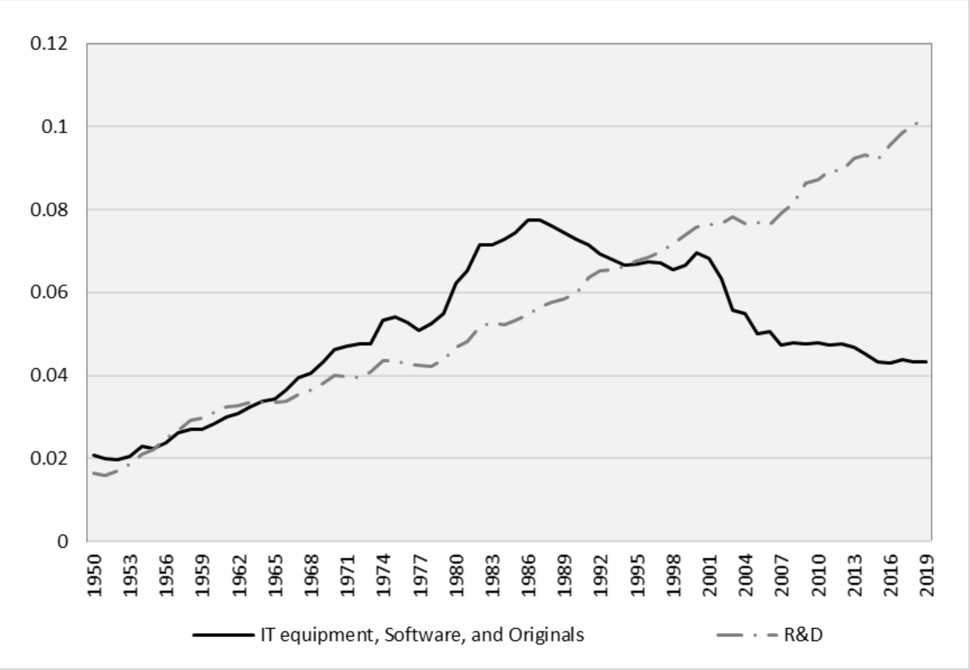
Current prices, US private sector, 1950-2019



Source: Authors' calculations based on official BEA accounts.

Figure 4.5. Capital-stock-to-output ratios for IT equipment, software, originals and R&D

Current prices, US private sector, 1950-2019



Source: Authors' calculations based on official BEA accounts.

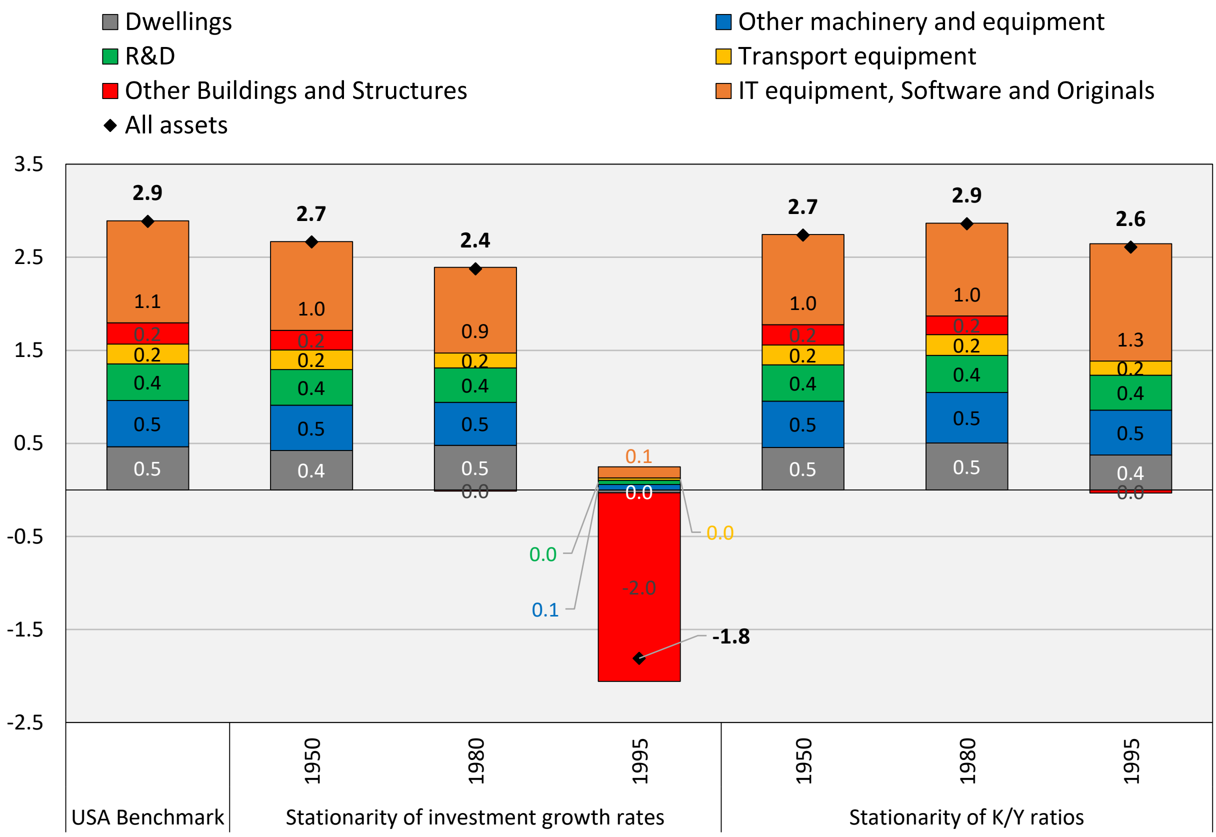
4.3. Sensitivity of capital services and MFP growth to initial capital stock estimates

54. Figure 4.6 shows that the combination of stationarity assumptions on investment growth rates and short investment time series may lead to very inaccurate estimates of capital services growth. This reflects to a large extent the difficulty to estimate initial capital stocks, and hence capital services, for real-estate assets when relying on stationarity assumptions on investment growth. Long investment time series are required to mitigate this problem.

