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Abstract

The recent decline in aggregate labor productivity growth in leading economies has been widely described as a puzzle, even a paradox, leading to extensive research into possible explanations. Our review confirms the magnitude of the slowdown and finds that it is largely driven by a decline in total factor productivity and capital deepening. Disaggregation reveals that a significant part of the slowdown is due to sectors that experienced the large benefits from ICTs in the previous period, and that an increasing gap between frontier and laggard firms suggests slower technology diffusion and increasing misallocation of factors. We evaluate explanations that attempt to reconcile the paradox of slowing productivity growth and technological change, including mismeasurement, implementation lags for technologies, and creative destruction processes.

JEL codes: O40, E66, D24

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1. Introduction

Labor productivity growth is widely seen as the main long-run determinant of per capita output growth and improving living standards. The decline in measured labor productivity growth over recent decades has raised serious concerns, both in academic circles and among business and policy decision makers. Three decades after Robert Solow's famous quip that 'you can see the computer age everywhere but in the productivity statistics' (Robert M. Solow, 1987), this slowdown remains a puzzle, not least for those who believe technological change has accelerated.

The slowdown, which started before the financial crisis and subsequently worsened, is indisputable. Table 1 demonstrates that labor productivity growth rates have roughly halved since the 1995-2005 period, making GDP per capita in 2018 several thousand dollars lower than it would have been had the previous trend continued.

Table 1 Labor productivity slowdown and missing GDP per capita

	LP growth 1995-2005	LP growth 2005-2018	Slowdown	per capita GDP 2018	Missing per capita GDP 2018
France	1.66	0.62	1.05	$44,078	$6,341
Germany	1.69	0.83	0.86	$51,507	$5,992
Japan	1.86	0.68	1.17	$44,451	$7,225
United Kingdom	2.28	0.46	1.82	$45,466	$11,936
United States	2.51	1.01	1.50	$62,117	$13,127

Growth of labor productivity per hour worked (LP), in percent, and GDP per capita, in 2018 PPP $US. Data from the Conference Board. See Appendix for details.

Why is productivity slowing down? By definition, a slowdown is by comparison to a previous period of faster growth. An important point, therefore, is to note that productivity levels should not necessarily be expected to increase *ad infinitum*. If the growth of inputs stops, and there are no further improvements in institutions and technology, we should expect no further growth in labor productivity. At the firm level, the available skills, capital stock, managerial abilities, technologies, as well as regulations and other constraints determine a similar bound on productivity levels.

While on long run historical time scales, fast productivity growth is a relatively recent phenomenon, within the 20th century there have been several accelerations (Bergeaud, Cette, & Lecat, 2016), and thus slowdowns, encouraging the development of analytic methods and ideas which remain relevant today. In the US, which has been studied extensively, labor productivity growth rates accelerated during much of the first half of the 20th century, peaked soon after the end of the Second World War, and experienced a particularly noticeable slowdown after the oil crisis of the 1970's. Early research emphasized the importance of the relative share of different industries. Nordhaus (1972), for example attributed the 1965-71 slowdown to a changing industry mix towards industries with a lower productivity level. Baily and Gordon (1989) argued that there is a one-off effect of technology, where productivity growth is interpreted as an adjustment toward a higher level, while accounting for implementation lags. The 1970's slowdown, was largely attributed to the productivity-reducing adaptation of capital to rising energy costs (Bruno, 1982). Notions of input utilization and mismeasurement were prominent, with for instance the idea of a decrease of the capital services obtained from a given level of capital stocks, because energy-intensive capital is utilized less intensively and scrapped faster (Baily (1981). Sichel (1997) and Baily and Gordon (1989) looked into the effect of mismeasurement and found that it did not help explain more than a third of the aggregate slowdown. Mismeasurement and lags in technological adoption also featured prominently in explanations of the productivity paradox of the 90's, together with an emphasis on complementary investment and adjustment costs (Brynjolfsson, 1993; Brynjolfsson & Hitt, 1996; Brynjolfsson & Hitt, 2000; David, 1990).

This paper seeks to explain the current slowdown, which began in the early years of this century, as we show in Table 1 by comparing the decade before 2005 with the following period, until 2018. In considering what constitutes an effective explanation we have sought to satisfy three criteria. First, a good explanation must be quantitatively significant (the *scale* criterion). Roughly speaking (see Table 1), we are looking for a missing 1 percentage point of labor productivity growth per year. For this reason, as an example, while price indexes in the high-tech sectors probably overestimate inflation, the bias is small, and these sectors themselves are not large enough in size to explain a significant part of the slowdown.

Second, a good explanation needs to show time consistency in the sequencing of cause and effect (the *sequencing* criterion). At least for the US, there is a broad consensus that productivity started slowing down around 2004-05. To explain this, a causal factor needs to exhibit a change around or before that period. Therefore, for instance, because the global financial crisis of 2007-08 occurred after the start of the slowdown it can be dismissed as a cause, even though, as we show below, it may have accentuated and deepened the slowdown. On the basis of this criterion, explanations which depend on slow secular developments, such as ageing or a changing pace of technological change, are also unlikely to provide an explanation for a break in trend as observed in the US. The sequencing criterion is not as sharply defined for Europe, where there was no obvious productivity revival around the turn of the century, so that secular factors may not be excluded there based on the sequencing criterion.

Third, a good explanation needs to have wide geographical scope and applicability (the *scope* criterion). The productivity slowdown is to a large extent a worldwide phenomenon, with almost all OECD countries and many emerging economies exhibiting lower productivity growth over a similar period (Askenazy, Bellmann, Bryson, & Moreno Galbis, 2016; Cusolito & Maloney, 2018; Erber, Fritsche, & Harms, 2017; OECD, 2015). It is implausible that all these countries experienced the slowdown at roughly the same time but for different reasons, which is why the synchronised collapse in productivity leads us to identify factors that go beyond local conditions. So, for example, changes to labor market institutions unique to a specific country are unlikely to explain either the sustained national or global scope of the productivity slowdown (Askenazy et al., 2016).

This paper synthesizes a large literature that attempts to explain the slowdown. We consider in turn the arguments grouped under the following broad areas: mismeasurement, labor quality, capital growth, composition effects, global factors and trade, and technology. In each section we review the evidence and conclude with a short summary where we critically evaluate the extent to which the evidence satisfies the scale, sequencing and scope thresholds necessary to explain the slowdown in productivity growth.

Before evaluating the wide-ranging literature on causes of the slowdown, in Section 2 we clarify the nature of the problem by using standard growth accounting for five large developed countries, France, Germany, Japan, US and the UK, with data from the EU KLEMS. We confirm two findings that are important for evaluating potential explanations. First, changes in labor composition have not contributed substantially, as compared to capital deepening and TFP. Second, the decline in TFP appears to predate the crisis.

Section 3, reviews the extensively debated mismeasurement explanation for the slowdown. This explanation contends that systematic measurement biases, in various forms, have caused a decline in *measured* productivity growth. It is compelling as an explanation for the productivity *paradox* since it reconciles the slowdown with perceived rapid technological change. The mismeasurement hypothesis also coincides with a significant increase in intangible capital linked both to a real and mismeasured slowdown effect. However, the conclusions in many of the proposed sources of such bias fall short of explaining a *change* in productivity growth, at least of sufficient magnitude to explain the scale and sequencing of the measured slowdown.

The following sections consider the dynamics of the inputs of productivity growth, starting in Section 4 with the composition of the labor force, and more specifically education, skills, migration, ageing, and labor market institutions. We show that these have not demonstrably contributed to the slowdown in productivity growth, although the demand for new skills driven by technological change, as well as the impact of an ageing population at times play a role in explaining differences in productivity performance.

A decline in the rate of capital deepening has contributed to the slowdown, and Section 5 distinguishes two core arguments to explain this phenomenon. The first relates to the financial crisis and suggests that the decline in investment is a cyclical phenomenon driven by financial constraints and weak aggregate demand. A second candidate explanation recognizes that the slowdown started in the years preceding the crisis, and suggests that structural factors may have been important, including primarily a change in the composition of capital towards intangibles (which are riskier), but also slowing competition and increasing short-termism.

Section 6 discusses various attempts to understand the slowdown by looking at the firm, industry and regional level disaggregated evidence. First, traditional industry-level growth accounting studies reveal that specific sectors (such as retail) contributed most to the slowdown, in large part because they benefited from high productivity growth thanks to computerization in the previous period. Second, a recent strand of literature documents an increasing dispersion of firm-level productivity, suggesting slower technology diffusion and/or slower factor reallocation. Together with evidence on lower business dynamism (entry-exit) and increasing market power, these micro studies help us understand deeper causal factors and possible sources of policy intervention.

Section 7 investigates the role of trade and globalization. Growing international trade and better organization of international production into global value chains led to productivity gains in the past. Due to the recent slowdown in trade, it is possible that the productivity slowdown reflects the end of an adjustment to higher level due to static gains from trade having been reaped. On the basis of our synthesis of recent studies, we are unable to confirm that changes in trade contributed significantly to the slowdown, not least as the slowdown is not uniformly preceded by trade frictions and different industries and countries integrated at different speeds, which our sequencing and scope criteria suggest undermines the significance of these explanations.

Section 8 examines explanations related to technology. We first find that research efforts do not appear to have slowed dramatically, but there does appear to be a decline in how well research translates into productivity. As Gordon (2016) has prominently pointed out, the technologies of the past 150 years have had such a profound impact that it is not surprising if current technologies are not able to produce the same impressive effects. However, for others, such as Brynjolfsson, Rock, and Syverson (2017), current technologies do have a transformative potential, although it may not be fully realized yet. We present and critically examine the arguments of this debate by describing how creative destruction has had negative short-term effects and taken a long time to materialize into productivity gains in previous periods of transformative technological change.

Finally, in Section 9 we summarise the key findings and conclude by showing that while no single factor accounts for the slowdown entirely, a small number of explanations taken together appear to match the scale, sequencing and geographical scope of the slowdown.

2. Growth accounting

The basic idea of growth accounting is that aggregate output may grow either because more inputs are utilized, or because they are used more efficiently. Robert M Solow (1957) put this idea on firm ground by identifying how this decomposition follows from clear economic assumptions: a stable and smooth functional relationship between inputs and outputs at the economy-wide aggregation level, inputs paid at their marginal product, constant returns to scale, and Hicks-neutral technical change. Robert M Solow (1957) originally found that most of post-war US growth was not due to the growth of inputs, but to inputs being used more efficiently. The "Solow residual" was born and soon re-baptized "a measure of our ignorance", prompting a significant strand of research into improving measurement of inputs to reduce this unexplained growth of output. In particular, Jorgenson and Griliches (1967) demonstrate that improvements in human capital are a major determinant. As we shall see, most research today still concerns better measurements of inputs, such as intangible capital.

While major efforts of data collection and harmonization have taken place, modern growth accounting still often starts from a relatively simple decomposition, which we report here. We decompose the growth in real output per unit of labor, y_t, as

$$\Delta \log y_t = \alpha_t \Delta \log h_t + (1 - \alpha_t) \Delta \log k_t + \Delta \log A_t, \tag{1}$$

where A_t denotes TFP, k_t represents capital services per unit of labor, h_t is an index of the composition of labor, and α_t is the labor compensation share of income. To get relatively long time series, we follow Gordon and Sayed (2019) and merge data from two vintages of EU-KLEMS (see Appendix for details). Labor productivity is measured as value added per hour worked. Figure 1 reports the 5-year moving average of labor productivity growth and its three components. A relatively long moving average makes it more difficult to evaluate the effects of the financial crisis but helps highlight the secular trends.

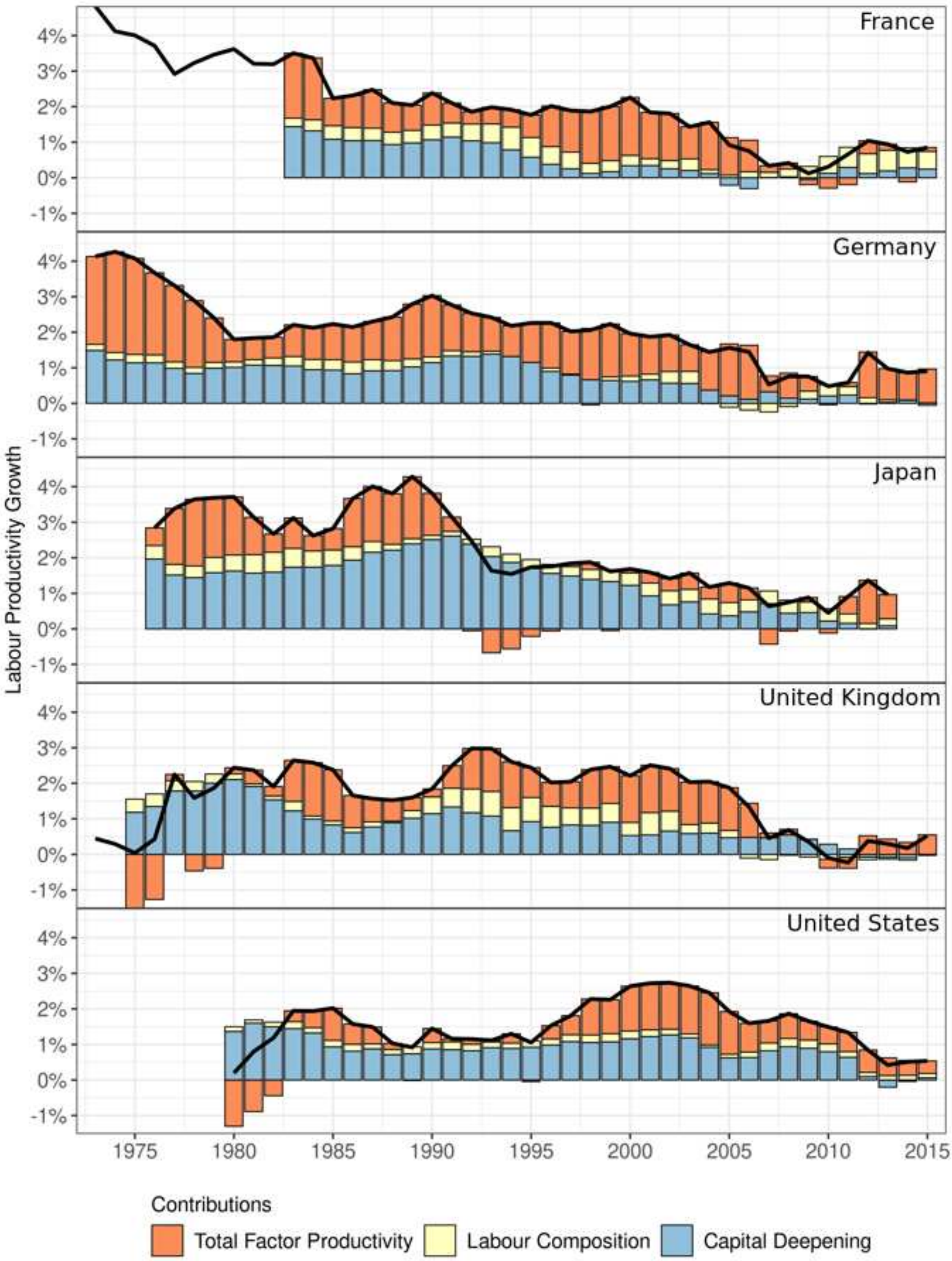

Figure 1: Decomposition of labor productivity growth rates. The line shows the growth rate of aggregate labor productivity. All variables are centered 5-year moving averages. The data is obtained by merging all available data from the 2012 and 2019 releases from EU KLEMS, see Appendix for details.

While it is hazardous interpret the patterns by simply visualizing 5-year moving averages, Figure 1 appears suggests that the productivity slowdown precedes the financial crisis, although the crisis may have made the situation significantly worse. The slowdown cannot be attributed to labor composition, as this contributes relatively little to overall labor productivity growth. Instead, capital deepening as well as TFP growth are responsible for most of the growth. In the pre-crisis period, Figure 1 suggests noticeable differences between countries in terms of the evolution of the relative contribution of capital deepening and TFP. In the US, the absolute contribution of capital is fairly constant, suggesting that TFP is responsible for most of the fluctuations, but this is not as clear for other countries. The situation is different post-crisis, where the pro-cyclicality of investment may have made the slowdown worse, although it is difficult to evaluate this with 5-year moving averages; we discuss this further in Section 5. Figure 1 also contextualises the productivity paradox of the 90's: the productivity revival in the US between 1996 and 2005, typically attributed to the gains from computerisation, is far from obvious in the other countries. In contrast, the slowdown after 2004 is pervasive.

