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Labor Productivity in France: Is the Slowdown of its Growth Inevitable or are there Levers to fight it?

By Catherine Bruneau[*] & Pierre-Luis Girard[±]

Labour productivity in most advanced countries has slowed in successive stages since the 1970's and, after the 2008 crisis, it has reached its lowest level since World War II. Here we analyze the trend evolution of the aggregate labor productivity per hour worked in France, over the last four decades, with two main questions. 1) Is the slowdown of labor productivity growth a process which began far before the Great Recession and should it continue with just temporary yet persistent effects of the 2008 crisis and 2) are there levers to reverse the current trend? We proceed in two steps. First, the trend (log) productivity is described as a deterministic piecewise linear function of time, involving so-called structural breaks, and, second, without breaks, as a linear function of fundamentals derived from an augmented growth model including Human capital. We propose a thorough econometric investigation with multiple robustness analyses involving sector-specific analyses. The structural specification we retain is able to explain the evolution of labor productivity over the last four decades. The accumulation of human capital has been the main driver of productivity growth over the period of interest while France is close to the technological frontier.

Keywords: *labor productivity, trend component, structural breaks, long run target, augmented growth model with human capital*

Introduction and Literature Review

"Finally, and most ambitiously, as a society, we should explore ways to raise productivity growth. Stronger productivity growth would tend to raise the average level of interest rates (…) But more importantly, stronger productivity growth would enhance Americans' living standards. (…) Many possibilities in this arena are worth considering, including improving our educational system and investing more in worker training; promoting capital investment and research spending, both private and public; and looking for ways to reduce regulatory burdens while protecting important economic, financial, and social goals." - Janet Yellen, speech made on 8/26/2016.

Changes in labor productivity are one of the most watched international statistics. First, considering labor productivity, measured as GDP or gross value added per hour worked, is important as its evolution determines the growth path of other aggregate variables of interest. Its growth is decisive in determining the

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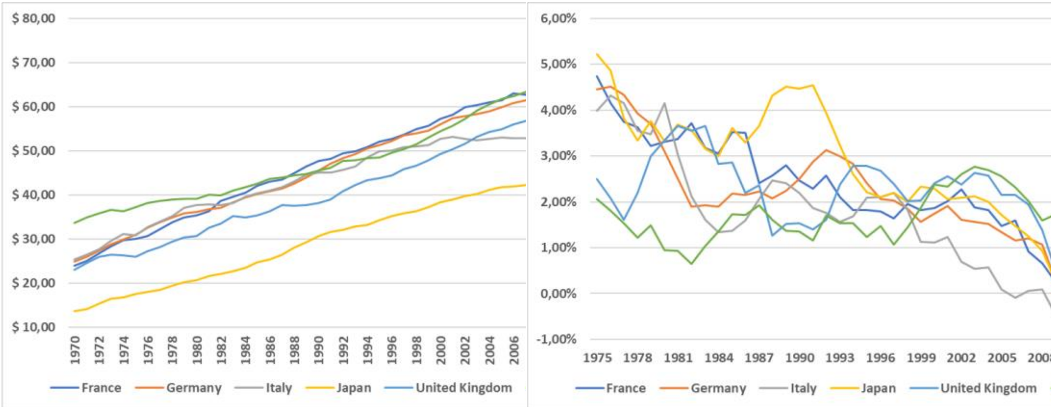
average growth in worker's compensations (Feldstein 2008, Biesebroeck 2015, Cahuc et al. 2014). Moreover, productivity growth historically contributed to explain the increase in average standards of living (Koen et al. 2004, Ivanic and Marin 2018) particularly in terms of consumption and savings (Fournier and Koske 2010).

More specifically, it is broadly accepted that the slowdown of labor productivity growth is one important explanation for the sluggish growth in GDP experienced by advanced economies in recent years. In the context of the Great Recession, the average productivity growth rate reached its lowest level in most advanced economies since World War II. Indeed, the average growth of productivity measured by hours worked dropped from 2% to less than 1% per year, from the 1990's to the 2010's, in France, Germany, the United Kingdom and the United States (see Figure 1).

Figure 1. *Evolution of Aggregate Labor Productivity per Hour Worked (GDP per Hour Worked, in US Dollars, Constant Prices and PPPs) in the Main Developed Countries Labor Productivity is measured as*

1a *Labor Productivity in Level*

1b *Labor Productivity in Average Growth over Five Years*



Source: OECD

One often attributes the slowdown of productivity growth observed over the past decades in mature economies to the 2008–2009 crisis. The slowdown could be seen as a persistent yet temporary effect of the financial crisis, and, more precisely as the result of a resource misallocation and/or a fall in demand. Conversely, following the Hansen's thesis developed during the Great Depression in the 1930s, Summers (2014) or Baldwin and Teulings (2014) emphasize persistent weaknesses in demand or excess savings, jointly with structural imbalances (notably zero-lower bound interest rates and ageing population), to explain the productivity slowdown.

Yet, in some countries, productivity growth slowed before the Great Recession and did not yet returned to the growth rates of the 1990s and early 2000s (Cette et al. 2017). Some authors, such as Robert Gordon (Gordon 2012, 2013, 2014, 2015), argue that the low productivity growth measured in all major countries since the beginning of the 21st century could be a sustainable phenomenon, due to the inability of current technological innovations to generate productivity gains comparable to those observed after the previous technological revolutions. In response, some economists argue that developed countries are experiencing a mere temporary slowdown in technological progress: a widespread digitalization of the economy, with the development of AI and robotics, will be a leading driver of both economic growth and radical changes in labour demand in the near future when technology enters "deployment phase" (Van Ark et al. 2016).

Besides these discussions on technological progress that are often concomitant with periods of economic slowdown and transition between two industrial revolutions (Mokyr et al. 2015), some authors highlight national specificities, changes in labor market and globalization as factors leading to productivity slowdown. Globalization has accelerated the tertiarization process of the developed economies via the outsourcing of manufacturing productions. Moreover, globalization increases productivity dispersion among firms: frontier firms can increase their market shares and their capacity to adopt innovations whereas market openness may be detrimental to laggard firms (Andrews et al. 2016).

A question therefore arises from these discussions: can we ascertain whether the impact of the 2008 crisis on productivity is structural and thus lasting or, despite persistent effects, it only contributes to cyclical fluctuations and the structural breaks is prior to 2008?

To answer this question, we propose a robust econometric analysis of the trend behavior of the labor productivity. We focus on the French case, note only to decide whether the effect of the 2008 crisis on the labor productivity is temporary or lasting, but also to identify levers that could allow to reverse the current trend of labor productivity. Nowadays, France experiences one of the highest labor productivity level, close to the one measured in the United States, after experimenting a slowdown in its labor productivity growth since the late 1990, like other OECD economies.

We use aggregate data over the last four decades to determine fundamentals of the trend labor productivity. Beyond mere academic interest, investigating the sources of the slowdown of labor productivity growth is important for public as well as for private sectors of the economy. Indeed, without understanding the forces which cause productivity slowdown, firms cannot have realistic expectations about future growth. What's more, it will be difficult for policy makers to design proper policy tools to enhance productivity growth.

The econometric analysis we propose provides us with robust results. We organize it in two steps.

First, we adopt a deterministic characterization of the trend component of the labor productivity and, more precisely, as a linear time trend with a few breaks in the level and in the slope. We obtain a decreasing step function specification which other authors already adopted in the literature (Bergeaud et al. 2015, Cette et al. 2017). However, contrary to previous analyses, the dates of the breaks are identified in order to isolate the cyclical component, obtained as a stationary series after removing the piecewise linear trend from the observed labor productivity.

Second, we aim at finding observable factors which can explain the trend component of labor productivity with the usual linear time-trend accounting for technology progress but without breaks. In short, we look for explanatory factors that can replace the structural breaks. Thus, as Arnold et al. (2007) and Thévenon et al. (2012), we refer to an economic model – more precisely the Solow growth model augmented with human capital – to find a coherent set of relevant explanatory factors whose combination allows to define a long run target labor productivity. This target is expected to exert an error-correcting mechanism which contributes to the evolution of the productivity growth.

We find that human capital captured through education is the main determinant beside propensity to invest in physical productive capital, or workforce population growth. This result is robust to changes in the measure of education level.

First, our paper contributes to the literature studying the identification and the nature of breaks (i.e., cyclical or structural) in the evolution of productivity, either labor or total factor productivity. Most of articles on this issue use the Bai-Perron test (1998) to identify them. This test, for which changes in equilibrium productivity growth occur at specific dates, aims at identifying jointly the optimal number of breaks and their dates. We can mention the analyses by Bosquet and Fouquin (2008) Bergeaud et al. (2015) and Cette et al. (2017) which cover respectively the periods 1960–2008, 1890–2012 and 1976–2016 and focus respectively on the main developed countries, developed and emerging countries and France. Note that Benati (2007) compares the Bai-Perron test with Stock and Watson (1996, 1998) methodology which allows variable coefficients, from which a progressive change in growth regime can be tested.

We adopt the Bai-Perron test to analyze the hourly labor productivity adjusted or not by the capacity utilization rate (CUR) in manufacturing industry at an aggregate level but also at a sectoral level to better explain the origin of breaks identified for the global economy. Three over different estimation periods are considered for robustness checks[1].