55. By contrast, Figure 4.6 also shows that stationarity assumptions on capital-stock-to-output ratios to estimate initial capital stocks give relatively accurate estimates of US capital services growth, even when short investment time series are available. Nevertheless, the same caveat as for the estimation of net capital stocks holds (Section 4.2). Indeed, our findings are only limited to the US, for which the average capital-stock-to-output ratios estimated by Inklaar and Timmer (2013) on a large cross-section of countries work reasonably well. In light of the dispersion in capital-stock-to-output ratios across countries, this method may give less reliable results for other countries than the US.

Figure 4.6. Sensitivity of capital services growth to initial capital stock estimates

Average annual percentage changes, US private sector, 1997-2019



Note: This figure shows the sensitivity of capital services growth to initial capital stock estimates. Two different methods (relying on stationarity assumptions on investment growth rates or capital-stock-to-output ratios) and three possible starting dates for investment time series (1950, 1980 and 1995) are considered.
Source: Authors' calculations.

56. As shown by Table 4-3, the sensitivity of MFP growth to initial capital stocks estimates reflects the sensitivity of capital services growth, although in a mitigated way due to the weighting (by roughly one third) of capital services growth in explaining economic growth. Indeed, MFP growth estimates only stand out as inaccurate when initial capital stocks are estimated in 1995 by assuming stationary investment growth rates over the past.

Table 4-3. Sensitivity of MFP growth to initial capital stock estimates

Average annual percentage changes, US private sector, 1998-2019

	USA - Benchmark	Stationarity of investment growth rates			Stationarity of capital-stock-to-output ratios		
		1950	1980	1995	1950	1980	1995
1999-2019	**0.7**	0.7	0.8	3.1	0.7	0.7	0.8
1999-2006	**1.0**	1.0	1.1	3.4	1.0	1.0	1.0
2006-2012	**1.5**	1.6	1.6	3.4	1.6	1.6	1.6
2012-2019	**-0.3**	-0.3	-0.2	2.5	-0.3	-0.3	-0.2

Note: This table shows the sensitivity of MFP growth to changes in initial capital stock estimates. Two different methods (relying on stationarity assumptions on investment growth rates or capital-stock-to-output ratios) and three possible starting dates for investment time series (1950, 1980 and 1995) are considered.
Source: Authors' calculations.

5. Conclusion

57. The measurement of capital stocks in an economy typically implies estimating initial capital stocks at a given date in the past and then cumulating and depreciating investment flows over time. In this paper, we discussed the sensitivity of capital and MFP measurement to changes in the depreciation and retirement patterns of assets, and to the way initial capital stocks are estimated. These two aspects were left out in a previous sensitivity analysis of capital services by Inklaar (2010), who focused on the sensitivity of capital services to changes in the asset boundary and the measurement of capital user costs. Therefore, our two papers can be seen as complementing each other. By considering France, Germany, Italy and the UK, and assessing the reliability of different methods to estimate initial capital stocks, we also complemented a more recent sensitivity analysis by Giandrea *et al.* (2021), focusing on asset depreciation patterns in Canada and the US.

58. In order to capture differences in combined depreciation and retirement patterns across countries, we focused on geometric approximations of cohort depreciation patterns. This method allowed us to compare the asset depreciation and retirement patterns used by national accountants in the US and Canada, like Giandrea *et al.* (2021), but also in France, Germany, Italy and the UK, where functional forms for asset depreciation and retirement differ from those used in Canada and the US.

59. Applying the same geometric cohort depreciation rates in the US as in Canada, France, Germany and the UK would reduce the net investment rate and the net capital stock of the US private sector by up to one third. Through an increase in the CFC of the government sector, the US GDP would also be revised upwards by up to 0.5%. This largely reflects the faster depreciation of dwellings and non-residential buildings in Canadian, French, German and UK national accounts. Switching to Italian depreciation rates, which are closer to those used in the US, would have a much more limited impact. Compared to the absolute levels of net capital stocks and CFC, the growth rates of net capital stocks, capital services and MFP appear less sensitive to changes in depreciation and retirement patterns, no matter which country's depreciation rates are used.

60. We also assessed the accuracy of two commonly used approaches to estimate initial capital stocks and their impact on capital and MFP measurement. These methods involve stationarity assumptions on either investment growth rates or capital-stock-to-output ratios. While the estimation method of initial capital stocks is innocuous for rapidly depreciating assets, it has a more significant impact for long-lived assets.

61. The US example shows that real-estate assets may exhibit large trends and fluctuations in investment growth. Therefore, we do not recommend relying on the stationarity assumption of investment growth rates to estimate initial capital stocks for such assets, except if the PIM is run over several decades before the resulting capital stocks and capital services start to be used for economic analysis.

62. On the contrary, relying on the capital-stock-to-output ratios estimated by Inklaar and Timmer (2013) on a large cross-section of countries works reasonably well to estimate initial capital stocks for the US private sector. Even shortly after the estimation date of initial capital stocks, the resulting capital stocks and capital services are quite accurate. Nevertheless, given the wide dispersion in capital-stock-to-output ratios across countries, this result may not be universally true and relying on the cross-country average of capital-stock-to-output ratios may give less reliable results for other countries than the US. We leave it for further research to explore this issue.