Growth accounting points at the causes of the slowdown and helps organise this paper. According to Eq. (1), the slowdown can be due to a decrease in the growth of physical capital, human capital, and/or TFP. While we cannot fit all explanations into the growth accounting framework, two major classes of explanations that are prominent in the literature can be made explicit (see Appendix). We may introduce output mismeasurement by assuming that true and observed output differ, and we can also assume that TFP is the sum of a "pure technology" and an "allocative efficiency" effect, leading to a (conceptual) extension of Eq. (1),

$$\underbrace{\Delta(\log y_t^{TRUE} - \log y_t)}_{\substack{\text{Mis-measurement} \\ \text{(Section 3)}}} + \Delta \log y_t = \underbrace{\alpha \, \Delta \log h_t}_{\substack{\text{Human Capital} \\ \text{(Section 4)}}} + \underbrace{(1-\alpha) \, \Delta \log k_t}_{\substack{\text{Physical Capital} \\ \text{(Section 5)}}} + \underbrace{\Delta \log A_t^{ALLOC}}_{\substack{\text{Dispersion and Trade} \\ \text{(Sections 6 and 7)}}} + \underbrace{\Delta \log A_t^{TECH}}_{\substack{\text{Technology} \\ \text{(Section 8)}}} \quad (2)$$

This extension (Eq. 2) of the simple factor decomposition broadly reflects the organization of the paper, providing a conceptual structure that helps navigate the various explanations that have been put forward in the literature. Nevertheless, at present, no unique conceptual, let alone empirical framework can encompass all the mechanisms that have been discussed in the literature. Many explanations affect multiple terms at the same time, making the mapping between the growth accounting framework above and the organization of our review imperfect.

For example, the mismeasurement section evaluates whether mismeasurement of output has increased, due to an increasing deterioration in the quality adjustment of price indices, or for other reasons. The mismeasurement section also discusses whether intangibles are well measured, which concerns the left-hand side of the Eq.2 since investment is an output, but also the right-hand side, because intangibles are inputs. Intangible capital, when measured, is often aggregated with physical capital (k_t) (e.g. in KLEMS), but intangibles include ``economic competencies'', which may be conceptually better aggregated with human capital h_t. There is also evidence that intangibles affect TFP, the returns to ICT capital, and the interaction between firms and financial markets.

Another example, central to the debate, is technology, which we discuss in Section 8. Often, the role of technology is summed up under the TFP term, but this is not adequate for two reasons: TFP itself is "a measure of our ignorance" and includes a lot more than technology; and technological change is also reflected in other terms, because it is embodied in capital inputs, and it profoundly affects the returns to different types of skills, allocative efficiency through monopoly rents or changes in business dynamism, and the relevance of our measurement systems.

The conceptual framework summarised above clarifies key dimensions of productivity growth, and helps us to organise our analysis, even though it necessarily cannot adequately capture the full set of factors or the complexity of their interactions. To address this, we now turn to a comprehensive thematic discussion, beginning with mismeasurement.

3. Mismeasurement

While the level of labor productivity is directly affected by a mismeasurement of output, it is only when mismeasurement increases that it could explain a slowdown in productivity growth. This could occur because mismeasurement in a given sector increases, or because the most mismeasured sectors are becoming a larger share of the economy.

In this section we discuss the areas where mismeasurement might exist and whether it is linked to the productivity slowdown. These are sectors of the economy that are either hard to measure (notably in services), belong to the non-market economy (household and public sectors), are informal and/or unobserved thus lacking official reporting (including a range of legal and illegal activities), or where corporate tax differences across countries may affect productivity estimates.

We look into the emergence of free goods and unmeasured consumer surplus, predominantly as a result of Information and Communications Technologies (ICT) adoption. We then examine the pitfalls of providing quality adjustments to economic output and accurate price indexes for new goods and products. Last, we discuss the implications from the growing role of intangible capital as an input of production and whether this coincides with the period of the observed slowdown across the world.

3.1 Shifts in reporting, boundaries and profits

Some of the sectors that are included in national accounts pose considerable measurement challenges due to the lack of market valuation (non-market sectors) and the conceptual difficulty in defining a unit and constructing price indices, namely the household sector, the public sector and the service producing sectors (Hulten, 2010). We discuss the services sectors in section 3.1.1 and the non-market sectors in 3.1.2. Apart from these cases, some economic activities are either not observed (alluded to as the Non-Observed Economy, see NOE reports), informal (where the unit of production is not officially registered) or fall within the intersection of NOE and informal activities. These may include "the care of one's own children, unpaid volunteer work for charities, and illegal activities" where the lack of data makes it hard to accurately measure their value (Pritzker, Arnold, & Moyer, 2015). We define these activities under the broad definition of the informal sector and discuss their measurement issues in Section 3.1.3. Last, we discuss the effects of tax favourable reporting that is linked to profit shifting practices of multinational firms (Section 3.1.4) to explore whether changes in this may have contributed to the observed decline in productivity growth.

3.1.1 Services sectors

The national accounts framework is best suited for goods-producing sectors but less so for services, leading in a long history of failed attempts to monitor their performance[†]. The reasons are both related to data availability and the conceptual underpinnings of their measured productivity. Prices for the goods-producing sectors have been easier to collect, in contrast to prices from the services sectors which have suffered from a lack of coverage (unreported at the firm level) and direct price comparisons. Because of this, relatively arbitrary ("makeshift") deflators have been used for real outputs along with estimates directly proportional to specific inputs (Griliches, 1992). The issue is made worse by the fact that services outputs are very heterogenous, and there if often an absence of information about "what is being transacted" and "what services correspond to the payments made to the providers" (Griliches, 1992). The data shortcomings have been partly addressed, as a result of the attention probed to these issues by the 1995 Boskin commission [‡]. Triplett and Bosworth (2008) argue that serious service data did not begin in the US before the 1980s and 1990s and there are still no annual surveys conducted for half of the service industries or PPI services price indexes. As the value-added from services sectors has reached 70% of GDP for OECD and 65% for all economies. around the world, this explanation meets the scope and sequencing criterion but fails in the scale as the change over the past 20 years is 5 p.p for all economies and 10 p.p. for OECD ones (World Bank, 2020).

3.1.2 Non-market sectors

Non-market sectors like education and health and are often not adequately addressed by the productivity literature (Baily & Gordon, 2016). Spending on health has steadily increased since the 2000s (from 12.54% in 2000 to 16.9% of GDP in 2018 in the US[§]), while spending on education has barely increased (rising from 5.8% of US GDP in 2000 to 6.1 of GDP in 2018[**] with a similar trend for the majority of OECD countries). Average TFP growth in the US was -1.3% for the health sector during 1987-1995, -0.6% during 1995-2004 and -0.3% during 2004-2014[††]. Meanwhile, productivity in education in the US has remained largely constant over the past four decades with slight increases over time. In the EU, education has seen small reductions in productivity growth rates for most of the period, although there are considerable doubts regarding the veracity of these numbers (Triplett & Bosworth, 2008). There is little agreement on how to measure productivity in education and also a range of uncertainties in the interpretation of productivity measures in healthcare, in part due to gaps in the allocation of healthcare costs (Triplett & Bosworth, 2008). To achieve a better understanding of the

[†] The collection of economic data in the US goes back to 1810, first as a by-product of population censuses and later in the 1860s in an attempt to monitor the goods producing sectors along with transportation and communications. "Selected" service sectors were gradually added over the 20th century censuses but the volume of data and practical limitations prevented their inclusion in sufficient detail to inform productivity research.

[‡] The Boskin commission led statistical agencies to achieve a vast expansion in inputs coverage, introduced service-specific price measures (PPI), new deflators for high-technology capital goods, improved capital stock measures and the NAICS as the new industry classification in the US

[§] Similar changes in health spending have been shown in Japan and the UK and a slower growth in Germany and France. All these countries have reached very close to the level of 10% of GDP in 2018. The composition of this expenditure by private and public means is - for the majority of high income countries – less than 30% for private whereas in the US private spending is more than 50% of total health spending (OECD, 2018).

[**] https://data.oecd.org/eduresource/education-spending.htm

[††] Bureau of Labor Statistics' Multifactor Productivity Tables.

expenditures in health services (for example are expenditures increasing because of higher prices, more people receiving healthcare, or for other reasons) the Bureau of Economic Analysis (BEA) developed a new satellite account (HCSA) that measures healthcare spending by disease type instead of the goods and services purchased (Dunn, Rittmueller, & Whitmire, 2015). The goods and services data approach nevertheless is still used to populate official statistics for healthcare - like GDP. At the heart of this issue, is the reliability of price deflators for medical prices. Several studies have pointed to inflated CPI growth for healthcare (Aizcorbe & Highfill, 2020; Dunn, Grosse, & Zuvekas, 2018) and show that the medical CPI growth in the US is higher by 1 p.p. per year compared to other deflators that better capture overall and disease-specific treatment costs. These effects result in a misleading increase in medical costs and hence asmaller implied productivity growth of the sector. Despite these findings, the goods and services data approach nevertheless is still used to populate official statistics for healthcare - like GDP[‡‡]. Given the increasing importance of the sector as a percentage of total output and the slower actual growth rate in costs, this mismeasurement explanation fits the sequencing and scope criteria but largely fails to meet the scale criteria as the difference is not big enough to impact significantly on overall productivity growth. With the exception of owner-occupation of dwellings and the services of paid domestic staff, personal and domestic services by members of households for their own final consumption are excluded from the reported economic production- if they were included, the vast majority of unemployed would need to be counted as self-employed (*System of National Accounts 2008*). For the period which is of interest to us, it is conceivable that household's own production increased, as since the early 2000s an increasing investment in consumer electronics and a sharp rise in the equipment and network quality has led to a higher proportion of *time* spent on this subsector. We will come back to the question of unmeasured consumer surplus in Section 3.2.

ICTs may also have affected the production boundary through the rise of digital platforms that have enabled households to offer transport and house rental services (through the likes of Uber and AirBnB)[§§]. While this practice is not new, as households have been offering informal services for a long time, its scale is unprecedented.: in 2017 the capitalization of AirBnB exceeded the combined capitalization of Hilton and Hyatt. The extent to which GDP captures this depends on the ways that household and corporate incomes are reported as any additional household income will show up in national statistics if platforms require their users to do so. Ahmad, Ribarsky, and Reinsdorf (2017) estimate that in the UK, total investment would increase by only 0.04% if Uber drivers' cars were accounted for as investment which is far too low to contribute to the persistent slowdown in productivity observed. However, this is only one part of the change that can arise from variations in the treatment of consumer durables in national accounts, as is further explored in the next section, notably for the case of ICT services which, like cloud computing, are under-reported in official statistics (Byrne & Corrado, 2017).

There are undoubtedly measurement issues in the public sector, but the impact of these on economic output is less pronounced compared to the ones we already discussed. As most of public sector output is not distributed through markets (and even when this is done, the prices do not reflect the full costs but most often their labor inputs) it is hard to have reliable valuation data and even worse, reliable

[‡‡] https://www.bea.gov/data/special-topics/health-care
Accessed on 14/01/2020
[§§] There have been several initiatives across countries to report the profits from rental platforms and transport services

output price indexes (Hulten, 2010). This leads to cost based input measurements as a proxy for real output. With these reservations in mind, it appears that the sector has experienced a slowdown for the period between 1972 and 2015 in the US and across the EU. In the US even in the period 1995-2005 when the rest of the economy experienced an increase in productivity, in the public sector it stagnated (Gordon & Sayed, 2019). However, in the EU since 2005 labor productivity for the public sector recorded almost twice the rate of productivity growth compared to the rest of the economy (1.11% compared to 0.63% for the entire economy).

3.1.3 Informal sectors

In this section we consider the non-observed and the informal parts of the economy. This includes a range of activities that correspond to different motives and policy environments which shape economic measurement. At times, for example, flexible – informal – work arrangements might be encouraged, while others are made illegal and curtailed, and considered tax avoidance or in breach of regulations (SNA, 2008). Aspects of this include the household services that shift from own-consumption to the production boundary (discussed in the previous section), illegal market activities (such as the manufacture and distribution of narcotics, illegal transportation in the form of smuggling of goods and of people, and services which in certain jurisdictions are illegal, such as prostitution) as well as legal but unobservable exchange of and services (goods or services provided by ineligible or unregistered entities).

The informal sector is estimated to represent on average 17% of GDP in a sample of 162 countries during the period 1999 – 2007 (F. Schneider, Buehn, & Montenegro, 2010)[***]. The estimated size of the shadow economy is significant even in OECD economies, although thanks to better capture of informal activities, not least to address money laundering and terror financing concerns, it is reported to be declining. In the US the shadow economy is estimated to have dropped from 8.5% of GDP in 2003 to 5.1% in 2018, in Germany from 16.7% to 9.6% and in Japan from 11% to 8.5% during the same period (Enste, 2018; F. Schneider & Boockmann, 2018). Alternative methods for measuring the size of the shadow economy also point to a decreasing trend across most countries, with considerable variation in the extent of this decline (Medina & Schneider, 2018). However, the decline in the informal sector is unlikely to be a significant contributor to slowing productivity. For one, it is not clear that it is less productive than the rest of the economy, so its absorption into official data could work in the opposite direction and offset productivity declines. While the size of this sector is non negligible in scale, the sequencing of changes in the measurement of the sector's activities did not occur prior to the observed changes in productivity growth, so changes in the measurement of informal activities are not a satisfactory explanation of the slowdown.

3.1.4 Profit shifting activities

Profit shifting is another possible source of mismeasurement which has been increasing significantly since the early 1980s across OECD countries. It is worth emphasizing that not all forms of profit shifting affect national accounts in the same way. For example, profit shifting through intragroup

[***] In Sub-Saharan Africa the shadow economy is estimated at more than a third of economic activity (38%), in Europe and Central Asia it is 37% and in high income OECD countries it averaged 14%.

interest payments is not relevant, but transfer prices (the prices that each firm buys or sells at within its divisions, group and subsidiaries) and the offshoring of intangibles affect GDP, corporate operating surpluses, factor shares, and trade balances. The latter correspond to 6/7 of the profits globally shifted to tax havens (Tørsløv, Wier, & Zucman, 2018)[†††]. As a result, the missing profits of multinational firms can affect productivity estimates and possibly explain a part of the observed slowdown. It is estimated that the level of the misreported profits globally accrued to almost $600 billion in 2015 or 40% of the total multinationals' profits, mainly in the form of profits which are realised outside the country of incorporation of the multinational companies not being appropriately reported (Ahmad & Schreyer, 2016; Tørsløv et al., 2018). Global profit shifting comes predominantly from revenues originating from the OECD countries (Cobham & Janský, 2018). Bruner, Rassier, and Ruhl (2018) and Tørsløv et al. (2018) estimate that the US GDP for 2015 would be 1.5% higher if shifted profits were reported in the country in which the activity really takes place.

Interestingly, the rate of profit shifting has been rising since the 1970s with a sharp protracted increase after the 1990s until 2015. During that period (1970-2015) the pre-tax profitability of US multinationals in tax haven affiliates has increased from 50% to 350% compared to a rather stable 50% margin in non-haven affiliates. The large European countries are not excluded from this trend, as capital shares are apparently under-estimated by about 2 to 2.5 p.p for Germany, the UK, France and Italy, almost twice the 1.1 p.p figure found for the US (see Tørsløv et al. (2018)). Given the scale and timing of profit shifting, this could represent a significant part of the explanation of the slowdown. Profit shifting also helps explain the exceptional economic performance of the relatively small tax-haven countries, which unlike other countries have experienced robust GDP and productivity growth, particularly since the financial crisis. For example, in Ireland labor productivity growth ranged between 5.3-9.6% during 2009-2011 and despite the Euro crisis grew at 5.8% in 2014, a remarkable 21.8% in 2015, before settling back to 2.4% in 2016, still well above the Euro area growth of 1.8% in that year[‡‡‡].

Guvenen, Mataloni, Rassier, and Ruhl (2017) using confidential survey data of US multinationals, construct US GDP adjusted for profit shifting. Using this corrected measure of output, labor productivity growth was 0.25p.p. higher in 2004 to 2008, as compared to official statistics, and 0.09p.p. lower after 2008. These adjustments have direct effects on low tax countries GDP estimates too, not only for the smaller ones where the effects are 4-5 times their annual GDP for the period of study (like Bermuda, British Virgin Islands and Cayman) and also but also for countries like Ireland and the Netherlands where these activities are estimated to account for 9-13% of their annual GDP. Interestingly, the drop in the corrected measures in 2008-2014 might be related to multinationals' decision to exit the survey that was used to estimate these results.

3.2 Free goods and unmeasured surplus

There is a growing consensus in the literature that digital technology is increasingly affecting consumers directly, in ways that are excluded from the scope of GDP. In the framework of Hulten and Nakamura (2017), innovation can be 'output-saving'. Rather than saving inputs when TFP growth shifts

[†††] The statistics presented in (Tørsløv et al., 2018) are corrected for the share of shifted profits that affect macroeconomic outcomes.

[‡‡‡] Source: https://www.oecd-ilibrary.org/industry-and-services/oecd-productivity-statistics-volume-2017-issue-1/labor-productivity-growth-total-economy_pdty-v2017-1-table2-en

the production function, innovation implies that less (measurable) output is needed to achieve the same utility levels.