Second, we contribute to the literature on the macroeconomic impact of human capital on productivity growth. These studies are mainly based on the papers by Mankiw et al. (1992), and Lucas (1988), which, broadly speaking, focus on the analysis of the determinants of convergence processes towards the technological frontier. The first paper refers to the Solow growth model and includes a stock of human capital, which accumulates like physical capital, with decreasing returns to scale and transitional effects of productive investment on economic growth. The second paper considers human capital as a labor augmenting input in order to have perfect substitute between these two terms, with constant returns to scale and persistent effect of investment.

Early empirical estimates, mainly referring to Mankiw et al. (1992) model, like the ones obtained by Bernanke and Gurkaynak (2001), Canarella and Pollard (2003), find no evidence of such permanent effects of investment. This is the same for studies which use expansions of this model, for instance, Bajo-Rubio (2000) who developed a generalized model with *n* inputs and Daniels and Kakar (2017) who considered a CES production function instead of the Cobb-Douglas one. Yet,

[1]The lack of robustness of the breaks we estimate with the Bai-Perron test is often highlighted: the specification of the period affects the identification of structural breaks.

the augmented Solow growth model may be criticized because of the difficulty to appreciate the propensity to invest in human capital, which is usually measured by education-related variables only.

Arnold et al. (2007) and Thévenon et al. (2012) specify an alternative model which directly involves the stock of human capital, still restricted to education, instead of the propensity to invest in this type of capital. They also substitute a panel data approach to the usual cross-country approach. Their econometric strategy aims at estimating an error-correction model in which the productivity growth depends on error correction mechanism towards a steady state target, characterized from relevant long-term determinants. Their specification also has the advantage of being broad enough to allow to test both approaches by Mankiw et al. (1992) and Lucas (1988). They thus highlight a strong speed of convergence to the steady state, which is consistent with the Uzawa-Lucas model, instead of the augmented Solow growth model. Note also the work by Botev et al. (2019) who propose a new measure of human capital based on years of schooling with time-varying and country-specific returns. If they find a significant positive link between human capital and productivity for OECD countries, their estimates are statistically different from a one-to-one relationship assumed by the Uzawa-Lucas model.

Our contribution to this literature consists in estimating an augmented growth model with human capital in the lines of Arnold et al. (2007) by focusing on France over the last four decades. The use of error correction models aims at estimating successively 1) a two-step model (Phillips and Hansen, 1990) so to analyze the structural model augmented with the structural breaks we have identified before, 2) a univariate error correction model to confirm the results obtained with the first approach, and 3) a vector error correction model (Johansen 1995) to account for possible endogeneity issues. We also use two definitions of the stock of human capital and examine several estimation periods for robustness checks.

The paper is organized as follows. Next section presents the methodology, including the empirical models and the theoretical references. Afterwards, we precisely describe data, in particular, the variable of human capital, because we depart from the most usual specification adopted in the literature. Then follow the results and right after we discuss the robustness of our findings and finally we conclude.

Methodology

The aim is to propose a specification of the trend labor productivity and to examine how to estimate it. In the following section, we focus on the labour productivity per hour worked.

$$lprod_t = lnVA_t - LnH_t = va_t - h_t$$

$lnVA_t$ and LnH_t are the Napierian logarithm of the real gross value added and the number of hours worked by both employees and independent workers respectively.

As announced in introduction, we propose two specifications. The first one is a deterministic one, for which trend productivity is characterized as a piecewise linear function of time. The shifts in the slope of the function at some specific dates account for what is called "structural" breaks.

The second characterization is more structural; it is obtained by linearly combining observable explanatory factors and a linear trend without breaks, which is usually justified to account for the technical progress.

Both specifications are complementary for the questions we address. By using the estimation results obtained for the deterministic specification, we can decide whether the 2008 crisis is associated with a structural break or not. On the other hand, the second specification allows us to identify possible determinants that may explain the slowdown in the labor productivity growth.

We adopt the same principles to identify the trend productivity for both specifications. As announced in introduction, the productivity, when adjusted for its trend component, must be stationary, i.e., without unit root, and therefore purely cyclical. Moreover, the trend productivity has to play the role of a long run target which constantly exerts an error mechanism in the short run fluctuations.

Specification of the Trend Productivity as a Piecewise Linear Time Trend

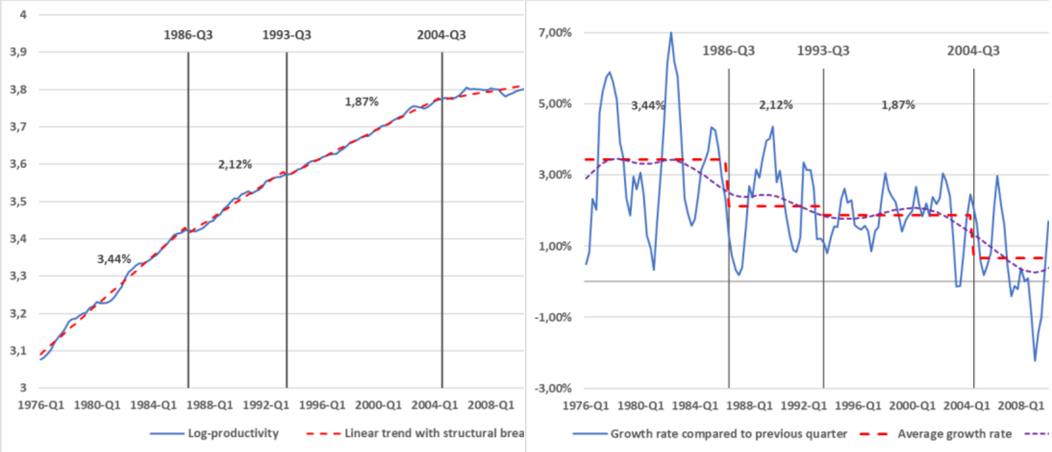
It is usually admitted that the technical progress contributes to the trend labor productivity. Generally, a linear function of time is used to capture the technological progress. When we consider such a linear time trend to characterize the trend of the log-productivity, we have to admit that the equilibrium labor productivity growth rate is constant over time.

However, when observing the time evolution of the French labor productivity (in logarithm) over the last four decades, we notice that it has an increasing trend but its growth rate displays a clear slowdown (Figure 2). This slowdown can be measured after the 2008 financial crisis but it was already significant at the beginning of the 2000's. The same type of evolution can be observed for other European countries and for the US.

So, we conclude that a specification with only linear time trend is not adapted to capture the trend component of our productivity series. A simple way to modify this linear time trend involves adding changes in the level and/or the slope at some dates which have to be in limited number. Thus, the productivity growth rate is rather piecewise constant and the trend labor productivity is a decreasing step function. This characterization has already been adopted, notably by Jimeno et al. (2006), Bergeaud et al. (2015) or Cette et al. (2017). Except in Jimeno et al. (2006), who develop a multivariate analysis, all of these analyses use the Bai and Perron test to identify structural breaks in labor productivity.

Figure 2. *Evolution of Aggregate Labor Productivity per Hour Worked (Value Added per Hour Worked, in Euro, Constant Prices) in France with Structural Breaks*

2a *Labor Productivity in Level* 2b *Labor Productivity Growth Rate*



Source: INSEE.

According to a terminology that has been broadly used since the contributions of Perron (1990, 1994) to analyze the interplay between structural change and unit root, we interpret these rare changes of the trend component as structural breaks in the (log) productivity.

Thus, the aim is to identify the number of the breaks and the dates of these breaks.

The logarithm of the productivity is decomposed into a long run component $lprod_t^{lT}$ and a cyclical part according to:

$$lprod_t = lprod_t^{lT}(+\mu * CUR_t) + Z_t \qquad (1)$$

with CUR_t the capacity utilization rate and Z_t the error-correcting variable, which contributes to the short-run fluctuation besides U_t according to:

$$\Delta lprod_t = \gamma * Z_{t-1} + U_t$$

CUR_t, Z_t and U_t have no unit root contrary to $lprod_t^{lT}$.

The capacity utilization rate is supposed to capture cyclical fluctuations and to allow a better identification of $lprod_t^{lT}$ according to Lequien and Montaut (2014) and Cette et al. (2017).

Moreover, the trend (log)productivity $lprod_t^{lT}$ is specified as a deterministic piecewise linear function of time:

$$lprod_t^{lT} = \alpha + \sum_{k=0}^{m} \alpha_k \mathbb{1}_{t \geq t_k} + \beta t + \sum_{k=0}^{m} \beta_k \mathbb{1}_{t \geq t_k} * t$$

where $\mathbb{1}_{t\geq t_k}$ is a dummy variable which is equal to 1 if date t is posterior to the break date t_k and to 0 otherwise.

We aim at finding the smallest set of break dates, *K*, which allows to make the series $(Z_t)_t$ stationary (i.e. without unit root). To do so, we refer to the Bai et Perron test (1998); the set of breaks K and the break dates $t_k, k = 1, \dots, K$ are determined by calculating the OLS estimates of the α_k and β_k parameters for all K-partitions and by choosing the partition which minimizes the sum of the corresponding squared residuals Z_t. An important point is thus that the test procedure rules out the possibility to have unit roots in the errors Z_t, which is precisely a main requirement we have imposed *a priori*.