63. Overall, the empirical evidence presented in this paper calls for a more frequent review of the methods used by statistical agencies to estimate the depreciation and retirement patterns of assets in order to ensure that differences across countries reflect country-specific factors rather than measurement errors. It also calls for a careful use of stationarity assumptions to estimate initial capital stocks, especially for long-lived assets. Efforts should be made to extend investment time series as much as possible based on historical vintages of national accounts, and to use the external information on capital stocks provided by population censuses, company accounts and administrative sources whenever possible.

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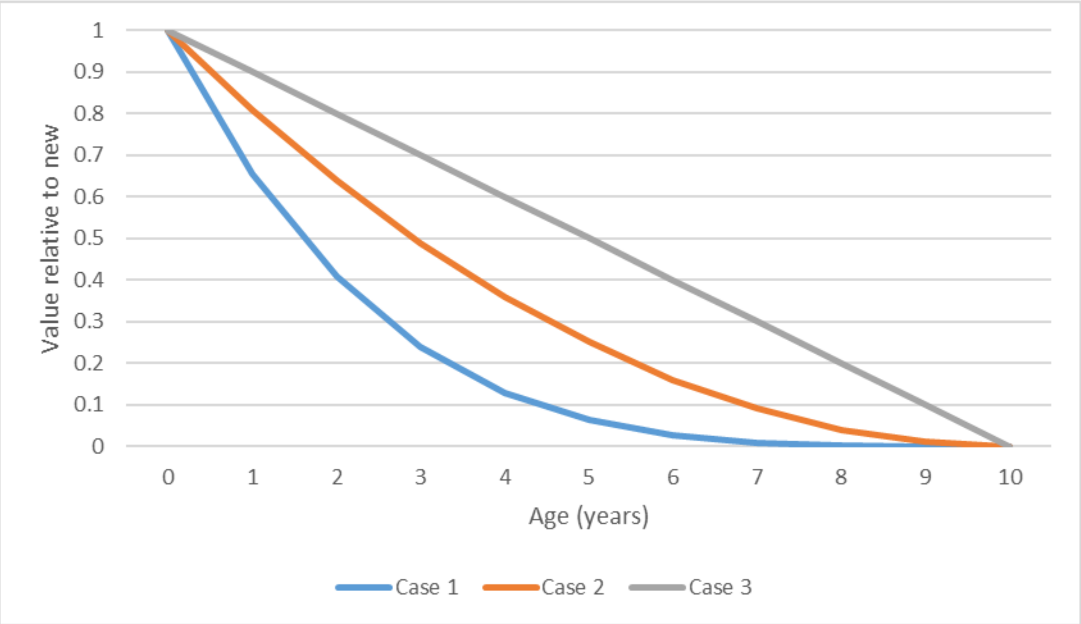
Annex A. Interpretation and limits of Declining Balance Rates (DBRs)

64. Age-price profiles describe how the value (i.e. the market price) of single assets declines over time due to the shortening of their remaining service life. In this Annex, we consider three different age-price profiles that belong to the same family of (power) functions. Like age-price profiles that can be derived from linear and hyperbolic age-efficiency functions (OECD 2009, Chapter 3), those in cases 1 and 2 are convex to the origin. Case 3 considers a linear age-price profile (Figure A.1).

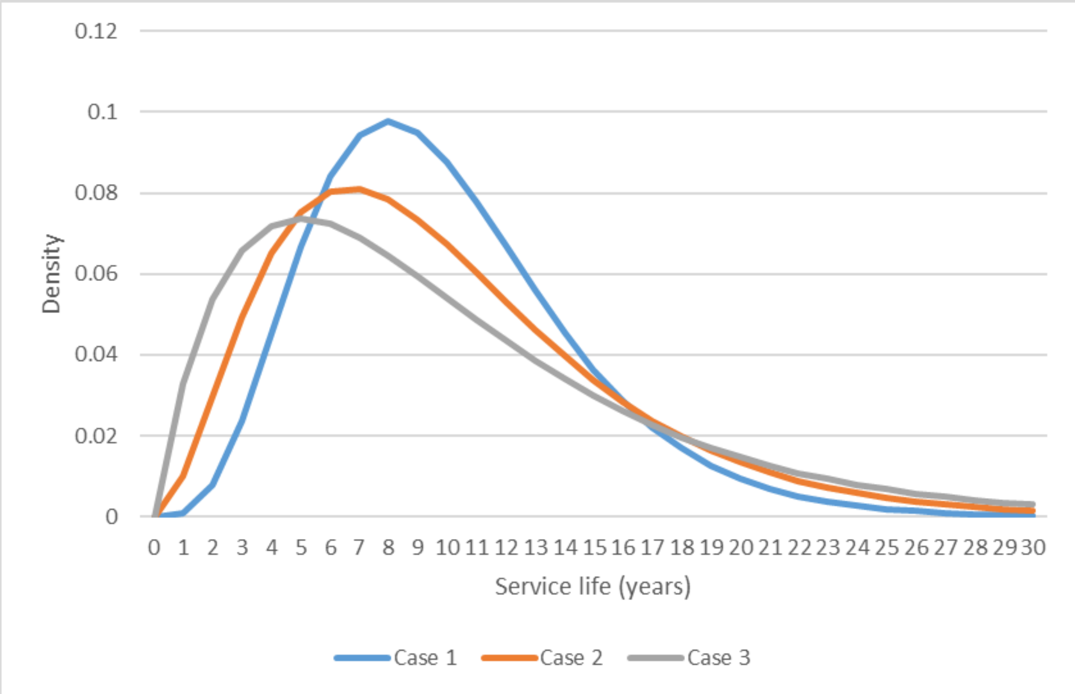
65. Each age-price profile is then combined with a specific retirement profile, belonging to the same family of (gamma) functions. These three retirement profiles are consistent with an asset average service life of 10 years and even though their shapes differ, they are all skewed to the left, in agreement with many asset survival studies (Figure A.2).