Departing from growth accounting, a large set of studies has been devoted to evaluating the effects of free or mismeasured digital goods on consumer surplus. Byrne, Fernald, and Reinsdorf (2016) and Byrne, Oliner, and Sichel (2017) evaluate the contributions of internet quality and e-commerce, finding that TFP growth in 2004-2014 would be only five basis points higher. Along with Syverson (2017), they review recent studies estimating the value of free digital goods, and found generally modest effects, even though the numbers vary considerably. One approach is to measure the time consumers spend online. With their valuation of individuals' time, Brynjolfsson and Oh (2012) estimate that the consumer surplus created by these services is around \$100 billion per year in the US alone, a significant number but one that still represents only 3.3% of Syverson's 'missing' \$3 trillion from the economy. Using much more generous assumptions, Syverson's (2017) find that the extra surplus from these services could be values to up \$863 billion, closer to explaining a third of the missing growth.

More recent estimates by Brynjolfsson, Collis, and Eggers (2019), using discrete choice experiments, suggests a rather high estimate, with the median consumer requiring \$17,530 to be willing to give up all search engines for a year. In contrast, using different valuation methods, for instance based on observed prices for internet tracking and advertising, Ahmad et al. (2017) find that Wikipedia represents an insignificant value as compared to GDP. They evaluate that adding advertising-funded 'free' media into household expenditures would increase GDP marginally, for instance 0.04 p.p for 2011-13 in the US. While the consensus in the literature appears to be that unmeasured consumer surplus from new digital services is not large enough to explain a major part of the productivity slowdown, there is a recognition that measuring the effects of the new wave of digital services on consumer welfare is imperfect.

Following the traditional accounting framework, L. Nakamura, Samuels, and Soloveichik (2017) model the impact of free goods on private businesses as business information that affects their intermediate inputs and as "consumer information" or "consumer entertainment" for households. Viewers of "free" goods are effectively paid to view advertising or marketing material, and this is subsequently matched to their cost of production. The impact of "free" goods on real annual GDP growth (for the US) for the period 1995-2014 would be around 0.089 p.p and TFG growth by 0.048 p.p. – not enough to be a major contributor to the productivity slowdown. While many free digital goods are financed by advertising, Ahmad et al. (2017) note that advertising-financed 'free' goods still appear in GDP through the higher price paid for the advertised products.

3.3 Quality adjustment of price indices

Increased efficiency and product quality may lead to lower measured real output and productivity if output statistics do not reflect improvements in the quality of goods and services. If, say, a constant number of units is sold but quality increases and the price stays constant, we would expect our true measure of real output to increase. This will only be the case if our price index is quality-adjusted, so that price per quality-adjusted unit decreases (Boskin, Dulberger, Gordon, Griliches, & Jorgenson, 1996; Gordon, 1990; Nordhaus, 1996). This issue has become even more relevant today due to the growth of the digital economy and ICT services (Abdirahman, Coyle, Heys, & Stewart, 2017).

A typical example that highlights this effect is that the price of a phone bill has remained largely unchanged over the last decade, yet the volume of text messages, minutes, and data provided in new bundles has grown substantially (OFCOM, 2014). Other examples related to smartphones are digital photos and high accuracy GPS services. In both cases, consumption (for example, number of photos taken) has increased rapidly, but the sales of standalone cameras and GPSs have gone down, and the quality-adjusted price of cell phones has reduced rapidly but not dramatically, by an annual average of 21.9 percent for the period 2000-2004, 15.3 percent for 2004-2008 and 16.3 for 2008-2014 (Byrne & Corrado, 2017).

Several recent studies have attempted to estimate quality-adjustment in key digital products. For instance, Abdirahman et al. (2017) find that official prices of telecommunication services could have fallen by up to 90%, instead of the 10% reported between 2010 and 2015. Byrne et al. (2017) suggest that the recent observed slowdown in decrease of microprocessor prices is an artefact of the matched model methodology adopted for constructing the PPI and disappears once a hedonic method accounting for wider dimensions of performance is adopted. Ahmad et al. (2017) found very significant differences between ICT-related price indices in different countries, and noted that this mismeasurement translates into an upper-bound revision to GDP growth rates of 0.2% per year. National accounts fail to pick up the actual impact of ICT technologies for another reason: as ICT moves from a commodity to a service delivery sector (through cloud computing and containerization) the demand for hardware appears to stall and the levels of utilization increase but are harder to detect (Byrne & Corrado, 2017). The strong growth in cloud services and system design services point to them making a bigger contribution on GDP, which may not be adequately identified. The productivity growth of the ICT sector based on corrected prices has been estimated at 1.4 p.p per year for the period 2004 –2014 largely due to prices falling at an annual rate of 26% for servers and storage. Even with these corrections, the slowdown in the ICT sector is real and the experience of the 1990s and early 2000s is likely a poor indicator for the relative productivity growth of ICT in the future (Byrne & Corrado, 2017).

Another well-known issue relates to the measurement of new types of goods. For example, the comparisons of tablets to (older) laptops is far from perfect. Statistical offices offer a range of techniques to compare "new models" with previous ones, including a matching process or judgmental adjustments[§§§] to construct price indices. While this is a difficult endeavour, it can be effective and does not necessarily lead to inflation: under competitive conditions, one can expect the prices of incumbent goods to move in tandem with the new good and capture a reasonable portion of the price change (Triplett, 2006).

More subtly, however, if new types of goods replace existing ones, the procedure followed by statistical agencies to impute price changes from the average of surviving products will overestimate inflation. This is compelling as an explanation of the productivity *paradox*, because this implies that it is precisely when creative destruction is accelerating that growth would be more significantly

[§§§] Lowe (1999) states: "The weakness of this method lies in that it relies on the skill and experience of the individual collector, on the fact that it is inconsistently applied, and that the collector's evaluation appears to be coloured by the price difference between the old and new items." Triplett (2006) adds that "whatever the merit of the judgemental quality adjustment method for, say, clothing, it is doubtful that it has much merit for the "high tech" electronic goods".

mismeasured.[****] Aghion, Bergeaud, Boppart, Klenow, and Li (2019) estimate that missing growth from this effect represented 0.5% annually in the US, with slightly higher numbers post 2006. Missing growth is mostly sectors such as hotels and restaurants rather than manufacturing and hence this explanation does not fit well the sequencing criterion.

Mismeasured ICT prices are likely to explain a part of missing productivity. However, the relatively small contribution of ICT to GDP, combined with the stagnating productivity growth in non-ICT sectors suggests that for reasons of scale this does not adequately explain the slowdown. Moreover, the relatively abrupt slowdown in productivity growth (at least in the US) was not preceded by a rapid change in ICT, so it does not satisfy our sequencing criterion. Nor does it satisfy our scope criterion, as countries with significant variations in ICT intensities and different adoption rates have experienced similar slowdowns, even when a range of corrected PPI and investment deflators are used for the relevant subsectors (Syverson, 2017).

3.4 Intangibles

A further source of mismeasurement arises from the distinction between intermediate inputs and capital. In the last decades, it has increasingly been recognised that many non-physical assets provide services over multiple years and should therefore be treated as capital rather than intermediates. If the growth of intangible investment is underestimated, output growth is underestimated because investment is a share of output. It also implies that inputs are mismeasured, because investment increases the capital stock, causing a bias in the decomposition of growth between capital and TFP.

3.4.1 What are intangible inputs and how mismeasured are they?

Corrado and Hulten (2014) and Corrado, Hulten, and Sichel (2009) consider three broad categories of intangible inputs: computerized information for software and data, innovative property for research and design, and economic competencies for advertising and organisational structures. One example for the last category is that they estimate that 21% of the wage costs of workers in management, marketing, and administration with tertiary education can be considered as investment into organisational capital. The 2008 revision of the System of National Accounts for the US, and the 2014 ONS National Accounts Blue Book for the UK, recognized the importance of accounting for intangibles, and included the capitalisation of certain types of R&D investment.

Measuring the stock of intangible capital and its depreciation rates is inherently difficult. Unlike tangible goods, where units are clearly defined, intangibles, such as intellectual property or branding, are difficult to quantify, even before any quality-adjustments are to be considered. The literature offers methods to calculate depreciation rates for various types of intangibles through R&D surveys or a 'software' model derived from a traditional industry surveys, complemented with accounts drawn from employment and wage data in specific occupations. An updated review of estimates of the depreciation

[****] This argument builds on the work of Feenstra (1994) on price indexes and product varieties, Bils and Klenow (2001) on the effect of product variety and quality adjustments, Bils (2009) on observed price increases of durable goods into quality changes and true inflation, Broda and Weinstein (2010) on the missing growth from entry and exit of products in the nondurable retail sector and Byrne et al. (2017) on the missing growth in the semiconductor sector.

rates can be found in de Rassenfosse and Jaffe (2018), who estimate a rate of R&D depreciation between 1-5%, although this rate can be higher in the first two years.

Natural capital is another form of intangible capital (corporations using allowances for emissions treat them as such in their books) and accounting for this, in the form of positive or negative externalities that enter the system of national accounts, has been the focus of a large strand of the literature that relates to intangible capital. Accounting for natural capital, in the form of positive or negative externalities that enter the system of national accounts, has been the focus of a large strand of the literature that relates to intangible capital. For example, the negative externalities due to air-pollution for some industries have been found to exceed their value added by 0.8-5.6 times (Muller, Mendelsohn, & Nordhaus, 2011). In this vein, Obst and Vardon (2014), describe the ways to include environmental assets in the system of national accounts while Schreyer and Obst (2015) demonstrate a consistent approach to account for energy and mineral resources with an application to Australia. Pertaining to the core argument of this paper Brandt, Schreyer, and Zipperer (2017) include the impact of natural capital in productivity measurements and show that the direction of productivity growth adjustments depends on the rate of change of natural capital extraction relative to the rate of change of other inputs. Similar work is underway at the IMF[††††] and the United Nations[‡‡‡‡].

3.4.2 How intangible mismeasurement affect productivity statistics

Investment, including intangible investment in principle, is a part of output. Thus, if the rate of growth of non-measured investment has risen in recent years, output growth in underestimated, and so is the growth of output per worker. Investment also increases the capital stock, which is itself an input in growth accounting. As a result, because TFP is computed as a residual, the mismeasurement of intangibles can have non-trivial consequences on measured TFP growth. Brynjolfsson et al. (2017), discussing the recent high growth in investment in artificial intelligence, point out that in initial stages of investment in a new domain, the growth rates of investment tend to be higher than the growth rates of capital, while the reverse is true in later periods. If investment and capital in this domain are not measured, this creates a TFP mismeasurement cycle: In early periods, output is more underestimated than inputs, so TFP growth is underestimated. In later periods, it is the effect of the capital stock that is more underestimated, so too much growth is attributed to TFP where it should be attributed to intangibles capital growth.

3.5 Summary

Recent studies have found that although there are significant measurement errors in national accounts, not least in the ICT sector, these have not worsened to the point that in their scale, sequencing or scope they would completely explain the slowdown in productivity growth. Neither has the economy dramatically shifted towards sectors where real output of final goods is thought to be underestimated, including heathcare. Nevertheless, there are two major findings in this section that appear to be linked. First, the digital economy does provide large unmeasured benefits, and there is a clear shift towards sectors and assets that are measured with more uncertainty, such as various forms of intangible capital.

[††††] https://www.imf.org/external/pubs/ft/qna/pdf/na.pdf
[‡‡‡‡] https://seea.un.org/home/Natural-Capital-Accounting-Project

Second, these assets can be moved to tax havens and escape official statistics as shown by the rapid rise in multinational profit shifting over the past two decades. While the introduction of ICT and other new technologies are challenging for measurement systems, as is profit shifting and the measurement of intangibles, the scale, scope and sequencing of introduction of these technologies and of changes in accounting for value added and intangibles does not provide an adequate explanation of the slowdown in productivity growth.

4. Labor force composition

Our growth accounting decomposition in Eq. 2 includes an input that covers potential explanations for the slowdown that are linked to the characteristics of the workforce. Within this input, we broadly categorise labor characteristics under education and skills, migration, ageing, leisure technologies, and labor market institutions. In this section, we examine aggregate measures of human capital accumulation, like educational attainment, and consider whether the skill mismatch may have increased. Demographic factors, including migration and ageing, may affect productivity in the future through direct channels (age-productivity relationships) as well as indirect channels (savings or shifting consumption preferences). We examine these and an emerging literature on the role of technology in lowering labor supply, as well as the possible impact of the recent rise of digital labor markets, before reviewing the discussion surrounding labor market institutions and concluding with an assessment of the possible contribution of issues associated with labor markets to the productivity slowdown.

4.1 Education and Skills

4.1.1 Educational Attainment

A possible explanation for the productivity slowdown could be a slowdown in educational attainment or a growing skill mismatch. The importance of education for labor productivity and wages is one of the most established relationships in the economic literature (Mincer, 1958). In a traditional framework, wages are equal to the marginal product of labor, and subsequent wage premia imply higher output (Heckman, Lochner, & Todd, 2006).

In this context a slowdown in productivity could be caused by a general slowdown in educational attainment in the advanced economies. The OECD provides data that differentiates between different types of education. The share of people with less than a secondary education dropped steadily (OECD total, France, UK), but subsequently stabilized (US and Germany), which is consistent with the literature on the plateauing of high school diplomas in the US (C. Goldin & Katz, 2008; OECD, 2017a). Meanwhile, the share of the population with tertiary education has been increasing in a stable, linear fashion for each country studied. Goodridge, Haskel, and Wallis (2016) also find that the labor force composition has improved overall in the UK. As a result, a secular slowdown in educational attainment is not a candidate explanation for the recent global productivity slowdown.

Whether this trend will be sustained going forward is unclear, and concerns have been raised about rising student debt (Gordon, 2016). In a recent paper, Corrado, O'Mahony, and Samek (2018) establish that growth in UK enrolment numbers, while still positive, has declined. The trend is similar in the US, where fees also increased significantly. However, credit constraints seem to have played a less significant role in the slowdown in university admissions in the US, given the high returns to education compared to the real interest rates faced by young scholars (Heckman et al., 2006). Jorgenson, Ho, and

Samuels (2016) point out that the emergence of IT-producing industries drove higher college premia, yet these are expected to plateau in the near future. They project that the rates of growth of average educational attainment to decline in the period 2014-2024. The forecasts in Bosler, Daly, Fernald, and Hobijn (2016) are similar, noting that educational attainment in the medium run could even turn negative if employment rates of low-educated workers rebound to pre-recession levels.

4.1.2 Skill mismatch

In view of the continued rise in educational attainment, a potential explanation for the productivity slowdown is that, while the overall supply of skills is still growing, there is mismatch between the supply and demand of specific skills. For instance, in periods of fast technological change, we should expect the skills associated to new technologies to be in too short supply and that skill biased technological change will lead to a differential impact on a range of occupations (Acemoglu & Autor, 2011).

There is a consensus that skill biased technological change led to the hollowing out of the wage distribution in the 2000s, when middle wage cognitive routine occupations were automated (Goos, Manning, & Salomons, 2014). This may have led to deskilling technological change, contributing to the skills mismatch and pushing workers with intermediate levels of education to take low productivity jobs. In combination with the emergence of digital platforms, a larger share of such workers now participates in the gig economy (Coyle, 2017).

Recent research on changes in the allocation of workers in the context of the productivity slowdown is inconclusive. On the one hand, Goodridge et al. (2016) find that employment was re-allocated towards high-productivity industries in the UK. Patterson, Şahin, Topa, and Violante (2016) calculate that most labor was reallocated to low productivity occupations, accounting for up to two-thirds of the slowdown. These findings can be reconciled by the fact that the latter considers sectoral differences in matching frictions, which means that a larger fraction of workers are placed in low productivity occupations irrespective of industry and employee characteristics. However, the extent of reallocation between sectors with high productivity *levels* makes it unlikely that reallocation between sectors is significantly contributing to the slowdown in productivity growth. Research by the OECD on cross-sectional data suggests that low mismatch is correlated, along with other factors, with good policies on bankruptcy laws, residential mobility, and the flexibility of wage negotiations (McGowan & Andrews, 2017).

4.2 Migration

Net migration has increased in the OECD countries since the 1960s with significant fluctuations as a response to business cycles as well as national policies and geopolitical events. These changes have manifested themselves with significant variation across countries and different categories of migration (OECD, 2018a). In practice, migration enters the productivity discussion by predominantly affecting labor supply. The productive use of migrants' skills and their reflection in national accounts cannot be ascertained a priori.

One approach to identify the effects of migration on productivity is to evaluate the impact of refugee waves on local economies. Studying the impact of events like the Mariel boatlift of Cuban refugees in the US has not led to a consensus on the employment, wage or productivity impacts (Borjas

& Monras, 2017; Card, 1990; Peri & Yasenov, 2015). There are several reasons for this outcome. First, surges in refugees have particular characteristics which differ markedly from each other, including in the origin, education, skills and age of the refugees and in their destination. Refugees also differ from migrants, who tend to be of working age and drawn to employment opportunities. The clustering of economic migrants in dynamic cities also differentiates their impact – they are both a source of dynamism and drawn by the dynamism of rapidly growing cities.