To check that this property is verified, we perform an ADF unit root test on the series o Z (residual of the linear regression corresponding to equation (1). The critical thresholds are then obtained by simulation because the standard thresholds given by MacKinnon (2010) are relevant only in the absence of breaks.

We then consider the equation of the growth rate of productivity:

$$\Delta lprod_t = b_0 + \sum_{k=1}^{m} b_k \mathbb{1}_{t\geq t_k} + \gamma * \hat{Z}_{t-1} + \sum_{j=1}^{p-1} \varphi_j \Delta lprod_{t-j} + u_t$$

with not serially correlated residuals u_t and p the optimal number of lags that we determine with the usual information criteria. We check that the coefficient γ of Z_{t-1} is significantly negative, which proves the existence of an error-correcting mechanism, according to the two-step cointegration analysis proposed by Engle and Granger (1987). All parameters are estimated with the two-steps Fully Modified OLS (FMOLS) method introduced by Phillips and Hansen (1990).

Finally, we make sure that the break dates can be interpreted from a retrospective review of the main structural changes which may have influenced the evolution of hourly labor productivity (notably changes in technology or in public policy).

Structural Approach: Trend Productivity and its Fundamentals

Then, we aim at finding observable factors $X_i, i = 1, \dots, I$, which explains the trend productivity and remove all structural breaks entering the first specification, according to equation (2), which replaces equation (1):

$$lprod_t = a + bt(+m * CUR_t) + \sum_{i=1}^{I} \delta_i X_{it} + Z_t \qquad (2)$$

In that case, the trend (log)productivity $lprod_t^{lT}$ is stochastic and specified as a linear combination of relevant determinants X_{it}, in the lines of Arnold et al. (2007) and Thévenon et al. (2012) for example. These determinants must be persistent, that is they must have a unit root like the log-productivity. More precisely, they must share common (stochastic) trends with productivity, which is equivalent to say that productivity and determinants are cointegrated (Wickens 1996).

Thus, as before, Z_t, which represents the cyclical component, is expected to have no unit root and to enter the so-called short-term equation of the productivity growth according to an error-correction mechanism:

$$\Delta lprod_t = b_0 + \gamma * \hat{Z}_{t-1} + \sum_{j=1}^{p-1} \varphi_{11,j} \Delta lprod_{t-j} + \sum_{i=1}^{I} \sum_{j=1}^{p-1} \varphi_{1i,j} \Delta X_{i,t-j} + u_t \quad (3)$$

If the series Z_t has no unit root with γ significantly negative, the X_{it}-factors are defined as fundamental determinants of labor productivity. In this case, there is no need to refer to ad hoc critical thresholds obtained by simulation to check the stationary behavior of the *Z*-series. Indeed, as there are no breaks, we can directly use the standard critical thresholds (MacKinnon 2010).

Hence, our set of factors explains a structural break if 1) the introduction of factors allows to remove breaks whose coefficients become not significant and 2) the model has all the relevant features: stationary long-term residual, significant error-correction term and not serially i.i.d. short-term residual u_t, whether we estimate the model with or without the non-significant break.

For the estimation of the parameters, we proceed in the same way as for the first specification; that is with a two-step FMOLS estimation procedure. First, we estimate the long-term equation with the labor productivity in level depending on factors and potential breaks according to equation (2). We then verify that the series of residuals, Z_t, is stationary by computing the usual stationarity ADF tests which we compare with critical thresholds obtained by simulation[2]. We then estimate the short-term equation (equation (3)) to confirm the existence of an error-correction mechanism and we verify that the error terms u_t are not serially correlated. We proceed as long as structural breaks remain in the specification. Once all structural breaks are "explained", we use the Bai and Perron test to check whether residual breaks remain.

Let us mention that we have performed different robustness analyses. In particular, we have examined how results about the structural breaks are affected by the estimation period. To do that we have considered different periods which start respectively in 1949, 1960, 1976 and 1980. The results are not modified.

Concerning the structural model, we have used two additional estimation procedures to confirm the results obtained with the two-step procedure proposed by Phillips and Hansen (1990). First, in the lines of Banerjee et al. (1997), the long run parameters δ_i are estimated alongside the remaining $\varphi_{11,j}, \varphi_{1i,j}$ and γ in a single step using nonlinear least squares (NLS).

[2]Because the introduction of breaks makes the asymptotic distribution of the ADF statistics not standard.

Second, to exclude any endogeneity issue, a multivariate approach is adopted to estimate the dynamics of the system composed of the log-labor productivity $lprod_t$ and its fundamentals X_{it}. We use the Johansen (1988) and Johansen and Juselius (1990) procedure with the test of information criteria and the rank cointegration test. We then estimate a Vector Error Correcting model (VECM).

Note that we have also identified the breaks at a sectoral level, notably to improve the interpretation of the structural breaks identified for the global economy. Finally, we have examined how the breaks can be removed, or not, depending on the choice of the structural fundamentals in particular, depending on the variable retained to capture the human capital.

As announced in introduction, we have to justify the set of these fundamentals from a theoretical point of view. Thus, we refer to the generic augmented growth model with human capital, by Arnold et al. (2007), which allows to study convergence process to steady state, and whose principles and main predictions are presented in next section.

The Augmented Growth Model with Human Capital

We consider the human capital-augmented Solow growth model first presented by Mankiw et al. (1992) to analyze labor productivity in the long run. Following Arnold et al. (2007), this model provides a framework in which output per worker can be expressed as a function of the propensities to invest in productive physical capital, the stock of human capital, the working age population growth rate, the level of technological progress, captured by the average growth rate of the total factor productivity, and the constant depreciation rate of capital. Moreover, this approach allows to study output per worker in as well as out a steady state: the change in output per worker depends on a convergence components, technological progress and other determinants measured in level that may shift the steady-state output per worker in long-run. We also describe how changes in these determinants may influence output per worker in the short-term. Studying productivity by hours worked also involves augmenting the model with the total amount of hours worked by workers, which has decreased over time. Yet, the decline in working time observed at the macroeconomic level in most developed countries is linked to several trends whose effects are difficult to disentangle through econometrics (Beffy and Fourcade 2004), like:

1) Development of part-time jobs and greater flexibility in the labor market. Generally following policies which aimed at reducing unemployment; for example, targeted tax cuts on low skilled workers to lower their relative cost with respect to capital and skilled workers.
2) Technical progress which allows to optimize the production process and the use of inputs thanks to productivity gains, either by reducing the number of hours worked per head or by reallocating it for other activities. The impact mainly depends on the exposure of company to competition and the degree of rigidity within the production unit and in the markets for goods, services and labor.

3) Development of new information and communication technologies from the 1980s to 1990s which might also have induced a decline in working time and (low) productivity gains observed in the manufacturing sector in some developed countries.
4) Finally, the reduction in working time may results from political decisions to reduce unemployment (e.g., the 35-hour workweek law in France). These policies aim at redistributing the total stock of hours worked and increasing job creation. Indirectly, they can have an impact on the restructuring of production process within companies: they can either optimize the use of their workforce or adopt new productive and/or managerial practices (Crépon et al. 2004).

Following Mankiw et al. (1992) and Beffy and Fourcade (2004), we consider a standard Cobb-Douglas function augmented with a stock of human capital and hours worked per worker

$$Y(t) = K(t)^{\alpha} Q(t)^{\beta} (A(t) h^{\rho} L(t))^{1-\alpha-\beta}$$

where $K(t)$and $Q(t)$ stand for productive physical capital and human capital respectively, $L(t)$ is the total amount of labor, $A(t)$ the level of technology, h the number of hours worked by workers. α and β are the partial elasticities of output with respect to physical and human capital. These coefficients also represent the share of each input in value added. The parameter ρ measures the potential impact of a change in hours worked on labor productivity. Depending on the inputs' substitutability, a decrease in hours worked may boost hours productivity as well as slow down productivity per employee.

Both types of capital can be accumulated according to:

$$\dot{K}(t) = s_K(t) Y(t) - \delta K(t)$$
$$\dot{Q}(t) = s_Q(t) Y(t) - \delta Q(t)$$

where s_K and s_Q stands for the propensity to invest in productive physical and human capitals and δ for the rate of depreciation of capital, supposed to be the same for the two types of capital. Having different depreciation rates would not change the general results.

We assume there are two exogenous sources of growth, technological progress and working age population, which is equal to the total amount of labor. Both of them evolve according to:

$$\dot{A}(t) = g_A(t) A(t)$$
$$\dot{L}(t) = g_L(t) L(t)$$

where $g_A(t)$ and $g_L(t)$ stand for the corresponding growth rates.

By dividing the variables $\mathrm{Y}(t)$, $\mathrm{K}(t)$and $Q(t)$ by $A(t)L(t)$, we obtain new variables (in small letters) entering a stationary model from which we can deduce the expression of labor productivity per hour worked:

$$lnprod(t) = ln\big(A(t_0)\big) + \sum_{k=1}^{K} a_k \mathbb{1}_{t \geq t_k} + g_A(t - t_0) + \sum_{k=1}^{K} b_k \mathbb{1}_{t \geq t_k}(t - t_0) - \left(1 - \gamma \frac{1 - \alpha - \beta}{1 - \alpha}\right) \ln\big(h(t)\big) + \frac{\alpha}{1 - \alpha} \ln\big(s_K(t)\big) + \frac{\beta}{1 - \alpha} \ln\left(s_Q(t)\right) - \frac{\alpha}{1 - \alpha} \ln(g_A(t) + g_L(t) + \delta) \quad (3)$$

See Appendix 1 for the details of the derivation.