Figure A.1. Three individual age-price profiles, each with a service life of 10 years



Note: In this example, all age-price profiles are based on power functions of the type $\left(1-\frac{s}{L}\right)^{\nu-1}$ where s stands for the age of the asset and L for its service life. The parameter ν is set at 5, 3 and 2 in cases 1, 2 and 3, respectively. All assets shown in Figure A1 have a service life of 10 years.

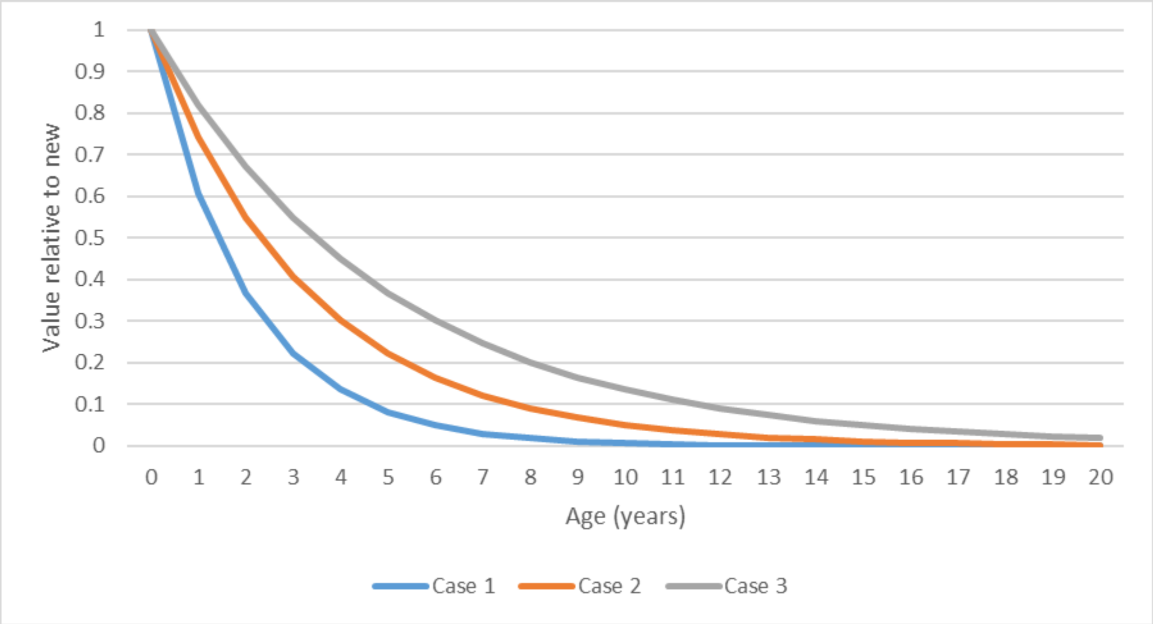
Figure A.2. Three retirement functions, each with an average service life of 10 years



Note: Retirement functions capture the randomness in asset service lives. In this example, Gamma functions with a density $\delta^{\nu} \cdot L^{\nu-1} \cdot \frac{e^{-\delta L}}{\Gamma(\nu)}$ are used. They are parameterised by ν (same parameter as for age-price profiles) and δ. Their mean is given by the ratio $\frac{\nu}{\delta}$ and corresponds to the asset average service life. It is fixed at 10 years, thus implying that the parameter δ is set at 0.5, 0.3 and 0.2 in cases 1, 2 and 3, respectively.

66. Sliker (2018) demonstrates that the combination of such age-price and retirement profiles leads to exactly geometric depreciation patterns for cohorts of assets. The implied geometric parameters depend on the parameters of the underlying depreciation and retirement functions. Figure A.3 shows that the implied geometric cohort depreciation rates are different in all three cases, even though the average service life of assets remains fixed at 10 years.

Figure A.3. Implied geometric cohort depreciation profiles combining age-price and retirement profiles



Note: Sliker (2018) shows that the combination of the depreciation and retirement functions used in Figures A.1 and A.2 leads to exactly geometric functions parameterised by the same parameter δ as in the retirement functions used for Figure A.2.

67. This example shows that DBRs depend on the shape of the underlying depreciation and retirement functions. Therefore, DBRs are country specific, and estimating geometric depreciation rates for a country based on its asset service lives (ASLs) and the DBRs of another country would be misleading. This is further illustrated in Table A.1 showing that assets with similar ASLs in Canada and the US (e.g. medical buildings) may have very different geometric cohort depreciation rates, and conversely that assets with similar geometric cohort depreciation rates (e.g. construction tractors) may have very different ASLs. This shows the wide heterogeneity of DBRs across countries, including for similar assets.