In both the US and European Union, the impact of immigration on productivity has been shown to be positive (Beerli & Peri, 2017), with immigrants contributing both skills and entrepreneurial activity (Borjas & Doran, 2012; Mitaritonna, Orefice, & Peri, 2017; Ottaviano, Peri, & Wright, 2013). One study suggests that they are three times more likely to be innovators and start businesses than the average citizen, in part because they are more likely to move to highly productive areas in the first place (MGI, 2016). Peri (2012) shows that immigration is positively correlated with TFP growth in the US, with the efficiency gains larger for unskilled workers than skilled. Comparing migration flows in OECD economies against their impacts on labor markets and controlling for the skills of immigrants, Boubtane, Dumont, and Rault (2016) found that the US and Germany exhibit productivity changes close to zero or even negative, while the UK and France benefited from these inflows.

The effects on entrepreneurship are also significant: 40% of all Fortune 500 companies were founded by first- or second-generation immigrants, and more than half of US startups valued at $1 billion or more before going public (often referred as unicorns) have at least one immigrant co-founder (I. Goldin, Pitt, Nabarro, & Boyle, 2018). Immigrants accounted for 28.5% of all new US businesses formed in 2015 despite accounting for just 14.5% of the overall US population. In addition, in both the UK and US they are almost twice as likely as the native-born population to establish their own business (I. Goldin, Cameron, & Balarajan, 2011).

Despite the role that migrants can play in enhancing innovation and productivity, it is not possible to link the decline in labor productivity growth to changes in migration policy. In terms of our criteria of scale, sequencing and scope, the large fluctuations between countries and across time in migrant inflow do not match changes in productivity, which typically predate significant changes in migration policy in OECD countries. To give one example, the addition in the period 2000 to 2004 of 15 countries to the Schengen area of Western Europe, which allows free migration, did not lead to increased productivity. Meanwhile, Japan has experienced a decline in aggregate productivity on the same scale as Germany, despite Germany having experienced significant inflows of migrants.

4.3 Ageing

Two demographic trends are responsible for an ageing population globally: increasing longevity and declining birth rates. Research for the US documents an overall improvement in life expectancy across all age groups, with the possible exception of US late-middle-aged white males (Case & Deaton, 2015). In other advanced countries and in many emerging economies, similar trends in life expectancy are evident, with a resulting surge in the number of people aged over 65 as a compared to those aged 16-64. The notable exception is Africa which is still experiencing a youth bulge (*World population prospects: The 2017 revision*). Here we discuss three potential effects of ageing on productivity: a direct effect due to a link between age and productivity, a macroeconomic effect of ageing on saving rates, and a structural change effect due to changing patterns of demand.

4.3.1 Age and productivity

Understanding how productivity changes with age is often problematic due to selection bias (old workers remain in the workforce because of good health, and are therefore not representative), omitted variables in determining wages (seniority and anti-ageism laws), and generational effects (Lee, 2016). Analysing Austrian data, Mahlberg, Freund, Crespo Cuaresma, and Prskawetz (2013) neither determine a negative correlation between firms' productivity and their shares of older employees, nor find evidence of overpayments. In a similar strand, Börsch-Supan (2013) examine the relevant empirical literature attempting to estimate a decline in productivity linked to ageing and rebuke this hypothesis. The concerns regarding lower productivity of the older population also are largely dismissed in a report by the US National Research Council (NRC, 2012).

While firm-level evidence hardly points at negative effects of age on productivity, regional or country level differences offer a different perspective. Maestas, Mullen, and Power (2016), exploiting variation across US states, find that a higher share of population above 60 is associated with slower labor force growth and slower labor productivity growth, and report sizable effects: per capita GDP growth during 1980-2010 was 9.2% lower than what it would have been if the share of under 60 had been constant. Liu and Westelius (2016) find that the share of mid-age population at the prefecture level in Japan was positively associated with higher productivity growth. Liu and Westelius (2016) find that the share of mid-age population at the prefecture level in Japan was positively associated with higher productivity growth. Recent research has investigated the link between ageing and entrepreneurship, with Liang, Wang, and Lazear (2014) finding that countries with an older population exhibit lower rates of business formation.

Overall, this suggests that the effect of age on productivity is, if anything, indirect. For instance, it is possible that firm-level productivity is not affected by age, but aggregate regional productivity is affected by age because the structure of demand is different; we come back to this issue below. In any case, while gradual ageing may explain some of the secular decline in productivity, it does not provide a good explanation for the sharper collapse observed in the US after 2004, or in other countries after the crisis.

4.3.2 Macroeconomics of ageing

Population ageing affects the availability and rates of returns of both labor and capital inputs, but there is no consensus on the nature and extent of the effect on productivity (Lee, 2016). Lee (2016), Eggertsson, Mehrotra, and Summers (2016) and Teulings and Baldwin (2014) argue that ageing may have an indirect effect in causing secular stagnation by driving interest rates to the zero lower bound. Lower and negative population growth rates would increase the supply of savings, to the extent that individuals need to save for retirement. At the same time, a higher saving rate would lead to lower demand for consumption goods, reducing investment opportunities for firms. Both shifts lead to a lower equilibrium rate of interest. However, Eichengreen (2015) found that empirically increases in dependency ratios have roughly equally negative effects on both the demand and supply of savings.

An ageing labor force combined with low cost of capital also leads to a stronger incentive towards capital-biased technical change, leading to higher productivity. Acemoglu and Restrepo (2017) observed a faster rate of adoption of automation in countries with older populations, which more than offsets any effects on output caused by labor scarcity. However, the direction of this effect may well reverse once the shift in the population pyramid becomes more pronounced in the coming decades.

4.3.3 Consumption patterns and Baumol disease

Some sectors intrinsically have slower rates of technological progress, often because by their very nature it is difficult to incorporate new machines and technologies in their production process. This ``cost disease'' observed originally for orchestras by Baumol and Bowen (1966) has important consequences for aggregate productivity growth: if for demand-side reasons the share of low-productivity growth sectors tends to increase, aggregate productivity growth may be expected to slow down.

Consumption baskets may change drastically as individuals age, so aging is a potential source of a shift of aggregated consumption baskets towards low-productivity growth sectors, as healthcare and entertainment are often seen as low productivity growth sectors. Siliverstovs, Kholodilin, and Thiessen (2011), using country-level panel data, found that an older population was associated with a shift of employment shares away from agriculture and industry towards personal services and the financial sector. Moreno-Galbis and Sopraseuth (2014) find that ageing helps explain job polarization, as it increases the demand for low wage personal services. While aging may have a non-negligible effect, we will see in Section 6.1 that the overall magnitude of the changes in sectoral shares appears too small to explain a large part of recent the productivity slowdown.

4.4 Leisure technology and labor supply

New leisure technologies could play a role in labor force participation rates. Hall (2017) points out that an additional 1.6 hours for men and 1.2 hours for women are spent every week on leisure activities, which largely include time watching television and playing video games. Aguiar, Bils, Charles, and Hurst (2017) directly relate improvements in technology to increasing leisure demand and find that this explains a large part of the decreasing labor supply of young males. However, Bridgman (2018) develops a method to impute the value of leisure time for the post-war period in the US, and found that household consumption of digital goods is not large enough to have a significant impact on the value of leisure; in fact he finds that the productivity growth of leisure time has been falling.

A more direct channel is that digital technologies may disrupt productivity directly, for example because of working hours spent on social media, and indirectly, by forming new distracting habits that reduce capacity to work (Khawand, 2010; Mark, Gudith, & Klocke, 2008). While intuitively attractive, this area still lacks thorough economic analysis, given that it presents an important measurement challenge. In fact, it is not immediately obvious which direction this bias would take; while such habits certainly could worsen productivity at work, the same technologies may have enabled a rise in working time outside the office, while commuting, at home, travelling or on holiday. Time-use surveys could provide an opportunity to investigate this phenomenon.

4.5 Labor market institutions

Labor market institutions create the frameworks within which labor markets operate. Such structures do not directly change the labor force composition, and thus generally manifest as a residual item in a standard productivity decomposition. We synthesize the literature on this by identifying three ways by which labor market institutions may have contributed to the slowdown in labor productivity growth: labor hoarding, worker mobility, and digital labor markets.

4.5.1 Labor hoarding and wage flexibility

Labor hoarding, by which firms keep workers on the payroll despite falling demand to avoid future re-hiring costs, may have become more significant since the financial crisis. If output decreases but paid hours worked is constant, labor productivity falls. As noted by (Askenazy et al., 2016), institutional differences across European countries suggest that different propensity of labor hoarding may explain some differences in countries' experiences post-crisis.

Hoarding may be easier in countries where wages are less rigid, such as the UK. Pessoa and Van Reenen (2014) make the point that low unemployment with low productivity growth in the UK after the crisis can be explained by high wage flexibility. After the financial crisis hit, workers accepted a lower real wage, and unemployment recovered quickly. Combined with credit constraints that made capital less attractive, firms substituted capital with labor, resulting in lower capital per worker ratios that are detrimental to labor productivity. This may explain the lower contribution of capital deepening to labor productivity growth post the financial crisis.

4.5.2 Worker mobility

Using harmonized measures of job creation and destruction in a sample of industrial and emerging economies, Haltiwanger, Scarpetta, and Schweiger (2014) find evidence that stringent hiring and firing regulations tend to reduce the pace of job reallocation. Cette, Fernald, and Mojon (2016) looked into the productivity effects from anticompetitive regulations in product and labor markets and simulate the effects of large structural reform programs. Their results suggest that all countries could expect sizeable gains in TFP from the implementation of pro-competitive regulation practices. However, considering regulation more broadly as an explanation of the productivity slowdown, Fernald, Hall, Stock, and Watson (2017) found no evidence that industries with the highest increase in regulation (measured by a text-based index) generally experience slower productivity growth.

In the labor market, worker mobility may be hampered by noncompete agreements, whereby employees agree not to join competing firms within a particular timeframe or location. (Starr, Prescott, & Bishara, 2019) find that such agreements bind 20% of labor force participants in the US at any given point in time, with measurable effects on wages for both high- and low-skilled workers. They estimate that signing a noncompete agreement before accepting a job raises wages by almost 10%. (Fallick, Fleischman, & Rebitzer, 2006) suggest that the difficulty in enforcing noncompete clauses in California is a prime reason for high rates of job-hopping in Silicon Valley, which has facilitated the diffusion of talent and spurred innovation. "No-poaching" agreements are similar in nature to noncompete contract, but are agreed between employers instead of between employers and their employees. (Krueger & Ashenfelter, 2018) find that a staggering 58% of major franchises in the US include agreements by which employers agree not to 'poach' employees from each other. They are particularly widespread in low-wage occupations in the US and provide a potentially fruitful area for future research into the effects of restricted competition on labor market outcomes.

4.5.3 Digital labor markets

In the UK, a persistent increase in self-employment, zero-hour contracts, and the rise of the "gig economy" may be responsible for a recent increase in unskilled labor (Coyle, 2017). In addition to skill mismatch (see Section 4.1.2), the gig economy may be detrimental to overall labor productivity because, as compared to longer-term job contracts, it is associated with lower rates of investment in skill accumulation, experience and lower levels of loyalty of workers to their contractors. In spite of this, such platforms often improve utilisation rates for certain services, with the most notable case being that of Uber (Cramer & Krueger, 2016). This may enhance skill matching, especially for rarer skills, and reduce hiring costs (A. O. Nakamura, Shaw, Freeman, Nakamura, & Pyman, 2009). While the effects of digital labor markets on unemployment duration are covered extensively by Kuhn and Mansour (2014) and work cited therein, their effects on wages and productivity are not clear (Cramer & Krueger, 2016). Goldfarb and Tucker (2019) also emphasise the role of collaboration through digital platforms, although much of this is constrained within traditional boundaries of the firm. A benefit from the digital platforms is that they provide new, large-scale and precise data on labour markets, expanding the boundaries of research going forward.

4.6 Summary

The growth accounting exercise set out in Section 2 suggests that changes in labor force composition are not a significant explanation for the slowdown in labor productivity. However, technology has made specific skills scarce and others obsolete, possibly increasing a skill mismatch and worsening TFP growth. This is likely to become more significant as artificial intelligence and associated technologies substitute for and augment different segments of the workforce in the coming decades.

There are concerns that an older population may be less entrepreneurial, and that older consumers may also shift consumption towards low productivity growth services. However, ageing also increases incentives for automation. The effect of an ageing population may also be felt through the operation of capital markets, but again in a direction that is not obvious a priori. Ageing is pervasive in developed countries, satisfying our scope criterion. Some reported estimates suggest that the scale may also be non-negligible. However, ageing fails our sequencing criteria: it may contribute to secular patterns, but clearly cannot explain a more sudden drop in productivity. The argument that new leisure technologies may decrease labor supply remains under-researched, but presents potential avenues for future work. Changes to labor market institutions are emerging from the introduction of digital platforms, which may fit the sequencing and scope of the slowdown. TFP would capture many of these elements as they are currently measured, which underscores the earlier point that future productivity growth is largely a result of the efficient use of skills, rather than simply their supply.

5. Physical and intangible capital

As we have seen in Section 2, labor productivity decompositions show that while TFP is the dominant factor, a slowdown in capital deepening is also a major cause of the slowdown. For the US, TFP and capital deepening each contributed only 0.5 p.p to labor productivity growth in the post 2004 period, against 1.7 p.p for TFP and 1.2 p.p for capital in 1995-2004 (Baily & Montalbano, 2016). We review several reasons for the slowdown of investment: a cyclical slowdown due to the financial crisis, an increase in market concentration, and the nature of intangibles.

5.1 Cyclical effect from the financial crisis

Decomposing cyclical and secular factors is particularly important in order to understand whether slow labor productivity growth is "the new normal" or not.

For the OECD, Ollivaud, Guillemette, and Turner (2016) compute that (trend) labor productivity growth fell from about 1.8% to 1% from 2000 to 2008, with most of the decline being due to the slowdown of TFP growth from about 1% to 0.4%. In contrast, the post-crisis period was marked by a further decrease of trend labor productivity growth which can be attributed to a slower growth of capital deepening.

The TFP slowdown also started before the crisis in the US. But while a slowdown in investment may be responsible for part of the post-crisis slowdown, Fernald et al. (2017) argue that investment had a "normal" cyclical behavior, and the particularly disappointing recovery must thus be attributed to slower TFP growth and weaker labor force participation. This finding is based on removing cyclical fluctuations based on the assumption of a stable relationship between macroeconomic variables (for example, output) and unemployment (Okun's law) and comparing investment with previous periods of recovery. But simpler or alternative methods lead to similar evaluations (see, for example, the discussion by Reichlin in Fernald et al. (2017). Most strikingly, the capital-output ratio returned to its pre-recession trend in these models.

We list three explanations for a cyclical crisis-driven slowdown of investment. The first is that the crisis led to a substantial increase in financial frictions. The returns on productive capital (including intangibles) have remained relatively stable around 6.5%, while the returns on safe assets have decreased, suggesting a substantial increase in the risk premia. This has been the case since 2000, but has become more marked since the financial crisis of 2008 (Caballero, Farhi, & Gourinchas, 2017). Besley, Roland, and Van Reenen (2020) derive an aggregate measure of credit frictions by modelling firms' probability of defaulting, and find that credit frictions may have contributed to a half of the 9.3% fall in labor productivity levels between 2008 and 2009.

The second explanation for procyclical investment behavior is that depressed aggregate demand led to slower investment growth (Askenazy et al., 2016). Calibrating investment equations for the OECD with an accelerator effect, whereby investment depends on output, Ollivaud et al. (2016) estimate that the demand shock from the financial crisis may explain half of the decreased contribution of capital to labor productivity growth. Using a different method and looking at the US, Reifschneider, Wascher, and Wilcox (2015)'s unobserved components model also suggests sizable effects of the financial crisis on output, through a lower potential output endogenous to these demand shocks.

The third is that government investment also fell post-crisis, contributing around a fifth of the fall of investment as a share of GDP, with potentially longer-run (and harder to measure) consequences for productivity (Ollivaud et al., 2016).

We will discuss the role of intangibles as a secular trend below, but we briefly note here two ways in which the financial crisis affected intangibles and TFP. First, the negative consequences of a lack of investment in infrastructure also apply to "soft" infrastructure. These "public intangibles", as defined by Corrado, Haskel, and Jona-Lasinio (2017b), are built from investments in information, scientific and cultural assets, and investment in societal competencies, such as human health and knowledge capital built through a nation's health and school systems. Second, Redmond and Van Zandweghe (2016), looking at US data, found that stricter credit conditions prevailing during the crisis led to a substantial decline of R&D investment, and thus of TFP growth.

5.2 Structural effects

While it is clear that investment is pro-cyclical, it is less evident that investment is behaving "normally". Using data on publicly traded firms in the US, Alexander and Eberly (2018) found that the slowdown of investment relative to fundamentals started in the early 2000s, and ascribed this to two factors: a shift of investment towards industries in which capital cannot be relocated easily (for example, energy production or telecommunication transmission), and a shift toward intangibles.