Data

We mainly use INSEE database, but also other specific databases for some variables of interest. The data are measured at quarterly levels, in national currency for monetary variables, and according to domestic concepts for employment variables. We consider the period 1976–2018 to analyze the productivity which allows us 1) to use the full dataset on capacity utilization rate for the identification of structural breaks, 2) to analyze productivity over four decades and 3) to avoid the high volatility in the data prior to the oil shock.

We focus on Labor productivity in logarithm, i.e. the difference between the logarithms of the gross value added and of the number of hours worked. The gross valued added is better adapted to sectoral analyses, although we may face misallocation issues when we analyze specific sectors and activities. Following OECD, we choose to refer the total amount of hours worked as the unit of labor input measure, which is more precise than productivity per employee. This way, we are able to capture the impact of changes in hours worked and to account for self-employment or part-time employment.

We first focus on the aggregate economy which we split between non-farm business sector on the one side and farm activity and public administrations on the other side. Analyzing the non-farm business sector that aggregates the B to N and R to T activities according to the ISIC rev. 4 allows to emphasize its role as the main driver of economic fluctuations. Considering the public administrations enables to have an exhaustive overview of aggregate economy, although the way of measuring productivity in this specific sector is controversial. Finally, we break down non-farm business sector into three different sectors, manufacturing industries (the C activity in ISIC rev. 4), business services (which aggregate the G to N and R to T activities) and construction (the F activity). This split aims at comparing productivity dynamics in different sectors and better capturing the nature of the structural breaks we identify in the aggregate economy and non-farm business sector.

Gross value added is measured in Laspeyres chain-linked volume with 2014 as reference year. Chain-linked index reflects the changes within the structure of the domestic economy as well as the mutual relations between prices and quantities produced. Yet, the main weakness of this method is the loss of additive consistency, i.e., the total is no longer equal to the sum of its parts apart from the reference period and the next one. Thus, for sector analysis, we use a specific method proposed by Eyraud (2007). For all details, see Bruneau and Girard (2020).

We define the average number of hours worked per worker as the ratio between the total number of hours worked in a quarter and the total number of workers. Considering both employees and self-employed people from domestic concept allows us to have the real contribution of workforce to the production. Likewise we question the precision of valued added measurement, the number of workers and hours worked may be misallocated too, because of part-time employment and overtime working hours.

Investment propensity is defined as the non-dwelling gross fixed capital formation to value added ratio. It measures the acquisition of immaterial and material fixed assets less the disposals. We do not account for the households' investments, i.e., the subsection "Dwelling" in national accounts database, to focus on productive investment from business sector and general government. As for value added, we also use the method of Eyraud (2007) to avoid miscalculating business investment whose components are measured in chain-linked volume prices.

Concerning human capital, it is approximated by education variables, either the share of 25–64 years-old people with a given level of education in workforce or their average total years of schooling.

We use two different databases, by Barro and Lee (2013) and Goujon et al. (2016) with the double benefit of using harmonized data for many countries over long-term periods. Both of them provide five-year data from 1950 to 2010 and from 1950 to 2020 respectively. To estimate the missing values for the Barro-Lee dataset over the period 2010–2018, we use the method by Lee-Lee, (2016) which involves estimating a logistic model from which the missing value can be extrapolated. Therefore, we consider two sets of variables, the average years of schooling of adults, and the share of adults with at least secondary schooling. See appendix 2 for the derivation of these variables. Moreover, the data are interpolated to have quarterly[3] series although it may generate potential autocorrelation issues. It gives an approximation of what the data would have been at quarterly level, while assuming, as very long-term variables, their short-term variations are very small or null. However, we face correlation issues between trend and education trend variable(s), which may bias the coefficient estimates (Thévenon et al. 2012).

The population growth rate is measured over the working age population, that is the 15-64-year-old population, and we interpolate the intra-annual missing values, from which we can either compute the quarter-to-quarter growth rate or the

[3]We interpolate the data with the following formula $(\frac{q^{25-64}(\mathrm{j,a})}{q^{25-64}(\mathrm{j,a-5})} - 1)^{\frac{1}{20}}$, where $q^{25-64}(\mathrm{j,a})$ is our human capital variable (either years of schooling or educational attainment *j* over the adult population, at the year *a*.

growth rate compared to the same quarter of the previous year. Following Mankiw et al. (1992) and other studies of growth model, we assume constant depreciation and technical progress rates[4] we compute from data over France, from INSEE and AMECO.

As announced before, to better identify the trend productivity, we use the capacity utilization rate in manufacturing industry, measured over 1976–2018. Cette et al. (2017) also use this variable to adjust the deterministic relation in order to identify the effective structural breaks. Although the measure is restricted to the industry which accounts for less than 10% of gross value added in France, this activity is still the main engine of the rest of economy growth. We also use an alternative measure of capacity utilization rate in the business sector, over the period 1980–2016, calculated from the European commission's methodology, to test the robustness of our results.

Results

First, we present and discuss the results on the identification of the structural breaks when the trend labor productivity is characterized as a piecewise linear function. Then we turn to the structural analysis including the fundamentals derived from the augmented growth model with human capital. Here, we focus on total economy. Finally, we present and comment the results of some robustness analyses.

Identification of the Structural Breaks in Aggregated Labor Productivity

As explained before, the period we retain is 1976Q1-2018Q4. First, we check that the logarithm of the labor productivity has a unit root, for the total economy as well as for the sectors which will be considered later. We find that none of the series is stationary, i.e., they have all a unit root.

Then we implement the Bai-Perron test to identify the structural breaks, dates and magnitude, for the total economy. These dates are given in Table 1. We find at most four structural breaks, one in each of the four decades. As expected, the number of breaks and the corresponding dates depend on whether capacity utilization is included or not.

[4]We could have considered varying depreciation and technical progress growth rates as we did for population growth rate. Yet, not using a constant value for technical progress growth might have biased the estimation of the linear trend coefficient due to simultaneity issue.

Table 1. *Results of the Bai-Perron Test for the Global Labor Productivity per Hour over the Period 1976–2018*

Deterministic Trend				
CUR-adjusted productivity	1986Q3	1993Q3	2004Q3	
Observed productivity	1986Q3	1993Q1	2002Q2	2008Q2

Source: France Stratégie.

The first break is found in 1986, the second break in 1993 and the third one in 2002, without CUR, and 2004, when we include the CUR. A break in 2008 only appears when productivity is not adjusted with the capacity utilization rate in manufacturing industry. This result tends to indicate that the effect of the 2008 crisis rather contributes to cyclical fluctuations of the productivity. In other words, the economic crisis in 2008 did not cause a structural break in equilibrium labor productivity, but it might have amplified a previous structural break.

Table 2 gives the estimations. All parameters are significant at 1% except the break in level in 2008. There is a significant error correction term in the short-term equations and 40% to 50% of the variance of the productivity growth rate is thus predicted. Yet, without CUR, the residual displays some heteroskedasticity. Figure 2 give the aggregate labor productivity in level and in growth with the breaks we identify with the capacity utilization rate. Figure 2b gives the effective growth rate compared to the same quarter of the previous year, the average growth rate between two structural breaks and the trend growth rate obtained with a Hodrick-Prescott filter.

To explain the break in the 1980s, Cette et al. (2017) emphasize the impact of the two oil shocks that occurred in the 1970's. The important variations in the price of oil would have brought out structural imbalances in developed countries and the underlying inflation of the 1960's accelerated in the 1970's and the 1980's due to overinvestments, inflationist structure of the financial system and the wage growth. Moreover, at the beginning of the 1980's (in 1983 in France with the so-called "Tournant de la rigueur"), the fight against inflation became a priority in most of developed countries. In France, the government explicitly removed the wage indexation to inflation in 1982. More generally, governments in developed countries aimed at removing the relation between inflation and wage increases, and promoted flexibility and targeted the relative cost of low-skilled jobs vis-à-vis high-skilled jobs through targeted social tax cuts (Bergeaud et al. 2016).

Table 2. *Estimation Results for the Deterministic Long-Term Productivity Equation*

	Breaks identified with the CUR included	Breaks identified for the observed productivity
Intercept	3.083***	3.083***
	0.005	0.004
Time-trend	0.0083***	0.0083***
	0.0002	0.0002
Break86	0.071***	0.061***
	0.020	0.018
Break93	0.073***	0.088***
	0.026	0.024
Break02		0.225***
		0.042
Break04	0.366***	
	0.024	
Break08		0.071
		0.044
Break86*t	-0.0022***	-0.0019***
	0.0004	0.0003
Break93*t	-0.0013***	-0.0015***
	0.0004	0.0004
Break02*t		-0.0020***
		0.0004
Break04*t	-0.0032***	
	0.0002	
Break08*t		-0.0007**
		0.0004
ADF statistics	-5.965	-6.528
Lagged Error-correcting term	-0.327***	-0.436***
	0.044	0.059
Adjusted R^2	0.403	0.497
Jarque-Bera test: P-value	0.106	0.030
Heteroskedasticity BPG test P-value	0.969	0.907
Number of observations	172	172

Source: Authors Calculations.