Table A.1. Comparison of geometric cohort depreciation rates (δ), average service lives (ASLs) and declining balance rates (DBRs) for specific assets in Canada and the US

Asset SNA code	Country	Asset label	δ	ASL (years)	DBR
N1121	US BEA	Medical building	0.02	36	0.89
	Statistics Canada	Hospitals, health centres, clinics, nursing homes and other health care buildings	0.06	35	2.17
N1139	US BEA	Household appliances	0.17	10	1.65
	Statistics Canada	Small electric appliances	0.21	11	2.29
		Major appliances	0.23	10	2.31
N1139	US BEA	**Construction tractors**	0.16	8	1.31
	Statistics Canada	**Logging, mining and construction machinery and equipment**	0.17	13	2.23

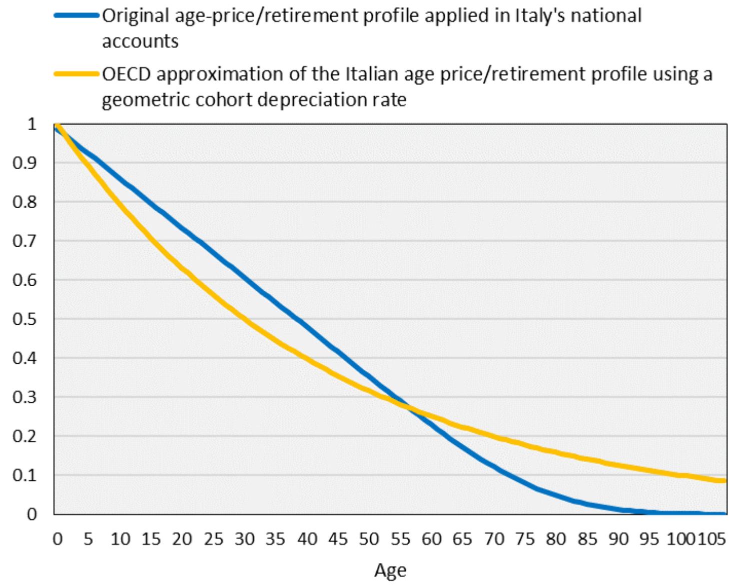
Source: BEA, Statistics Canada, and Giandrea *et al.* (2021).

Annex B. Geometric approximations of combined asset depreciation and retirement patterns

68. In France, depreciation for a cohort of assets is calculated by combining a log-normal retirement distribution with a straight-line depreciation pattern for single assets. In Germany, straight line depreciation is combined with a Gamma retirement function. In Italy, with the exception of R&D, cohort depreciation is calculated by combining a straight line depreciation with a truncated normal retirement function. In the UK, with the exception of R&D, the age-price (i.e. depreciation) profile is derived from a hyperbolic age-efficiency profile and then combined with a truncated normal retirement function. In all these cases, the combination of depreciation and retirement profiles leads to a cohort depreciation profile that is convex to the origin.

69. Cabannes *et al*. (2013) estimated the geometric profiles that best approximate the combined retirement and depreciation profiles applied in France. We follow a similar approach for Germany, Italy and the UK. For each asset and industry indexed by i, we first derive the combined profile $Z_{i,s}$ that is consistent with the actual assumptions on asset depreciation and retirement assumptions in each country. We then approximate $Z_{i,s}$ with a geometric profile $Z^*_{i,s} = (1-\delta_i)^s$ and estimate the parameter δ_i using non-linear least squares.

Figure B.1. Combined depreciation and retirement pattern and its geometric approximation for dwellings in Italy

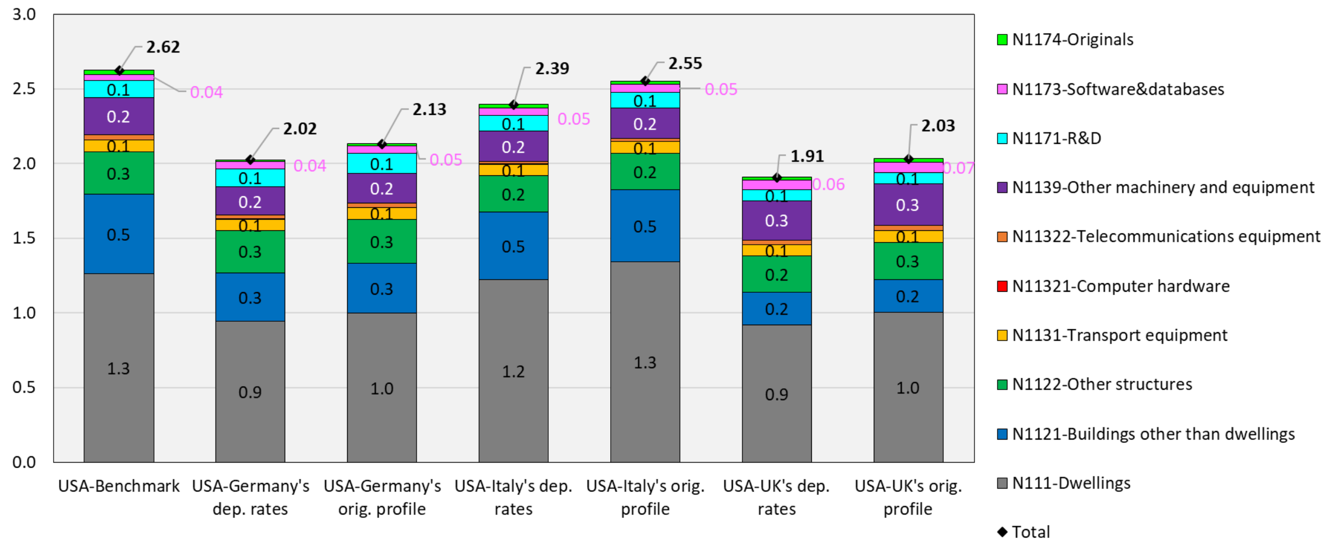


Source: Authors' calculations based on information provided by ISTAT.