Another factor unrelated to the crisis is increasing concentration and decreasing competition. Average markups in the US have more than tripled since 1980 across almost all industries, mostly driven by an increase at the top decile, and De Loecker and Eeckhout (2017) argue that this is due to an increase in market power, rather than higher costs. Gutiérrez and Philippon (2017) find evidence for the US that decreasing domestic competition leads to lower investment, especially into intangible assets, by the industry leader. Through causal analysis with three different identification strategies, they find that investment would increase significantly with higher competition, even if it were only through the threat of entry of competitors. As we will discuss in Section 6.2.4, however, the relationship between concentration, competition, investment and innovation is not straightforward and increased concentration may be a sign of increased competition benefitting to most productive firms. Haskel and Westlake (2017) use data from a handful of OECD countries to demonstrate how the rise in markups is particularly pronounced in industries which are intensive in their use of intangible capital. Thus, while the rise in markups may reflect a rise in market power, markups did not increased substantially once capital stocks are adjusted for intangibles (Ayyagari, Demirguc-Kunt, & Maksimovic, 2018). Other explanations for the low investment rates may still be necessary. Declining investment rates could also be due to an increase in short-termism amongst top managers (Haskel & Westlake, 2017; Lazonick, 2014). In firms where the pay of the top management is linked to firm performance on the stock market, with the purpose to align the incentives of managers with those of the firms, Lazonick (2014) finds that an increasing amount of resources are spent on stock buybacks instead of long term investment which would improve productivity. Similarly, Gutiérrez and Philippon (2017) argue that this change in corporate governance within a large number of firms led to lower investment rates in long-term projects.

5.3 Intangible capital

Broadly defined intangibles have been the largest systematic driver of growth over the last 50 years (Corrado & Hulten, 2010) and represent a growing share of investment in the US, the UK and Japan (Corrado et al., 2009; Fukao, Miyagawa, Mukai, Shinoda, & Tonogi, 2009; Haskel & Westlake, 2017; Marrano, Haskel, & Wallis, 2009). In fact, business investment in intangibles has been higher than investment into tangible capital since the late 1980's.

Once the stock of intangibles is accounted for, capital deepening in revised accounts is responsible for half of labor productivity growth in the US, and TFP contributions decrease accordingly

(Corrado & Hulten, 2014). In fact, absorbing R&D intensity into a separate TFP term shows that tangible capital deepening explains no productivity gains whatsoever (Fernald & Jones, 2014; C. I. Jones, 2002). According to these calculations, R&D intensity alone explains up to 58% of productivity growth in the US between 1950 and 2007.

These startling effects on productivity bring us back to the nature of intangible capital, which allows established firms to accumulate market power (Haskel & Westlake, 2017). This happens because some forms of intangible capital benefit from synergies, such as knowledge capital that can be recombined into new forms and is often easy to scale at near zero marginal cost, thus generating increasing returns for incumbents. Additionally, smaller firms or startups can face barriers to entry in the form of funding opportunities, since the difficulties related to valuing such capital make it hard to list as collateral. Intangible investment of larger firms can also benefit smaller firms, for example through the diffusion of new technology.

Precisely because of their higher spillover effects compared to tangible capital, a slowdown in intangible investment is worse than a slowdown in physical capital investment. As a result, while there is evidence that investment into intangibles has been impacted by the financial crisis to a lesser extent than tangible investment, its overall adverse impact on labor productivity might have been worse. This idea is reinforced in Goodridge et al. (2016), who suggested that part of the TFP growth slowdown might be due to missing lagged spillovers, resulting from the slowdown of R&D investment in the 90's and 2000's. Corrado, Haskel, and Jona-Lasinio (2017a) find a substantial effect of intangible investment on TFP growth. Using EUKLEMS data for 1998-2007, they estimate a contribution 6 times as large for intangibles than for workforce skill. They also find evidence that the returns to ICT capital are stronger when intangible capital is higher, in line with the idea that there are complementarities between ICT capital and intangible capital (Brynjolfsson et al., 2017).

A shift of capital towards intangibles could also dampen risk appetites as investment in intangibles is generally sunk and thus riskier. Consequently, the more economies shift to higher shares of intangibles in production the more the risk profile of the capital stock is deteriorating (Haskel & Westlake, 2017). This effect was also amplified during the financial crisis, as credit constraints may have affected productivity by reducing intangible investment, which is more difficult to use as collateral than physical investment. (Duval, Hong, & Timmer, 2017) present evidence that the financially more vulnerable firms had a higher decline in TFP growth after the crisis, and this effect was stronger in countries with a higher credit supply shock

Besides R&D, intangibles also include economic competencies and good management practices. Haldane (2017) argues that management practices are indeed a good predictor for productivity at the firm level, and slower diffusion of best practices could help explain the productivity gap between frontier and laggard firms, which we discuss in the next Section. To translate into productivity improvements, technological change often requires a change in companies' internal processes and organization. During the productivity paradox of the 90's, insufficient organizational change was identified as one of the key points holding back technology diffusion (Brynjolfsson, 1993; Brynjolfsson & Hitt, 1996; Brynjolfsson & Hitt, 2000). Similar arguments can be made today, where organizational change complementary to the development of AI are just starting and will take time to fully impact on businesses and productivity (Brynjolfsson et al., 2017).

5.4 Summary

The weakness in investment is a major cause of the slowdown. The key question is whether investment has declined because of cyclical or structural reasons. On the one hand, cyclical explanations are strong – the financial crisis depressed aggregate demand, and increased financial constraints, both for firms and governments. These effects have been evaluated quantitatively and taken together can account for a sizable portion of the decline in the post-crisis period. The financial crisis was global, and we may expect financial frictions to be affected in a relatively similar fashion in all countries. On the other hand, the slowdown in investment started, at least in the US, in the early 2000's, before the crisis, so structural explanations are necessary to account for the part of the slowdown due to lower capital deepening. Several explanations have been put forward, such as a higher share of intangible capital, a decline in competition, and a rise in short-termism, all of which may have applied relatively similarly in advanced economies, satisfying our scope criteria, and that taken together have a plausibly important impact, satisfying our scale criteria.

6. Productivity dispersion

Growth decomposition suggests that most of the secular slowdown is due to a slowdown of TFP. TFP is a residual, so many factors that are not directly measured as inputs can affect it, but it remains customary to think of TFP growth as mostly driven by technological progress. When considering aggregate TFP, however, it is important to realize that growth can be due not only to technological progress of smaller units, but also to a change in the relative sizes of the different units.

In this section, we first discuss the idea that productivity is slowing down because low productivity growth sectors are becoming a bigger part of the economy, a classic theme of the previous productivity slowdown literature. Next, we review the recent work on the distribution of firm-level productivity, which points to the simultaneous rise of superstar firms co-existing with zombie firms, suggesting that misallocation has increased and knowledge diffusion from frontier to laggard firms has slowed down. Finally, we briefly discuss the evolution of regional disparities.

6.1 Sector-level productivity growth and structural change

Are some specific sectors responsible for the slowdown and are stagnating productivity sectors becoming a larger part of the economy? William Baumol famously pointed out that aggregate productivity growth would under certain conditions asymptotically equal the rate of progress of the slowest industry (Baumol, 1967). In the context of the productivity slowdown, it may well be that the rapidly innovating sectors are capturing a declining share of total output, or are not systemically important (Oulton, 2001).

Decomposing the growth of US TFP by sectors shows that manufacturing, wholesale and retail trade, services and agriculture were responsible for a large fraction of both the acceleration of aggregate TFP growth between 1995-2004 compared to 1987-1995, and its slowdown in 2004-2015 compared to 1995-2004 (Baily & Montalbano, 2016). This highlights a point often emphasized by Gordon (2016): productivity growth can be thought of as an adjustment of the levels, with an innovation leading to a new normal level of productivity, that is, a transitory period of high productivity growth. Baily and

Montalbano (2016) relate the experience of the retail sector to the rise of large scale retailers driving out small shops, until they reached overcapacity in the post 2004 period.

Using a different sectoral aggregation, (Cette et al., 2016) found that in the US most of the 1990's productivity surge was due to ICT producing industries. Consistent with (Baily & Montalbano, 2016), market services such as retail had a strong productivity growth in the early 2000's, benefiting from ICT-related reorganization, but fell back to lower growth after 2004. Murray (2017) found that almost all the slowdown in average labor productivity growth between 1995-2004 and 2004-2015 in the US can be explained by a within sector slowdown, with labor reallocation playing no role. (Byrne et al., 2016), using new TFP growth rates while keeping industry shares fixed to 1987, do not find any evidence that growth of low TFP growth industries as a share of output explains much of the productivity slowdown. If anything, it complicates the puzzle. However, using a different period (1947-67 vs 1996-2016), dataset (World KLEMS), and measure of productivity (output per unit of labor services), Duernecker, Herrendorf, and Valentinyi (2017) found that that around a third of the slowdown can be attributed to changing shares. Taken together, this suggests that Baumol disease may be behind some of the secular decline, although the slowdown in recent years is hardly associated with changing sectoral shares.

In the UK, Haldane (2017) and Billet and Schneider (2017) examined productivity growth trends at the sectoral level pre- and post- financial crisis and found that all sectors have been affected by the recent slowdown in productivity growth. Goodridge et al. (2016) show that 35% of the TFP growth slowdown can be explained by the performance in the oil and gas, as well as financial service industries, while Haldane (2017) notes that financial services account for almost a third (0.5% out of 1.7%) of the pre- vs post-financial crisis difference. Tenreyro (2018) traced three quarters of the productivity slowdown to manufacturing and finance (post vs pre- financial crisis, excluding 2007-09), with ICT and professional, scientific and technical services explaining the rest. In manufacturing, the slowdown in labor productivity growth is due to both a slowdown in capital deepening and TFP, which themselves may be attributed to both low levels post crisis but also high levels pre-crisis. A one-off improvement due to structural transformation and offshoring was taking place during the 2000-07 period, creating a sharp contrast between pre- and post-crisis periods. The slowdown is also marked in finance, because of a pre-crisis high level, perhaps partly due to measurement issues. In contrast to manufacturing, the slowdown can be overwhelmingly attributed to TFP, not a lack of investment.

Attempting to summarize the industry-level evidence on both sides of the Atlantic, (Gordon & Sayed, 2019) interpret the European experience as similar to the US but with a lag. They do confirm that the productivity growth surge of 1995-2005 is a US experience, by contrast to the rather clear and uninterrupted downward trend in Europe after the 1970's, as shown in (Bergeaud et al., 2016). On the industry level, (Gordon & Sayed, 2019) make it clear that most of fluctuations (upward and also downward, with the slowdown) are due to commodities-producing industries, not services. Looking at OECD STAN data for 10 countries, Cantner, Graf, and Prytkova (2018) confirm that the slowdown is mostly due to a within sector decline, particularly strong and consistent across countries in manufacturing industries.

Taking stock of this literature, it does not seem like Baumol's cost disease is a valid explanation for the current productivity slowdown, since sectoral shares of GDP have not changed significantly. However, key sectors that are large in size experienced a significant productivity slowdown, especially when compared to the previous decades where they tended to overperform. The industry-level evidence suggests that the current slowdown may reflect a pause in the adjustment of productivity towards higher levels made possible by the ICT revolution.

6.2 Firm-level productivity dispersion

There are strikingly large productivity differences between firms, even within highly disaggregated industries (Andrews, Criscuolo, & Gal, 2016; Syverson, 2011). Dispersion is, at first sight, a sign of misallocation – if productivity levels are given, aggregate productivity would increase if the inputs of low productivity firms were reallocated towards high productivity firms. Thus, aggregate productivity growth is driven not only by an increase in the average productivity of firms, but also by increasing allocative efficiency: low productivity firms shrinking or exiting, high productivity firms growing faster, and new entrants being more productive on average.

As a result, even if the average productivity growth of existing firms was constant, a productivity slowdown could occur as a result of a decline in allocative efficiency alone. We start by discussing some salient empirical patterns that suggest that this may be the case: entry-exit rates and job reallocation flows have declined, and productivity dispersion has increased. To interpret these facts, we provide a discussion of the recent advances on the measurement of misallocation. We then briefly discuss potential causes, including lower competition and technological change.

6.2.1 Falling business dynamism

Over the last decade, a decline in business dynamism has been documented, mostly using two indicators. First of all, the prevalence of young firms in the US economy appears to have declined. Decker, Haltiwanger, Jarmin, and Miranda (2014) and Foster, Grim, Haltiwanger, and Wolf (2019) document a decline in the share of employment young firms. While the decline appears secular at an aggregate level since the late 1980s, it hides a substantial boom and bust in the high tech sector in the period 1995-2005, which coincides with the labor productivity revival for the US. Gutiérrez and Philippon (2017) show that in the census data, entry and exit rates have fallen since the 1980s, from around 0.13 to around 0.09 in 2015.

Second, employee flows have decreased. Hyatt and Spletzer (2013) document that hires, separations, job creation, job destruction, and job-to-job flows have all declined since the late 1990's, in a staircase fashion (stable during normal time and falling during recessions). About half of this decline is due to the decline in single quarter jobs, and compositional effects (such as an aging population) do not explain entirely the decline.

Decker, Haltiwanger, Jarmin, and Miranda (2018) contrast two explanations for a slowing job reallocation: either the dispersion of the shocks has decreased, or frictions and adjustment costs have affected the responsiveness to these shocks, that is, firms with higher productivity did not increase employment as quickly or strongly. They find that responsiveness has decreased, particularly for young firms in the high tech sector. While this lower reallocation was driven by the consolidation of the retail sector into highly productive "big-box" (large volume) shops in the pre-2000 period, the post-2000 slowdown in job reallocation is associated with ICT producing and using sectors[§§§§].

Overall, however, business dynamism statistics are a direct but imperfect measure of creative destruction. For instance, if the dominant source of innovation is innovation by incumbents, an acceleration or slowdown of innovation will not be reflected in business dynamism statistics (Hsieh & Klenow, 2018). As a result, rather than documenting reallocation, the recent literature attempts to evaluate misallocation and the changes in allocative efficiency. Before delving into the methods and results from this literature, we discuss the evidence of productivity dispersion.

6.2.2 Superstar vs zombie firms

There is a substantial divergence between firms at the 'frontier,' defined as the top 5% most productive firms in the distribution, and the rest of the firms, in a sample of 23 OECD countries (Andrews et al., 2016). Those at the frontier have increased their productivity by around 40% on average since 2010, while the rest experienced slow, if any, productivity growth. The firms with the highest productivity growth tend to be exporters, foreign-owned, located in productive regions, concentrated in a small number of sectors, relatively larger, and invest substantially in R&D (Haldane, 2017). Moreover, superstar firms tend to arise mostly in sectors that are characterized by high patent intensity (Autor, Dorn, Katz, Patterson, & Van Reenen, 2017), or, more generally, by intangible capital intensity (Haskel & Westlake, 2017).

In addition to this divergence, there is an observed decline in turnover at the productivity frontier (Andrews et al., 2016). Out of the firms at the top 5% of the productivity distribution, there are now significantly more which were already at or near the frontier two years before, as compared to a period at the beginning of the 2000s. In fact, the UK the productivity slowdown post-crisis emerges from the slowdown in productivity growth for the already-productive firms at the frontier (P. Schneider, 2018).

In contrast to superstar firms, zombie firms can be thought of as firms that manage to survive despite negative productivity. While many unproductive firms failed during the financial crisis, a significant fraction of them are still in operation. Among the reasons for this lack of exit are the lack of competitive pressure and bank forbearance (Andrews et al., 2016; Andrews, McGowan, & Millot, 2017). Since the financial crisis, quantitative easing and the associated exceptionally low interest rates have allowed zombie firms to live on cheap credit, with fiscal forbearance through tax exemptions and subsidies increasing the life of firms, not least those with political weight arising from their large number of employees or significance to the local economy.

Zombie firms hold labor and capital that could otherwise be employed more productively. Citing evidence from Japan, Caballero, Hoshi, and Kashyap (2008) emphasise that zombie firms also hamper productivity growth rates in healthy firms by appropriating not just inputs, but also bank lending. However, as Haldane (2017) and Arrowsmith et al. (2013) point out, the effects on aggregate productivity of the exit of those zombie firms would not be very large, so forbearance is unlikely to

[§§§§] Redmond and Van Zandweghe (2016) investigated whether credit conditions affected TFP through job reallocation. Tighter credit constraints led to a lower rate of creation of new and potentially more productive jobs, but also to a higher rate of destruction of (presumably less productive) jobs. As a result, the overall effect of credit constraints on reallocation and thus TFP growth was likely to be small.

account for a large proportion of the missing productivity growth. Thus, while the persistence of low productivity firms suggests that productivity could be improved by reforming exit policies (Andrews et al., 2017), explain the full scale of the productivity slowdown requires establishing a broader decline in the contribution of allocative efficiency to growth.