FMOLS Estimation; Break02 is a dummy variable which is equal to 0 until last quarter of 2001 (included) and 1 otherwise. The associated coefficient measures the change in the level at first quarter of 2002 (2002Q1). The coefficient of Break02*t measures the change in the slope at the same date. *, ** and *** indicate significant coefficients at 10%, 5% and 1% risk levels respectively. The error-correcting term is the lagged *Z* variable It is associated with a negative and significant coefficient, which confirms the existence of an error correcting mechanism toward the long run target. ADF statistics indicates the value of the Unit Root test statistics. The coefficient associated to each break in the slope indicates the magnitude of the decrease of the productivity growth rate from the corresponding date until the end of the observation period. Accordingly, one can calculate the average growth rate between two successive dates of break t_j and t_{j+1} is the sum of the coefficients associated with all changes in the slope until date t_j included. The BPG test (resp. Jaque-Bera) is the Breusch Pagan Geoffrey test for heteroskedasticity (resp. for normality) applied to the short run residuals.

Concerning the break in the 1990s, it is well documented in the literature. The employment policy, as structural policy, may have caused the slowdown of productivity in this period, as claimed by Beffy and Fourcade (2004,) who identify a break in 1992 when they analyze the labor productivity in the French non-farm business sector over the period 1978-2003. Cette et al. (2017) identify a break either in 1995 or 1996 depending on whether the series of productivity is adjusted or not. Finally, the relatively slow spread of information and communication technologies (vis-à-vis the United States mainly) may have contributed to the weak productivity growths. In particular, economists noticed a gap between the productivity growth rate in the United States and the one in the other developed countries. Economic literature highlights the role of market rigidities and lower educational level as main determinants (Cette and Lopez 2012).

Concerning the break in the 2000's, it is identified in 2002 by Cette et al (2017) who focus on the capacity utilization-adjusted productivity and in 2000 by Bergeaud et al. (2016) who consider productivity without adjustment but over a far longer period (1890–2012). It corresponds to the most important decrease in the labor productivity growth over the period 1976–2018. If economists still highlight the role of employment policy as its effects may last over decades, other economists point out the more global impact of innovation. According to some of them (Gordon 2012, 2013, 2014, 2015), the third industrial revolutions already ended and did not cause a wave of productivity growth as important as the second revolution did. On the contrary, other economists emphasize a resources misallocation issue among sectors which slows down the reallocation process or the real industrial revolution is about to happen with the deployment of new technologies, like Artificial Intelligence for instance (Van Ark et al., 2016).

The second step of our analysis involves estimating a structural model based on an augmented growth model with human capital to substitute determinants to the structural breaks. We start with the previous specification including the CUR in manufacturing industry.

Estimation of the Structural Model for the Global Economy

To estimate the augmented growth model, we have investigated different measures of human capital, notably the average total years of schooling and the share of adults with at least secondary education. The former measure rather captures the stock of human capital while the latter emphasizes the qualitative evolution of education output. However, we only present the results obtained with the share of adults with at least secondary education as a measure of human capital, using the database by Barro and Lee (2013). Indeed, this specification allows to remove all structural breaks and, accordingly, to adopt a multivariate estimation method in addition to the single-equation analyses, which the specification with the years of schooling does not allow to do. The results obtained with the other specifications of Human capital using this database, and the one by Goujon et al. (2016), are available upon request.

The period is 1976–2018. The estimation results are reported in Table 3. As we are able to specify a stationary model without structural breaks, we can estimate the VECM to avoid any endogeneity issue. If the break in 1993 finally remains significant at 5%, the specification of the model without this specific break has meanwhile the desired properties (stationarity of the long-term residual, significant coefficients with expected signs in the long-run equations, and significant error-correction mechanism).

Table 3. *Different Estimation of the Structural Form of the Trend (log) Productivity*

Hourly labor (log-) productivity	FMOLS in two steps	Univariate error correcting model	VECM
$\ln(h_t)$	-0.843***	-0.988***	-0.859***
	0.074	0.105	0.111
$\ln(s_{K.t})$	0.039*	0.048	0.116***
	0.021	0.013	0.028
$\ln(q_t)$	0.397***	0.363***	0.382***
	0.019	0.039	0.027
$\ln(n_t + g^{tot} + \delta)$	-0.029	-0.071	-0.077**
	0.021	0.015	0.033
Intercept	8.755***	9.560***	8.887
	0.433	0.948	
Time trend	0.0007***	0.0005***	0.0003**
	6.82E-05	6.50E-05	0.0001
Error correcting variable Z_{t-1}	-0.283***	-0.362***	-0.205***
	0.090	0.098	0.046
ADF statistics	-5.539		
5%-Critical threshold	-4.817		
Adjusted R^2	0.353	0.362	0.487
Jarque-Bera test: P-value	0.515	0.874	
Heteroskedasticity BPG test P-value	0.587	0.176	
Number of observations	172	172	172

Source: Authors Calculations.

For the estimation of the error-correcting equation in a single stage, the long-term coefficients have been divided by the estimated value of the coefficient of the error correcting variable, in order to be compared with the estimated values obtained with the other estimation methods.

*, ** et *** désigne respectivement une significativité à 10%, 5% et 1%.

ADF: ADF Unit Root test statistics. 5% critical threshold comes from Mac-Kinnon tables (2010).

The error-correcting term is the lagged Z variable It is associated with a negative and significant coefficient, which confirms the existence of an error correcting mechanism toward the long run target.

The adjusted R^2 is related to the short-term equation. We do not indicate the adjusted R^2 for the long-term equation which is artificially close to 1 while the Durbin-Watson test is significantly different from 2.

The BPG test is the Breusch Pagan Godfrey test for heteroskedasticity in the residual of the short-term equation, for which we give the $T * R^2$ statistic and its p-value. If we only refer to the BPG test, we also considered the ARCH LM test and the White test.

It is worth emphasizing that the results obtained with the different estimation methods are very similar: the two single-equation approaches, either in two steps with FMOLS, in the lines of Phillips and Hansen (1990) or in one step according to the non-linear estimation proposed by Banerjee et al. (1997) provide results which are very close to the ones obtained with the multivariate approach of Johansen (1990). Therefore, we can be confident in the results; in particular we can exclude any endogeneity issue. When focusing on the results obtained when estimating the VECM, the rank test indicates one cointegration relationship. The estimates of the long run parameters are consistent with what is expected from the Solow growth model. In particular, we have symmetry in our results for the parameters of propensity to invest and workforce population growth rate.

The estimated elasticity of productivity to the propensity to invest in productive physical capital is significantly positive and in the low range of estimates found in the literature. On the contrary, the estimated elasticity of productivity to hours worked per worker is significantly negative and falls into the high range of estimates found in the literature. This result is consistent with the growth model previously derived without the coefficient ρ in the equation 3. This indicates that any change in working hours is offset by changes in the hourly labor productivity in the long-term.[5]

When we refer to the results obtained in the literature for the OECD countries, whose economies are heterogeneous, yet comparable to France we can conclude that our results are similar to the ones obtained in the literature, in terms of significance and magnitude.

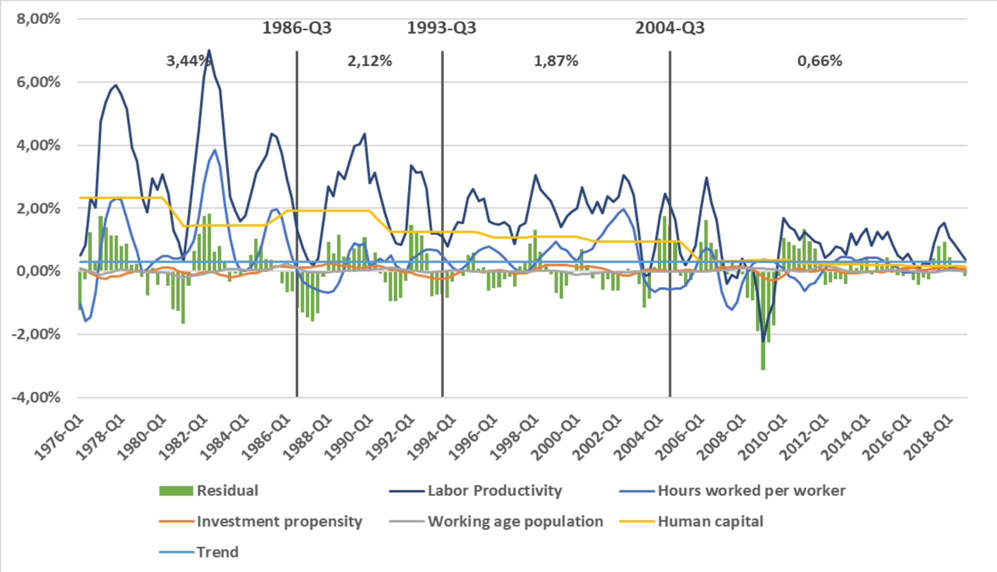
Finally, we assess the contribution of the different determinants to the annual growth rate of the labor productivity and we examine how these contributions evolve over time. The contributions are derived from the long run equation by differentiating the theoretical equation as follows:

$$\frac{lprod_t - lprod_{t-4}}{lprod_{t-4}} \approx \theta_1 \frac{h_t - h_{t-4}}{h_{t-4}} + \theta_2 \frac{s_{k,t} - s_{k,t-4}}{s_{k,t-4}}$$
$$+\theta_3 \frac{q_t - q_{t-4}}{q_{t-4}} + \theta_4 \frac{g_{L,t} - g_{L,t-4}}{g_{L,t-4}} + 4 * g_A + \Delta\varepsilon_t$$

The θ - parameters take the values which are estimated with the two-step FMOLS procedure. The results are summarized in Figure 3.