70. Figure B.2 shows alternative estimates of US net capital stocks when the cohort depreciation profiles of the BEA are replaced with the original profiles of Germany, Italy and the UK, and their geometric approximations. The original profiles of Germany, Italy and the UK, on the one hand, and their geometric approximations, on the other hand, lead to very similar net capital stocks. Since geometric (approximations of) cohort depreciation rates simplify cross-country comparisons, we consistently use them in this paper.

Figure B.2. Alternative estimates of the US net capital stock when the cohort depreciation profiles of the BEA are replaced with the original profiles of Italy and the UK or their geometric approximations

Ration of net capital stock to gross value added, US private sector, 2019



Source: Authors' calculations based on information provided by DESTATIS.

Annex C. Cohort depreciation rates and asset correspondence across countries

BEA asset label	OECD asset code	OECD asset label	Geometric cohort depreciation rate					
			United States	Canada	France	Germany	Italy	United Kingdom
RESIDENTIAL ASSETS								
1-to-4-unit structures-new	DWE	Dwellings	0.0114	0.02	0.071	0.035	0.023	0.036
1-to-4-unit structures-additions and alterations	DWE	Dwellings	0.0227	0.04	0.071	0.035	0.023	0.036
1-to-4-unit structures-major replacements	DWE	Dwellings	0.0364	0.04	0.071	0.035	0.023	0.036
5-or-more-unit structures-new	DWE	Dwellings	0.014	0.02	0.071	0.035	0.023	0.036
5-or-more-unit structures-additions and alterations	DWE	Dwellings	0.0284	0.04	0.071	0.035	0.023	0.036
5-or-more-unit structures-major replacements	DWE	Dwellings	0.0455	0.04	0.071	0.035	0.023	0.036
Brokers' commissions and other ownership transfer costs /26/	DWE	Dwellings	0.1375	1	0.071	0.035	0.023	0.036
Manufactured homes	DWE	Dwellings	0.0455	0.081	0.071	0.035	0.023	0.036
Other structures	DWE	Dwellings	0.0227	0.081	0.071	0.035	0.023	0.036
Equipment	DWE	Dwellings	0.15	0.081	0.071	0.035	0.023	0.036
MACHINERY AND EQUIPMENT								
Communications	COM	Telecommunications equipment	0.111	0.228	0.154	0.153	0.282	0.178
Nonelectro medical instruments	OMEW	Other machinery and equipment	0.135	0.301	0.117	0.153	0.138	0.129
Electro medical instruments	OMEW	Other machinery and equipment	0.1834	0.236	0.117	0.153	0.138	0.129
Nonmedical instruments	OMEW	Other machinery and equipment	0.135	0.236	0.117	0.153	0.138	0.129
Photocopy and related equipment	HARD	Computer hardware	0.18	0.242	0.244	0.153	0.261	0.241
Office and accounting equipment	HARD	Computer hardware	0.3119	0.323	0.244	0.153	0.261	0.241
Other fabricated metals	OMEW	Other machinery and equipment	0.0917	0.198	0.117	0.153	0.138	0.129
Steam engines	OMEW	Other machinery and equipment	0.0516	0.086	0.117	0.153	0.138	0.129
Internal combustion engines	OMEW	Other machinery and equipment	0.2063	0.093	0.117	0.153	0.138	0.129
Metalworking machinery	OMEW	Other machinery and equipment	0.121	0.197	0.117	0.153	0.138	0.129
Special industrial machinery	OMEW	Other machinery and equipment	0.102	0.195	0.117	0.153	0.138	0.129
General industrial equipment	OMEW	Other machinery and equipment	0.106	0.182	0.117	0.153	0.138	0.129
Electric transmission and distribution	OMEW	Other machinery and equipment	0.05	0.113	0.117	0.153	0.138	0.129
Light trucks (including utility vehicles)	TRANS	Transport equipment	0.1925	0.235	0.171	0.153	0.172	0.162
Other trucks, buses and truck trailers	TRANS	Transport equipment	0.190	0.238	0.171	0.153	0.172	0.162
Aircraft	TRANS	Transport equipment	0.106	0.138	0.171	0.153	0.098	0.162
Ships and boats	TRANS	Transport equipment	0.0611	0.112	0.171	0.153	0.098	0.162
Railroad equipment	OMEW	Other machinery and equipment	0.0589	0.099	0.117	0.153	0.138	0.129
Household furniture	OMEW	Other machinery and equipment	0.1375	0.25	0.117	0.153	0.137	0.129
Other furniture	OMEW	Other machinery and equipment	0.1179	0.26	0.117	0.153	0.137	0.129
Other agricultural machinery	OMEW	Other machinery and equipment	0.1179	0.178	0.117	0.153	0.138	0.129
Farm tractors	TRANS	Transport equipment	0.1452	0.178	0.171	0.153	0.098	0.162
Other construction machinery	OMEW	Other machinery and equipment	0.155	0.172	0.117	0.153	0.138	0.129
Construction tractors	TRANS	Transport equipment	0.1633	0.172	0.171	0.153	0.098	0.162
Mining and oilfield machinery	OMEW	Other machinery and equipment	0.15	0.172	0.117	0.153	0.138	0.129
Service industry machinery	OMEW	Other machinery and equipment	0.150	0.265	0.117	0.153	0.138	0.129
Household appliances	OMEW	Other machinery and equipment	0.165	0.222	0.117	0.153	0.138	0.129
Other electrical	OMEW	Other machinery and equipment	0.1834	0.115	0.117	0.153	0.138	0.129
Other	OMEW	Other machinery and equipment	0.1473	0.193	0.117	0.153	0.138	0.129