The prominence of the discussion of zombies and superstar firms makes it clear that the size of the tails of the productivity distribution matter are important. As we will see in the next section, other measures of dispersions have been used, typically the standard deviation of the logarithm of labor, capital or total factor productivity. A notable issue is that the detailed properties of the distribution of productivity are not yet fully understood. We do not know, for instance, if the high prevalence of extreme values in the micro data is a real phenomenon, an accounting artefact, or a measurement error. It is concerning that even for the US, the "corrections" that are done prior to making the data available to researchers may well be driving most results on dispersion and misallocation (Nishida, Petrin, Rotemberg, & White, 2016). Yang et al. (2019), looking at 9 million observations over ten years in Europe, show that firm-level labor productivity is well fitted by a Lévy distribution, a distribution with power law tails and infinite variance. This suggests that extreme values are a normal feature of the data and that trimming, a common practice, may drive some of the existing results in the literature. A related, and potentially very significant finding is that many firms have negative value-added, implying that their negative profits, or losses, are higher than their wage bill. , (Ardanaz-Badia, Awano, & Wales, 2017; Yang et al., 2019). Chart 17a in Haldane (2017) shows that in UK administrative data, the 10th percentile of the distribution of gross value added per worker was very close to zero in 2009. As a result, log-transforming the data to measure growth rates, value-added TFP, or the standard deviation of the log levels, is impossible unless one discards some of the most valuable datapoints to understand misallocation.

With these caveats in mind, we now discuss the findings of a rising firm-level productivity dispersion, and relate it to the productivity slowdown.

6.2.3 Misallocation

Business dynamism and productivity dispersion are largely indirect and clearly imperfect measures of misallocation. Similarly, there are many sources of productivity dispersion so that relating it to misallocation and the productivity slowdown is far from straightforward. An increasing dispersion driven by a fast-expanding technological frontier is in itself positive, although it begs the question of why laggard firms do not catch-up (Foster et al., 2019). In contrast, a slowdown in the firms pushing the frontier, a slowdown in those catching up, and a slowdown in exit of the least productive could independently or collectively be responsible for an aggregate productivity slowdown. The literature generally distinguishes between statistical and structural productivity growth decompositions. Estimates based on purely statistical decompositions, most recently the Olley-Pakes covariance method, suggest that that allocative efficiency has been a very large contributor to aggregate productivity growth. Decker, Haltiwanger, Jarmin, and Miranda (2017), using comprehensive micro data for the US, decomposed US average labor productivity growth between a negative within-firm productivity growth (slightly less than –3%), and an Olley-Pakes covariance (between productivity and size), which measures allocative efficiency, of around 4%. They found that the post-2004 period, compared to 1997-99, is marked by a decline of the Olley-Pakes covariance term only, suggesting that a lower contribution of allocative efficiency can explain most of the productivity slowdown.

Ultimately, however, statements about allocative efficiency ought to refer to a benchmark of optimal allocation. A number of recent contributions to the literature have developed more "structural" productivity decompositions,, characterizing misallocation through model-based identifying assumptions (see Restuccia and Rogerson (2017). One important issue is that we generally observe firm-level revenue (price times quantity) but not prices, so that measures of TFP are based on revenue (TFPR) rather than on physical output (TFPQ). The framework of Hsieh and Klenow (2009) has been highly influential because it provides a method to evaluate misallocation when data is scarce: under their assumptions, all the dispersion in TFPR is due to distortions, rather than to fundamental differences in TFPQ. However, this result relies on strong assumptions that are unlikely to hold (Haltiwanger, Kulick, & Syverson, 2018), so differences in TFPR may reflect not only misallocation but also intrinsic differences between firms such as demand shifters, or even forces that we expect to have a positive long-run effect, such as innovative firms pushing the frontier faster.

Despite methodological issues, several recent studies of misallocation speak to the productivity slowdown by evaluating the evolution of misallocation over time. An interesting result is that capital misallocation appears to have increased significantly, while labor misallocation does not, at least in some countries. Gopinath, Kalemli-Özcan, Karabarbounis, and Villegas-Sanchez (2017) found that the within industry standard deviation of the logarithm of the marginal revenue product of capital had a clear upward tendency in Spain, Italy and Portugal (but not in central Europe or the US) since the 90's. In their estimate for Spanish manufacturing, efficient TFP is roughly the same in 1999 and 2012, while the observed TFP is 6-12 pp lower, so rising misallocation had sizeable effects on the slowdown. They interpret this as a rising capital misallocation, and, as Cette et al. (2016), point to low interest rates as the main cause. Barnett, Batten, Chiu, Franklin, and Sebastia-Barriel (2014) look at firm-level data in the UK and also find an increasing dispersion of the rates of return on capital, starting around 2007 and until the end of their sample (2011). They postulate that capital reallocation slowed down after the financial crisis, and present evidence that the positive relationship between investment incentives (firm-level capital rates of returns) and actual investment (firm-level capital growth rates) disappeared after the financial crisis.

When discussing misallocation patterns, an important distinction should be drawn between the distance to the efficient frontier, and the contribution of allocative efficiency to aggregate growth (Baqaee & Farhi, 2019). First, in an economy with frictions, the equilibrium allocation is not at the efficient frontier so that a higher allocative efficiency could be achieved by reducing frictions and thus moving toward the frontier, although this would only be a level effect. Baqaee and Farhi (2019) find that the distance to the frontier has slightly increased in recent decades, due to increasing markups. Second, when idiosyncratic frictions or technical efficiency change, aggregate productivity increases as a direct result, but also because the new equilibrium dictates that producers reallocate their input demand towards the most productive suppliers – the latter effect is a form of improvement in allocative efficiency (by contrast to technical efficiency), and the authors find that it has contributed about half of the growth of aggregate TFP in the last two decades in the US.

6.2.4 Competition, markups and concentration

If misallocation has increased, or if reallocation is less dynamic, what is the cause? The theoretical literature often specifies generic "frictions", without being specific as to the underlying causes. As noted above, in the last few years, however, a number of papers have found that markups have increased and concentration has decreased, suggesting a decline in competitive pressure. De Loecker, Eeckhout, and Unger (2020), in particular, have documented an increase in markups since the 1980s in the US, broadly speaking in all sectors. They observe that this increase is mostly due to the upper tail of the distribution and operates through reallocation: superstar firms with high markups are becoming larger; it is also these firms that have a low labor share, so this pattern contributes to the aggregate fall of the labor share (Autor, Dorn, Katz, Patterson, & Van Reenen, 2017).

The rise of markups and concentration suggests that some firms are able to exert market power, possibly erecting barriers to entry and protecting rents. However, superstar firms being the more productive, a reallocation towards them should have *increased* aggregate productivity growth. As Syverson (2019) argue, increased concentration may be due to *higher* competition. It is possible, for instance, that digital innovation has made it easier for consumers to substitute across firms, perhaps thanks to online retail. This increased competition may have "legitimately" benefitted the most productive firms (Autor et al., 2017), leading to increased concentration. In support of this hypothesis, Autor et al. (2017) also find that sectors with the strongest rise in markups and concentration are also the most technologically dynamic, in terms of patent intensity. It remains possible, of course, that an increase in concentration initially due to fairer competition eventually leads to welfare-reducing outcomes.

6.3 Regional disparities

The economic geography literature often distinguishes between different types of agglomeration externalities, such as labor, input markets pooling and knowledge spillovers, with an ongoing debate on whether these externalities operate within narrow sectors (as in Marshallian districts), or if diversity in large cities is a support to innovation. This provides several candidate mechanisms to explain the productivity slowdown. The changes in sectoral shares, geographical allocation of resources, and the nature of spillovers may collectively induce patterns that affect aggregate productivity. While regional disparities are well studied, there is a dearth of studies evaluating a specific mechanism quantitatively that is tied to the productivity slowdown.

An interesting fact is that in the last two decades, within-country regional dispersion has increased whereas OECD-wide dispersion has declined due to the significant catch-up from poor regions in Eastern Europe, Chile and Mexico, and mostly thanks to an increased specialization in tradable sectors (OECD, 2018b). Martin, Sunley, Gardiner, Evenhuis, and Tyler (2018), in a rare attempt at dissecting the productivity slowdown at the city level, analysed city-level data for the UK after 1971. They find that the shift towards service sectors has been a negative contributor to productivity, leaving manufacturing regions of the North more affected by this structural change. But their data also suggest that regions have converged in terms of their sectoral structure, and that within sector productivity dynamics is largely responsible for the slowdown.

Thus, the limited available evidence available points to sector-specific dynamics, which we reviewed above, and the role of trade, which we turn to in the next section. There is room for further research in this area, for example, by evaluating whether the increasingly intangible nature of investment changes agglomeration economies, and how this affects aggregate productivity quantitatively.

6.4 Summary

Overall, accounting for changing sectoral shares does not help to explain the slowdown in labor productivity growth, at least not the sharp most recent decline. It is insufficient in scale and also does not fit the sequencing criteria. Sectoral disaggregation, however, reveals that the slowdown permeates the economy across all sectors. The ending of a period of high productivity growth in ICT and ICT-using sectors such as manufacturing and retail and wholesale trade, at least in the US, has had some impact on productivity growth.

At the firm level, there is a divergence in productivity between firms at the frontier and the rest. Simultaneously, concentration and markups are also increasing across a number of economically significant industries. This begs the question of why the factors boosting the productivity of superstar firms are not diffusing, or not as fast as in the past. One hypothesis is that superstar firms are increasingly able to erect barriers to entry, perhaps because intangible capital is easier to appropriate, and the regulations to prevent this are not yet in place or are not enforced. Another hypothesis is that diffusion takes a long time, and we should expect long lags from the point when an initial innovation pushes the productivity frontier, and its full impact on aggregate productivity, a point emphasized by the optimists in the productivity paradox debate.

Many estimates of rising misallocation are quantitatively large, but do not necessarily fit well our scope criterion. Capital misallocation appear to have risen more in southern than in northern Europe, for instance. It is difficult to evaluate our sequencing criteria, simply because comprehensive firm-level datasets are too recent to evaluate secular changes. There does not appear to be a large change in 2004 for the US or after the GFC everywhere, and while productivity dispersion has increased, this was mostly before the GFC.

7. Globalization, trade and offshoring

Globalisation is thought to be an important driver of productivity growth in the last decades. Firms' improved access to foreign markets, both for production supply chains and for the export of final goods, has led to staggering growth of trade in goods and services. Gains from trade are essentially gains in world allocative efficiency, which is why in Eq. (2) we put this section under the allocative efficiency. But as we see below, trade also affects investment in physical, intangible and human capital, as well as innovation efforts.

We first draw from the extensive trade literature to explain why growth in trade expanded and has subsequently plateaued. We then identify several channels through which trade increases productivity and show how given the microeconomic evidence, the slowdown in the growth of labor productivity relates to the slowdown in the growth of trade. For reasons we explain, it is not possible to fully ascertain that changes in trade are associated with the overall slowdown in productivity.

7.1 Slowdown in global trade

Trade has been a significant driver of economic growth for much of the past century, but its growth has stagnated as the export-to-GDP ratio for the world has not changed since the financial crisis (Baldwin, 2009; Hoekman, 2015). Causes for the slowdown include cyclical factors related to the financial crisis, as trade is historically highly responsive to changes in output. Structural components might also keep growth in trade supressed permanently, such as the one-off integration of China and former communist countries or technological advancements that enabled the spread of long and complex Global Value Chains (GVCs).

Weakness in demand in the aftermath of the global financial crisis may be a primary cause of the slowdown in trade, as it has been notably more pronounced in countries hit hardest by the crisis (Constantinescu, Mattoo, & Ruta, 2016). Import volumes for the US and the Eurozone are 20% below their pre-crisis trend, while GDP levels are 8% and 13% lower, respectively. The collapse of investment accounts for a significant share of the slowdown in trade growth for the G7 countries, as imports are much more responsive to investment than changes in private consumption (Bussière, Callegari, Ghironi, Sestieri, & Yamano, 2013).

Constantinescu et al. (2016) acknowledge that weakness in aggregate demand accounts for roughly half the gap between trend and realised import growth, concluding that structural components have played a role as well. The rate of increase in trade between the mid-1980s and mid-2000s may itself have been an outlier, largely due to the emergence of China as an exporter, as well as the collapse of communism. In addition to these geopolitical factors, technological advancements, notably in communications and transportation, have fuelled an expansion in the use of GVCs (Baldwin, 2016). Thus, the slowdown in trade can be linked to the slowdown either in the development of new technologies, or in the adoption of new technologies. Protectionist policies have not been found to explain much of the slowdown in trade, but may pose a significant headwind going forward (Hoekman, 2015). Overall, these structural components would indicate that trade has become less responsive to output growth, and the slowdown in the growth of trade may be permanent.

It is unclear the extent to which the slowdown in trade influenced productivity growth rates, with endogeneity posing a challenge for analysis. In one example, Constantinescu, Mattoo, and Ruta (2019) estimate that a 10% increase in backward GVC participation (foreign value added in gross exports) leads to a 1.6pp increase in average labor productivity growth rates in manufacturing, acknowledging uncertainties in their estimate and identification strategy. As the foreign value added share of exports appears to have grown roughly 2% a year in the decade starting 1995, but dropped to significantly less than 1% in the years between 2005 to 2014, this may explain roughly 0.2pp of the missing labour productivity growth per year in manufacturing sectors. This would be consistent with the observed slowdown in terms of its scope and sequencing.

7.2 Reorganization of global value chains

Criscuolo and Timmis (2017) discuss how the emergence of GVCs has enabled cheaper production, specialisation, competition, and the diffusion of technologies and knowledge. They also highlight the strong complementarity between the rise of services in developed countries and the diffusion of GVCs, a point elaborated in Baldwin (2016).

7.2.1 Offshoring and outsourcing

Offshoring is not only a way to exploit efficiencies abroad, usually through cheaper labor costs in developing countries, but also increases a firm's access to foreign markets. A helpful model in understanding a firm's dual decision of supplier location and production location is developed in Antràs and Helpman (2004), who highlight the tendency for highly productive firms to offshore, contingent on their reliance on 'headquarter' inputs.

The model receives empirical support in numerous studies, such as Helpman, Melitz, and Yeaple (2004) for the US, and Delgado, Fariñas, and Ruano (2002) for Spain, who find that (i) firms choosing to export are highly productive prior to exporting, and (ii) among firms choosing to engage in foreign trade the most productive will commit to offshoring. Productivity gains from offshoring are significant, and are usually captured by already-productive firms (Schwörer, 2013).

7.2.2 Specialisation in high skilled work

The overall impact of trade on human capital is debatable. Exposure to Chinese import competition in the US has contributed to a 25% decline in manufacturing employment within commuting zones, with similar findings for local labor markets in Europe (Autor, Dorn, & Hanson, 2013; Bloom, Draca, & Van Reenen, 2016). However, using evidence on the expansion in export activity in the US, Feenstra, Ma, and Xu (2017) estimate that the net effect of access to foreign markets on employment is near zero within commuting zones. This would indicate that labor reallocates into other notably high skilled, occupations less prone to being moved offshore. Indeed, Feenstra and Hanson (1996, 1999) suggest that offshoring increased employment of high skilled workers within industries in the US, increasing the skill premium by 15% between 1979 and 1990.

7.2.3 The role of competition

The role of competition is scrutinized in Melitz (2003), who proposes that aggregate productivity in an industry rises through the exit of the least productive firms and the extra exports generated by the most productive firms. Exporting alone has been shown to significantly boost firm productivity by up to 19% in American plants sampled between 1984 and 1992(Bernard & Jensen, 1999).

Foreign competition could also affect the rate of domestic innovation, although the evidence here is limited. Bloom et al. (2016) find by observing patenting behaviour that Chinese import competition led to higher technological innovation within firms in Europe. Despite similar impacts for local labor markets, the US experienced a lower issuance of patents following increased exposure to Chinese imports within regions (Autor, Dorn, Hanson, Pisano, & Shu, 2016).

7.2.4 Offshoring of services and knowledge spillovers

Traditionally, services provided abroad through foreign investment are often supplied at the location of production. Recent innovations in ICT technologies have changed that paradigm, whereby a growing number of service inputs are offshored, and outputs are sold to suppliers and consumers abroad (Freund & Weinhold, 2002). Amiti and Wei (2009) show that the offshoring of services has grown at an annual rate of 6.3% in the US between 1992 and 2000. They find that service offshoring has accounted for 10% of the average growth in labor productivity in those years, arguing that this is largely due to a re-allocation of labor to more productive tasks.

The offshoring of services also contributes significant knowledge spillovers. Javorcik (2004) estimates that a 4% increase in the share of foreign-owned firms increases output of domestic firms by 15% in a sample of Lithuanian firms. In some instances, FDI inflows come in the form of acquisitions with the intent to acquire skilled workers and technological expertise (Griffith, Redding, & Van Reenen, 2004; OECD, 2008).

Antràs and Helpman (2004) note the importance of strong property rights in enabling the outsourcing of administrative, or 'headquarter' services. This point has been investigated in the context of R&D specifically: protection of intellectual property rights abroad leads to faster offshoring of R&D and higher aggregate rates of innovation, especially for high-tech industries (Canals & Şener, 2014; Şener & Zhao, 2009).

7.3 Summary

While the efficiency gains from trade are clear, the varied nature of productivity benefits from trade hinder precise estimations of the full impact from the slowdown in trade. Although it is uncertain that the slowdown in trade meets our scale criterion, it is appealing for its good fit of the geographical scope criterion. As for the sequencing, trade features the cyclical effects from the Great Recession, as well as structural components that have also emerged through the integration of developing countries and the completion of adoption of new communication and transportation technologies. However, the latter would not adequately explain the change in productivity trend in the US from around 2004. Even if trade did not cause the slowdown, it may be hampering the recovery. Protectionism may be a further blow to the recovery of international trade and therefore to improvements in productivity going forward.