[5]Note that Beffy and Fourcade, (2004) augment a CES production function with a strictly positive compensation factor which is supposed to vary between 0 and 1, so that part of the working hours can be redistributed in the form of job creation. Such redistribution mechanism can therefore reduce the equilibrium aggregate productivity growth over the medium term.

Figure 3. *Decomposition of the Annual Growth Rate of the Labor Productivity for the Whole Economy (1976–2018)*



Source: Authors Calculations.

The growth rate of the labor productivity is decomposed into the contributions of the different determinants, with no remaining structural break. The stock of Human Capital is calculated from the data base of Barro and Lee (2013). The histogram indicated the part of the growth rate which is not explained by the model. A positive residual means that the productivity has increased more than its determinants.

We find a persistent effect of human capital on productivity growth until the beginning of the 2000s from which its contribution starts to decline. Neither the propensity to invest in physical productive capital nor workforce population growth rate has a persistent impact, which is consistent with the studies of Jones (1995). The residual is well cyclical, with a larger contribution during the 2008 crisis that the model does not capture totally. From the 2000s, a larger part of the productivity growth rate remains unexplained, due to the decrease in the contributions of human capital and hours worked. Hence, other factors may have contributed to the evolution of labor productivity.

Discussion about the Robustness of the Results

As announced before, we consider several estimation periods. In addition to the one used to get the estimations presented before, the period 1949–2018 allows us to account for the evolution of the French economy on all the available data on labor productivity. The period 1970–2018 includes the first oil shock, without the period of economic catching-up following the Second World War. Finally, the period 1980–2016 allows to emphasize the analysis after the period of high volatility that characterizes the decades prior to the 1980's, and to use another measure of capacity utilization rate which is related to the business sector and computed according to European commission's methodology. The results presented in Table 4 are very similar to the first ones.

Table 4. *Identification of the Structural Breaks for Different Estimation Periods and with/without CUR Adjustment*

Periods	Identified breaks				
1949Q1–2018Q4	1969Q2	1981Q4	1992Q3	2002q4	
1970Q1–2018Q4	1975Q1	1986Q4	1991Q3	2002Q1	2008Q4
1976Q1–2018Q4		1986Q3	1993Q1	2002Q1	2008Q2
1976Q1–2018Q4 for the CUR-adjusted productivity		1986Q3	1993Q3	2004Q3	
1980Q1–2016Q4		1986Q3	1996Q2	2002Q2	2008Q4
1980Q1–2016Q4 for the CUR-adjusted productivity		1986Q3	1996Q1	2002Q2	
1980Q1–2016Q4 for the CUR-adjusted productivity		1987Q1	1995Q2	2002Q2	2009Q3[6]

Source: Authors Calculations.

Then, we turn to sectoral analyses of break identification following the same procedure as before. Here we just comment the results obtained without detailing the estimation results, which are available upon request. Beyond robustness analyses, this comparison allows us to improve the interpretation of the breaks that have been identified at the aggregate level.

For the non-farm business sector and public administration with farm activities, a first break is identified in the 1980s. The one identified for the non-farm business sector is shared with total economy, which means a business origin. The break of the early 1990s and 2000s are shared by the two sectors considered (i.e., non-farm business sector and public administrations), as well as by the total economy. A break at the time of the 2008 crisis is identified only on the observed productivity for the two sectors. When we check for potential effects of cyclical components with the CUR in manufacturing industry, no significant structural break is identified for the public administration after the 1990's, while a break is identified before the crisis for the non-farm business sector in 2007.

The slowdown in productivity growth in the first decade of the 2000s was most pronounced in the non-farm business sectors than in the public administration whose productivity growth remains unchanged. In the non-farm business sector, it could be due to an increase in low-skilled and more precarious jobs which directly slows down aggregate productivity growth. On the other side, the development of high-skilled employment may affect the cyclicality of labor productivity: a firm is more likely to maintain this type of employment despite a slowdown in activity, as suggested by Askenazy and Erhel (2018).

[6]The break is not significant at 10%.

In all cases, all of our estimation procedures identify a significant convergence parameter with a negative sign. This result is consistent with the hypothesis of an error-correction mechanism that guarantees a convergence to a long-term equilibrium. The speed of convergence is higher for the non-farm business sector, whose estimated coefficient is close to the one we estimate for the total economy, than for public administrations.

It is worth noting that the non-farm business sector gets the same characteristics as the total economy, with the only difference being that a fourth break is identified just before the 2008 crisis. Only the analysis over the period 1949-2018 does not conclude that there was a break on that date. Indeed, we do observe a significant variation in labor productivity growth at this period, due to the joint evolution of manufacturing industries and business services.

Concerning the sectors of Manufacturing industries, business services and construction, the breaks are distributed in the same way as for total economy and for non-farm business sector. There is at most a break for each decade of the 1980s, 1990s and 2000s and a potential break after the 2008 crisis. Note that the sector of construction should be considered carefully. Indeed, the evolution of the productivity is indicated by a curve which shows a very marked concavity, which is not observed in the other sectors of the analysis.[7]

Several points can be made about estimated breaks for the sectoral activities. The structural breaks identified in the 1980s are common to manufacturing industries and business services. The break in the first part of the 1990s came from the business services as well as construction activities, while it did not concern manufacturing industries. Beffy and Fourcade (2004) already highlight these findings. The structural break identified in the early 2000s is shared by manufacturing and business services, with a stronger break for the former (whose growth rate yet remains higher than all other sectors or activities we have considered). Finally, it is noted that no slope break is identified after the 2008 crisis when we control for potential cyclical component in the observed labor productivity by adding the CUR in the deterministic specification for all sectors we analyze. Only the construction activity experienced an additional but positive break in 2012.

In the same way as before, we analyze labor productivity over other periods lengths and with another characterization of the CUR to test the robustness of structural breaks we identify over the period 1976-2018. The results are available upon request. The structural break of the late 1980s is the most robust and is shared by all sectors and activities, suggesting a global shock. For the manufacturing sector, the Bai-Perron test identifies a break in the early 2000s and/or before 2008, suggesting an origin other than the financial crisis. Similarly, the business services activities experienced a break before the last crisis, either the analysis is done over the period 1949–2018 or we control for the potential cyclical components in labor productivity with the CUR in manufacturing industry.

For the second step of our study, we perform other robustness analyses concerning the estimation of the structural model. In particular, we estimate the

[7] In this case, there is not a decline in productivity gains – i.e., the growth rate of labor productivity - in the early 1990s, but a decline in the level of productivity.

growth model augmented with human capital for the total economy over different period lengths (1976–1999, 1976–2004, 1976–2007 and 1960–2018). We also consider alternative measures to approximate the stock of human capital, keeping the other variables unchanged. We still focus on the share of adults with at least secondary education we measure with the database by Goujon et al. (2016).

Hence, all specifications and estimations provide us with very similar results: they explain the structural breaks, display the relevant features and are robust to the different econometrical approaches. Accordingly, we can claim that the results we obtain and present above are very robust.

Conclusion

Considering that the labor productivity growth has reached its lowest level in most advanced economies since World War II, we investigate its evolution in France over the last four decades with two main questions. Is the slowdown of labor productivity growth a lasting process which has begun far before the Great Recession and the financial crisis in 2008? Or, on the contrary, is the last decrease observed after this crisis just cyclical and, in this case, are there levers to reverse the current trend?

To answer these questions, we proceed in two steps. First, we confirm stepwise slowdown of the trend (hourly) labor productivity growth. We identify what we call structural breaks, one per decade, which we interpret in the light of historical observations. Concerning the 2008 crisis, we find that its impact has rather induced a lasting but transitory demand shock, which may still have amplified the last structural break observed in the 2000s. This result is confirmed at a sectoral level, whatever the sectors may be considered.

Then we explain this slowdown from fundamentals we derive from an augmented growth model including Human capital, in addition to the propensity to invest in productive physical capital, the average number of hours worked per worker, the growth rate of the workforce population and a usual linear time trend. By introducing these determinants, we remove all structural breaks, keeping just a linear time trend to account for the technical progress, as it is usual in the literature. For both characterizations, two essential properties of the dynamics have been verified. First, the labor productivity, once corrected for its trend component, displays only cyclical (stationary) fluctuations and, second, the trend component acts as a long run target which permanently exerts an error correcting mechanism on the evolution of the productivity growth.