BEA asset label	OECD asset code	OECD asset label	Geometric cohort depreciation rate					
			United States	Canada	France	Germany	Italy	United Kingdom
NON RESIDENTIAL ASSETS								
Office	BOD	Buildings other than dwellings	0.0247	0.068	0.067	0.057	0.039	0.075
Hospitals	BOD	Buildings other than dwellings	0.019	0.062	0.067	0.057	0.039	0.075
Special care	BOD	Buildings other than dwellings	0.0188	0.062	0.067	0.057	0.039	0.075
Medical buildings	BOD	Buildings other than dwellings	0.025	0.062	0.067	0.057	0.039	0.075
Multimerchandise shopping	BOD	Buildings other than dwellings	0.0262	0.093	0.067	0.057	0.039	0.075
Food and beverage establishments	BOD	Buildings other than dwellings	0.026	0.081	0.067	0.057	0.039	0.075
Warehouses	BOD	Buildings other than dwellings	0.0222	0.081	0.067	0.057	0.039	0.075
Mobile structures	BOD	Buildings other than dwellings	0.056	0.062	0.067	0.057	0.039	0.075
Other commercial	BOD	Buildings other than dwellings	0.0262	0.087	0.067	0.057	0.039	0.075
Manufacturing	BOD	Buildings other than dwellings	0.031	0.075	0.067	0.057	0.039	0.075
Electric	OST	Other structures	0.0211	0.055	0.031	0.031	0.039	0.050
Wind and solar	OST	Other structures	0.030	0.065	0.031	0.034	0.039	0.050
Gas	OST	Other structures	0.0237	0.074	0.031	0.032	0.039	0.050
Petroleum pipelines	OST	Other structures	0.024	0.074	0.031	0.032	0.039	0.050
Communication	OST	Other structures	0.0237	0.104	0.031	0.032	0.039	0.050
Petroleum and natural gas	OST	Other structures	0.075	0.117	0.031	0.053	0.039	0.050
Mining	OST	Other structures	0.045	0.159	0.031	0.040	0.039	0.050
Religious	BOD	Buildings other than dwellings	0.019	0.055	0.067	0.057	0.039	0.075
Educational and vocational	BOD	Buildings other than dwellings	0.0188	0.056	0.067	0.057	0.039	0.075
Lodging	BOD	Buildings other than dwellings	0.028	0.081	0.067	0.057	0.039	0.075
Amusement and recreation	BOD	Buildings other than dwellings	0.03	0.081	0.067	0.057	0.039	0.075
Air transportation	OST	Other structures	0.024	0.102	0.031	0.032	0.039	0.050
Other transportation	OST	Other structures	0.0237	0.08	0.031	0.032	0.039	0.050
Other railroad	OST	Other structures	0.018	0.063	0.031	0.029	0.039	0.050
Track replacement	OST	Other structures	0.0249	0.063	0.031	0.032	0.039	0.050
Local transit structures	OST	Other structures	0.024	0.092	0.031	0.032	0.039	0.050
Other land transportation	OST	Other structures	0.0237	0.063	0.031	0.032	0.039	0.050
Farm	BOD	Buildings other than dwellings	0.024	0.089	0.067	0.057	0.039	0.075
Water supply	OST	Other structures	0.0225	0.057	0.031	0.031	0.039	0.050
Sewage and waste disposal	OST	Other structures	0.023	0.062	0.031	0.031	0.039	0.050
Public safety	OST	Other structures	0.0237	0.062	0.031	0.032	0.039	0.050
Highway and conservation and development	OST	Other structures	0.023	0.101	0.031	0.031	0.039	0.050

BEA asset label	OECD asset code	OECD asset label	Geometric cohort depreciation rate					
			United States	Canada	France	Germany	Italy	United Kingdom
INTELLECTUAL PROPERTY PRODUCTS								
Prepackaged software	SOFT	Computer software and databases	0.550	0.550	0.244	0.359	0.325	0.256
Custom software	SOFT	Computer software and databases	0.33	0.33	0.244	0.359	0.325	0.256
Own account software	SOFT	Computer software and databases	0.330	0.330	0.244	0.359	0.325	0.245
Pharmaceutical and medicine manufacturing	RD	Research and development	0.1	0.275	0.1	0.168	0.200	0.287
Chemical manufacturing, ex. pharma and med	RD	Research and development	0.160	0.275	0.160	0.184	0.200	0.287
Semiconductor and other component manufacturing	RD	Research and development	0.25	0.275	0.25	0.208	0.200	0.287
Computers and peripheral equipment manufacturing	RD	Research and development	0.400	0.275	0.400	0.249	0.200	0.287
Communications equipment manufacturing	RD	Research and development	0.27	0.275	0.27	0.214	0.200	0.287
Navigational and other instruments manufacturing	RD	Research and development	0.290	0.275	0.290	0.219	0.200	0.287
Other computer and electronic manufacturing, n.e.c.	RD	Research and development	0.4	0.275	0.4	0.249	0.200	0.287
Motor vehicles and parts manufacturing	RD	Research and development	0.310	0.275	0.310	0.225	0.200	0.287
Aerospace products and parts manufacturing	RD	Research and development	0.22	0.275	0.22	0.200	0.200	0.287
Other manufacturing	RD	Research and development	0.160	0.275	0.160	0.184	0.200	0.287
Scientific research and development services	RD	Research and development	0.16	0.275	0.16	0.184	0.200	0.287
Software publishers	RD	Research and development	0.220	0.275	0.220	0.200	0.200	0.287
Financial and real estate services	RD	Research and development	0.16	0.275	0.16	0.184	0.200	0.287
Computer systems design and related services	RD	Research and development	0.360	0.275	0.360	0.238	0.200	0.287
All other nonmanufacturing, n.e.c.	RD	Research and development	0.16	0.275	0.16	0.184	0.200	0.287
Private universities and colleges	RD	Research and development	0.160	0.275	0.160	0.184	0.200	0.287
Other nonprofit institutions	RD	Research and development	0.16	0.275	0.16	0.184	0.200	0.287
Theatrical movies	ELAO	Entertainment, literary, and artistic originals	0.093	1.000	0.331	0.110	0.172	0.183
Long-lived television programs	ELAO	Entertainment, literary, and artistic originals	0.168	1	0.331	0.181	0.172	0.183
Books	ELAO	Entertainment, literary, and artistic originals	0.121	0.121	0.331	0.137	0.172	0.183
Music	ELAO	Entertainment, literary, and artistic originals	0.267	0.267	0.331	0.273	0.172	0.183
Other entertainment originals	ELAO	Entertainment, literary, and artistic originals	0.109	0.109	0.331	0.125	0.172	0.183