8. Technological change

The debate around the productivity slowdown is often presented as an argument between techno-optimists and techno-pessimists. Gordon (2016) argues that past waves of technological change, such as steam power, electricity, or the internal combustion engine had a major but temporary impact on productivity. He argues that current new technologies, in particular digital, are unlikely to have such a significant impact as they affect only specific aspects of human activity, such as communication and entertainment. Moreover, most of the productivity benefits of digitization may already have been harvested, through greater automation in manufacturing, retail, logistics and finance, in the late 1990's and early 2000's.

In contrast, Brynjolfsson and McAfee (2012, 2014) and Brynjolfsson et al. (2017) argue that the ICT and AI revolutions are still in their infancy, and that it will take some time for their full potential to unfold. They argue that the technologies are still being developed, and that complementary investments, innovation, organizational changes and diffusion are needed before the full productivity potential of the ICT industrial revolution will be realized. Mokyr (2014)'s analysis, similar to Gordon's in that it is also rooted in extensive historical analysis, suggests that there are new technologies being currently developed that have the potential to become GPTs, enabling sustained productivity growth and welfare improvements, for example genomics. Pratt (2015) argues that the fusion of ICT with other new technological areas, notably robotics, will generate spectacular new gains in living standards.

In this section, we consider these arguments and investigate four sources of a potential decline of innovation or its effects on the real economy. These are: lower investment in R&D and inventive activities, escalating cost and complexity of innovating, lags in the diffusion of innovations, and a faster depreciation of existing capital and infrastructure due to current innovation.

8.1 Research and innovation efforts

The OECD (2017b) reports that aggregate R&D expenditures have not slowed dramatically across OECD countries after the recession, yet the level of funding by governments has plateaued since 2010. The decline in government investment has been offset by the increase in business R&D spending, accounting for more than 60% of total R&D expenditure in the OECD. While all types of research grew steadily in OECD countries both before and after the crisis, funding into basic science grew faster relative to applied and experimental research. This changing composition stems from a larger contribution from universities to R&D funding, although large variations persist between countries. Notably, basic science research performed by businesses in the US has more than doubled between 2005 and 2015.

Besides differentiating between applied and basic science research, Mervis (2017) uses data from the National Science Foundation to show that medical research funding by the US government has experienced the largest increase. This shift of funding towards the health sector may be expected to have a negative impact on productivity growth, because technological progress in health and pharmaceutical research is known to be increasingly costly and suffer from decreasing returns (DiMasi, Grabowski, & Hansen, 2016). Additionally, health services are consumed directly by households, which has implications for productivity. A workforce in good health is more productive. In fact, to make this mechanism more explicit, it is arguable that we should extend national accounts so that public investment in the health system contributes to the growth of public intangible capital (Corrado et al., 2017b). However, McNerney, Savoie, Caravelli, and Farmer (2018), using the World Input-Output database, report Health and Social Work to be one the lowest output multiplier sectors. Research that improves productivity in intermediate sectors, such as energy or capital goods, would thus be expected to have a larger aggregate effect, everything else being equal, because they have a higher output multiplier (Baqaee & Farhi, 2017).

The availability of skills and researchers in the labor force is unlikely to explain the productivity slowdown. Although the supply of doctorates in science and engineering shows ‘some signs of slowdown’ (OECD, 2016), except for Japan the number of PhDs awarded continued to grow between 2002 and 2012. According to data from the OECD, the number of full-time researchers in OECD countries has kept rising, from 3.2 million in 2000 to 4.8 million in 2015.

Policies play an important role in stimulating innovation. Edler, Cunningham, Gök, and Shapira (2013) examined seven different sets of policy measures to stimulate the generation and dissemination of innovation by businesses and concluded that there are large differences in the effect of those policies. For example, policy measures can have different effects on the relative rate of ‘radical’ versus ‘incremental’ innovation. Meanwhile, some strategies like standardization and the introduction of production norms could have altogether negative effects on innovation despite boosting productivity growth. Complicating matters further, the OECD (2017b) finds substantial heterogeneity in the levels of tax incentives for R&D in different countries, and that the most innovative are not those with the highest tax incentives. While innovation policy matters, to explain the slowdown there would need to be an important *change* in policy that occurred prior to the synchronized slowdown. No such dramatic change, common to all countries affected by the slowdown and with the right timing, appears to have been identified. Similarly, it is conceivable that different sectors and different technologies react differently to policy, so that structural change would imply a change in the aggregate effects of policy. Yet, structural change has taken place rather smoothly in advanced economies.

The OECD (2017b) also documents that commercial R&D is a highly concentrated activity, both across firms and across countries. Across countries, most of the high-impact research papers and patents are produced in only four or five countries, and within advanced economies the 50 businesses with the largest R&D expenditures on average account for around half of the total business R&D spending. Veugelers (2018) points out that inequality in R&D expenditures has not increased in Europe and may have even slightly decreased before 2012. She notes that churn among the R&D leaders is low, yet whether this phenomenon is new is unclear.

An increasing share of global R&D is now performed in emerging economies. After the 1999 decision in China to accelerate economic development through innovation, R&D expenditures by firms located there rose from 0.5% to 1.5% of GDP between 2000 and 2013 (Boeing, Mueller, & Sandner, 2016). According to data from the OECD, China spends almost as much as the US on R&D, in PPP terms. Little is known about the impact of a changing composition of global R&D on productivity growth in advanced economies. Micro-level evidence for the US suggests that firms enjoy spillovers from R&D done by other firms if they are close in the technological space, but suffer from R&D done by firms operating in similar markets (Bloom, Schankerman, & van Reenen, 2013). Thus, the effect of emerging economies R&D on advanced economies productivity is unclear a priori.

Because both R&D and rates of adoption of specific technologies are procyclical, it has been suggested that lower technology adoption resulted from the financial crisis (Anzoategui, Comin, Gertler, and Martinez (2019) but this has not been demonstrated. Finally, (Phelps, 2013) argued that innovation started slowing down in the 1960's, after a period of mass flourishing. He attributes the slowdown in innovation to a change in values and institutions.

Overall, growth in R&D expenditure has not slowed noticeably on aggregate, although its composition may have changed. A larger share of R&D expenditure is being taken up by private businesses, and more is being allocated to the funding of basic science. There is also some evidence of reallocation in government research efforts to the healthcare sector, which could be one potential source of a slowdown in aggregate productivity stemming from changes in innovation.

8.2 Research Productivity

While research efforts may not have declined noticeably, innovation rates could still be lower if research *productivity* declines. Here we discuss theoretical arguments regarding changes in research productivity as knowledge accumulates, and then turn to the empirical evidence.

One of the simplest arguments about research productivity is the fishing-out hypothesis: there is a fixed pond of ideas, and we are fishing the easiest first. In other words, the low-hanging fruit has already been picked (Cowen, 2011). Gordon (2016), for example, argues that many of the drivers of productivity of previous industrial revolutions (steam, electricity) were innovations that could only be made once (such as urbanisation and the hygiene revolution) and have a level effect, not a growth effect on productivity.

On the other hand, knowledge should become easier to find as knowledge progresses because new ideas arise out of existing ideas. The more ideas there are, the more ideas can be found (Arthur, 2009; Weitzman, 1998). However, as the space of ideas expands, it may become increasingly hard to explore. B. F. Jones (2009) suggests that an expanding scientific frontier also creates a 'burden of knowledge', as generating original scientific contributions requires more and more knowledge. In support of this theory, empirical evidence suggests that (i) the age at which scientists and inventors make their most significant contributions has been increasing, (ii) the share of scientific papers and patents that is written by a team of several authors is increasing (B. F. Jones, Wuchty, & Uzzi, 2008; Wuchty, Jones, & Uzzi, 2007), suggesting that researchers cope with the increasing burden of knowledge by being more specialized and working in teams, and (iii) the likelihood of switching field is decreasing, again suggesting that the burden of knowledge is creating higher barriers to entry into fields.

It has been argued that ICT, by making knowledge more accessible or by making science more automatable (see for instance King et al. (2009) could make research more productive. If we push the argument to the extreme, artificial intelligence could eventually lead to rising research productivity and an intelligence explosion (Bostrom, 2014). Similarly Mokyr, Vickers, and Ziebarth (2015) argue that the tools available for science and technology (especially ICT) can help search across information silos, store vast amounts of data and analyse it at a fraction of the cost compared to a decade ago. These tools allow further combinations of existing resources and knowledge to be exploited in the future (Brynjolfsson & McAfee, 2012). Yet, testing a number of macroeconomic implications of this "accelerationist" view, Nordhaus (2015) finds little evidence for it.

An indicator to determine research productivity is measures of research inputs per patent. Griliches (1994) is an early example, showing that the number of patents per researcher in the US economy has been on a more or less continuous decline for several decades. However, the OECD (2017b) shows that research spending per patent is highly heterogenous across countries. To test this hypothesis directly, endogenous growth models suggest that we need to determine whether a constant level of research effort leads to a constant productivity *growth* (Bloom, Jones, Van Reenen, & Webb, 2017). Under this assumption, if research inputs stay constant, TFP should keep growing at the same rate. This hypothesis is overwhelmingly rejected, as is evident in the raw numbers: TFP growth in the US has been at best stable or even declining since 1930, whereas measured research input has increased by a factor of 23. In other words, while productivity keeps growing at a constant, or even lower rate, the efforts to achieve this have been increasing. Anzoategui et al. (2019) suggest that a decrease in R&D productivity started in the early 2000's. Estimating a standard DSGE model extended to endogenize TFP growth as depending on innovation and adoption decisions, they find that the pre-crisis TFP slowdown starting around 2005 could be attributed to lags in the consequences of a decrease in R&D productivity.

The decline at the aggregate level could mask differences in research productivity trends at the micro level. The pharmaceutical sector is one area where declining research productivity has been emphasised. Research spending per drug has increased continuously and substantially, so much that it has been termed 'Eroom's law,' with the letters reversing the seemingly exponential increase in computing power associated with Moore's law. Indeed, Bloom et al. (2017) confirm the decline in research productivity in medical research, and present similar evidence for agricultural yields and even for Moore's law itself, which was only upheld by a significant expansion in research effort. Repeating the exercise at the firm level and measuring research output as increases in sales, they find that research productivity increased only for a small fraction of firms. A large majority have seen their research productivity decline, sometimes substantially so.

Looking at new molecular entities specifically, Myers and Pauly (2019) put forward evidence for the low-hanging fruit hypothesis. Since the demand for medical products in increasing, the industry responds by increasing research effort; however, in a world where good ideas are researched first, the marginal productivity of R&D is declining so that increasing demand leads to lower average research productivity.

8.3 Diffusion and lags

One explanation for the productivity paradox, by which productivity growth slows down despite accelerating innovation, is simply that it takes time for new technologies to diffuse, for companies and workers to adapt, and for complementary investments to take place.

This argument was put forward by David (1990), addressing Solow's observation that the benefits of computers were not yet evident in productivity numbers. David draws a historical parallel between the diffusion of the computer and the electrical dynamo during the electrification of the US in the late 19^{th} century. For both the dynamo and the computer, there were significant time lags between the first key inventions and their impacts on aggregate productivity. The key explanation is the prevalence of old technologies in the existing capital stock. First, old methods and capital remain more efficient during the initial phases of the GPT's development, so firms have no financial incentive to switch early to the new technology. Thus, investments to improve the GPT, as well as complementary innovations are needed before the new GPT becomes superior, and firms have little incentive to scrap existing capital. Such investments require time to make and are lumpy, so that improvement in the GPT itself can take decades, as was the case for the dynamo, which only superseded steam four decades after the first major inventions. Major productivity effects for firms occurred only when a complete reorganization of factories was realized. David (1990) also emphasizes inherent mismeasurement issues when new technologies are introduced.

The evidence for long lags is also documented in Gordon (2016), who argues that the revolutionary century after the Civil War was made possible by the unique clustering of great inventions in the late 19th century, such as the railroad, the steamship and the telegraph. These were followed by electricity, but also a range of inventions that changed lifestyles and improved the standard of living: canned food, electric refrigerators, sewing machines, public waterworks, X-rays, antibiotics, and others. For Gordon, the inventions since 1970 concern a narrow sphere of the economy, having to do with entertainment, communication, and the collection and processing of information - by contrast to other goods and services like clothing, shelter, transportation, health and working conditions, whose progress he argues slowed down after 1970.

While an assessment of the nature of technological change in different periods poses considerable challenges, many concur with Gordon in viewing productivity growth as successive adjustment of the levels ("one big wave" (Gordon, 1999) or "the great leap forward" (Gordon, 2016)), with each jump based on a different GPT. Jovanovic and Rousseau (2005) find that measured aggregate productivity growth first slows down for extended periods, before it picks up significantly, as a GPT emerges. However, even during the productivity slowdown, the economy shows signs of restructuring and innovative activity, as firm dynamism increases, the number of patented inventions grows, initial public offerings take progressively younger firms to market, and investment into young firms increases relative to investment by old firms. They also derive and test a number of other empirical predictions for the previous two GPT waves, which they mostly confirm for both waves: (i) the skill premium rises, since demand for skilled workers to enable the firms' transition increases, (ii) TFP growth slows at the beginning of the wave, (iii) entry, exit, and mergers of firms increases, (iv) stock prices fall initially as old capital depreciates in value, (v) younger and smaller firms do better than larger and older firms in terms of stock market performance and investment, and (vi) interest rates rise while the trade deficit worsens because of higher consumption. In considering these factors, they do not find that ICT technologies diffused faster than electricity, challenging arguments for current innovations having manifested themselves immediately.

Bresnahan (2010) delivers an updated survey on the literature on GPTs, emphasising diffusion lags and the need for complementary innovation and investment. Furthermore, slow productivity growth in itself is not an unusual historical occurrence. Rather, periods of fast TFP growth are the exception. Without new technologies, TFP growth arguably comes from improved allocative efficiency, which by itself cannot sustain TFP growth rates indefinitely. Brynjolfsson et al. (2017), reviewing existing explanations for the current productivity paradox, also conclude that lags in implementation are the most significant explanation. Similarly, van Ark (2016) supports the idea that the digital economy is still in its 'installation phase,' and productivity effects will occur once the technology enters the 'deployment phase.'

Bergeaud et al. (2016) describe the experience of 13 advanced economies over the 20th century as driven by two waves, a big one in the early to mid-20th century in the US (later in in Europe), driven by inventions from the Second Industrial Revolution, and a smaller one towards the end of the century driven by ICTs. This concurs with Gordon and Sayed (2019) in explaining the European post 1970's slowdown as the end of a period of convergence with the US.

Improvement in technology can also have effects on the shorter run. Basu, Fernald, and Kimball (2006) argue that technological improvements are contractionary in the short run due to a drop in utilization of existing capital and a reduction in investment. Inputs and investment recover with increases in output over the next few years.

8.4 Creative destruction and faster depreciation

In addition to lags, there are reasons to believe that when a new technology is introduced, older capital depreciates faster. If this is the case, it provides a plausible explanation for the productivity *paradox*: it is precisely because innovation accelerates that productivity growth slows down more quickly. For instance, based on a few examples such as Amazon replacing brick-and-mortar bookshops, Komlos (2016) argues that creative destruction has become faster. This suggests that one should use faster depreciation or scrapping rates, both for tangible and intangible capital for technologies which are advancing more rapidly.

The review of the literature by Li and Hall (2016) suggests rates of depreciation of R&D capital ranging from negative rates to 100% a year. Their own methodology produces estimates ranging from 6% to 88%, depending on the sector and dataset. A recent study by de Rassenfosse and Jaffe (2018) examined the revenue stream associated with Australian patents, obtained through survey, and estimated a rate of R&D depreciation between 2-7%. Overall, this suggests that there is a large degree of uncertainty regarding the stock of R&D capital, implying a potential for mismeasuring TFP growth by a large amount. Goodridge et al. (2016), investigating the productivity puzzle in the UK using ONS data, computed an alternate series for various types of capital using alternate depreciation rates. Assuming higher post-2009 depreciation rates (multiplied by 1.5), they found that under reasonable assumptions this premature scrapping might explain up to 15% of the missing 13 p.p of productivity growth in the UK.

While the argument in Goodridge et al. (2016) for this is motivated by the financial crisis, there is a more general theoretical argument: during phases of profound technological transformation, society as a whole has to adapt. During the previous industrial revolution and the 1970s and 80s introduction of computing, it took a long time for firms and workers to adapt and complementary innovations to develop (David, 1990). As an example, consider AI and autonomous vehicles: not only may the education system need to be reformed to train people with the right skills, but other institutions such as contract and the judiciary systems need to be reformed, for instance to deal with the responsibility of autonomous non-human entities. Creative destruction makes entire branches of knowledge obsolete and requires new frameworks, as well as sets of institutions, including government regulations, but this is extremely hard to capture in the data.