On the structural characterization, it is worth emphasizing that the augmented growth model proves to be very efficient to explain the trend labor productivity in France over the period of study, in particular when Human capital is captured by the share of adults with at least secondary educational level. We find a significantly positive elasticity of the trend productivity to the propensity to invest in productive physical capital, with a value in the low range of what is found in the literature. Therefore, propensity to invest in productive physical capital has a temporary effect on labor productivity, which is consistent with the augmented

Solow approach. Yet, the high magnitude of the error-correction parameter is more consistent with endogenous growth model à la Uzawa-Lucas. The sensitivity of the trend productivity to hours worked per worker is significantly negative and close to -1, indicating that any change in working hours is mainly offset by changes in the hourly labor productivity in the long-run. As predicted by the model, the growth rate of working-age population has a negative contribution, even if the significance is more fragile. Finally, human capital has as significant positive impact on the trend productivity, with an elasticity between 0.4 and 1 depending on the measure used to approximate the stock of human capital.

These results are robust, as proved by the different investigations we have conducted, with different estimation methods, over different periods, for different sectors and with different Human capital series. Accordingly, the augmented Solow growth model appears very efficient to account for the slowdown of the French labor productivity over the last four decades.

It is interesting to mention results we have obtained with the same type of analysis applied to other countries. For Germany, once the reunification shock is considered by limiting the analysis after 1991, we obtain similar results, except for the effect of the 2008 crisis which appears to have a stronger persistent effect, but this may be due to the relatively shorter observation period. However, for Italy and UK, it is not possible to find determinants derived from the Solow growth model to characterize the long-term labor productivity without structural breaks, respectively in the late 1990s and at the early 2000s.

In addition, it is worth adding a remark about the effect of hours worked. For both France and UK, a change in hours worked is largely offset by a change in hourly productivity. This is not the case for Italy and Germany, where such a change rather has an impact on the productivity per worker and thus job creation.

To come back to the French case, we can claim that the paradigm shift rather occurs at the beginning of the 2000's and the last decrease in the context of the Great Recession should be considered as transitory. Moreover, the slowdown in labor productivity could be mainly explained by a decline in the trend growth of Human capital. We claim that acting on this capital could be particularly profitable in the case of France whose economy is close to the technological frontier.

Investing in education and professional training in tight relation with technological innovations could be the best lever to revert the decreasing trend of the labor productivity growth. Assuming that new technologies, such that AI and robotics, will drive productivity growth in the long-run, the improvement of the quality of training aims at reducing their cost of adoption and skill mismatch, while the contribution of secondary education to productivity growth reaches its lower bound and more and more people have tertiary education.

However, taking this result as given, the unexplained part of the trend productivity appears to be relatively more important over the most recent period. This finding should be confirmed by additional investigations exploiting finer information about the worker training to improve the measure of human capital. For instance, a micro-founded labor quality index from a Mincerian perspective, based on both education and experience of workers, could be used to better approximate the stock of human capital. Such measure would allow to take into account the evolution of the labor market and the rise of low-skill works. Moreover, we just consider a quantitative measure of human capital calculated over the number of years of schooling or the share of adults with at least secondary schooling. Thereby, measures of changes in the quality of education and skills may allow to improve our approximation. Finally, the study could be extended to other developed countries to analyze the contribution of human capital to the evolution of labour productivity and to verify whether the persistent effect of human capital's accumulation on productivity growth is shared.

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Appendix 1. *Augmented Solow Growth Model with Human Capital, Derivation of the Long Run Equilibrium Productivity*

We consider a standard Cobb-Douglas production function

$$Y(t) \; = \; (K(t))^{\alpha}(Q(t))^{\beta}(A(t)h^{\rho}L(t))^{1-\alpha-\beta}$$

With the notations of the main text.

where $Y(t)$ is the total production, $K(t)$ the stock of productive physical capital, $Q(t)$ the stock of human capital, $A(t)$ the Harrod neutral technical progress, h the number of hours worked per worker and $L(t)$ the labor. We assume that we have decreasing returns to reproducible factors, i.e. $\alpha + \beta < 1$. Indeed, a more generic model:

$$Y(t) \; = \; (K(t))^{\alpha}(Q(t))^{\beta}(A(t)h^{\rho}L(t))^{\theta}$$

does not have a unique steady-state without other assumptions on the parameters α, β and θ.

We assume there are two sources of exogenous growth in our model, workforce and technical progress. Both of them grow at a rate of $g_A(t)$ and $g_L(t)$ respectively such that :

$$L(t) = L(t_0)\exp\left(\int_{t_0}^{t} g_L\,(s)ds\right)$$
$$A(t) = A(t_0)\exp\left(\int_{t_0}^{t} g_A\,(s)ds\right)$$

Evolutions of the physical and human capitals are described by the equations:

$$\dot{K}(t) = \; I_K(t) - \delta K(t)$$
$$\dot{Q}_t = \; I_Q(t) - \delta Q(t)$$

where I_K and I_Q are investments in productive physical capital and human capital respectively. For simplicity, we assume that the depreciation rate δ is identical for the two types of capital, which does not change the main results.

A share of the outcome $Y(t)$ is invested in the two types of capital, such that $I_K(t) = s_K Y(t)$ and $I_Q(t) = s_Q Y(t)$

To derive the steady-state equilibrium, we define each variable in intensive terms, i.e., $y(t) = \frac{Y(t)}{A(t)L(t)}$, $k(t) = \frac{K(t)}{A(t)L(t)}$, and $q(t) = \frac{Q(t)}{A(t)L(t)}$.

The production function in intensive terms becomes:

$$y(t) \; = \; (k(t))^{\alpha}(q(t))^{\beta}(h^{\rho})^{1-\alpha-\beta}$$

The accumulation equations for productive physical capital in intensive terms are:

$$\dot{k}(t) = s_K y(t) - (g_A(t) + g_L(t) + \delta)k(t)$$
$$\dot{q}(t) = s_Q y(t) - (g_A(t) + g_L(t) + \delta)q(t)$$

We can rearrange the two last equations so to have the growth rates of the two types of capital:

$$\frac{\dot{k}(t)}{k(t)} = s_K h^{\gamma} e^{-(1-\alpha)\ln(k(t))} e^{\beta \ln(q(t))} - (g_A(t) + g_L(t) + \delta)$$
$$\frac{\dot{q}(t)}{q(t)} = s_Q h^{\gamma} e^{\alpha \ln(k(t))} e^{-(1-\beta)\ln(q(t))} - (g_A(t) + g_L(t) + \delta)$$

Moreover, taking the logarithm of the production function in intensive terms and differentiating yield the growth rate of the output as a weighted average of the two capitals:

$$ln\big(y(t)\big) = \alpha \ln\big(k(t)\big) + \beta \ln\big(q(t)\big) + \gamma(1-\alpha-\beta)\ln(h)$$
$$\frac{\dot{y}(t)}{y(t)} = \alpha \frac{\dot{k}(t)}{k(t)} + \beta \frac{\dot{q}(t)}{q(t)}$$

We then replace the two inputs growth rate by their expression obtained from the accumulation equations and we assume constant population and technological growth rates for simplicity:

$$\frac{\dot{y}(t)}{y(t)} = \alpha(s_K h^{\gamma} e^{-(1-\alpha)\ln(k(t))} e^{\beta \ln(q(t))} - (g_A(t) + g_L(t) + \delta)).$$
$$+\ \beta(s_Q h^{\gamma} e^{\alpha \ln(k(t))} e^{-(1-\beta)\ln(q(t))} - (g_A(t) + g_L(t) + \delta))$$

Taking a two-dimensional first-order Taylor expansion gives:

$$\frac{\dot{y}(t)}{y(t)} = -(1-\alpha-\beta)\alpha s_K h^{\gamma} e^{-(1-\alpha)\ln(k^*)} e^{\beta \ln(q^*)}\big(\ln\big(k(t)\big) - ln(k^*)\big)$$
$$-(1-\alpha-\beta)\ \beta(s_Q h^{\gamma} e^{\alpha \ln(k^*)} e^{-(1-\beta)\ln(q^*)}\big(\ln\big(q(t)\big) - ln(q^*)\big)$$

Now, the steady state conditions derived from the two accumulation equations can be used:

$$s_K h^{\gamma} e^{-(1-\alpha)\ln(k^*)} e^{\beta \ln(q^*)} = g_A^* + g_L^* + \delta$$
$$s_Q h^{\gamma} e^{\alpha \ln(k^*)} e^{-(1-\beta)\ln(q^*)} = g_A^* + g_L^* + \delta$$

and we get:

$$\frac{\dot{y}(t)}{y(t)} = -(1-\alpha-\beta)\big[\alpha(g_A^* + g_L^* + \delta)\big(\ln\big(k(t)\big) - ln(k^*)\big)$$
$$+ \beta(g_A^* + g_L^* + \delta)\big(\ln\big(q(t)\big) - ln(q^*)\big)\big]$$

$$\frac{\dot{y}(t)}{y(t)} = -(1-\alpha-\beta)(g_A^* + g_L^* + \delta)\ \big(\ln\big(y(t)\big) - ln(y^*)\big)$$
$$\frac{dlny(t)}{dt} =\ -\lambda\big(\ln\big(y(t)\big) - ln(y^*)\big)$$

with $\lambda = (1-\alpha-\beta)(g_A^* + g_L^* + \delta)$

We can rearrange the equation and multiply both sides by $e^{\lambda t}$ and we finally find:

$$\frac{d(ln(y(t))e^{\lambda t})}{dt} = ln(y^*)\frac{d(e^{\lambda t})}{dt}$$

Thus,

$$ln(y(t))e^{\lambda t} = ln(y^*)e^{\lambda t} + K$$

Moreover, we can deduce a value for K from any arbitrary period s such that:

$$K = lny(s)e^{\lambda s} - ln(y^*)e^{\lambda s}$$

Which gives:

$$ln(y(t)) - ln(y(s)) = -\phi(\lambda)(ln(y(s)) - ln(y^*)) \qquad (1')$$

Where $\phi(\lambda) = 1 - e^{-\lambda(t-s)}$. This relation can be estimated for any time interval.