Note: This Table provides a mapping between the different assets types considered by national accountants at Statistics Canada, INSEE (France), ISTAT (Italy), the ONS (UK) and the BEA (US), and compares the corresponding geometric cohort depreciation rates.

For Canada, these depreciation rates are averages across industries. They correspond to the "weighted averages of many asset categories" provided by Giandrea *et al.* (2021). Canadian cohort depreciation rates are not available for books, music, and other entertainment originals. The present sensitivity analysis keeps the US depreciation rates unchanged for these assets.

For France, the geometric approximations of combined depreciation and retirement patterns provided by Cabannes *et al.* (2013) are used. French cohort depreciation rates are not available for R&D. Our sensitivity analysis keeps the US depreciation rates unchanged for these assets.

For Germany, Italy and the UK, geometric approximations of combined depreciation and retirement patterns are calculated based on the information provided by DESTATIS, ISTAT and the ONS (UK).

Annex D. Estimation of endogenous rates of return

71. In this paper, we compute endogenous rates of return for 13 aggregate industries belonging to the US private sector (Table D.1).

Table D.1. Industry level at which the internal rates of return are estimated

NAICS code	NAICS label	OECD code	OECD label
11	Agriculture, forestry, fishing, and hunting	VA0	Agriculture, forestry and fishing
21	Mining	VB	Mining and quarrying
22	Utilities	VD+VE	Electricity, gas, steam and air conditioning supply & Water supply; sewerage, waste management and remediation activities
23	Construction	VF	Construction
31-33	Manufacturing	VC	Manufacturing
42 & 44-45	Wholesale trade and retail trade	VG	Wholesale and retail trade; repair of motor vehicles and motorcycles
48-49	Transportation and warehousing	VH	Transportation and storage
51	Information	VJ	Information and communication
52-53	Finance, insurance, real estate, rental, and leasing	VK+VL	Financial and insurance activities & Real estate activities
54-56	Professional and business services	VM+VN	Professional, scientific and technical activities & Administrative and support service activities
61-62	Educational services, health care, and social assistance	VP+VQ	Education & Human health and social work activities
71-72	Arts, entertainment, recreation, accommodation, and food services	VR+VI	Arts, entertainment and recreation & Accommodation and food service activities
81	Other services, except government	VS	Other service activities

Note: OECD codes are industry codes used in the OECD Annual National Accounts database.

72. Estimating the residual income KInc accruing to capital is not straightforward. This aggregate corresponds to the sum of the gross operating surplus (GOS), the capital income component of mixed income, and taxes less subsidies on production. [28] For each industry, the BEA accounts include a single aggregate summing up GOS and mixed income. We denote this aggregate by GOSMXI. In addition, the BEA provides for each industry the number of employees, in headcounts and full-time equivalent (FTE) units, and the total number of persons employed (TPE), defined as the sum of the number of self-employed workers and the number of employees in FTE units. No information is available on hours worked by self-employed workers.

[28] These are taxes net of subsidies that enterprises incur as a result of engaging in production, independently of the quantity or value of the goods and services produced or sold. They may be payable on the land, fixed assets or labour employed, or certain activities or transactions (e.g. property taxes).

73. In order to estimate the labour component of mixed income, we assume that self-employed workers receive the same labour compensation as full-time employees working in the same industry.

74. Summing up, we estimate the residual income $KInc_{it}$ accruing to capital in each industry *i* as follows:

Step 1: We calculate the number of self-employed workers (SE_{it}) in each industry i as the difference between the total number of persons employed (TPE_{it}) and the number of employees in FTE units (EE_{it}):

$$SE_{it} = TPE_{it} - EE_{it}$$

Step 2: We impute a labour compensation (LMX_{it}) to self-employed workers based on the average labour compensation of full-time employees working in the same industry:

$$LMX_{it} = \frac{COE_{it}}{EE_{it}} * SE_{it}$$

where COE_{it} is the total compensation of employees in industry i in period t.

Step 3: We subtract the labour component of self-employed income from GOSMXI and add taxes less subsidies on production ($D29\_D39_{it}$):

$$KInc_{it} = GOSMXI_{it} - LMX_{it} + D29\_D39_{it}$$

75. We source data on taxes less subsidies on production from the OECD Annual National Accounts database, where they are available by ISIC rev. 4 industry. We then use the correspondence between NAICS and ISIC Rev. 4 shown in Table D.1. This allows estimating endogenous rates of return for the 13 aggregate industries, which are then used for the calculation of capital services.