An understanding of the role of creative destruction requires a deeper knowledge of what underpins the decisions to innovate and adopt new technology. A key element in that respect is competition. Schumpeter (1942) argued that increasing concentration could drive innovation but Arrow (1962), for instance, argues for a linear negative relationship. Scherer (1967) proposed an inverted-U relationship leading Cohen and Levin (1989) to state the empirical results bearing on the Schumpeterian hypotheses are inconclusive. Goettler and Gordon (2011) study the Intel and AMD duopoly – a case of ICT durables, not services – using a model that includes firms' dynamic pricing and investment decisions while taking into account the dynamic behavior of consumers. They find a negative link between competition and innovation, partly due to the need for a monopolist of a durable good to maintain demand and partly because of the higher margins they earn. Product differentiation is directly linked to innovation and competition: with near perfect substitute products firms need to innovate to survive, but when differentiation declines innovation drops and then picks up again (U-shaped curve) in response to firms' local market power. Goettler and Gordon (2014) expand their approach for a dynamic oligopoly market with endogenous innovation rate and market structure. In line with the ICT durables' findings they argue that low differentiation increases innovation but as quality increases the market enters a winner-take-all environment, leaving lagging firms to fight over decreasing residual profits. We consider this approach as a significant differentiation from research that fixes market structure or allows it to vary exogenously with innovation and this is a key reason why these endogenous changes of market structure give contradicting results compared to other work.

More broadly the interplay between competition and productivity appears to be treated differently in economics: the Industrial Organization literature often looks into market power questions with strong assumptions about marginal costs while the trade literature has interpreted observed productivity growth as indicative of greater efficiency, although this is only valid under perfect or monopolistic competition (De Loecker & Van Biesebroeck, 2016). Despite their differences, both the trade and IO literature neglect key aspects of the interplay of competition and productivity, including the potential contribution of imported intermediate inputs and in geographical proximity to suppliers and markets. It also blurs the differences between global and local competition.

8.5 Summary

Ultimately, long run aggregate labor productivity growth comes from innovation. Aggregate investment in R&D activities does not appear to have slowed significantly, but to some extent has shifted from public to corporate funding, where it is highly concentrated, as well as towards health and pharmaceuticals, which may not have spillovers as high as ICTs did. Nevertheless, a new wave of technological development is taking place, especially in digital technologies, that have the potential to be considered GPTs. The rewards from investment should not be expected to be reaped immediately. Historically, complementary investments are necessary, there are significant lags in diffusion, and replacing the existing capital stock can lead to the stranding of assets. Finally, while there are opposite theoretical arguments regarding the evolution of research productivity as knowledge increases, it appears that maintaining a steady rate of productivity growth has required an increasing number of researchers.

The timing of the slowdown in productivity cannot be associated with any synchronised significant change in research funding or diffusion across the range of countries which experienced the slowdown. Besides, we do not see why recent technologies are, as has been suggested, comparatively inferior to the ones that emerged during the 19th and the early 20th century. The ICT deal primarily with digitized information, its transmission and analysis, which appears to be at least be as important, if not more, to the development of every economic sector as were many previous GPTs. This view is more optimistic than the Gordon hypothesis that dismisses the significance of current technological progress. It nevertheless is difficult to agree with the techno-optimists, as the effects from new technologies remains to be proven. Even if we are currently experiencing a highly significant technological transition taking place with lags, these lags may not necessarily be the result of a normal adaption process. Weaker competition due to excessive market power, for example, may have potentially limited the gains from ICT over the past decades. Clearly, technological development and diffusion are central to productivity growth, but to date we see insufficient evidence that changes in this account for the scale, sequencing or scope of the decline in productivity in the early 2000s.

9. Conclusion

The possible reasons for an observed generalised slowdown in productivity across a wide range of countries over a relatively short period of time are wide and varied. It is a mistake to identify any one single factor as the dominant or primary reason which explains the slowdown everywhere. Our review nevertheless identified a small set of forces and mechanisms that taken together are likely to explain most of the slowdown. In the process, as they do not meet our criteria of scale, scope and sequencing, we also have eliminated many candidate explanations for the slowdown in productivity growth as being largely inconsequential.

There are clear measurement issues in times of intense technological change, creating substantial uncertainty. First, the rising dependence on intangible capital can affect national accounts through direct measurement implications on the inputs and outputs, but also indirectly, as intangibles are much easier to relocate to tax havens and more likely to escape national accounts. Second, even if increasing mismeasurement of ICT-related goods and services is unlikely to explain all the slowdown, it may have contributed a non-negligible fraction of the difference. Overall, the literature shows that accounting for these factors can significantly change measured productivity growth.

In terms of the role of labor markets during the slowdown period, we looked into the changes in population structure due to ageing, in the composition of the demand for skills, in policies with respect to immigration, and in new institutional arrangements in labor markets. We found that they may all have had some relationship to aggregate productivity growth, although none of these are individually substantial enough to account for the productivity slowdown. We noted that while labor productivity decomposition exercises tend to exclude labor quantity or quality as the main factor behind the slowdown, the potential effects reported in the literature are likely to be reflected in a decreased TFP.

Investment, whether into tangible or intangible capital, does form a significant part of the explanation both because of cyclical and structural reasons. The recent recession depressed aggregate demand, and increased financial constraints, both for firms and governments. The cyclical explanation is only partial though, as the decline in investment rates started much earlier (early 2000s in the US). This suggests a role for structural explanations, including a rising share of intangible capital, the increase in concentration and a rise in short-termism.

Further disaggregation highlights new angles of the slowdown. First, there is a consensus that most sectors are affected, and the sectoral shares have not changed enough to support the Baumol hypothesis that the increasing size of low-productivity sectors is responsible for the slowdown. At the firm level, we observe a divergence between firms at the frontier and the rest, coupled by increasing concentration and market power across industries. The factors that drive productivity growth for the industry leaders are not diffusing as quickly as they did in the past. One interpretation is that superstar firms are increasingly able to erect barriers to entry, perhaps because intangible capital is easier to appropriate and the regulations to prevent this are not yet in place and even if they are, these are not enforced.

The slowdown in trade may have also damaged the rate at which domestic productivity accrues benefits from foreign competition and export markets through its varied channels. Many of the gains from trade are static, so it is possible that the slow productivity of the current period reflects the end of a one-off effect. Greater trade-openness may have led to the development, now more or less achieved, of highly productive global value chains. This would explain why the slowdown is global, although there is insufficient evidence to fully assess this effect quantitatively.

The slowdown in TFP is large, and having dismissed many of the explanations above suggests that technological change is a strong candidate cause for the slowdown. We have shown however that both the techno-optimists and techno-pessimists are likely to be missing the key drivers of the slowdown. The evidence is that investments in technology have not drastically diminished, although productivity gains from these investments are becoming lower, in the sense that more researchers are needed to achieve a constant rate of productivity growth. We are not convinced by the techno-pessimist view that ICTs are in principle comparatively inferior to previous GPTs, and believe that it is entirely possible that a vastly improved capability to transmit and analyse digitized information and the progress in artificial intelligence could be as significant as the capabilities arising from previous GPTs. We, however, also are not convinced by the techno-optimists, as the hypothesis of lags remains an act of faith that can only be tested in the future. Meanwhile, the current slowdown is more dramatic than previous periods where adjustments costs and lags have had a smaller impact on productivity, so even if the techno-optimists are proved right in anticipating big increases in productivity, they do not explain the scale, sequencing and scope of the current slowdown.

Our final remarks relate to factors that could be considered in this discussion and which we have not highlighted. First, advanced economies are the focus of the paper, and the extension of our analysis to other economies is an important area for research. While some of the mechanisms presented above are relevant for developing and emerging economies, they are likely to be characterized by different dynamics. Second, while there is some research on specific market regulations, the broader role of institutions is not fully addressed in the literature. Our paper suggests that improvements in aggregate productivity do not only require investment in plant, equipment and infrastructure, or the hardware of economies, but also in health, education, R&D and regulatory reforms, or the software, with these intangibles having become more significant. Last, the explanations considered in this paper are often overlapping and can jointly help explain the observed slowdown, but there is no complete, coherent theoretical framework that can be applied empirically to fully capture these complexities. This would be another valuable area for future research.

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Appendix

Missing GDP

In the spirit of Syverson (2017), to highlight the consequences of slowing productivity, we compute what GDP would have been, should the productivity slowdown not have occurred. We use data from The Conference Board Total Economy Database™, April 2019. We use the “original” instead of “adjusted” data, because we do not want our numbers to be corrected by one and only one explanation (ICT deflators, which is what is adjusted in the “adjusted” version). Our measure of labor productivity is output per hour worked, and the GDP numbers are real GDP expressed in 2018 PPP $.

The realized (compound annual) growth rate of labor productivity is defined as

$$g = \left(\frac{y_{2018}}{y_{2005}}\right)^{\frac{1}{2018-2005}} - 1$$

The counterfactual growth rate, $\tilde{g}$, is the growth rate of the previous period, 1995-2005, computed similarly. Using a tilde to denote a variable should the slowdown not have occurred, the "missing" per capita GDP is

$$\frac{\tilde{Y}_{2018}}{N_{2018}} - \frac{Y_{2018}}{N_{2018}} = \frac{Y_{2018}}{N_{2018}}\left(\frac{\tilde{y}_{2018}}{y_{2018}} - 1\right),$$

where Y is real GDP, N is population, $y_{2018} = Y_{2018}/L_{2018}$ is labor productivity. Thus, we only need data on real GDP per capita, Y_{2018}/N_{2018} , and the ratio of counterfactual to real labor productivity, $\tilde{y}_{2018}/y_{2018}$, which is

$$\frac{\tilde{y}_{2018}}{y_{2018}} = \frac{y_{2005}\,(1+\tilde{g})^{(2018-2005)}}{y_{2005}\,(1+g)^{(2018-2005)}} = \left(\frac{1+\tilde{g}}{1+g}\right)^{(2018-2005)}$$

Putting this together,

$$Missing\ GDPpc = GDPpc_{2018}\left(\left(\frac{1+\tilde{g}}{1+g}\right)^{(2018-2005)} - 1\right)$$

In Table 1, we report $(\tilde{g} - g)$ as the "slowdown".

Growth accounting

This section details the methodology for decomposing labor productivity growth. The Total Economy database used for Table 1 also contains growth accounting data, but starts only in 1990. To obtain longer series, we closely following closely fromGordon and Sayed (2019) and merge two versions of EU KLEMS(Jäger, 2017),(O'Mahony & Timmer, 2009). The 2019 release generally covers 1995-2017, while the 2012 release covers 1970-2010, but not for all variables and [*****]. The overall trends in the two datasets are similar, but productivity growth in the US is noticeably lower in the EU-KLEMS data as compared to the Conference Board data. It should be noted that changes in accounting standards, from the ESA 1995 to ESA 2010, may cause minor discrepancies between the two

[*****] For the 2019 release, we extract data for the listed countries and variables from the statistical database, which we downloaded from the main webpage http://www.euklems.eu/query/. (Release date: November 2019. Downloaded February 2020). The 2012 release comes in the form of Excel spreadsheets, which we downloaded separately for each country on the main site in July 2019 (All files can be accessed at http://www.euklems.net/eukISIC4.shtml. For example, the US file is http://www.euklems.net/data/nace2/USA_output_12i.xlsx).

releases. For example, the 2019 release, which follows the ESA 2010, separately reports the stock of R&D and other intellectual property products.

Table 2: EU KLEMS variables definition

Variable Name	**Description in EU KLEMS**
EU KLEMS 2012 release	
LP_I	Volume index of value added per hour worked (computed from aggregate value added and hours worked)
$VAConLC$	Contribution of labor composition change to value added growth
$VAConTFP$	Contribution of TFP to value added growth
EU KLEMS 2019 release	
$LP1\_G$	Growth rate of value added per hour worked (computed from industry "bottom-up" contributions)
$LP1ConTangNICT$	Contribution of tangible non-ICT capital services to the growth of value added per hour worked
$LP1ConTangICT$	Contribution of tangible ICT capital services to the growth of value added per hour worked
$LP1ConIntangSoftDB$	Contribution of intangible software and databases capital services to the growth of value added per hour worked
$LP1ConIntangRD$	Contribution of intangible R&D capital services to the growth of value added per hour worked
$LP1ConIntangOIPP$	Contribution of intangible other intellectual property products capital services to the growth of value added per hour worked
$LP1ConLC$	Contribution of labor composition change to the growth of value added per hour worked
$LP1ConTFP$	Contribution of TFP to the growth of value added per hour worked

Table 3: Use of EU KLEMS variables for growth accounting

EU KLEMS release	Labor productivity growth	Contribution of labor composition	Contribution of capital deepening	Contribution of Total Factor Productivity
2019	$LP1\_G$	$LP1ConLC$	$LP1ConTangNICT + LP1ConTangICT + LP1ConIntangSoftDB + LP1ConIntangRD + LP1ConIntangOIPP$	$LP1ConTFP$

2012	$\Delta \log LP\_I$	$VAConLC$	$\Delta \log LP\_I - VAConLC - VAConTFP$	$VAConTFP$

To merge the data, we first perform growth decomposition for each possible year in each release, so that labor productivity is expressed in growth rates and is decomposed using data from the same release. We then preferentially use data from the 2019 release, and complement it as needed by data from the 2012 release. Table 2 lists the data series in EU KLEMS needed to complete the decomposition. Table 3 shows how each variable necessary for growth accounting is subsequently computed.

Two points to note are that, following Gordon and Sayed (2019), (i) we use a slightly different concept for labor productivity growth over the two releases; (ii) In EUKLEMS 2012, capital deepening contribution is computed as a residual. We have tested alternative methods, for (i) by computing "LP1_Q" from the bottom-up in EUKLEMS 2012, and for (ii) by computing the contribution of capital ourselves, using the labor share and the growth of hours worked. The differences were small enough that for simplicity and transparency we use the simplest methodology here.

Conceptual framework

While growth accounting cannot provide a full-fledged framework to encompass all explanations reviewed here, extending the basic "sources of growth'' framework with two additional terms is enough to provide a relatively accurate map of our paper. Let us start by repeating the basic growth accounting equation, as used e.g. by KLEMS[†††††].

$$\Delta \log\, y_t = \alpha\, \Delta \log\, h_t + (1-\alpha) \Delta \log\, k_t + \Delta \log\, A_t, \qquad \text{(A1)}$$

Our review, of course, addresses these three terms: a potential decline of the growth rates of human capital (h_t, see Section 4 on *Labor force composition*), physical capital intensity (k_t, see Section 5 on *Physical and intangible capital*), and a decline of TFP growth, often associated with technology (A_t, see Section 8 on *Technological change*).

The literature, however, proposes two additional major explanations for the slowdown, and it is possible to make them appear explicitly. The first one is mismeasurement, which can concern inputs and output. Real output can be mis-measured because of boundary issues or because of inaccurate price indices. In the relevant section (Section 3, *Mis-measurement*), we cover all these forms of mis-measurement. For simplicity here, we assume that only output is mis-measured. We can write the identity

$$\Delta \log y_t^{TRUE} = \Delta \log y_t + \Delta(\log y_t^{TRUE} - \log y_t) \qquad \text{(A2)}$$

For the right-hand side of (A1) to match the left-hand side of (A2), we need to be a bit careful. If we assume that inputs are well measured, the terms $\Delta \log\, h_t$ and $\Delta \log\, k_t$ will not change, but the parameter α might. In practice, α is taken to be the labor compensation share of *nominal* income, so if output mismeasurement only comes from a mismeasurement of the price index, α need not change. TFP

[†††††] Our derivations here are purely for exposing concepts. In particular, Eq. (A1) differs from Eq. (1) by having the parameter α being time-independent. In Eq. (1), we write explicitly the time dependence since KLEMS uses a time varying labor share compensation of income.

growth, of course, would be different. We omit the notation α^{TRUE} for convenience (or assume that mis-measurement only comes from the price index), and write

$$\Delta \log\ y_t^{TRUE} = \alpha\, \Delta \log\ h_t + (1-\alpha)\Delta \log\ k_t + \Delta \log\ A_t^{TRUE}. \tag{A3}$$

The second major source of explanation for the slowdown is a composition effect, either through a sector-level Baumol disease effect, or as firm-level misallocation. The most basic idea is that aggregate TFP can grow because each sector or firm becomes more productive, or because the more productive sector or firms become a higher share of the aggregate. At a conceptual level, we may write

$$\Delta \log\ A_t^{TRUE} = \Delta \log\ A_t^{ALLOC} + \Delta \log\ A_t^{TECH}, \tag{A4}$$

where we use changes in logs only to suggest that each term would usually be a growth rate. There exists a large literature that discusses different methods to perform this decomposition, possibly with extra terms such as productivity growth due to entry and exit. Without going into details, the two basic approaches are statistical and theory-based decompositions. Even though much of the differences between the different methods boils down to the choice of weights to be used for performing a weighted average of the TFP growth of individual firms/sectors (see e.g. . Baqaee and Farhi (2019) for a recent discussion), different methods give different results and different notions of allocative efficiency or reallocation. Also, the interpretation often changes if we consider the decomposition across firms rather than sectors. Substituting Eq. (A4) and (A2) into (A3) yields Eq. (2) in the main text.