Estimating the two equations of capital accumulation in steady-state, i.e. without growth dynamics, yields:

$$\dot{k} = 0 \text{ and } \dot{q} = 0$$

$$s_K(k^*)^\alpha(q^*)^\beta(h^\gamma)^{1-\alpha-\beta} = ({g_A}^* + {g_L}^* + \delta)k^*$$

$$s_Q(q^*)^\alpha(k^*)^\beta(h^\gamma)^{1-\alpha-\beta} = ({g_A}^* + {g_L}^* + \delta)q^*$$

$$k^* = \left(\frac{s_K}{{g_A}^* + {g_L}^* + \delta}(q^*)^\beta(h^\gamma)^{1-\alpha-\beta}\right)^{\frac{1}{1-\alpha}}$$

$$q^* = \left(\frac{s_Q}{{g_A}^* + {g_L}^* + \delta}(k^*)^\alpha(h^\gamma)^{1-\alpha-\beta}\right)^{\frac{1}{1-\beta}}$$

Replacing one partial definition into the other allows to deduce the steady-state expression of the two types of capital and yields to the usual output equation in intensive terms in steady state:

$$y^* = h^\gamma\,(s_K^*)^{\frac{\alpha}{1-\alpha-\beta}}\,(s_Q^*)^{\frac{\beta}{1-\alpha-\beta}}({g_A}^* + {g_L}^* + \delta)^{\frac{\alpha+\beta}{1-\alpha-\beta}}$$

As a function of propensities to invest in the two types of capital and working age population growth rate.

Yet, from an empirical point of view, we can better approximate the stock of human capital with educational variables rather than the propensity to invest in this type of capital (Arnold et al. (2007)). Therefore, from the steady-state accumulation equations, we only consider the level of the productive physical capital, as a function of the investment rate s_K, the population growth rate g_L augmented with the depreciation rate δ and the technological process growth rate g_A, and the stock of human capital q^*.

$$k^* = \left(\frac{s_K}{{g_A}^* + {g_L}^* + \delta}(q^*)^\beta(h^\gamma)^{1-\alpha-\beta}\right)^{\frac{1}{1-\alpha}}$$

We replace k^* by this expression in the production function in intensive terms to have its expression in terms of human capital stock,

$$y^* = \left(\frac{s_K}{{g_A}^* + {g_L}^* + \delta}(q^*)^\beta(h^\gamma)^{1-\alpha-\beta}\right)^{\frac{1}{1-\alpha}}(q^*)^\beta(h^\gamma)^{1-\alpha-\beta}$$

That is, by regrouping terms,

$$y^* = \left(\frac{s_K}{g_A{}^* + g_L{}^* + \delta}\right)^{\frac{\alpha}{1-\alpha}} (q^*)^{\frac{\beta}{1-\alpha}} (h^\gamma)^{\frac{1-\alpha-\beta}{1-\alpha}}$$

Finally taking the logarithm gives:

$$lny^* = \frac{\alpha}{1-\alpha}\ln(s_K) + \frac{\beta}{1-\alpha}ln(q^*) + \gamma\frac{1-\alpha-\beta}{1-\alpha}\ln(h) - \frac{\alpha}{1-\alpha}\ln(g_A{}^* + g_L{}^* + \delta) \quad (2')$$

Substituting (2') in (1'), considering the effective hourly labor productivity, developing $A(t)$ as a piecewise linear trend, and adding lags of the variables to account for short-run components gives the following error correction equation

$$\Delta ln\left(\frac{\tilde{y}(t)}{h(t)}\right) = -\phi\left[ln\left(\frac{\tilde{y}(t-1)}{h(t-1)}\right) + \theta_1 ln\big(h(t-1)\big) - \theta_2\ln\big(s_K(t-1)\big) - \theta_3\ln\big(q(t-1)\big) + \theta_4 ln(g_L(t-1) + g_A + \delta) - \ln\big(A(t_0)\big) - \sum_{k=1}^{K} a_k \mathbb{1}_{t\geq t_k} - g_A(t-t_0) - \sum_{k=1}^{K} b_k \mathbb{1}_{t\geq t_k}(t-t_0)\right] + \sum_{i=1}^{p-1}\kappa_{1i}\,\Delta ln\left(\frac{\tilde{y}(t-i)}{h(t-i)}\right) + \sum_{i=1}^{p-1}\kappa_{2i}\,\Delta ln(h(t-i)) + \sum_{i=1}^{p-1}\kappa_{3i}\,\Delta ln(s_K(t-i)) + \sum_{i=1}^{p-1}\kappa_{4i}\,\Delta ln(q(t-i)) + \sum_{i=1}^{p-1}\kappa_{5i}\,\Delta ln(g_L(t-i) + g_A + \delta) + + \sum_{i=1}^{p-1}\kappa_{6i}\,\mathbb{1}_{t=t_k} + U_t$$

Where the $\left(\theta_j\right)_{j\in[\![1;4]\!]}$ are function of the parameters of the model and $\tilde{y}(t) = \frac{Y(t)}{L(t)}$.

Appendix 2. *Derivation of the Variables for Human Capital*

We use two databases to approximate Human capital, as measured by its educational component only, by Barro and Lee (2013) and Goujon et al. (2016). Both of them provide harmonized data for many countries over long-term periods based on UNESCO classification (ISCED) for five-year age categories over total population (with a breakdown between male and female). They provide five-year data from 1950 to 2010 and from 1950 to 2020 respectively. Yet, the way of defining levels of education differs from one database to the other.

Barro and Lee (2013) consider four different levels of education, "no schooling", "primary", "secondary" and "tertiary". "Primary" level aggregates incomplete and complete primary education (which mainly covers the first level of the ISCED); "secondary" aggregates the two levels of secondary educations (that is middle school and high school or equivalent, or, equivalently, the second and third levels of ISCED); and tertiary aggregates short cycle higher education, bachelor, master and PhD (the level four and over of ISCED). Every level can be decomposed between "incomplete" and "complete" education. Moreover, the database provides detailed data on both total years of schooling and years of schooling per level of education ("primary", "secondary" and "tertiary").

Goujon et al. (2016) provides data for six different levels of education, "no education", "incomplete primary", "primary" (level 1 of ISCED), "lower secondary" (level 2), "upper secondary" (level 3) and "post-secondary" (level 4 and over), which overlap. For instance, "lower secondary" level aggregates the share of people who completed lower secondary schooling and the share of people who attained upper secondary schooling without completing. Goujon et al. (2016) also provides data for the total years of schooling.

We focus on the adult population, that is the 25-64 year - old population. Let us denote a, the five-year age category such that $a = 25-29, \ldots, 60-64$, j the highest educational level completed which takes the value "primary", "secondary" and "tertiary" for the database by Barro and Lee (2013), and "primary", "lower secondary", "upper secondary" and "tertiary" for Goujon et al. (2016). t denotes the period. b the database (i.e., either Barro and Lee, denoted "BL" or Goujon et al. (2016) denoted "W", in reference to the Wittgenstein Centre for demography and human capital).

We denote $q_{j,t}^{a,b}$ the share of the age category a of the total population whose highest level of education completed is j at time t from database b. The sum of all the shares over the different levels of education is always equal to 1 such that $\sum_j q_{j,t}^{a,b} = 1$. Similarly, $year_{tot,t}^{a,b}$ is the total years of schooling and $year_{j,t}^{a,BL}$ the years of schooling for the level j, from the Barro and Lee (2013) database, such that the sum over all educational levels is always equal to the total years of schooling, $year_{tot,t}^{a,BL} = \sum_j year_{j,t}^{a,BL}$. Finally, we denote $l_t^{a,b}$ the share of total population which is in the age category a.

We consider two categories of variables, the total years of schooling and the share of adults with at least secondary schooling. For the two databases, we define total years of schooling in the following way: $year_{tot,t}^{25/64,b} = \sum_a year_{tot,t}^{a,b} * l_t^{a,b}$. For the educational level of the adult population, we first define $q_{j,t}^{25/64,b} = \sum_a q_{j,t}^{a,b} * l_t^{a,b}$ the share of adult population with educational level j. Then, from Barro and Lee (2013), we have the following variable $q_t = q_{sec,t}^{25/64,BL} + q_{ter,t}^{25/64,BL}$ and, from Goujon et al. (2016), we test two different variables: $q_t = q_{lsec,t}^{25/64,W} + q_{upsec,t}^{25/64,W} + q_{ter,t}^{25/64,W}$ and $q_t = q_{upsec,t}^{25/64,W} + q_{ter,t}^{25/64,W}$. The second variables from Goujon et al. (2016) allow to focus on upper secondary and tertiary levels more precisely.